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Traditional Responses of Moisture Related Decay Mitigation in Timber Architecture of Travancore (Kerala) – A Search into the Traditional Knowledge Base

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ABSTRACT: Traditional timber buildings of Kerala in S. India can be dated back to 1600's with the wooden palace '*ThaiKottaram*' (mother palace) at Padmanabhapuram as the oldest representative of an indigenous tradition in timber construction. Most of these strictly adhere to '*Taccusastra*', the science of carpentry which may be considered as a regional version of *Vastusastra*. This indigenous knowledge in wooden craftsmanship was transmitted through generations in the form of tradition. Moisture stimulates biological activity and acts as catalyst through which reactions occur on timber. Whether there is appropriate design and construction measures employed in traditional timber architecture of Travancore (either in the traditional theory or in practice), to neutralize the deleterious effects of moisture was not investigated in depth earlier. Focusing on this, the research paper seeks to make a scrupulous study of traditional timber architecture built according to '*Taccusastra*', to explore into the 'traditional responses' of timber architecture in tolerating the deleterious effects of moisture.

1 INTRODUCTION

Traditional timber architecture forms a repository of the insight, wisdom and knowledge of the previous generations. Imbued with a message from the past, it preserves not only, the traces of the history of design and construction of timber buildings, but also, the craftsmen's understanding of the logic and nature of wood, as a building material: the strength of which, lies in the fact that it is often over centuries, well tested, which is indeed, a sufficient guarantee for their reliability and durability (Larsen and Marstein 2000). "Uncontrolled moisture is the most prevalent cause of deterioration in older and historic buildings" (NPS Brief) and timber, has the tendency to move markedly and fairly quickly, and deteriorate faster with changes, occurring due to moisture accumulation. Moisture stimulates biological activity and acts as medium or catalyst through which reactions occur on timber. Good design measures are therefore, essential to keep moisture out of the building, but when these measures are inadequate, dampness enter the building materials to cause their deterioration.

Most of the traditional timber buildings of Travancore strictly adhere to the canonical practices of '*Taccusastra*', the science of carpentry (a regional version of *Vastusastra*). This indigenous knowledge in wooden craftsmanship was transmitted through generations in the form of tradition. But most of the times, this knowledge carried by traditional craftsmen is regarded as purely practical skills[3]. Timber, though a perishable building material, if correctly produced, processed and finished, and rightly used in construction, can bear living testimony to many generations as it has been well evinced through the surviving timber palaces of Travancore.

2 THE ARGUMENT

Many argue that the traditional techniques are outdated without seeing the underlying wisdom and strength. There was a definite school of practice of traditional construction, which has lead to the formulation of a strong vocabulary of timber architecture guided by the traditional canonical practices of the region. The argument put forth in this technical paper is that, the traditional timber architecture of Travancore has some inbuilt mechanisms by which they could tolerate the deleterious decay effects induced by moisture accumulation, a specific feature of the warm humid climatic conditions of the region, without which these structures wouldn't have existed for so long, over centuries. The availability of legitimate products of highly developed traditional architectural knowledge base in timber construction, expertise of traditional craftsmen, and traditional literature in the form of treatise on *taccusastra* along with the warm humid climate, a strong determinant of timber decay due to moisture, makes Travancore an ideal laboratory for delving into an enquiry related to traditional timber construction.

3 THE RESEARCH QUESTIONS

The research questions formulated building up on the issue are:

1. Are there *specific construction methods* followed in Traditional Timber Architecture to tolerate the deleterious effects of moisture?
2. What is the *pattern of decay* due to moisture that occurs in traditional timber buildings of Travancore?
3. What is the *potential role of Traditional timber construction practices* in mitigating the decay effects due to moisture?

