Chapter 3

Methodology

- Descriptive Analysis to define the Historical Values and Outstanding Architectural Characteristics of *Tu Giac* Houses -

First, the study locates the *Tu Giac* houses in the timeline of historical development of Hue traditional houses (Fig.3.1). The *Tu Giac* houses were constructed during the French invasion, the time that Hue traditional architectural features were deeply blended with the French influences. Then the study analyzes the 6 outstanding characteristics (A_1 – A_6 in Fig.3.2 and Fig.3.3) to define the specific architecture of 8 *Tu Giac* Housing units. They are the significant components to compose the historical values of the *Tu Giac* houses in Hue City, Vietnam. The remedial treatment for the decays and destructions of the A_1- A_6 materials have been taken into account for the conservation methods according to the Venice Charter, ICOMOS and Vietnamese Conservation Principles through the step C, supporting step B and step D. The *Tu Giac* Housing Conservation 'prototype' will finally be carried in step E as the final product of this research study.

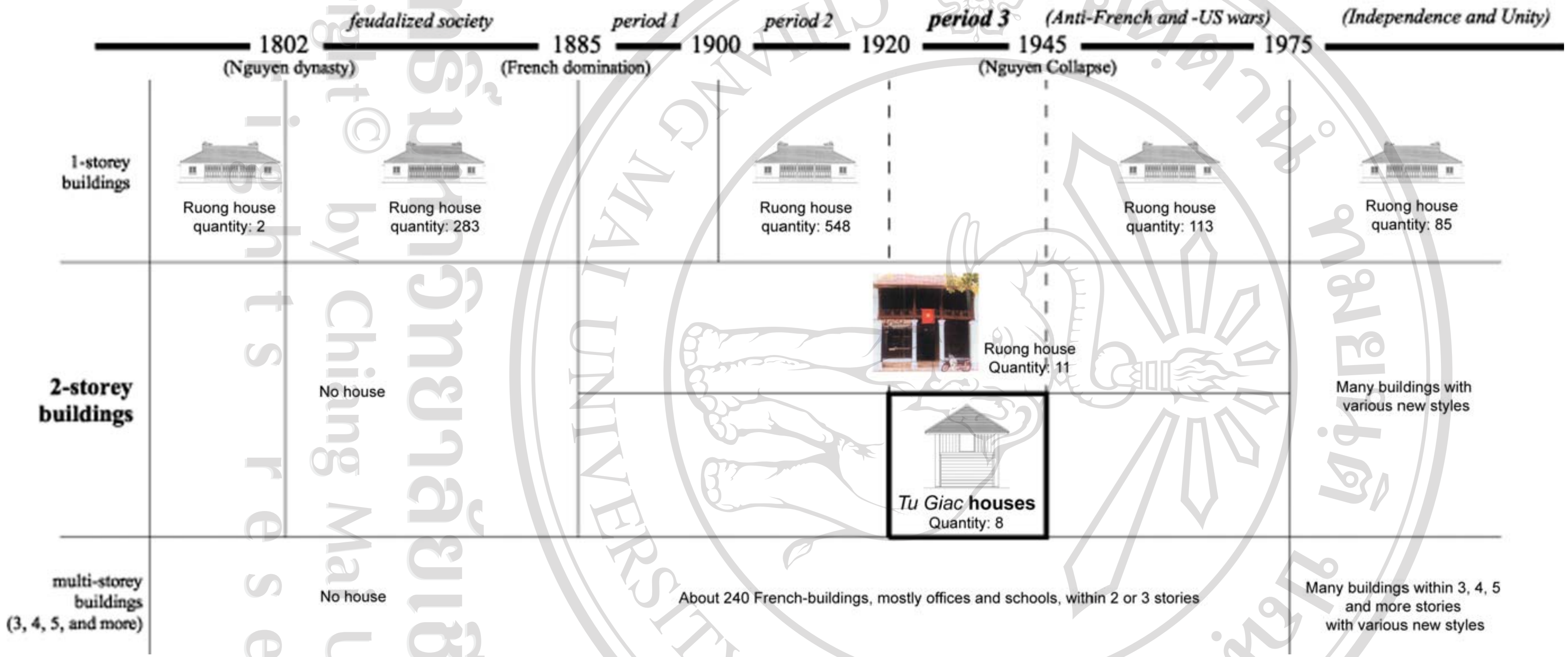


Fig.3.1 The timeline indicates that the 1-storey buildings were the most common and mostly built in the period 1802 – 1975 (944/1042 houses). The 2-buildings were present since French coming (1885), but having the modest number of 11. During colonial period, the French built about 240 buildings generally for French offices and schools within 2 or 3 stories. 8 *Tu Giac* houses built in the period 1920-1945 are the strong reflection of French-influenced architecture in Hue city.

The study is summarized in the diagram (Fig.3.2) which illustrates the approach steps of research, represented by the characters (A, B, C, D, and E). The reveal of 6 Characteristics (A_1- A_6) of the *Tu Giac* House in Row A is then assessed through their existing decays and destructions in Row B. The reviewing to the related Charters and Principles in Row C will help the study provide the possible conservation methods and techniques for all decayed parts of *Tu Giac* houses in Row D. Those methods and techniques are used to establish the *Tu Giac* Housing Conservation Prototype finally as the result of the study in Row E.

