Assessing the condition of traditional Khmer timber houses in Cambodia: A priority ranking approach

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Abstract

Traditional timber houses provide a significant image of the built environment heritage, especially for south-east Asia, which holds more than half of the timber species in the world. It is therefore vital for professionals to ensure that the timber houses are still in good condition. When judging the condition of the building, a comprehensive evaluation is desirable, so that a reliable recommendation can be made within the shortest possible time frame. The priority ranking system developed through this research is appropriate for this purpose. The streamlined methodology uses numerical coding for the survey pro forma. From the priority ranking, the data are used to determine the condition of the house: dilapidated, fair or good. As this is a pilot project, the system was tested on the small-scale traditional timber house called Khmer houses in Phnom Penh, Cambodia. We found that the survey effectively reflects the current state of the house.

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INTRODUCTION

Traditional timber houses remain one of the most valuable assets of some countries. Representing the man-made intellectual thinking of ancient times, such traditional houses stand today as proof of great carpentry, and they are being used and passed on to the younger generations one after another. Within south-east Asia, where timber was one of the preferred building materials for constructing houses in the past, most traditional houses are scattered in the peri-urban areas of the cities and in rural areas throughout the country. Some are fairly new, having been constructed in the last few decades, while a number were built more than a century ago. As these houses are growing old and 'antique' with time, it is becoming necessary to evaluate their maintenance to determine whether repair and replacement are required. This must be done to keep the houses functioning as well as to provide safety for the occupants. In addition, these traditional houses also have significant potential to be regarded as part of national heritage. We must try to realise this potential.

This research focuses on establishing the criteria to be used to evaluate timber defects for traditional houses. To date, very few studies have been published focusing specifically on rating these traditional houses. One significant effort was made by Syed Zainal (1995) through Badan Warisan Malaysia (Malaysian Heritage Trust); this study provides some valuable criteria in assessing which buildings should be classified as national heritage. This effort, however, focuses more on town buildings and colonial types of houses. A rating criteria was performed by Pitt (1997) and Alani *et al.* (2001), which actually inspired this research. Pitt (1997) and Alani *et al.* (2001) had come out with a rating criteria that is generally acceptable to be applied for any type of building, whereas Syed Zainal (1995) provides the criteria that is specifically designated to assess the performance of town buildings and colonial houses. With the aim of linking the gap, this research concentrates on providing criteria to be used when evaluating timber defects via building condition survey work and part of it is modified from Pitt (1997) and Alani *et al.* (2001). Apart from a descriptive survey, we try to develop a priority ranking system using numerical data for coding and analysing. The system also depicts the overall building condition and provides a severity index for each identified timber defect.

BRIEF DESCRIPTION OF KHMER TRADITIONAL HOUSES

Since as far back as 1800 to 1300 BC, Khmer houses have been constructed with a raised floor and rounded ends. Binding techniques were adopted to tie the building structures to one another (Tainturier, 2006). From around the 12th century, the jointing method was developed, in which a type of mortise-and-tenon replaced the binding technique. The jointing method is visible in the pile-built houses on bas reliefs at Bayon temple (Tainturier, 2006). For roof covering, thatching was used for 'commoners' houses, while palaces and high-ranking peoples' dwellings were tiled.

Following the features of traditional houses in south-east Asia, the Khmer house also has a multi-levelled floor and gable finials at both ends of the roof ridge. The hipped (or *limas*-style) and gabled roof in Cambodia resembles many examples identified in the Malaysian states of Terengganu and Kelantan, as mentioned by Tainturier (2006), making Malay influences significant during Cambodia's modern history. The originality of such influences is, however, debatable and should be researched thoroughly. Returning to the traditional Khmer house, an example of the roofing and flooring system is shown in Figure 1.