4 THE GENERIC BUILT FORM – *KOTTARAM* (PALACE)

The traditional builtform 'kottaram' could be a single chathurshala, a courtyard house, having four structurally independent shalas (four ekashala units) aligned around a courtyard, (nalukettu), double chathurshala (ettukettu), triple chathurshala (panthrandukettu) or a combination of four chathurshalas (pathinarukettu). A kottaram, whether it is a nalukettu, ettukettu, panthrandukettu or pathinarukettu is seldom found as an isolated structure but in combination with ancillary structures like padippura (gatehouse), thevarappura (bathhouse), homappura (house for pooja and associated rituals), etc., for ensuring security and facilitating the customary practices according to specific description and details as stipulated in the traditional treatises. For the sake of manageability, only the main Kottaram is studied in this research, assuming that the best of materials, construction techniques and human efforts were contributed to the making of the main structure. To understand the magnitude of such a multidimensional architectural knowledge, one has to perceive knowledge, as embodied in the architectural vocabulary of the traditional buildings at one level, as crystallized in traditional treatises at the second and as instilled in the craftsmen by transmission of tradition through generations and their hands own experience at the third level. Hence analysis is done at three levels in order to answer the research questions.

1) Architectural analysis of the built form to rediscover the traditional construction methods and practices.
2) Decay analysis of the various components constituting the built form to find the existence of any specific pattern of decay.
3) Analysis of the traditional practices to verify the role of theory in practice and vice versa and in mitigating the decay effects due to moisture.

5 ARCHITECTURAL ANALYSIS OF THE BUILT FORM

To validate the argument that the traditional timber constructions of Travancore incorporated good design measures that have helped them in tolerating moisture, the architectural analysis of the selected built form is conducted at site, building and component levels, interpreting its moisture relations with respect to Environmental and Constructional influences. The analysis of the various environmental influences is followed by a detailed analysis of the architectural components of the palace and the moisture relations, which is conducted with in a narrative framework, describing the components first, and then their moisture relations, analysing the quality and suitability of design, through the process of logical argumentation.

5.1 Environmental influences on the built form

The climatic index for the region is derived from the temperature and precipitation data for the years 1838-64 and 1990- 2004, (Meteorological data 1990-2004) using the formula,

$$\text{Climate index (Scheffer 1971)} = \sum_{January}^{December} \frac{[(T-2)(D-3)]}{16.7} \tag{1}$$

where, T is the mean monthly temperature (°C); D, the mean number of days in the month with 0.01 inch or more of precipitation. Accordingly for the years 1838-64, the annual climatic index is found to be 142.54 and that for 1990- 2004, 153.90, which appear to be much above the conditions most conducive to timber super structure decay. Theoretically, wood undergo minor changes in dimension, along with the normal changes in relative humidity (Brundrett 1990). The humidity of the region is of the range from 72 % to 87 %, throughout the year without much variation. Hence, there are chances for variation in the dimension of timber components. But, the temperature variation is from a minimum of 26.4 ºC (July) to a maximum of 29.4 ºC (May), and is fairly consistent. In such a situation, the moisture content of the timber in service falls with in the safe limit, where decay due to fungal propagation is impossible. This could be one probable factor, determining the life of timber (Burch Thomas 1991) in spite of the higher range of humidity, in the region. The rainfall of the region is comparatively high ranging between 1000 - 1650 mm (1991-2004) starting from the end of May through June, July till mid of August and in general, goes up to 400 mm, characterised by the southwest monsoon. A similar, but less intense rainfall distribution is found during the months of October and November (300 mm), characterised by northeast monsoon. The statistics shows the occurrence of moderate rainfall throughout the year, which aid in decay of timber components of the structure. The driving rain index shows a moderate grading i.e., 3.84 m^2/sec with an annual rainfall of 1400 mm and an annual wind speed of 2.4 m/sec.

The annual wind velocity of the region is 2.4 m/sec. When wind blows obliquely, it creates an average air velocity of 0.84 m/s indoors. Air movement is further, facilitated by the configuration of trelliswork supported on brackets, doors and windows along the walls forming a semi open enclosure with a total void space of 62.5 % to 68.4 %. So there is sufficient cross ventilation induced by the constant southwest winds as well as the microclimatic breezes. In the monsoon seasons, wind has a tendency to propel the rain to penetrate into openings in the structure. The external wooden enclosures of the palaces are mostly protected by adjoining buildings, reducing their exposure to external environment on these sides. The frequency of moisture problems is also directly related to occupant density (Wolde and Rose 1994). The palaces selected for study are reused as museums and so; they have floating population of an average of 100-300 tourists per day. The tourists are permitted in a group of 10 to 15, accompanied by a guide. Hence the amount of moisture load that can accumulate indoors, due to the occupancy load, is very negligible and does not account for any decay of indoor timber components. None of the intended original services of these buildings are activated and hence, doesn’t contribute to any physical decay of the structures due to moisture.