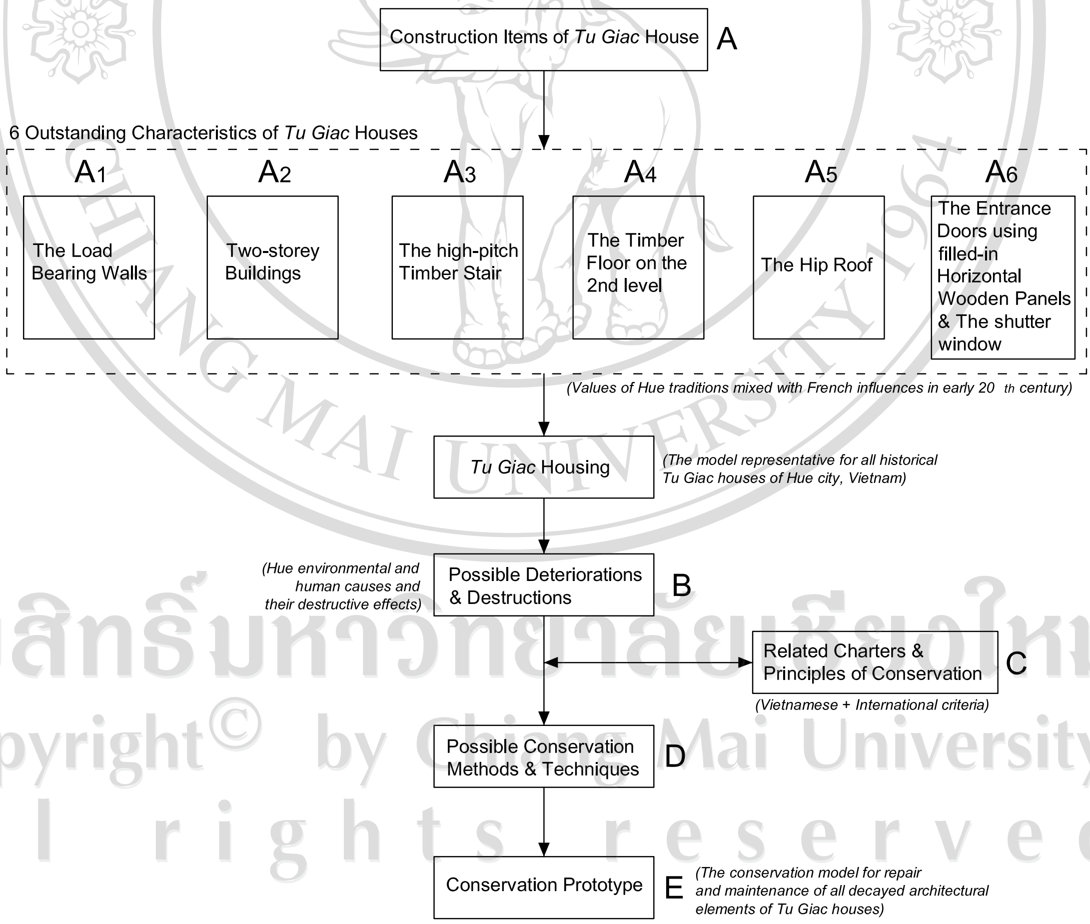


Fig.3.2 The diagram showing the outline of methodology from step A where 6 outstanding architectural characteristics of *Tu Giac* house being determined before feeding into step B and D. the related Charters and Principles of Conservation of step C is fed in to support step B and D. Finally, the 'conservation technique prototype' of *Tu Giac* houses is carried out.

In order to perceive all steps of the methodology, the list in which all sub-sections of this chapter are combined in the acronym characters, shown in Fig.3.3:

Fig.3.3 The correlation of acronym characters B, C, and D related to the 6 outstanding characters A_1 through A_6 of *Tu Giac* houses.

(A) The Outstanding Characteristics of *Tu Giac* House	**(B) Possible Deteriorations & Destructions**	**(C) Related Charters & Principles of Conservation**	**(D) Possible Conservation Methods & Techniques**
A_1 ***The Load Bearing Walls :*** ▪ Three- sided Load Bearing Walls (north, south, west) ▪ The dependent bracing supports from timber beams on the missing load-bearing wall ▪ The nonexistence of any wall bracing frame inside walls ▪ The *Vo* bricks ▪ The rareness in Hue today architecture	A_1-B ▪ Crack ▪ Moss ▪ Fungi and moulds ▪ The flakiness of plaster and finishing ▪ Man-made destructions	A_1-C ▪ Venice Charter (1964) ▪ ICOMOS Charter (2003) ▪ Law on Cultural Heritage of Vietnam (2001) ▪ *Ruong* House Conservation Principles (2003)	A_1-D ▪ Methods for Crack ▪ Methods for flaked and decayed plaster
A_2 ***Two-storey Buildings:*** ▪ The rareness in Hue traditional architecture ▪ The low interior spaces and the short buildings	A_2-B ▪ The encroachment of additional parts	A_2-C ▪ Venice Charter (1964) ▪ *Ruong* House Conservation Principles (2003)	A_2-D ▪ Remove additional parts vulnerable to the two-storey structure
A_3 ***The high-pitch Timber Stair:*** ▪ The reflection of Hue traditional multi-storey buildings ▪ The high pitch and small width to utilize the limited ground floor area ▪ The rareness in French-influenced and today architecture of Hue city	A_3-B ▪ Crack ▪ The aging of wood and fungal and pest attacks ▪ The damages of endpoints ▪ The movement out of its original position ▪ The encroachment on original narrow access	A_3-C ▪ ICOMOS Charter (2003) ▪ Principles for the Preservation of Historic Timber Structure (1999)	A_3-D ▪ Methods for decayed endpoints ▪ Methods for fungal and pest attacks ▪ Methods to maintain timber structures and slow down their aging process

A_4 ***The Timber Floor on the 2nd level :*** ▪ The reflection of Hue traditional architecture ▪ *Kien Kien* wood ▪ The rareness in French-influenced and today architecture of Hue city	A_4-B ▪ Cracks on the floor beams and planks ▪ The change of the original timber planks ▪ The fungal and pest attacks ▪ The damages of the endpoints of timber planks	A_4-C ▪ Venice Charter (1964) ▪ ICOMOS Charter (2003) ▪ Law on Cultural Heritage of Vietnam (2001) ▪ *Ruong* House Conservation Principles (2003)	A_4-D ▪ Methods for cracks ▪ Methods for decayed endpoints of timber planks ▪ Methods for fungal and pest attacks ▪ Methods to maintain timber structures and slow down their aging process
A_5 ***The Hip Roof :*** ▪ The new form of Pyramid in Hue traditional architecture ▪ Two traditional techniques of roofing *Liet* tiles ▪ The traditional roof-composition of three tile-layers ▪ The *Liet* tiles ▪ The use of traditional mortar for roof ridges	A_5-B ▪ Cracks of the roof ridges ▪ The aging of wood and the fungal and pest attacks ▪ Cracks of the timber truss frames ▪ Destructions of *Liet* tiles ▪ Man-made destructions	A_5-C ▪ Principles for Preservation of Historic Timber Structures (1999) ▪ ICOMOS Charter (2003) ▪ Law on Cultural Heritage of Vietnam (2001) ▪ Ruong House Conservation Principles (2003)	A_5-D ▪ Methods for cracks of the roof ridges ▪ Methods for decayed *Liet* tiles ▪ Methods for cracks of the timber trusses frames ▪ Methods for fungal and pest attacks, and to maintain timber structures and slow down their aging process
A_6 ***The Entrance Doors using filled-in Horizontal Wooden Panels & The shutter Windows :*** ▪ The traditional characteristic of filled-in horizontal wooden panels door representing the historical street facing houses of the old towns in Central Vietnam ▪ The labor intensive but strong of slotted horizontal wooden panels-door ▪ The response of Shutter Windows to the hot and humid region	A_6-B ▪ The aging of wood and fungal and pest attacks	A_6-C ▪ Principles for Preservation of Historic Timber Structures (1999)	A_6-D ▪ Methods for fungal and pest attacks, and to maintain timber structures and slow down their aging process