Figure 1: Roofing (left) and flooring (right) system for a traditional Khmer house (Sokol, 2006)

Figure 2: Model of a traditional Khmer house in Khmer village model villa

The timber species used for monastery buildings and royal residences is *kokir* (*Hopea odorata*). For commoners, several types of timber are used. Tainturier (2006) stated that for columns, the types are *kakah* (*Sindora cochinchinensis*), *tbaeng* (*Dipterocarpus obtusifolius*) and *sokram* (*Xilia dolabriformis*), while for woodwork *sralao* (*Lagerstroemia ovalifolia*) is used, and roofs, floors and walls are made of *phcoek* (*Shorea obtusa*), *kakah* or *khvao* (*Adina cordirolia*). The model of a traditional Khmer house as built by the Government of Cambodia, located in Phnom Penh, is shown in Figure 2.

SAMPLE HOUSES — CASE STUDY

Two houses were selected for this case study. Both are more than 120 years old and are located in Kandal province, about 100km from Phnom Penh (1 h by car). Figure 3 shows the location of Kandal province.

Located less than 70m from Mekong River, both of the houses have good views. Although the temperature is around 30°C, the location provides a fresh breeze from the river. Figure 4 shows pictures of the two houses.

Figure 3: Location of Kandal province (red circle) (Google Earth, 2006)

Figure 4: Khmer house 1 (left) and 2 (right)

Following past tradition, both of the houses share similar structures, namely post-and-beam. Bamboo wickerwork and wooden panelling are adopted as wall finishes for Houses 1 and 2, respectively. A tiled roof forms the roof covering for House 2, while House 1 has been changed to corrugated galvanised steel sheeting from its original thatching. As observed in the photo of House 2, there are gable finials at both ends of the ridge, indicating that the house did not belong to commoners. This is supported by the use of wooden panelling and a tiled roof. This is not seen in House 1. Furthermore, the type of timber used for House 1 is *phcoek*, which was normally used for commoners (Tainturier, 2006). These observations indicate that the case study covers both the houses of commoners and those of high-rank people. In terms of age, the presence of rounded columns confirms that both houses are older than 100 years, supporting claims by current residents. Tables 1 and 2 summarise the building information for both houses.

Table 1: Building information of Khmer Traditional House 1

No.	Category	Description
1	Building name	Khmer Traditional House 1
2	Building category	Residential — commoner
3	Building age	122 years (by 2008)
4	Year built	1886
5	Year renovated	1970 (approximately) — replaced with new materials, particularly finishes
6	Custodian names	Cheam Luy and Men Tem
7	Country	Cambodia
8	Timber type	Mostly in <i>phcoek</i> (<i>Shorea obtusa</i>)
9	Building system	Post-and-beam
10	Special features	Age
11	Building height	Total height is 5.5 m
12	Floor area	9 m×5 m=45 m ²

Table 2: Building information of Khmer Traditional House 2

No.	Category	Description
1	Building name	Khmer Traditional House 2
2	Building category	Residential — high rank
3	Building age	142 years (by 2008)
4	Year built	1866
5	Year renovated	Not applicable
6	Custodian name	No information
7	Country	Cambodia
8	Timber type	Mostly <i>kokir</i> (<i>Hopeo odorata</i>)
9	Building system	Post-and-beam
10	Special features	Age
11	Building height	Total height is 7 m (see sketch in this box)
12	Floor area	11.8 m×6 m=70.8 m ²
13	Technical sketches	Perspective (upper) and space arrangement (lower)

SURVEY AND RESEARCH APPROACH

The condition survey was done for both traditional Khmer timber houses. The people of Khmer generally stay outside during the day, making the condition survey work go smoothly with only surveyors inside the houses. People often sit together under the house and mingle with their neighbours. For House 1, the only area excluded was the bedroom. All other spaces were covered from ground level up to the roof beam, except for the roof structure. The same process was used for House 2.