5.2 Architectural and Constructional influences of the built form

The traditional palaces of Travancore are usually single or double storied *nalukettu* (single *chathurshala*) or double *chathurshala* (*ettukettu*), triple *chathurshala* (*panthrandukettu*) or a combination of four *chathurshalas* (*pathinarukettu*) (Koduveliparambil 1997) with mortar less chiselled granite base, timber superstructure and steeply sloping timber roof covered with mangalore tiles. They strictly adhere to the traditional building code, the "*Taccusastra*" and can be viewed as the progeny resulting from the marriage of traditional building technology, exquisite craftsmanship and superior knowledge of material science (Desai 2001). The basement (*Adisthana*) is mortarless chiseled granite masonry made up of granite slabs of highly impervious variety, in two or three layers without vertical joints. This prevents upward movement of moisture (through rising dampness) from the ground as the granite base, functions like a strong barrier to moisture infiltration from the ground level. The Courtyards (*Ankanam*) sloping either to the east or west are equipped with drains, facilitating rainwater flow towards the exterior of the building to the pond located in the east or the north. Terracotta pipes made of granite stones are laid, to drain rainwater from the courtyard to the pond. The flooring is of granite slabs and hence there is no possibility of rainwater sinking down, affecting the foundation.

Exterior skeleton structures of the palaces are of wooden trelliswork, made up of vertical members of Anjili wood (*Artocarpus Hirsuta* or Aini). These trellisworks rest on an *Arapady* or *Keezhpady* (sill beam), of Teakwood (*Tectona Grandis*), which is resistant to all kinds of biological decay, when kept dry. As the granite slab below, permits no entry to rising dampness, the sill beam is always found dry. More over in case of wind driven rain, the wet sill beam gets dried fast, due to its exposure to external atmosphere, where there is higher temperature gradient. Above this, exists a series of brackets of Anjili wood with the lower portion fixed on to the middle tie member (*Nadumpady*) (see Fig. 1) and upper portion on to the wall plate. The spaces in between the brackets are filled with horizontal members '*pattika*' (reapers). The wooden trelliswork thus formed facilitates efficient flow of air through the building, keeping all the wooden members ventilated protecting them from biological decay, which would otherwise propagate in humid damp areas. Small windows (*Kilivathil*) along the courtyard side facilitate airflow as they are aligned either with a door or a window along the periphery. This ventilation helps the timber components to dry up at a faster rate in case of wetting due to wind driven rain. Few of the pillars (*sthambha*) along the courtyard side have bases and shafts made out of granite, while the others are completely of wood. In traditional practice, wooden pillars, were given solid stone base up to half the height of the shaft, either to provide a strong base or to prevent moisture accumulation, from ground, or through wind driven rain. Since the basement is made up of highly impervious granite, the possibility of moisture ingression through capillary rise from the ground should be ruled out. The stone pillars facing the south, south west or the west have an increased possibility of their bases (if made of wood) to be affected, by the wind driven rain falling at a steep angle, of the southwest monsoon.

