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Identify Visual Component Inspection for Design Non-Destructive Pitch Roof Checklist

Mohamad Haszirul Mohd Hashim[1,2,*], Azlan Shah Ali[2], Farid Wajdi Akashah[2], Nurul Izza Abdul Ghani[3]

[1]Program of Building Surveying, Department of Built Environment Studies and Technology, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak Branch, Malaysia
[2]Department of Building Surveying, Faculty of Built Environment, University of Malaya, Malaysia
[3]Unit of Architectural Technology, Tapah College Community, Malaysia

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Abstract Inspection is the basis of building structure to obtain assessment information. Assessment is used to get evidence and study the current condition of structure. This is because any structural failure can endanger the safety and health of building occupants. Through inspection, important information can be provided for consistent budget planning. The purpose of this paper is to identify the list of components and subcomponents for pitched roof system to inspection maintenance. The list of components has been reviewed by 3 stakeholder experts consisting of architects and engineers in Malaysia for consideration of the real component in the pitched roof design. The research confirmed the importance of the entire identified component pitch roof based on the 30 experts in roof fabrication. This paper serves to promote awareness among the various building inspections about the list of pitched roof components to identify components quickly. This inspection checklist has been validated by the expert to get feedback on the development. This checklist is aiming to design standard inspection for pitched roof and to reduce bias comparison inspection between various inspectors and provide effective service to building owner.

Keywords Inspection, Checklist, Pitch Roof, Maintenance, Component

1. Introduction

Defects are defined as deterioration or lack of condition that may affect building elements [34]. This is because loss of performance depends on the level of reaction or sensitivity and structural exposure to the deteriorating agent [25]. Defects will get worse if not repaired immediately causing the structure to be collapse [52]. The defects will affect the safety and health of the building occupants [36] and strength of the structure [33].

Inspection is the fundamental in building structure assessing with providing information assessment [65]. The assessment inspection is for gathering evidence [39] and provides information about the current condition [62]. These techniques are capable determining the locating, size, and shape of defect. The purposes of inspections are used to reduce unplanned structural failure or eliminate defects [55]. Inspection is a strategy to minimize the cost of maintenance, improve the level of safety and health and reduce the level of failure [31]. Inspection can help in providing repair work order [24].

Inspection techniques are based on design specifications such as methods and components that need to be checked [24,53]. Defective information is used for the planning of maintenance strategy to ensure building structure in good condition [64]. This is because there is more unplanned maintenance [43] in building management. Unplanned

maintenance is performed after the structure fails and is repaired to its original state. This method will result in high repairing costs and dissatisfaction to building occupant.

Visual inspection is the most often specified technique in building assessment. Visual inspection is process using the eye as the mechanism in judgment about the condition of component to inspect [26]. Inspection method can also improve the work plan to avoid malfunctioning and prevent structural failures [25].

This study will be useful to the building engineer especially roof fabricator, building owner and building maintenance. This benefit listing of component pitch roofs can provide a basic requirement in designs. This guideline of component listing is to ensure faster inspection, less subjective information, and appropriate information for less experienced inspectors [27,35]. This is explained by [41], that is, subjective inspection will cause a comparison of the final decision between the inspectors. The subjective causes the results are not complete in consistent various inspectors.

This research seeks to achieve two objectives. The first is to identify the main and sub structure of pitch roof design and construction. The second objective is to develop a validated listing of components and subcomponent pitch roof for consideration by fabricator expert. The purpose of listing of component pitch roof is to present standardized inspection checklist for easy identification of components. This paper serves to promote awareness among the various inspectors in building inspection about standard component that should inspect especially pith roof.

2. Hierarchical Inspection

The hierarchical inspection stage is used to describe the task in the visual inspection process. Hierarchical inspection requires flexible sequence's structures and sub-structures [14]. This inspection processes can provide scientific methods to guide the standards and criteria in the assessment. This is to ensure the goal of the inspection which is to collect information defect on each component of the structure without repeated process [59] can be achieved. The use of hierarchical inspection also identifies the methods of maintenance and costing required for the component [63]. Hierarchical inspection aims to help minimize the difficulties of inspection by making state clearly and in detail the quality assurance activities and giving guidelines to the inspector.