The survey was carried out within two days in clear weather in November 2006. Visual inspection forms the main approach during the survey. Lee (1987) stated that in most cases, the method of visual examination by the experienced surveyor is fair enough in identifying the defect causes. A preliminary inspection is performed by walking around externally and internally, before proceeding with the detailed examination, as suggested by Hoxley (2002) and Johnson (2002). The building inspection is started from the exterior, from the outside-in. Figure 5 and Table 3 show the pro forma survey checklist and reference terms used, respectively. The checklist is very important in ensuring that the report is safely prepared (Hollis and Gibson, 2000). Apart from basic surveying tools, the surveyor also uses power tools, as listed below:

(a) *Laser technology (Impulse 200)*

Laser technology is used to measure any point of height in the building, particularly from ground level to ridge cap, in which the height cannot be determined by the

No.	Const. Element	Design and/or Const.	Building Survey		Prioritise Ranking					P.SM		Reference		Remarks
			Defect Diagnosis		(Refer TOR)					Measure	Search	Drawing	Photo	
			Causes	Types	(if any)					Mode	Mode			

Guidelines:

1 "Causes" code	1 Insects 2 Fungal 3 Weathering	4 Mechanical Failure 5 Others	3 Prioritise Ranking a Physical Condition b Fabric Effect c User Effect d Potential Risk e Risk Effect
2 "Types" code	1 Termites-Subterranean 2 Termites-Drywood 3 Termites-Others 4 Beetles 5 Other insects 6 Wet rot (brown) 7 Wet rot (white) 8 Dry rot 9 Soft rot 10 Blue stain 11 Other rot 12 Other defects		4 P.SM (Protimeter SurveyMaster SM) [Measure=Surface; Search=Below] L = Low : H=High

Figure 5: Condition survey checklist for timber defects

dimension master because the end-point target for reflection is not parallel to the instrument (dimension master). Height measuring is adapted from a simple geometric concept, namely triangulation formed by the object, that is, the ridge cap, the ground and the instrument.

(b) *Protimeter Survey Master MM*

A protimeter is used to identify the surface and internal moisture content of the timber element. The work is done in two modes, measure and search: the first indicates the moisture using the digital reading and the latter provides a colour-coded indication: green, yellow or red. Both measure and search mode will refer to the simple diagnosis chart shown in Table 4 to determine whether the timber member has a condensation defect, rising dampness or no defect at all.

Data are mostly collected in the form of numerical coding. With reference to Figure 6, the latter section of the survey pro forma indicates the information required to calculate the sum of timber defects in order to determine its priority. Two types of data must be collected: physical and risk data. Physical data deal with the current condition of the building at the time the survey is conducted, while risk data are associated with the potential hazard to the building, particularly risk of structural damage, which in turn leads to safety and health problems (if the building is occupied).

The physical and risk data are subdivided into five categories, with three and two types, respectively, as per Figure 5. The total score is 17, with a lower score having higher priority. Both of the data (physical and risk data) are then summed to get a ranking of defect priority. Finally, the building is rated as one of three conditions: Condition 1: Dilapidated; Condition 2: Fair or Condition 3: Good. The linguistic value and average ranking number of these three conditions is given in Table 5. The results of the condition surveys are presented in the next section of this paper.

ANALYSIS AND DISCUSSION

During the course of the survey, the ventilation metre indicated a surrounding temperature of 30°C, with an air velocity of 0.1 m/s. This shows that there may be low moisture

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 within the period of 1 month	Element/structure not functional at all
		1	Repair or replacement is needed within the period of 1–6 month(s)	Serious defect, cannot functional to an acceptable standard
		2	Repair or replacement is needed within the period of 6–12 months	Functional sound, but need an urgency repair or replacement
		3	Repair or replacement is needed within the period of 1–2 year(s)	Structurally functional, only minor defects
		4	No need for repair or replacement	Free from any visible defects
2	Fabric effect	1	Significant effect	If one particular 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	
3	User effect	1	Significant effect	If one particular 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 effect	1	Death or serious injury	Risk for structural damage, which in turn can lead to death or injury
		2	Injury	
		3	Minor injury	
		4	No risk associated	