The roof placed over the timber walls and trelliswork is also made out of timber with Mangalore tiles laid over. The height of the roof is fixed to be almost ½ the width so that it makes an angle of 42 degrees. The roof is the most significant element, which resists water in all forms and consists of elements like wall plate (*uttaram*), rafters (*kazhukkol*), ridge (*monthayam*), collar (*vala bandham*), and gable (*mukhapu*)[11]. The additional wall plate along the outer perimeter of the palace in the ground floor (*thadi uttaram*), on to which all the vertical members of the trelliswork are inserted, is of hard teakwood, with an additional wall plate *(chittutharam*) (refer Fig. 1.2) above. This additional wall plate is fixed to the main wall plate using wooden pegs (*kila)*. The rafters (*kazhukkol*), straight rafters as well as slanting ones are received by the additional wall plate, placed over the main wall plate. All the rafters are placed with head up and bottom down (according to the grains), which is a traditional practice, as there is a slight variation in weight and density in every lumber from head to bottom, even when the piece is absolutely uniform in size throughout. The rafters if placed upside down, with bottom on top and head down, will lead to structural failure due to uneven loading in a long run. They are all structural elements of the building transferring their self-load, as well as the load of the reapers and tiles of the roof, to the walls and columns. Since they are all of the same timber, and are in correct proportion with each other, fluctuations in humidity and temperature of the ambient air, will affect them uniformly. They fail only when, there is direct or indirect penetration of water through any part of the building. It is with a slope of 42^0 to normal, which wards off driving rainwater even when the rainfall is at an angle. The vertical drop (*kazhukkol thazcha*) of the eaves is 1 to 2 K (K – Kol, 1 Kol is 72 cm) deep from the lower level of the *thadi uthara*. This deep vertical drop protects the wooden trellis from direct rain. A deflection on every rafter end traditionally called as *jwala*, (1 A depression over a distance of 12 A, A = Angulam = 30 mm) exists along the edge, which provide a slight bent on the exterior end of the rafter forces the rainwater to sprinkle away from the roof edge. This protects the rafter edges from continuous wetting during rains.

The edge eave reaper (*thumbu vamada*) present all around the exterior perimeter of the building provides grip to prevent displacement and torsion of the rafters. This helps, in giving an upward tilt to the roof covering, at the tip, such that the water draining down from the roof is thrown away, preventing it from dripping along the edges. There is eave board (*thoovana-palakha* or *thoolimanam*) (Larsen and Marstein 2000) along the edge of the rafters fixed in such a way that its inner surface covers the exposed end grain surfaces of the rafters protecting the rafter ends, which are otherwise susceptible to decay due to moisture. The roof structure consists of a flat wooden ceiling (*Machu*), which is placed towards the inner side of the main wall plate connecting wooden joists, placed crosswise (Prabhu and Achyuthan 1998). Wooden cross-pieces are placed, connecting these joists with halved joints, with the cross pieces projecting into the beam to half the width of the latter. The top is leveled and covered with planks of suitable thickness without any crevices. The double roof (sloping roof and the flat false ceiling below) where the outer layer shades the inner building enclosure reduces heat accumulation. The heat that builds up between the two layers is carried away by cross ventilation. The temperature difference between the building interior and the ventilated air space is not so large, as to cause condensation problems. Moisture that penetrates through or develops beneath the outer skin evaporates or drips, along the inner surface to the eaves, leaving the inner roof layer unaffected by moisture. Roof tiles (*Mechil oodu*) form the first skin (layer), resisting the ingression of moisture into the building. They are kept in place, by providing reapers (*Pattika*), with width 17 *y* (6.375 cm) and thickness 9 *y* (3.375 cm), with a spacing of 35 cm center to center, which is sufficient enough to hold the roof tiles (y = yava, 1 yava is 0.375 cm).

There are different forces that can move moisture, through an opening in a wall or a roof. They are the forces of gravity, surface tension and air pressure differentials. The traditional construction techniques neutralise these forces that coerce moisture into a building by the method of providing wash, overlap, overhang, drip and rain shield assembly. The wash (slope given to a horizontal surface to drain water away from the vulnerable joint between the ground floor roof with the first floor wall, 3 A (9 cm) wide approximately, along with the projecting *Arapady* (sill beam) of the first floor provided all around the external perimeter of the structure neutralises the force of gravity and keeps water out. The adhering drops or even streams of moisture running down the roof or wall, is kept away from entering the building, by providing sufficient overhang. The deep vertical drop 1 K to 2 K wide and equally deep, serve as an overhang and protects the wall structure from direct penetration of rainwater. The roof tiles, keep water out by overlapping in such a way, that there is no direct path through or between them to let moisture force in. In laying the roof tiles, the higher surface is extended over half the surface of the lower tile, so that moisture moved in by the force of gravity cannot run behind or beneath the tiles. The ridge and the hip rafters are protected using '*kamathodu*' (ridge tiles), made out of the same material as the roof tiles (terracotta) and firmly bedded using lime mortar, forming a watertight seal. Edge eave reaper (*thumbu vamada*), running all around the exterior perimeter of the building, gives an upward tilt to the roof covering at the rafter end, such that the water draining from the roof, is thrown away preventing it from dripping along the edges, caused by surface tension. '*Jwala*', gives a deflection to the roof and forces rainwater to sprinkle away from the structure. Rainwater falling upon the few unprotected wooden parts is quickly absorbed by capillary action on the surface layer of wood, followed by adsorption within wood cell walls. The eave board protects the end grain surfaces of the rafters. The corrugated edge of the eave board prevents adherence of moisture particles and their movement into the rafter end grains. Moreover, the eave board is found below the bottom edge of the end grain surface of the rafter, so that there is no back flow into the vulnerable rafter edges. The sill beams have a continuous groove on the exterior surface of the projection like a drip, so that; gravity will pull the adhering water free of the overhang. The drip takes the form of decoration on the sill beams. They are 10 mm wide and 5 mm deep, (wide and deep enough) so that even a drop of water cannot bridge across it. A combination of washes and overhangs at the joint of sill beam prevent moisture from being pushed through the joint by air pressure differentials. This forms a rain shield assembly, blocking moisture movement due to pressure differentials.