3. Design Standard

Design standard is important in the design of pitched roof. Good roof design ensures that the external surface is tightly closed so that it cannot enter the water [47]. A design related to pitched roofs should be checked against all applicable standards to ensure that it is acceptable. Current design rules are seen as too inflexible. This is because designers are modified based on experience and assume standards as minimum specifications only [37]. Standards are represented as databases which are used when needed by design conformance checking [57]. But stated by [22] checking design conformance with governing standards, codes, specifications, regulations, and manuals is a mandatory step in designing engineering systems

4. Pitched Roof System

The roof is the top structure to provide shelter to occupant from sunshine and rainwater. The roof is a structure that tends to the problem [23]. This is because roof defect starts at the external physical part [9]. Roof defects are usually ignored until something leakage on the ceiling surface. Leaking will cause the structure to become decayed [37]. Severe defects result in structure collapse when internal component element fails [50].

This section presents a description of component in design and installation pitch roof. Pitched roofs are greater than 10° and less than 75° [16]. The pitch roof system should be airtight for the design life of building. These components were identified and presented in this paper upon the completion of two method tasks. The first task is reviewing the published literature in design and construction pitch roof such standards and research. The second task is interviewing the engineers of roof at stakeholder and fabricators to confirm the component of pitch roof. These engineers are considering being professional experts in the domain of design and construction. These components are present in ranking order. This is because the inspection process will start on the external surface [30],[34] through the internal structure of the roof truss [2]. These components are present in ranking order from the top to bottom and external to internal.

4.1. External Component Pitched Roof

The inspection approach for the external roof structure components is on the surface of the roof, drainage, eaves, and fascia board. Roof tile is inspected by mapping using the grid [30]. It is also suggested by [3] the methods and techniques of inspection with inspection area plans divided into several zones in alphabetical order to obtain the current state of the structure.

4.1.1. Ceiling

Ceiling installation is an architectural structure to cover the inside area of the roof of the building. Ceiling mounted on the bottom of ceiling or rafters [7].

4.1.2. Roofing Tiles

Roof tiles are products that are installed continuously on the pitched roof produced by the manufacturer. Broken and lost tiles are caused by heavy rain or wind [28], [40]. There are also tile pieces that are not properly installed where

connectivity is loose[60]. The roof tile installed without proper connection causes the flow of rainwater into the roof structure [1]. The roof inspection by [60] found that there were not properly installed roof tiles which caused the gap between the tiles and the tiles to be loose.

4.1.3. Ridge Tiles

Tiles should be overlapped at least 65mm or recommended by the tile manufacturer. The mortar should be placed to avoid separating the joint between the tiles (BS 5534: 2013).

4.1.4. Mortar

Installation of mortar on roof tile sets is covered by concrete and tile installation is manual. The mortar is used to tie between tiles and provide strength to prevent tiles removed from wind resistance [16]. Another aspect to consider in mortar inspection is that mortar is cracked after several years of installation.

4.1.5. Lightning Conductors

Lighting conductors should be mechanically fixed to resist wind loads and should adhere to [18]. Lightning conductors should be fitted to roofs of tall buildings in exposed positions.

4.1.6. Solar Panels

Solar panels should be in a position that does not compromise the integrity of the roof covering and should be mechanically fixed to resist the calculated wind loads for the building, its location and in accordance with the manufacturer's sitework instructions.

4.1.7. Ventilation Products

Ventilation products provide air passage from the outside environment into and / or out the roof space for ventilation in building. There is no British Standard for ventilation products [16].

4.1.8. Valley Tiles

The tile is used for interring two sloping pitch roofs. Ensure that continuous support is provided for ends tiles. [6] mention at the tile side installation of not less than minimum 65mm is mounted without mortar or nail. Valley width should be not less than 100mm.

4.1.9. Hip Tiles

The lap on the upper tiles must not be less than minimum lapof 75mm [16]. Lap tiles shall be placed mortar.

4.1.10. Verges Tiles

The unsupported side of the roof shall be not less than 38mm and not more than 50mm [16]. Using the side cover on the tile is installed according to manufacturer's requirements and shall be tied with screws [4]. Side cover should be installed in parallel at the end of the slope [58].