Table 4: Simple diagnosis chart for Protimeter Survey Master MM

Measure mode	Search mode	Interpretation and comment
Low reading	Low reading	Dry surface, dry below the surface — safe
Low reading	High reading	Dry surface, damp below the surface. Investigate further using Deep Wall Probes in Measure Mode
High reading	Low reading	Damp surface, dry below the surface — probable condensation
High reading	High reading	Damp surface, damp below the surface. Trouble. Investigate further with Deep Wall Probes

Source: Protimeter.

content, providing a dry surface for the whole site. The condition survey is done separately for traditional houses and therefore the analysis is also presented independently. Similarities and differences are highlighted in the summary.

Traditional Khmer House 1

Table 6 shows the results of the condition survey for House 1; it should be read concurrently with Figure 7 to locate defects easily. Twelve timber defects are identified. Insect attacks, specifically beetles, are the most common, followed by other types of rot. Termite attacks were found once. The defects are mostly found in the exterior parts of the houses.

For the analysis of timber defect priority rankings, the lowest total is eight, while the highest recorded is the greatest possible, 17. Priority should be given to the lowest score. In this condition survey, the column at the back (grid 15, according to floor plan) has serious defects caused by weathering; the type is other rot (see defect number 6 in

Figure 6: Data required in developing the timber defects priority ranking system (modified from Pitt, 1997)

Table 5: Condition assessment of the building

Condition	Linguistic value	Average marks
Condition 1: Dilapidated	√ Not safe for occupancy	04–09
Condition 2: Fair	√ Sign of defect in structural member (no effect on building stability) √ Needs repair or replacement	10–13
Condition 3: Good	√ Main structural member is strong and stable √ Defects that influence aesthetic value only	14–17

Table 7). The score for this defected column is 8 with an occurrence number of 1. The second serious defect with a total mark of 9 is caused by various agents: insect, fungal and weathering. According to Table 7, almost all defects found are located within the main structural member, except for the door and staircase.

The moisture content for the defective timber elements is also shown in Table 6, given under column P.S.M. Particular attention should be given to H (high) scores, regardless of whether the score is under measure or surface mode. Based on the survey results, the column in grid 15 indicates high readings for both the measure and surface modes. With reference to the Protimeter simple chart as per Table 4, damp surface conditions as well as below the surface make trouble for the defective column. In such situations, Deep Wall Probes should be used for further investigation, so as to confirm whether the defect is

Table 6: Analysis of building survey and priority timber defects for Khmer Traditional House I, Phnom Penh, Cambodia

No.	Construction element	Design and construction	Building survey defect diagnosis	Timber defect priority ranking system							P.S.M	References	Remarks		
				Causes											
				Types			a	b	c	d		e		Total marks	Priority ranking
1	Door	Fixed louvered timber with two door leaves (jointing without nail)	1	4	3	2	3	3	4	15	4	L	L	—	Near staircase
2	Column-u/neath (2)	250mm diameter round column	1	4	3	2	2	3	4	14	3	L	L	—	Front
3	Column-u/neath (4)	Round column	1	4	3	2	2	3	4	14	3	L	L	—	Back
4	Staircase	Not applicable	1	4	4	3	3	3	4	17	6	L	L	—	Front
5	Column-u/neath (1)	250mm diameter round column	3	11	3	3	3	3	4	16	5	L	L	—	Front
6	Column-u/neath (15)	250mm diameter round column	3	11	2	1	2	2	1	8	1	H	H	—	Back
7	Floor joist (1–5)	Double-beam	1	2	2	1	2	2	2	9	2	L	L	—	Outer beam
8	Floor beam (1–5)	Double-beam	2	8	2	1	2	2	2	9	2	L	L	D1/D2	Outer beam
9	Floor beam (1–5)	Double-beam	1	4	2	1	2	2	2	9	2	L	L	D1/D2	Outer beam
10	Floor beam (1–5)	Double-beam	1	4	2	1	2	2	2	9	2	L	L	D1/D2	Outer beam
11	Floor beam (1–5)	Double-beam	2	8	2	1	2	2	2	9	2	L	L	D3	Inner beam
12	Floor beam (1–5)	Double-beam	3	4	2	1	2	2	2	9	2	L	L	D4	Inner beam
Condition assessment										Total	138				
Average = 138/12 marks										12	(Condition 2: Fair)