5.3 Decay analysis of the various components constituting the built form

The decay analysis is conducted at three levels. At the first level, the recorded decay grades of the samples are reduced to Gamma maps, to plot and analyse the concentration of decay, to see whether any common pattern emerge out of it. Uni-variate analysis of the recorded grades of decay, gives the level of significance of decay of the samples, at the second level. The same is done with respect to the four cardinal directions, to verify whether the samples facing any particular direction suffered more decay. The moisture content of the samples is recorded using moisture meters and analysed to find their position in the dampness spectrum. At the third level, statistical analysis using bi-variate correlation and linear regression is done to validate the significance of measured moisture content of the samples, using SPSS. A comparative analysis of the expected and recorded moisture content readings of the samples is also done.

End-grain surfaces of sill beams and rafters, due to their high permeability, and exposure to rapid changes in moisture due to alternate drying and wetting are undergoing weathering of a higher level. In the reconnaissance survey, it is observed that, in general the end grain surfaces of the timber components on the south southwest and west suffered more decay than the ones on the north and east. This phenomenon is logically attributed to the severe SW monsoon of the region of Travancore and also to the intense solar radiations of southerly sun. So it is hypothesised that in all the structures, decay is found to be more on the south, southwest and west facing facades. The studies pertaining to decay bring out the following findings. The occurrence of moss growth at junctions where, intersecting sill beams meet the valley rafters in northeast, along the courtyard, in most of the cases confirm the influence of southwest monsoon rains, favouring the growth of biological agents. The gamma map analysis of the significance of decay of the samples reveals that there is no specific pattern of decay. But, there is a concentration of samples signifying higher levels of decay levels to a meagre degree, on the sides exposed to south, south west and west in some cases. So it is concluded that, the pattern of decay is largely dependent on the architectural vocabulary of the individual case. Uni variate analysis, too confirmed this finding.

The measured moisture content of 90 to 93 % of the samples is found to be in the green zone (up to 17 % Moisture content) of the dampness spectrum (Oliver 1997), where decay is impossible. The comparison of the measured moisture content and the equilibrium moisture content of the samples shows that the measured moisture content is always below the equilibrium moisture content predominantly. As long as timber is kept below its equilibrium saturation point, it will not decay. It is concluded that the timber in service in the cases studied, is kept dry and well below the equilibrium moisture content. Through Pearson Correlation and multiple regressions, it is found that the measured variable (Moisture Content) is not significantly related to the Temperature and Relative Humidity, recorded at the time of measurement of moisture content. Hence it is concluded that, the wood in service is not affected by the fluctuations of temperature and humidity of the ambient air, attributed mainly to the extreme dryness of wood achieved through proper seasoning. The wood used in construction, is heartwood, which is quite hard and less vulnerable (Oxley and Gobert 1994) to moisture fluctuations.