3.1 The Outstanding Characteristics of the *Tu Giac* houses (A_1 – A_6)

3.1.1 The Load Bearing Walls (A_1)

3.1.1.a Three-sided Load Bearing Walls (north, south, east):

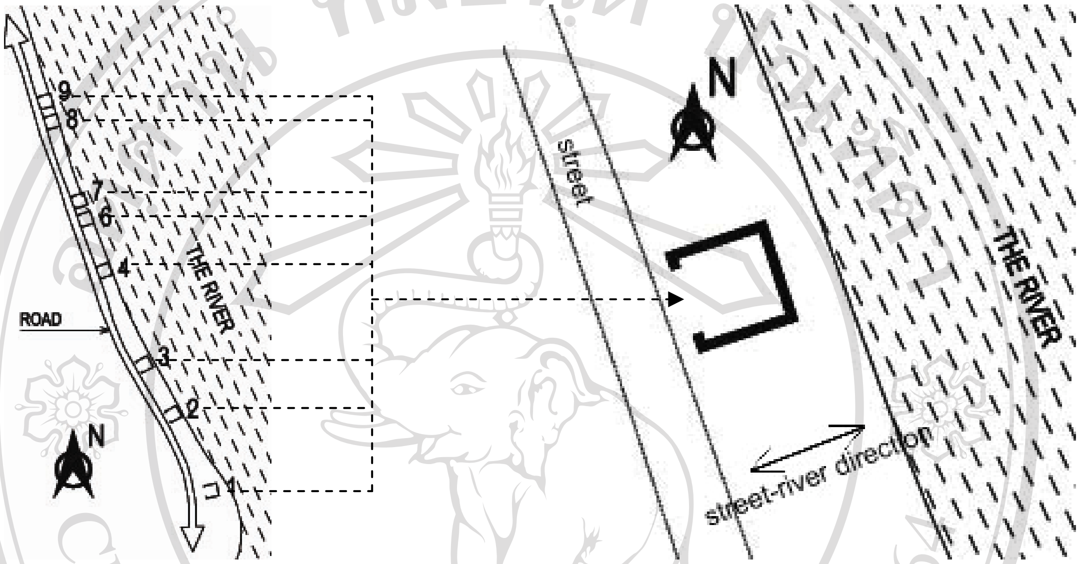


Fig.3.4 The same river-street direction of all 8 *Tu Giac* houses (left) leads to the same direction of three load bearing walls of all *Tu Giac* houses into the north, south, and east side (right).

Located alongside the Huong River and the street, all 8 *Tu Giac* houses have the same river-street direction which results in the same direction of their load bearing walls, originally, comprising three walls on the north, south, and east side (Fig.3.4). The missing load-bearing west wall facing the street does not exist because of the required large opening of the front-shop. These three walls will carry loads of the 2nd floor and the hip roof. Different from the common load bearing walls of the other French-influenced buildings generally enclosed by four walls in Hue city (Fig.3.5), the only three load bearing walls have made the structure of *Tu Giac* houses become outstanding in harmony with their initially historical functions of commercial houses.

One French-influenced building with 4 walls enclosing 4 sides in Hue city

A *Tu Giac* house with 3 walls enclosing 3 sides except for the front side covered by wooden bars

Fig.3.5 The difference between *Tu Giac* houses and other French-influenced buildings.

3.1.1.b The dependent bracing supports from the timber beams on the missing load-bearing wall:

In order to enclose three walls, two timber beams **B1** at the 2nd floor level and **B2** at the roof level are added on the west side to link the north and south walls, and play the same role of missing west-wall to stabilize the whole structure of the load bearing walls (Fig.3.6). The bracing strength of three load bearing walls is thus improved. The integration of two timber beams into three load bearing walls to consolidate the building structure on the opened-side has showed the particular of the *Tu Giac* load bearing walls in borrowing the supports from outside parts, which are unfound in other load bearing wall buildings of French influenced architecture in Hue city.