Figure 7: Floor layout of House I (all dimensions recorded in metres)

caused by condensation or rising dampness. These were not carried out because the owner did not allow for any destructive testing.

After prioritising each timber defect found, it is important to consider the overall condition of the house, that is, whether it is dilapidated, fair or good. This finding is much more useful for the safety of the occupants of the house. According to the rated scores of five types of data used in determining the timber defect priority ranking system, we extended the calculation to get a total average mark to rate the condition. The analysis reveals an average score of 12, indicating a fair condition (see the classification in Table 5). The calculation is shown in the bottom part of Table 6.

Further analysis has to do with the level of severity of each timber defect. This is determined by calculating the severity index. Two types of data are required, namely the frequency and the average score of risk effect for each particular defect. The frequency is determined by referring to the number of defects in the ‘defect diagnosis-types section’

Table 7: Analysis of severity index for Khmer Traditional House 1, Phnom Penh, Cambodia

Types of defects	'Types' code	Frequency	Frequency (%)	Average score of risk effect*	Accumulate multiplier	Severity index	Severity index (%)
Termites–drywood	2	1	8.33	2	0.75	6.25	11.11
Beetles	4	7	58.33	3	0.50	29.17	51.85
Dry rot	8	2	16.67	2	0.75	12.50	22.22
Other rot	11	2	16.67	3	0.50	8.33	14.81
Total		12	100.00			56.25	100.00

*Cross-reference			
Risk effect	Score	Multiplier	Accumulate multiplier
	1	0.25	1.00
	2	0.25	0.75
	3	0.25	0.50
	4	0.25	0.25

(as per Table 6). At first, the frequency is translated into percentage form. The average score of risk effect is then matched with the cross-reference table to get the accumulate multiplier. The accumulate multiplier is used to weight the average score of the risk effect, with 0.25 assigned for each score. In interpreting the result, a higher percentage indicates a more severe defect. More precisely, we assigned four escalating numerical values to the severity index: 0–25 per cent is not severe at all, 26–50 per cent is not very severe, 51–75 per cent is severe and 76–100 per cent is very severe. The formulation of the severity index is shown below.

$$\text{Severity index} = \text{Frequency (\%)} \\ \times \text{Accumulate multiplier of risk effect}$$

Based on Table 7, which analyses the severity index, the highest percentage is found to be around 52 per cent for beetles. The second highest is dry rot, with 22.22 per cent, and the lowest is around 11 per cent. From this finding and with reference to its numerical value, beetle attack is classified as a severe defect for Khmer Traditional House 1. Particular attention should be paid to this specific defect. The other three types of defects are considered not severe at all, since the severity index provides scores below 25 per cent. The finding of the severity index confirms and supports the score of condition assessment, which is good. It is important to mention here that the severity level for beetle attack represents its frequency of occurrence and not the stability of the house as a whole. In other words, beetle attack is important when discussing which deteriorating agent is attacking the house most and its level of attack (severity), or in questioning format, how severely is one particular defect attacking the house. From the survey and research conducted, the main finding is given below.

- (1) Element to be repaired (in order of priority) — for details see Table 6
 - (a) Column (underneath) at grid 15;
 - (b) floor beam (either outer or inner beam);
 - (c) column (underneath) either at grid 2 or 4;
 - (d) door near staircase;
 - (e) column (underneath) at grid 1; and
 - (f) staircase at front.