5.4 Analysis of the traditional practices

Traditional wisdom of Travancore is not only confined to excellent timber construction techniques but also involves a proper understanding of the material science (*Dravyavigyan*) of timber. Wood predominantly used, in construction are *Artocarpus Integrifolia* (Jack), *Artocarpus Hirsuta* (Aini) (both belonging to the category of *Anthasaram* i.e., one which has an inner heartwood and outer sap wood, of which only the inner part is used) and *Tectona Grandis* (Teak) and *Dalbergia Lalifolia* (Rosewood) belonging to the category of *Sarvasaram* (heartwood throughout) (Nazma et al. 1981) which underwent strict selection process. According to the traditional practice of tree selection, very old trees, twisted ones, grown near streets, religious buildings and burial grounds, ones struck by lightning, infested by insects and termites, honey bees, snakes, birds and animals, trees with medicinal value, affected by strong winds, and the ones which bear flowers and fruits in all seasons were avoided for construction purposes so as to eliminate weaker trees (Achary and Balakrishnan 1991) ensuring quality control. Timber craftsmanship begins with, the right selection of the day when the tree from which timber would be processed, is felled. According to *Taccusastra*, there are nine days (*padahari*) in a lunar month when tree felling is prohibited. The days when tree felling is prohibited, come under the following stars: *Aswini (Aswati), Bharani, Swati (Chothi), Vishakha, (Vishakam), Anuradha (Aniyam), Jyeshta (Triketta), Moola (Moolam), Sravana (Thiruvonam),* and *Satabisha (Cathayam).* When this is correlated to the calendar years, it is found that during the *utharayana* (northward declination of the sun) period more no: of days when tree felling was allowed fell after *amavasya* i.e. new moon (waxing moon period), while during *dakshinayana* (southward declination of the sun) period it happened after *poornima* i.e. full moon (waning moon period). When this is colligated with the apogee and perigee of moon, it is found that former, is during the perigee of moon and latter, during the apogee, which clearly suggests the influence of the position of the moon in timber felling and associated processing activities and the previous generations awareness about it. The moon is said to have a profound influence on all living things. The waxing moon sends powerful impulses of `growth' energy to the earth, and this affects all things that grow, causing them to increase in size and strength. As the moon wanes or declines in size, growing things similarly decrease in energy. On the basis of this theory, it is thought that the best time for felling trees for timber, is when the moon is on the decline as trees are weaker and yield more easily to the axe during the moon's wane. Plutarch instructed that the full moon caused such an increase in moisture content in timber, which was likely to become decayed and rotten, if cut at this time, and if cut at the new moon, they would be dry and brittle.

It is also well known that, tremendous amount of stress is released from wood after it is cut. These stresses, along with moisture content of wood, have a strong bearing on the influence of moon and timber might split and wrap during seasoning. The master carpenter (*perumtaccan*) along with his apprentices selected the tree to be cut and the timber thus obtained was ensured proper seasoning. Immersing wood in water and drying in shaded areas usually seasoned the timber. To choose the right size of tree, the carpenter starts out with the dimensions of the elements for which the tree was needed, with the guiding principle that no tree bigger than, what was required should be felled. Trees were classified as male, female and neutral in traditional timber construction practice. Of these, the ones with same diameter from bottom to top (head and bottom refer to the direction of growth of the tree) were males, the ones with head diameter lesser than bottom were females and vice versa come under the neutral category. Male timber piece was always fixed to another male piece, and female to female. Only in unavoidable situation male & female timber were joined together, but male or female timber was never joined to a neutral piece. It is well established that wood in use, absorbs and dissipates moisture, according to the fluctuation in moisture content of the surrounding ambient air. So it could be logically argued that, if the above canon is followed, then there will be consistency in moisture movement in the various components of a structure. This prevents structural disturbances, which might occur due to unequal moisture movement within the components of the structure.

The traditional practice was to hew the timber and cut into logs with a hand saw and season from months to years in shade. Then each piece is cut into the form of the component, for which it is intended, using wide and narrow chisels (*veethooli, uli*) and wooden. Then by using the timber-smoothing plane (*chintheru*), the surfaces are finished along the grains. The timber components show clean cut along the cell walls, rendering absolutely smooth finish, which prevents adsorption of moisture and associated penetration of water making wood resistant to biological decay. This excellent finish of timber components goes a long way towards explaining why a large percentage of original timber can still be found in the preserved buildings of Travancore belonging to the seventeenth and eighteenth centuries. Traditionally the timber surfaces were finished to get a glassy effect with the dried leaves of *therakam* (*Ficus Aspirina*), which was the common practice before the introduction of sand papers. Such smooth surfaces repel moisture and prevent decay due to moisture.