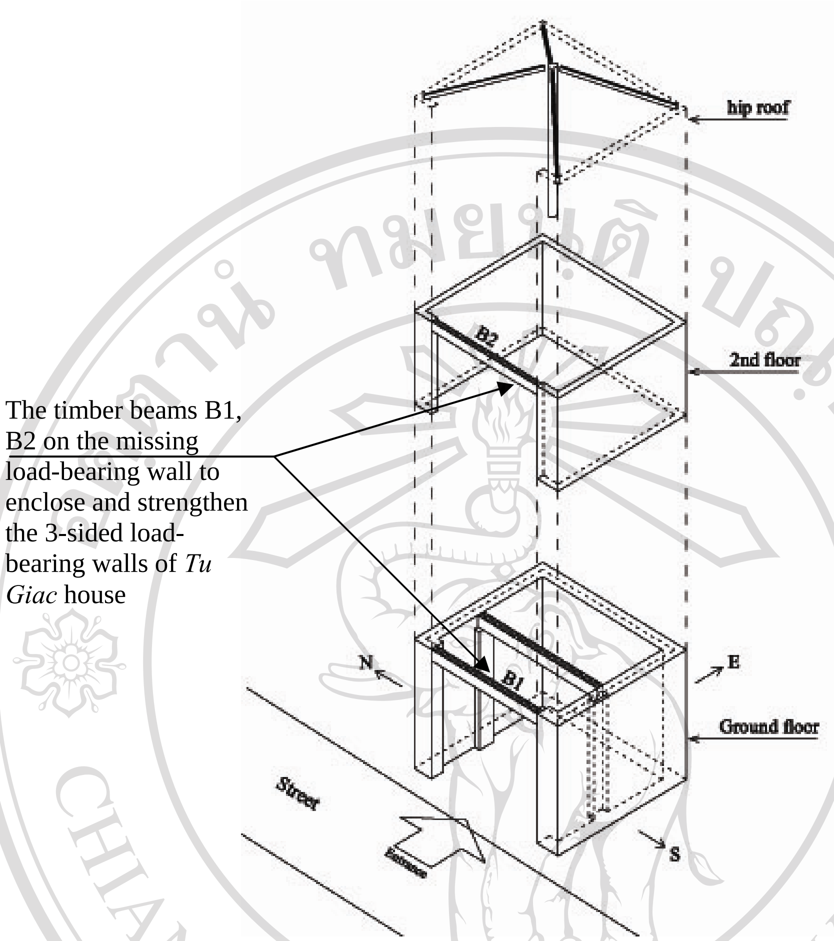


Fig.3.6 The graphical analysis of the way of working of the load bearing walls which makes *Tu Giac* houses become special and dissimilar to common load bearing walls in Hue city.

3.1.1.c The non-existence of bracing frame of the inside walls:

At the 2nd floor level, due to receiving the supports in bracing from the timber beams, the load bearing walls allow the absence of any bracing frame inside them. On the top, the hip roof functions as the wall bracing frame to keep the three walls stable. Therefore, it differs from the other French-influenced buildings of Hue city whose wall bracing frames are usually made of reinforced concrete at the floor and roof levels for their structural consolidation. The nonexistence of wall bracing frame as in the *Tu Giac* load bearing walls become a rare architectural construction technique in the Hue city and become the one of a kind of historical houses.

3.1.1.d The *Vo* bricks:

The *Tu Giac* load bearing walls are made from *Vo* bricks, one of the most common materials in Hue traditional architecture [1] with the bigger size than the currently common brick (Fig.3.7). Nowadays with the development of reinforced concrete for building structure, the walls play the role only as partitions which tend to be thinner. Therefore the *Vo* bricks with their bigger sizes are inappropriate and uncommon in Hue built environment currently. They are now produced by hand in the limited quantity only for the conservation work of historic buildings in Hue city, especially the royal architectural system of Nguyen dynasty (1802-1945) adopted as the world heritage in 1993. The use of *Vo* brick in *Tu Giac* load bearing walls has reflected the Hue traditional architectural characteristic needed to be preserved.

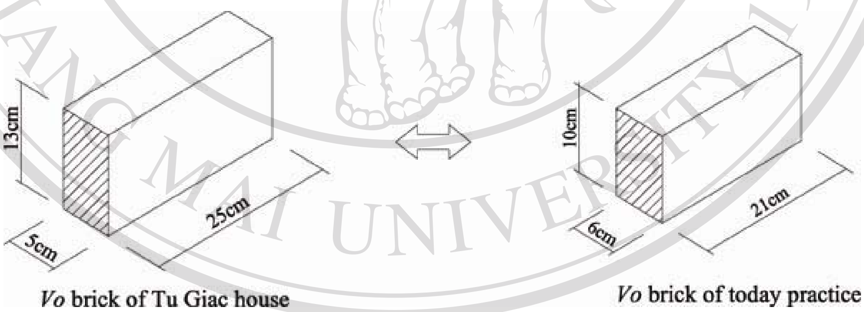


Fig.3.7 The *Vo* brick unit with bigger sizes than currently common brick unit.

3.1.1.e The rareness of Load Bearing Walls in Hue's today Architecture:

Due to the broad development of reinforced concrete as today, building structures tend to use the system of reinforced concrete pillars and beams to create a solid frame of reinforced concrete for carrying building loads. It makes the load bearing walls become a rare construction technique. This is a value creation for the

[1] Phan Thanh Hai. *Bricks, tiles, and system of characters in the Nguyen Dynasty*. Vietnamese Architecture Magazine., 2006, p. 52-56.

astonishing 3-sided load bearing walls of Tu Giac houses. In addition, it represents the French-influenced architecture of Hue city during the French colonized period.

3.1.2 Two-storey Buildings (A_2)

3.1.2.a The rareness in Hue traditional 2-storey architecture:

As mentioned in section 1.2 of chapter 1, the one-storey buildings are the most representative of Hue traditional architecture before the French coming, the time Nguyen feudal laws in construction started to be demolished. In 1.042 *Ruong* houses, the most numerous traditional houses of Hue city, there are only 11 houses within two storeys.[2] The two-storey buildings become rather rare in Hue traditional architecture. All 8 *Tu Giac* houses which were constructed within two storeys in the same period together with 11 above two-storey *Ruong* houses have showed their rareness and outstanding images in Hue traditional architecture (Fig.3.8).

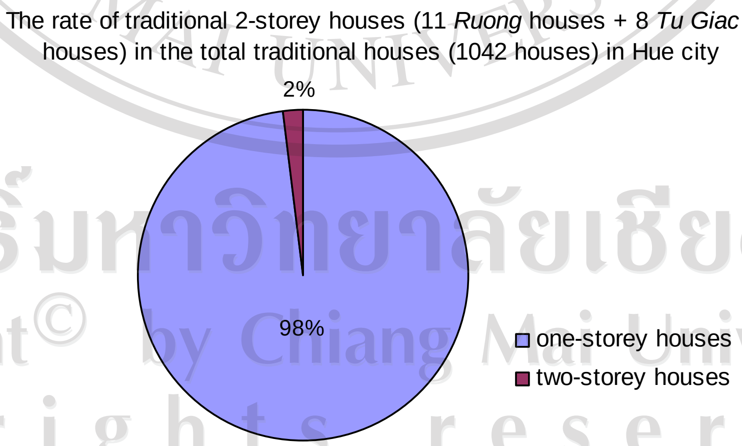


Fig3.8 The percentage 2% of the 2-storey houses in the total Hue traditional houses (*Tu Giac* and *Ruong* houses) showing their very rareness in Hue traditional houses.

[2] Tran Ba Tinh, 2004.