4.1.11. Fascia Boards

Fascia boards should be supported with fittings or suitable products to prevent deterioration [16].

4.1.12. Gutter

The gutter will be installed around the building parameters to discharge rainwater [5]. Drainage installation should be in acceptable position for the path from the roof which is fully supported to prevent the deterioration and water ponding [19]. Gutter is situated outside the building and supported by brackets. Lap metal drain is between 20mm to 25mm, and each overlap must be paved [10].

4.1.13. Down Pipe

Pipe is fitted to a gutter to lead rainwater from the gutter to the drainage system or sewer [19]. Down pipes should be tied with bolts and nuts, screws or welding.

4.2. Internal Component Pitched Roof

The roof truss inspection method should be carried out from one structure to another structure [13].

4.2.1. Ridge Beam

The ridge is the connector for the stability of the top of the rafters [38] and as setting the distance for the top of the roof [16]. Roof ridge runs perpendicular to the slope of the roof, either single or continuous span and may cantilever to support a verge overhang.

4.2.2. Jack Rafter

Short rafter adjacent with a hip rafter or valley rafter

4.2.3. Main Rafter

The structure is installed with the same thickness, bound by metal plate fasteners or plywood gussets. Rafters are roof members which run parallel to the fall of the roof and support roof battens or purlins. They may also support ceilings, either directly or via ceiling battens or joists [15]. The minimum distance of rafters is between 400mm to 600mm [15] or between 450mm to 1200mm [38].

4.2.4. Struts

To give support to purlin to prevent deflection and transmit roof loading to loadbearing structure below [16]. The struts size is normally 70mm x 70mm [11].

4.2.5. Collar Tie

Collar tie is installed on two raft structures and supported by struts [11]. Collar ties the roof together at purlin level and the size of the collar is minimum 70mm x 35mm [16].

4.2.6. Purlin

Support long span rafters to prevent deflection and

increase stiffness [15]. Beam parallel to the eaves giving support to sheeting or decking on pitched roofs. The minimum distance of purlin is between 1.2m up to 2.4m [16]. While the standard [38] states between 1.8m to 3.6m.

4.2.7. Roofing Underlay

An underlay should be installed for tiled roof [21]. The underlay will be placed on the rafter to avoid air entering the roof space to reduce condensation [20]. Underlay installed on rafter surfaces and under batten [12]. Lap the underlay on the side not less than 100mm while lap on the head not less than 75mm to 225mm [16].

4.2.8. Batten

Batten installation is for putting roof cover which is mounted on the rafter. The size, spacing and fixing of roof battens or purlins shall be in accordance with the approved specifications. Batten size is not less than 38mm wide x 25mm in length [16].

4.2.9. Bracing

Each roof structure should be bonded to each other in order to move the load to the support structure [8]. Each roof structure should ensure good stability by installing bracing at least size 100mm x 25mm [54]. The building designer should be responsible for designing this additional bracing and verifying the overall stability of the masonry wall [17].

4.2.10. Hanging Beam

Hanging beams are used to provide support for ceiling joists where supporting walls are widely spaced [11]. They are installed in the roof cavity above the ceiling joists, which are attached to the bottom edge. Distance between beams is between 1600mm to 3400mm. Hanging beam size is between 100mm x 38mm to 300mm x 50mm.

4.2.11. Strutting Beams

Strutting beams can be regarded as a ceiling member because it is fitted in parallel with the ceiling girder [11]. Strutting beams are near horizontal, single span beams installed within the roof space, clear of ceilings, which provide support to under purlins via struts. Strutting beam size 125mm x 38mm to 350mm x 75mm. The distance between beams is 2100mm to 5000mm.

4.2.12. Water Tanks

Whenever possible, supports for water tanks should be independent of the trussed rafters. The platform the water tank should fully support the tank over at least its entire plan area. The platform material should be a minimum 18 mm thick timber boarding or moisture resistant wood-based material [15].

4.2.13. Ceiling Joist

Ceiling joists are closely spaced members primarily intended to support ceiling linings attached to their bottom edge. Ceiling joist is mounted close if there is support such as pole to support the ceiling [11]. The minimum distance is 400mm to 600mm [16] and the ceiling joist size is between 75mm x 38mm to 200mm x 50mm [11].