- (2) Overall condition assessment — Condition 2: Fair
- (3) Severity index — severe for beetle attack with a severity index of about 52 per cent.

Traditional Khmer House 2

The result of the condition survey for House 2 is shown in Table 8 and should be read concurrently with Figure 8 to easily locate defects. Fifteen timber defects are identified. According to the frequency, insect attacks, specifically beetles, are the most common, followed by termites. House 2 was free from defects caused by fungal infestation at the time of the survey. The survey shows that insect attacks remain the main cause of timber defects, since more than half of the defects fall within this category. Apart from insect attacks, weathering also causes defects. The defects are mostly located in the exterior part of the house.

For the timber defect priority ranking, the lowest total mark is 9, while the highest is 16. Priority should be given to the lowest score. In this condition survey, the staircase is found to have serious defects caused by beetles and termites, and the primary type of defect is insect attacks (see defects number 1 and 2 in Table 8). The score for this defective staircase is 9 with an occurrence number of 2. The second serious defect, with a total mark of 11, is caused by termites and beetles. Other than this defect, weathering, with a rank of 4, is most common, as are timber defects, in second position.

The results of moisture content for defective timber elements are also shown in Table 8, listed under column P.S.M. Particular attention should be paid to H (high) scores, regardless of whether the score is under measure or surface mode. Based on the survey results, none of the timber defects recorded have high scores for both measure and search mode. With reference to the Protimeter simple chart, as per Table 4, dry conditions of the surface as well as below the surface indicate that the timber member was free from any dampness defects at the time the survey was conducted.

After prioritising each timber defect found, it is important to consider the overall condition of the house: whether it is dilapidated, fair or good. This finding is very useful for the occupants of the house in terms of safety. Using the scores of five types of data in determining a timber defect priority ranking system, this research has extended the calculation to get a total average mark to assess the condition. The analysis reveals an average score of 13, indicating a Fair condition (see the classification in Table 5). The calculation is shown at the bottom part of Table 8.

Further analysis has to do with the level of severity of each timber defect. This is determined by calculating the severity index. Two types of data are required, namely the frequency and the average score of risk effect for each defect. The frequency is determined when the survey is completed by referring to the number of defects in the 'defect diagnosis-types section' (see Table 8). At first, the frequency is translated into a percentage. Then, the average score of risk effect is matched with the cross-reference table to get an accumulate multiplier. The accumulate multiplier is used to weight the average score of risk effect, with 0.25 assigned to each score. In interpreting the result, a higher percentage indicates a more severe defect. More precisely, we assigned four escalating numerical values for the severity index: 0–25 per cent is not severe at all, 26–50 per cent is not very severe, 51–75 per cent is severe and 76–100 per cent is very severe.

Based on Table 9, which analyses the severity index, the highest percentage is found to be around 73 per cent for beetles. The second and last types of defects are both calculated

Table 8: Analysis of building survey and priority timber defects for Traditional Khmer House 2, Phnom Penh, Cambodia