3.1.2.b The low interior spaces below living standards and the short buildings:

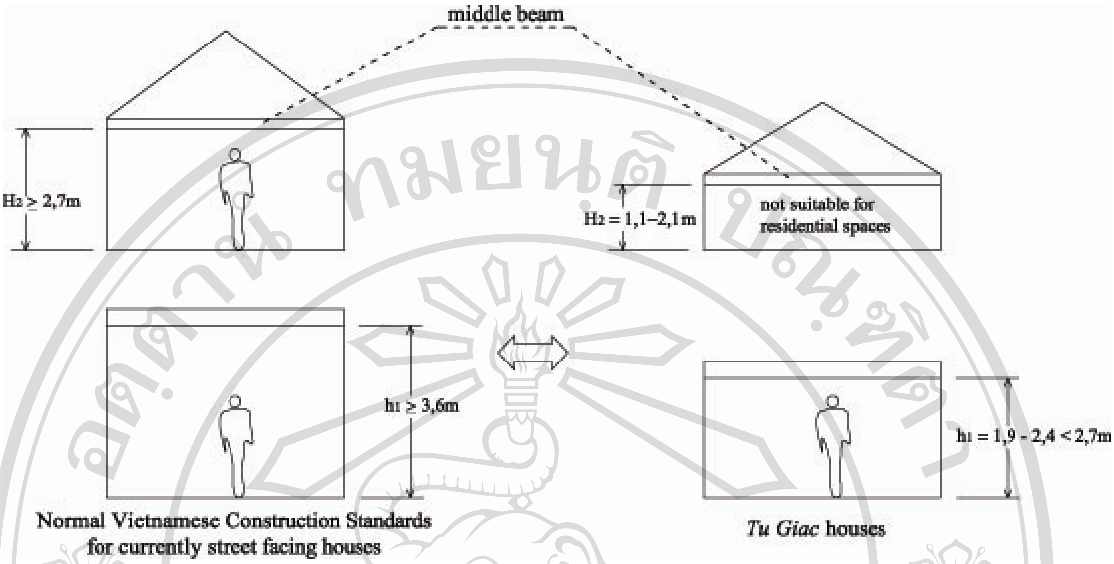


Fig.3.9 The dimensional comparison between *Tu Giac* houses with normal construction standards of the current street-facing multi-storey houses in Vietnam.

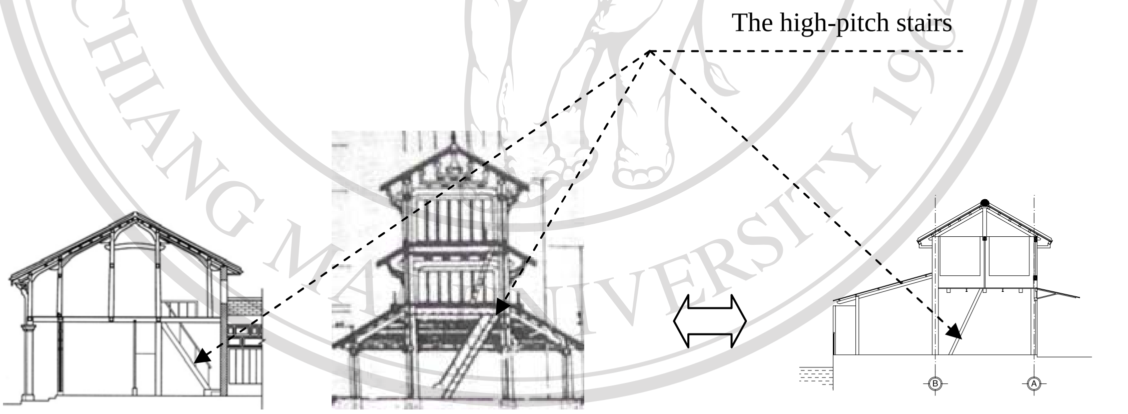
The structure of load bearing walls is not suitable for tall buildings because the higher, the thicker walls. Thus, the ground floors of *Tu Giac* houses initially used for selling and exchanging products requires the moderately adequate spaces for human activities within 1.9 – 2.4m high, but much lower than the normal standard headroom (3.6m) [3] for the ground-floor space of Vietnamese street-facing multi-storey houses (see $\mathbf{h_1}$ in Fig.3.9). The second floors of *Tu Giac* houses firstly used for storages are also similar since their headroom under the middle beam ranges from 1.1m to 2.1m, greatly lower than the normal standard headroom (2.7m) [4] of Vietnamese residential floor-spaces (see $\mathbf{H_2}$ in Fig.3.9). Such dimensional meanings reflect the history of the houses in relation to their original load bearing wall structure which makes them look shorter than normality and distinct with other two-storey buildings in Hue city.

[3] Vietnamese Construction Standards. TCXDVN 353: 2005
[4] Vietnamese Construction Standards. TCXDVN 4451: 1987

3.1.3 The high pitch Timber Stair (A_3)

3.1.3.a The resembling of Hue traditional multi-storey buildings:

In Nguyen royal architecture, the high pitch timber stair appears in the multi-storey buildings, especially in the highest building of Hue Citadel so-called Hien Lam Pavilion (3 stories), it becomes one of the most valuable parts.[5] In Hue traditional houses, this stair only appears in 11 two-storey *Ruong* houses in the total of more than 1.000 *Ruong* houses and in 8 two-storey *Tu Giac* houses. Despite the modest number of multi-storey buildings in Hue traditional architecture, the presence of high pitch timber stair in all of them has reflected the strong characteristic representing the historical traditional multi-storey buildings of Hue city (Fig.3.10).



The 2-storey Ruong houses of Hue local architecture

The 3-storey Hien Lam Pavilion of Nguyen royal architecture

The 2-storey *Tu Giac* houses of Hue local architecture

Fig.3.10 The similarity of high-pitch timber stair among *Tu Giac* houses and other multi-storey buildings of Hue traditional architecture.