4.2.14. Ceiling Batten

Ceiling battens are closely spaced continuously spanning members attached to the underside of rafters, ceiling joists, floor joists or trusses that provide direct support for ceiling linings [11]. The minimum distance is 1.2m to 2.1m [16] and 300mm to 600mm [11].

4.2.15. Wall Plate

The rafter usually supported on wall plates on flat surface. [8] stated wall plates are used to support roof truss structures. Designers should ensure flat wall plates for the rafter in the upright and straight arrangement [17].

4.2.16. Counter Beam

A counter beam is a ceiling member running parallel to ceiling joists and usually between them which provides support for hanging beams. The hanging beams are assumed butted to the sides of the counter beam.

5. Design Checklist

Inspection items should be logical, consistent, and clear to ensure that inspectors conduct inspection based on the same working instructions. Checklist is a systematic process for sequence method action to be taken to validate the work repair by assessing level of defect [67]. It has been explained by [48] that the inspectors should follow the work procedures by identifying the components to be checked. A good checklist can help if inspector has no expertise in any area [11]. Checklist is also the best method for less experienced inspector [11]. The standard checklist can help in the examination method to avoid differentiated information by various experiences, knowledge, and opinions [44]. It also can provide a rational framework for obtaining assessment results.

This preparation can reduce the various designs at different stages of the design development, avoid same mistake of design error in next project and easy to inspector to determine the components to be checked. If no guideline in inspection also causes inspection without parameter and wasting the time [36]. The guideline to ensure that each structure can be checked and avoid any overlooked component [42].

6. Methodology

Initial qualitative analysis is often encountered in the event of various choices and requires a strategy to conduct analysis. The purpose of this method is the commonly used and straightforward option for analyzing qualitative data [66]. To achieve the stated objectives of this research, the following has been conducted.

6.1. Literature Research

Literature review is a research method related to the identification and evaluation that may be referred those responsible from researchers, academics and practitioners who have been recorded [51]. Analyze the published literature in the domain of pitch roof installation in building project to identify the list of components and subcomponent design. The literature approaches standards from a variety of perspectives. Standards from Malaysia, America, British and Australia are also used as guidelines in design classification samples.

6.2. Site Observation

The observation inspection is conducted to obtain an overview of the information on the structure based on literature review. Observation is based on the self-experience or others to provide actual information [45]. Site visits observations are used as prerequisites for data collection to test the design of the proposed model [2]. This observation is conducted to see the real situation for basic information on components installation and defects that exist. This is to make comparisons through literature review and actual situations on the site visit.

6.3. Preliminary Data Collection

In the third of study, we complemented the survey with interview [61]. The interviews served to confirm the identified list of components and subcomponent pitch roof during the design and construction phase in Malaysia. Structured interviews and focus groups were carried out with three (3) key stakeholders. The preliminary data collection process to study previous research or model has been developing by conducting interviews that are gained with three (3) expert stakeholders.

The selection of stakeholders of expert is to assist in terms of knowledge, research, and practitioner. The stakeholder expert is comprised of engineers and an architect is a representative profession in any matter at local and international levels. Stakeholders also design and help in advising to government, local authorities on rules of design. Always provide technical training and activities to increase the level of competence and understanding of engineering structures. The detail of finding has provided foundation to suggest recommendation listing of components pitched roof.

This interview aims to identify, arrange and map component on pitch roof structure in accordance with the construction sequence. The experience profiles of the expert stakeholder have 10 years or more than of professional experience. They were asked to indicate needs or not component based on information difference, and they participated in during the requirements engineering phase in similar vein than in the survey.