There existed a traditional practice of preparing timber preservative oil from locally available, herbs, waxes, rhizomes and roots. This preservative has a pungent smell, which keeps away all organisms promoting bio deterioration of wood, which would otherwise occur in the humid climatic zone of Travancore. Dried and powdered *katukka* (seed of *Terminalia chebula*/ Chebulic Myrobalan), *vayambu* (root of *Acoras calamus*), *Manjal* (*Curcuma longa* / Indian Saffron / Turmeric) etc. in a specific manner are added to boiling gingely oil in specific proportion and stirred well. The preservative is then allowed to cool and applied over timber pieces to keep it safe from the attack of termites, fungus and insects. This oil protected the timber when it is moist, from fungal and bacterial infections.

6 THE FINDINGS AND CONCLUSIONS

The findings of the paper are as follows:

1. Tolerating moisture being an important consideration, specific construction methods were developed, to protect the various components constituting the traditional timber buildings and were followed in their construction.
   - The components of traditional timber construction that are most susceptible to decay due to moisture accumulation are the end grain surfaces of the rafters constituting the roof and the sill beams supporting the timber walls.
   - Traditional protection methods in the form of wash, drip, overhang, overlap and rain shield assembly were developed to protect the various components of the traditional construction.
2. There exists no 'specific' pattern of decay in the components of traditional timber architecture caused by moisture accumulation. However, there is a general trend that the timber components facing the southern, southwestern and western directions, decay faster owing to the heavy southwest monsoon and southwest wind driven rains.
   - The visual symptoms of decay of timber components are varied but can be classified, graded and mapped based on a scale, quantifying the 'loss of substance' as the indicator of decay.
   - Gamma mapping is found to be a useful tool in systematically and legibly recording the decay pattern.
   - As a general trend, it can be said that due to the particular climatic conditions, the components facing south, southwest and west are more susceptible to decay due to moisture.
   - Interestingly, it was discovered that the moisture content of wood in service, in the cases studied, was independent of the relative humidity and temperature of the surrounding air, in spite of the hygroscopic nature of wood.
3. The traditional theory of timber construction, '*taccusastra'*, is found to be 'a posteriori', as it followed the 'contingencies of practice' of timber craftsmen, developed through trial and error methods, and transmitted through generations.
   - Though a comparative analysis, of the canons prescribed by the traditional treatise with the selected palaces is achievable, it is not possible to make even an implicit, one to one link between the cannons and the cases.
   - It is found that the traditional timber architecture is designed and constructed in response to tolerating, the deleterious effects of moisture. The methods of construction, that are identified to be assisting in tolerating moisture, are predominantly the result of constant practice, rather than the traditional theory.

To conclude, it is found that traditional construction methods and practices were developed, in order to tolerate the deleterious decay effects of moisture. This comes from the understanding that, the climatic indices, humidity levels, driving rain indices and the degree of rainfall of the region are promoting decay of timber super structures through moisture accumulation. Fortunately, the temperature gradient is high and constant in the region, and this favours quick evaporation of moisture. The components, which are found, most susceptible to moisture and its decay, are protected effectively through traditional methods. With traditional buildings, roof spread is one of the more visible structural problems. A traditional timber structure with deep overhanging eaves carries, its own seed of destruction, as the eaves tend to sink, especially when the timber components are moist. Majority of the roof spreads of the palace typology studied can be safely left alone, as there are no visible signs of sagging anywhere. A large proportion of the timber components, in use are found to be kept so dry at all times, that they last indefinitely. Through the decay analysis, it is quite evident that, the structures, as such, are not under threat due to moisture related decay. Though the traditional canons guided the construction of buildings in general, the construction methods and practices developed and transmitted by the craftsmen as a traditional lineage, played the crucial role in determining the moisture related decay mitigation effects in the traditional buildings.