[5] Phan Thuan An

3.1.3.b The high pitch and small width of the staircase to utilize the limited ground floor area:

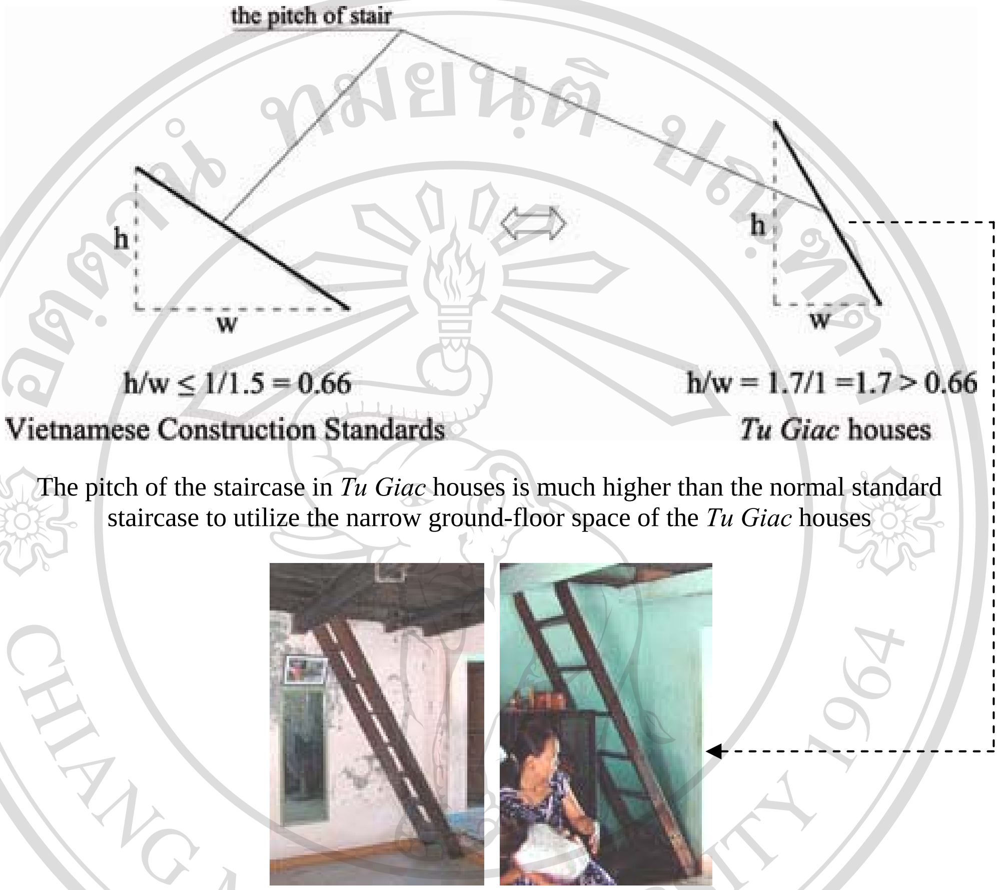


Fig.3.11 The dimensional comparison of the stair with the Vietnamese standards.

The narrow spaces of their ground floors less than 4m on each side do not allow the stair taking up enough space for its convenient pitch. It results in the high pitch of them with the ratio between their heights (h) and lengths (w) is very much higher than the normal Vietnamese standard (1.7 > 0.66) (Fig.3.11). In addition, the widths of the stairs are less than 0.6m and, obviously, under the normal Vietnamese standard (0.9m) and enough only for one person to carry objects up and down. In comparison with the standard stair of Vietnamese 2-storey houses in terms of occupancy, the high pitch timber stair of *Tu Giac* houses covers a very small area around 8% of the normal-stair area (Fig.3.12). It helps to utilize using areas effectively in the houses within the small ground-floor areas as in *Tu Giac* houses. The small percentage 3.3 – 5.7% of the high-pitch stair area on the total ground-floor area of *Tu Giac* houses (saving more than 90% of the small ground-floor spaces) has proven the significance of the high-pitch and small width of the stairs in the narrow interior spaces of ground floors (Fig.3.13).

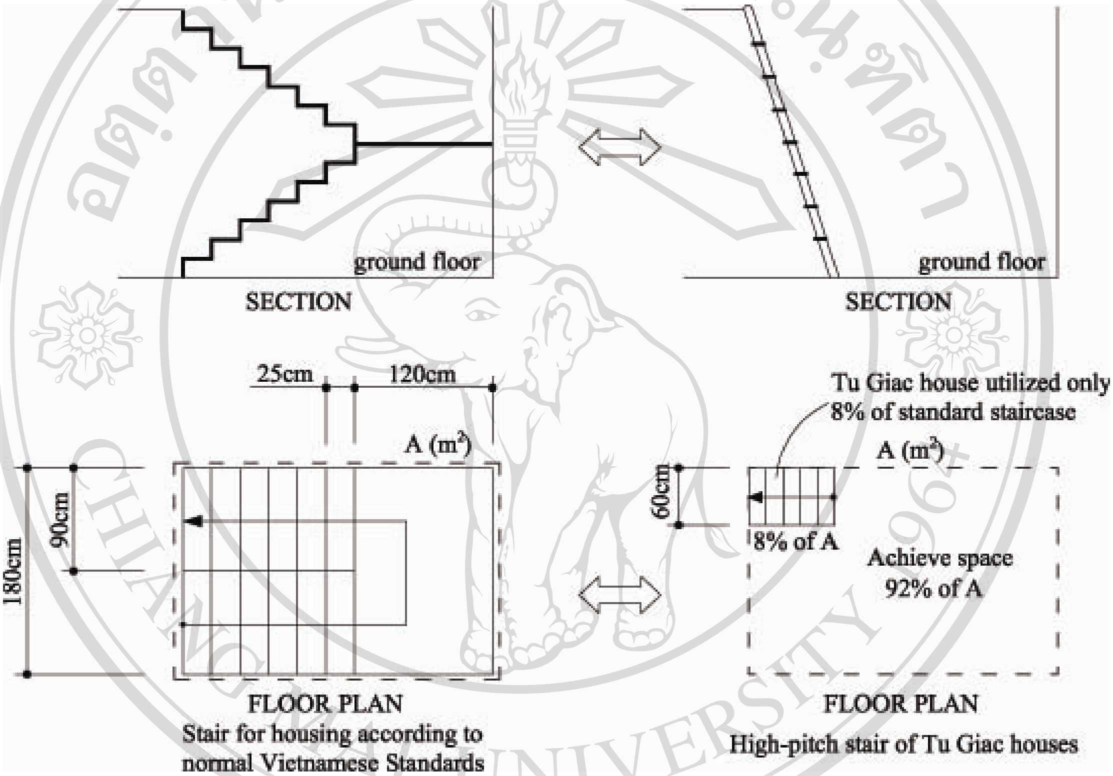


Fig.3.12 The comparison between the normal standard stairs in Vietnamese 2-storey houses and the high pitch stairs of *Tu Giac* houses shows the reduction 92% of area (A) if using high pitch stair.