Table 1. External Component Pitched Roof

No	Component	Expert 1	Expert 2	Expert 3	Agreement
1.	Ceiling	✓	✓	✓	3/3
2.	Roofing Tiles	✓	✓	✓	3/3
3.	Ridge Tiles	✓	✓	✓	3/3
4.	Mortar	✓	✓	✓	3/3
5.	Soffit Board	✓	✓	✓	3/3
6.	Solar Panels	X	X	X	0/3
7.	Ventilation Products	X	X	X	0/3
8.	Valley tiles	✓	✓	✓	3/3
9.	Hip tiles	✓	✓	✓	3/3
10.	Verges Tiles	✓	✓	✓	3/3
11.	Fascia Boards	✓	✓	✓	3/3
12.	Gutter	X	X	✓	1/3
13.	Down pipe	X	X	✓	1/3

Table 2. Internal Component Pitched Roof

No	Component	Expert 1	Expert 2	Expert 3	Agreement
1.	Ridge beam	✓	✓	✓	3/3
2.	Main rafter	✓	✓	✓	3/3
3.	Jack rafter	✓	✓	✓	3/3
4.	Struts	✓	✓	✓	3/3
5.	Collar Tie	✓	✓	✓	3/3
6.	Valley rafter	✓	✓	✓	3/3
7.	Valley jack rafter	✓	✓	✓	3/3
8.	Hip rafter	✓	✓	✓	3/3
9.	Hip jack rafter	✓	✓	✓	3/3
10.	Purlin	X	X	✓	1/3
11.	underlay	X	X	✓	1/3
12.	Batten	✓	✓	✓	3/3
13.	Bracing	X	X	✓	1/3
14.	Hanging Beam	X	X	✓	1/3
15.	Strutting Beams	X	X	✓	1/3
16.	Water tanks	X	X	✓	1/3
17.	Ceiling Joist	✓	✓	✓	3/3
18.	Wall plate	✓	✓	✓	3/3
19.	Verge Rafter	✓	✓	✓	3/3
20.	Counter Beams	X	X	✓	1/3

Listing of components pitched roof involves stakeholders in work product under review during activity and inspection as shown in Table 1 and 2. It attempts to

better integrate inspection with development activities and to reduce the perception in inspection as an unproductive add on activity. It requires stakeholder to help a normal day activity to achieve desired product qualities. This discussion is more effective about issues in work product under inspection that can interfere with completion of those activities.

6.4. Listing Component in Pitch Roof Systems

Listing of the identified in pitch roof systems was conducted. The survey respondents confirmed that these designs typically occur due to fabricator pitch roof experts' involvement during the design development and construction.

6.5. Description of the Respondents

An appointed panel of experts was assessed in construction from engineering organizations in pitch roof [56]. The expert selection sample is an individual who manages from the design stage, the selection of building materials, installation until a construction project is completed. In this category individuals need to have work experience of at least two (2) years to five (5) years of competent expertise [29].

There are suggestions from [49] to approach identifying the experts by comparing in terms of education in field related and specialization work.

Components of external and internal pitched roofs have been selected based on advice from stakeholder expert and on a thorough literature review. This listing of component has been assessed by 30 expert fabricators in a survey using questionnaire. A questionnaire survey to evaluate the importance level of each of the 31-listing component in pitch roof has been developed. Experts are required to indicate (X) the import Likert method for identified component listing by selecting one out of five assessment terms. These terms were 1 "very unnecessary needed", 2 "no needed", 3 "slightly needed", 4 "need" and 5 "strongly need". In this context the expert was a person with two (2) until fifteen (15) years' experience in pitch roof fabricators. All the professional experts have an academic degree in bachelor civil engineering.

7. Analysis

This research identified and assessed the most significant pitched roof system design in building construction in Malaysia. The research confirmed the high significance of all the identified pitched roof designs as shown in table 3 and table 4.

7.1. Analysis of the Component in Pitched Roof

This research identified and assessed the most significant component listing design in pitched roof project in Malaysia as shown in Table 3 and 4. The assessment results indicate that all the identified internal and external components were assessed as needed or slightly needed. This selection is based on the design and construction categories contained in the roof elements.