No.	Construction element	Design and construction	Building survey defect diagnosis		Timber defect priority ranking system					PSM		References	Remarks		
			Causes	Types	a	b	c	d	e	Total marks	Priority ranking			Measure mode	Search mode
1	Staircase	Timber straight-run stair with handrail at both sides	1	4	2	2	2	1	2	9	1	L	L	—	Holes in the timber
2	Staircase	Timber straight-run stair with handrail at both sides	3	3	2	2	2	1	2	9	1	L	L	—	Hole and crack in the timber
3	Column-u/neath (2c)	250 mm diameter round column	3	4	3	3	3	3	4	16	4	L	L	—	Vertical crack
4	Column-u/neath (3d)	250 mm diameter round column	3	4	3	3	3	3	4	16	4	L	L	—	Vertical crack
5	Column-u/neath (4e)	250 mm diameter round column	3	4	3	3	3	3	4	16	4	L	L	—	Vertical crack
6	Column-u/neath (4g)	250 mm diameter round column	3	4	3	3	3	3	4	16	4	L	L	—	Vertical crack
7	Column-u/neath (3c)	250 mm diameter round column	3	4	3	3	3	3	4	16	4	L	L	D5	Holes
8	Floor beam (3a to 3b)	Single beam	1	4	2	2	2	3	2	12	3	L	L	D6/D7	—
9	Sub-flooring	Timber strip flooring	1	2	2	2	2	2	3	11	2	L	L	—	Living room
10	Sub-flooring	Timber strip flooring	1	4	2	2	2	2	3	11	2	L	L	—	Living room
11	Window	Fixed louvered timber panel (two panels)	3	4	3	3	3	3	4	16	4	L	L	—	—
12	Wall board	Plywood	1	2	2	2	2	2	3	11	2	L	L	—	Living room
13	Wall board	Plywood	1	3	2	2	2	2	3	11	2	L	L	—	Bedroom
14	Roof	Truss	1	4	2	2	2	2	3	11	2	L	L	—	—
15	Roof	Rafter	1	4	2	2	2	2	3	11	2	L	L	—	—
Condition assessment										Total	192				
Average mark = 192/15										13	(Condition 2: Fair)

Figure 8: Floor layout of House 2 (all dimensions recorded in metres)

at about 13 per cent, reflecting equal frequencies. From this finding, beetle attack is classified as a severe defect for House 2; particular attention should be paid to this specific defect. The other two types of defects are considered not severe at all since the severity index provides a score below 25 per cent. The finding of the severity index is confirmed and supported by the condition assessment, which is Good. It is important to mention here that the severity level for beetle attack represents its frequency of occurrence and does not reflect the stability of the house as a whole. In other words, beetle attack is a deteriorating agent that is attacking the house most and it has a level of attack (severity), or in questioning format, how severely is one particular defect attacking the house? For quick identification, the main finding of the survey and research is given below.

Table 9: Analysis of severity index for Traditional Khmer House 2, Phnom Penh, Cambodia

Types of defects	'Types' code	Frequency	Frequency (%)	Average score of risk effect*	Accumulate multiplier	Severity index	Severity index (%)
Termites—drywood	2	2	13.33	3	0.50	6.67	13.33
Termites—others	3	2	13.33	3	0.50	6.67	13.33
Beetles	4	11	73.33	3	0.50	36.67	73.33
Total		15	100.00			50.00	100.00

*Cross-reference			
Risk effect	Score	Multiplier	Accumulate multiplier
	1	0.25	1.00
	2	0.25	0.75
	3	0.25	0.50
	4	0.25	0.25

- (1) Element to be repaired (in order of priority) — for details see Table 8
 - (a) Staircase;
 - (b) either subflooring, wall board or roof structure;
 - (c) floor beam; and
 - (d) either column (underneath) or window.
- (2) Overall condition assessment — Condition 2: Fair
- (3) Severity index — severe for beetle attack with a severity index of about 73 per cent.

Summary of timber defects for case study of Khmer traditional houses

This section discusses in detail the timber defects for Khmer traditional houses. Most of the timber defects are recorded externally rather than internally. In terms of the number of defects recorded, House 1 had 12 defects recorded and House 2 had slightly more (15). Beetles are the main cause of all defects found. This statement agrees with the finding obtained from calculating the severity index. The level of severity for beetle attack is severe for both houses. For moisture content, House 1 recorded a high reading for surface material as well as below the surface, which represents a risk for the defective element, namely one of the rounded columns. This finding is in contrast to House 2, in which no moisture readings are high enough to cause any of the timber defects identified.