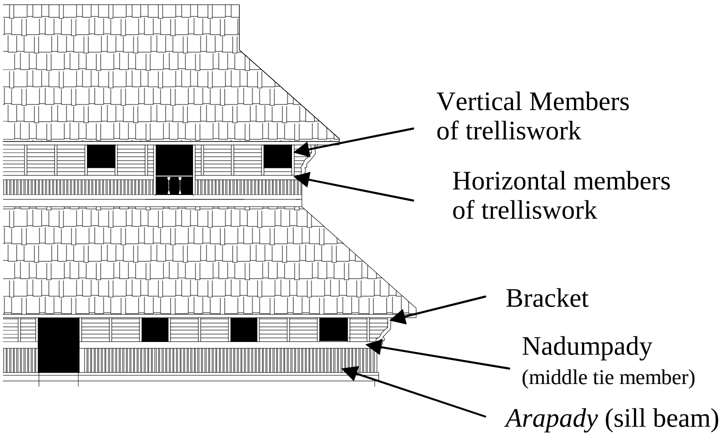

Figure 1 : Parts of a typical palace.

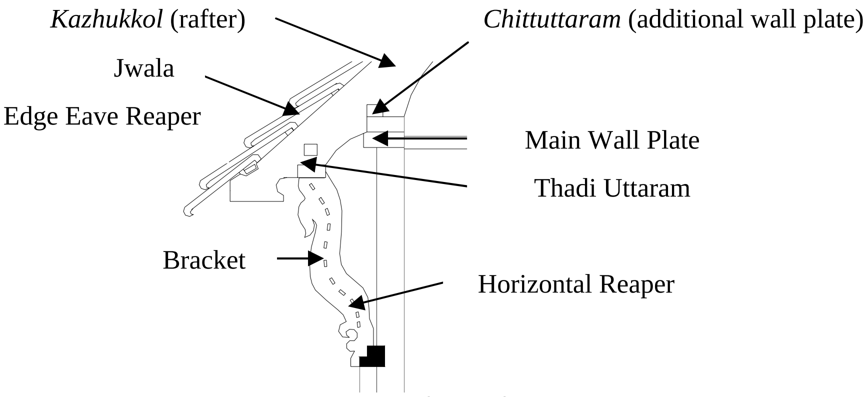

Figure 2 : Details at the end of the rafter.

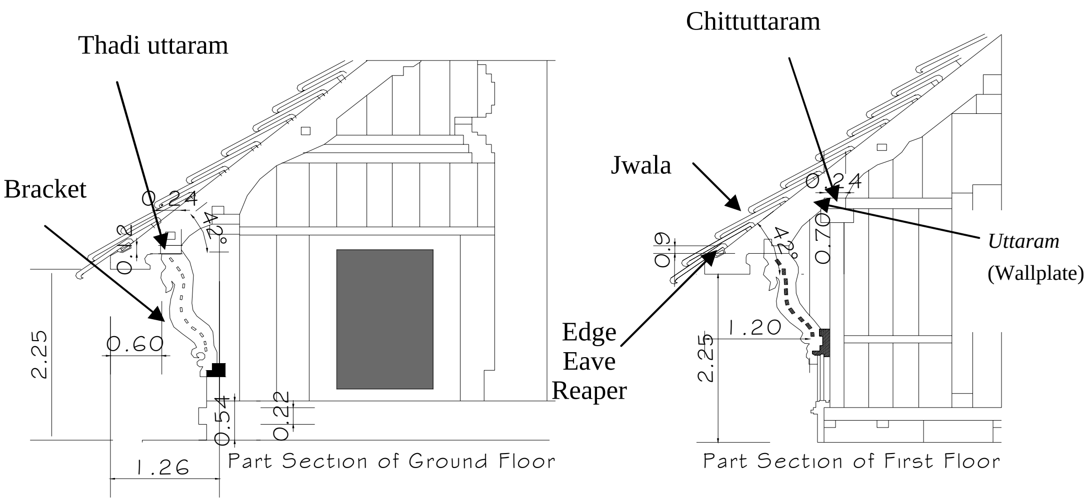

Figure 3 : Part sections of a typical palace superstructure.

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