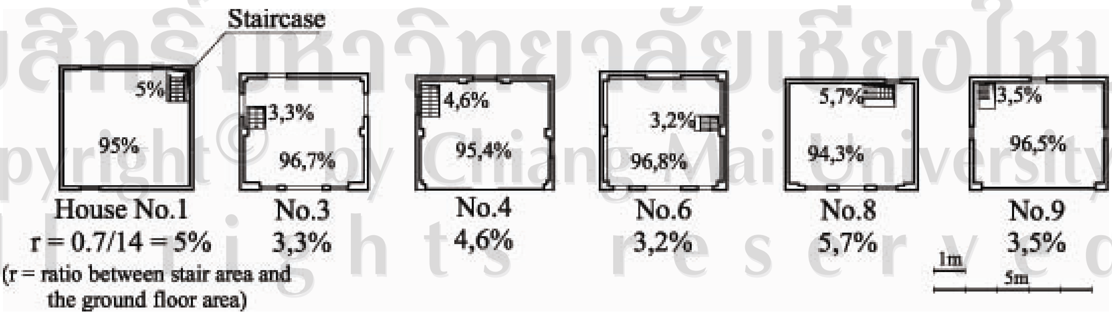


Fig.3.13 The saving of more than 90% of the small ground-floor spaces by using the high pitch timber stairs in *Tu Giac* houses.

3.1.3.c The rareness high-pitched stairs in today architecture of Hue city:

The stairs with lower pitch are more frequent than the high-pitch ones in other French-influenced and today architecture of Hue city due to the purpose of user-convenience which emphasizes the rareness of the high pitch timber stairs at the present and in the future time.

3.1.4 The Timber Floor on the 2nd level (A_4)

3.1.4.a The resembling of Hue traditional architecture (*Ruong* House):

The traditional architecture of Hue city is based on wood architecture in which all structural elements including floors are made from timber (during the time 18th – 20th century). In all historical multi-storey buildings (2 or 3 stories) of Nguyen royal architecture (1802-1945) and 11 two-storey *Ruong* houses (built in French domination period 1885-1954) in the total of 1042 *Ruong* houses, the floors are always made from timber. In *Tu Giac* houses, their floors are made of *Kien Kien* wood, one of the most numerous woods in Hue natural forests at that time with the highest compressive strength and the medium tensile strength in all 17 species of wood commonly used in Hue traditional houses (Fig.3.14). [6] It becomes the most common wood in Hue traditional houses. At the present time, the exhaustion of natural resources along with the development of new industrial materials like plywood, ceramics, aluminum, steels, or etc have led to the rareness of natural materials like *Kien Kien* wood in construction. Therefore, the 2nd timber floors of all 8 *Tu Giac* houses have reflected Hue traditional architectural characteristic, and be still genuine wood floors dating back to the French era.

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[6] Doan Cong Dien. *Wood in Traditional House Structure of Hue.* Hue Monuments Conservation Centre., 2002, p 401-406.

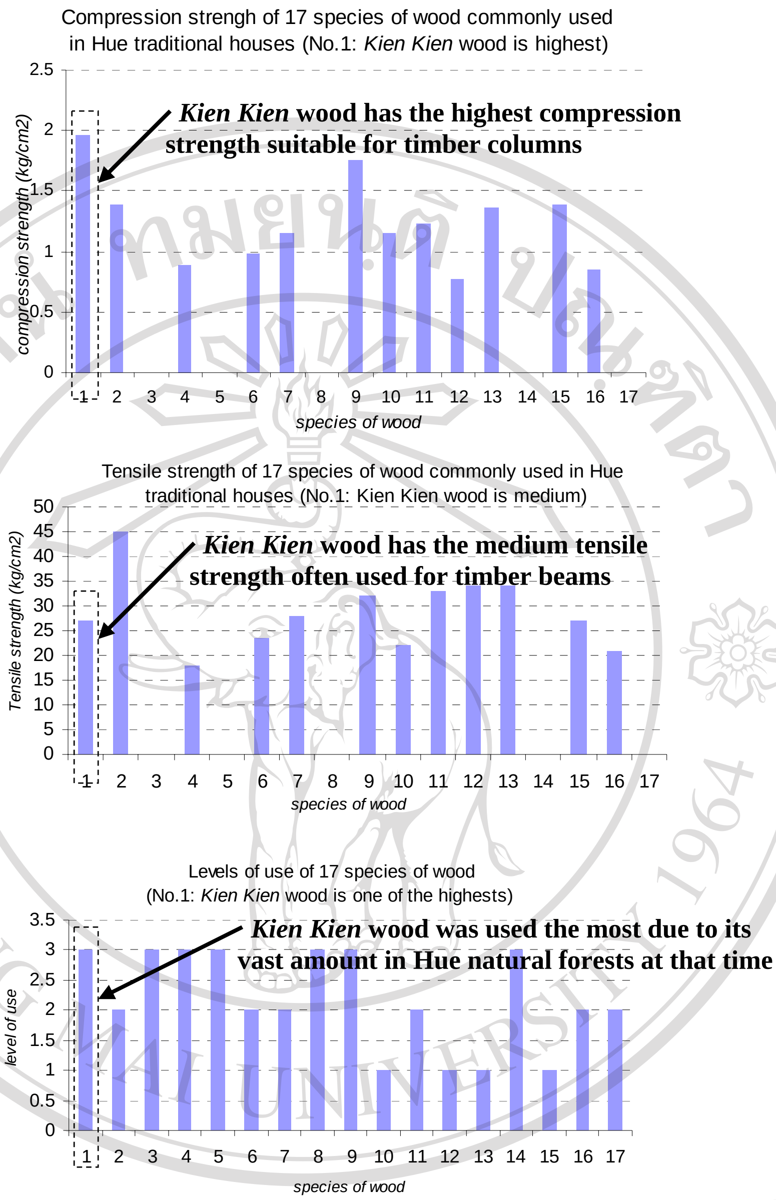


Fig.3.14 The comparison of physical properties of *Kien Kien* wood (No.1) with other 16 species of wood commonly used in Hue traditional houses.