Both houses have fair overall condition assessments, with scores of 12 and 13 for Houses 1 and 2, respectively. These scores fall within Condition 2: Fair, as shown in Table 4. This assessment is a sign of the true building condition when looking at the house with the naked eye, thus providing vital information to a layperson. It also confirms that the defects found do not affect the stability of the houses at the time the survey was conducted, but merely that some degree of attention should be paid to a number of defects that are expected to cause structural deterioration if left unattended for some time, particularly timber defects, which have first rank for both houses. In summary, even though the defects recorded are many, they do not endanger the houses.

CONCLUSION

Traditional Khmer houses are significant for the people of Cambodia. Two houses were selected for a case study. We carried out a building condition survey so as to develop a timber defect priority ranking system. The system also provides an assessment of the overall building condition in terms of building stability, as well as a determination of

the severity index for each type of defect. These two houses belonged in the past to commoners and high-ranking people for Houses 1 and 2, respectively.

The building condition survey reveals that both houses are still in good condition and are classified as Fair, which means safe for occupancy. Nevertheless, repair or replacement is needed to ensure that the defective elements do not become worse over time, which may result in loss or injury. For maintenance purposes, the owner of House 1 should give priority to repairing the rounded column in grid 15, while for House 2, priority should go to the staircase. In terms of the severity level, which represents total number of defect occurrences, both houses are attacked most by beetles. The level of attack is considered severe since the percentage of the severity index is within 50–75 per cent for both houses. The other types of defects, that is, termites and rot, are found to be not severe at all.

The limitation of this research is the reliability of the ranking system. Khmer traditional houses form one of the pilot projects for the system; it is likely that the findings do reflect the current states of the houses. More buildings should be surveyed using this system to evaluate the system reliability. Therefore, further research should include carrying out building condition survey work, particularly for traditional timber houses. In addition, architectural influences should also be researched thoroughly so as to anticipate any significant relations in terms of building design between Cambodian and Malaysian (specifically the houses of Kelantan and Terengganu) traditional houses, as cited by one research scholar (see Tainturier, 2006).

References

- Alani, A.M., Petersen, A.K. and Chapman, K.G. (2001) 'Applications of the developed quantitative model in building repair and maintenance — case study', *Journal of Facilities*, 19(5/6), 215–221.
- Google Earth. (2006) 'Satellite image of Phnom Penh Online: <http://earth.google.com>, accessed 15th December, 2006.
- Hollis, M. and Gibson, C. (2000) *Surveying Buildings*, 4th edn, RICS Books, Coventry, imprint.
- Hoxley, M. (2002) 'Condition inspections of residential property: a procedural framework', *Journal of Structural Survey*, 20(1), 31–35.
- Johnson, R.W. (2002) 'The significance of cracks in low-rise buildings', *Journal of Structural Survey*, 20(5), 155–161.
- Lee, R. (1987) *Building Maintenance Management*, 3rd edn, William Collins Sons & Co. Ltd, UK, reprinted by Blackwell Science.
- Pitt, T.J. (1997) 'Data requirements for the prioritization of predictive building maintenance', *Journal of Facilities*, 15(3/4), 97–104.
- Protimeter (n.d.). *Protimeter "Compleat" Dampness Kit MK II: Detailed Instructions for All the Instruments & Accessories Included In The Kit*, PROTIMETER plc, England, p. 11.
- Sokol, H. (2006) 'Sacred and Profane wooden architecture', in Tainturier, F. (ed) *Wooden Architecture of Cambodia: A Disappearing Heritage*, Center for Khmer Studies. Published with the support of the Rockefeller Foundation, New York, pp. 38–45.
- Syed Zainal, A.I. (1995) *Pemeliharaan Warisan Rupa Bandar (Conservation of Town Heritage)*, Badan Warisan Malaysia, Kuala Lumpur.
- Tainturier, F. (2006) 'Building in wood: notes on a vanishing age-old tradition', in Tainturier, F. (ed) *Wooden Architecture of Cambodia: A Disappearing Heritage*, Center for Khmer Studies. Published with the support of the Rockefeller Foundation, New York, pp. 12–37.