Table 3. Analysis External Component Pitched Roof

Component	Mean	Median	Mode (Level of Needed)	Standard Deviation	Interval quartiles	Consensus Value
Ceiling	3.76	4.00	Needed	.739	1	High
Ridge Tiles	4.34	4.00	Needed	.484	1	High
Mortar	4.07	4.00	Needed	.258	0	High
Roofing Tiles	4.14	4.00	Needed	.351	0	High
Valley tiles	3.97	4.00	Needed	.325	0	High
Verges Tiles	4.00	4.00	Needed	.378	0	High
Hip tiles	3.62	4.00	Needed	.494	1	High
Fascia Boards	3.79	4.00	Needed	.412	0	High
Soffit Board	3.76	4.00	Needed	.435	0	High
Gutter	3.72	4.00	Needed	.455	1	High
Down pipe	3.72	4.00	Needed	.455	1	High

Table 4. Assessment Internal Component Pitched Roof

Component	Mean	Median	Mode (Level of Needed)	Standard Deviation	Interval quartiles	Consensus Value
Ridge beam	4.34	4.00	Needed	.484	1	High
Main rafter	4.41	4.00	Needed	.501	1	High
Struts	3.59	4.00	Needed	.825	1	High
Collar Tie	3.59	4.00	Needed	.501	0	High
Valley rafter	3.97	4.00	Needed	.325	0	High
jack rafter	4.00	4.00	Needed	.378	0	High
Hip rafter	4.00	4.00	Needed	.378	0	High
Hip jack rafter	4.00	4.00	Needed	.378	1	High
Purlin	3.52	4.00	Needed	.509	1	High
Underlay	3.34	3.00	Slightly Needed	.484	0	High
Batten	4.14	4.00	Needed	.351	1	High
Hanging Beam	3.41	3.00	Slightly Needed	.501	1	High
Strutting Beams	3.41	3.00	Slightly Needed	.501	1	High
Ceiling Joist	3.41	3.00	Slightly Needed	.501	1	High
Ceiling Binder	3.41	3.00	Slightly Needed	.501	1	High
Bracing	3.41	3.00	Slightly Needed	.501	1	High
Wall plate	3.41	3.00	Slightly Needed	.501	1	High
Water tanks	3.41	3.00	Slightly Needed	.501	1	High
Water pipe	3.41	3.00	Slightly Needed	.501	1	High
Base Tank	3.41	3.00	Slightly Needed	.501	1	High

Based on the table that has presented eleven (11) external components and twenty (20) for internal component pitched roof, for external component found tiles components such as ridge, mortar, roof, valley, and verges were recognized by experts to be needed in pitched roof design. The expert agreed with the overall external components that have been presented which experts have given the need level with mean values between 3.62 and 4.34.

For internal component designs, finding ten (10) components 'needed' in listing pitched roof while nine (9) only 'slightly needed'. There are components specified by experts installed based on the suitability of the design due to suitability functions such as:

(1) Purlin function to improve the stability of the wide roof span provides additional support depending on the load.
(2) The main task of gutter is to drain water into the building drainage but require additional maintenance costs if the gutters are blocked. If rain is too heavy it will cause gutter to not hold much water until it spills into the roof.
(3) Strutting beam to support roof members and install below under purlin.
(4) Hanging beam is to reduce the ceiling binder span. It is to support ceiling joist and ceiling panel.
(5) The roofing underlay is a thermal insulation tool and requires a high installation cost.
(6) Water tank and accessories are not component in pitched roof but located at roof area.

7.2. Validation Design Checklist for Component Pitched Roof System.

This section presents the development of inspection design review checklist component pitched roof to be considered by the professional experts. The checklists were developed based on the identification and analysis of the listing component.

The development checklist can be considered external and internal component pitched roof.

The inspection checklists were validated by the interview experts from stakeholder and roof fabricator to get feedback on the development of this checklist. Validation of design work is important to influence performance and define perception functionality [46]. The checklist has been distributed to seven experts to assess and assist this design. Experts are asked to comment on

well-organized checklists and easy-to-understand structure components. The validation procedure of the inspection checklist utilized the previously stated methodology for assessing the component pitched roof system design.

8. Conclusions

The attention to maintainability concern during the design development is to provide potential for delivering high level of comfort and safety to building occupant, reducing maintenance cost, and life cycle cost of the building. This paper presented thirty-one (31) listings of component external and internal pitched roof based on assessment of the professional expert in fabrication pitched roof. The research also presents to validate inspection design review checklist for consideration by professional expert. The checklists were developing based on identification and analysis of the component listing. This is advantageous to provide standard framework inspection and design to component pitched roof on field activities. This paper works to promote awareness among the various experts in pitched roof design regarding the benefits of building inspection. Experts will give a view based on their knowledge and experience on the components to be checked.

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