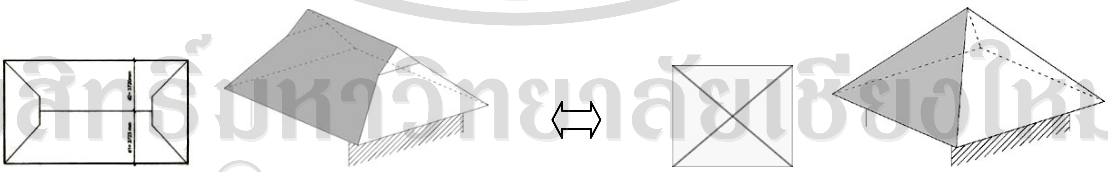
3.1.4.b The rareness of *Kien Kien* timber floor in today architecture in Hue city:

In French-influenced multi-storey buildings (2-3 stories), their floors which are supported by their load bearing walls generally were made of reinforced concrete (i.e. Hue Railway Station, Quoc Hoc high school, or Morin hotel), a new material first introduced into Vietnam by the French. In Hue today architecture with the advantages of reinforced concrete such as solidity, fungi- and pest-resistance, sound insulation, workability, and long life expectancy, it has been applied widely for all structural elements of buildings including floors. Timber is only an alternate material for floor- and ceiling-finishings. It makes the absolute timber floors as in *Tu Giac* houses become rarer (only found similar wood floors in 11 two-storey *Ruong* houses).

3.1.5 The Hip Roof (A_5)

3.1.5.a The new form of Pyramid Roof existed in the Hue City traditional architecture:

Before the French coming in 1885, two sloping roofs alongside the length of the house are the most representative roofs of Hue traditional architecture which can be seen in all *Ruong* houses and other royal buildings of Nguyen dynasty like Thai Hoa and Dien Tho palaces. The arrival of French together with new architectural styles in Hue city had influenced and blended with Hue traditional architecture. The new Pyramid form with 4 equal sloping roofs as in the hip roofs distinguishable from the traditional 2 sloping roofs is the good evidence (Fig.3.15). It shows the strong French influences of Hue traditional architecture in the early 20th century.



The common 2 pitch roofs of Hue traditional houses including *Ruong* houses

The 4 equal sloping roofs in pyramid shape of the hip roofs is the new architecture

Fig.3.15 The new architecture of the Pyramid of the hip roof.

3.1.5.b Two traditional techniques of roofing *Liet* tiles:

Because of the different patterns and ways of connection between *Liet* tiles and today roof-tiles (see 3.1.5.d), the techniques of roofing them are dissimilar. The way of roofing in Hue today architecture is quite simple with only one technique of putting the tiles on rafters while the way of roofing in the hip roofs is more complex which requires two traditional techniques: constructing roof ridges firstly (called *gầy ngói*) and roofing *Liet* tiles later (called *lợp ngói*).

In Hue traditional architecture, *Liet* tiles are usually fixed into the roof in the way without using mortar except for some places where it is needed to stick the tiles to avoid sliding down.

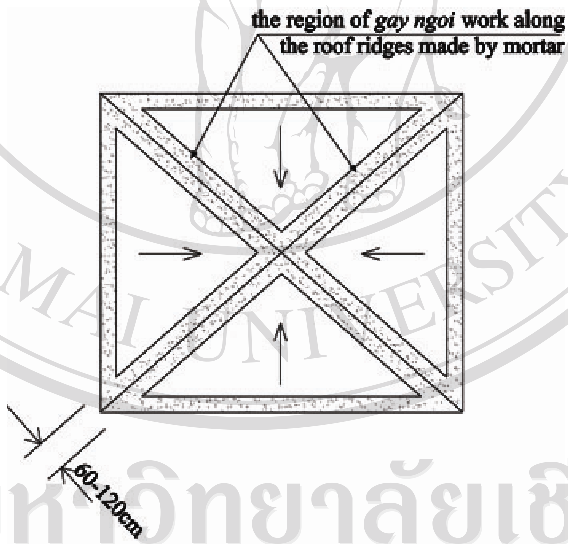


Fig.3.16 The first step of constructing the roof ridges on 4 diagonal timber trusses.

The first step of constructing roof ridges (*gầy ngói*) is the placement of bottom *Liet* tiles on timber rafters, call *Ngói chiếu*, on both sides of roof ridge within 60-120cm wide (Fig.3.16& 3.17).To stabilize them on sloping roof-planes, small iron nails are used to fix them directly to timber rafters. The middle and top *Liet* tiles, called *Ngói độn* and *Ngói lợp*, are fixed on the bottom *Liet* tiles by traditional mortar along the roof ridges afterward (Fig.3.17).

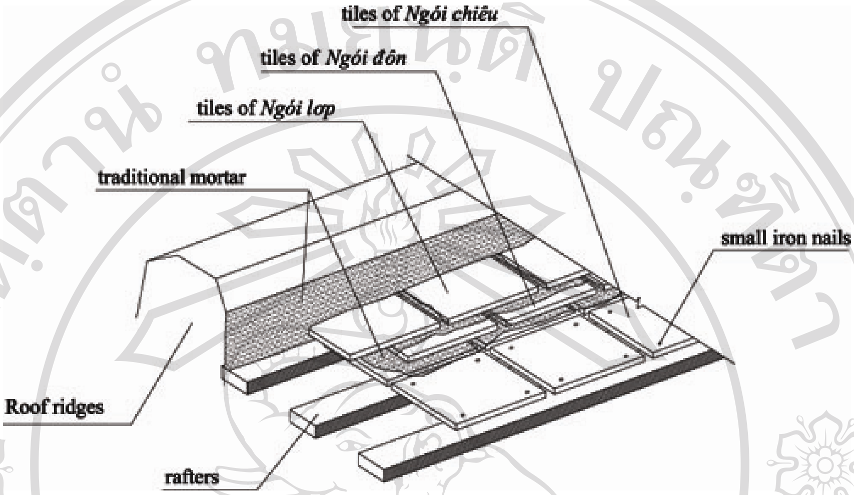


Fig.3.17 The composition of the hip roof by *Liet* tiles

The curved tiles, called *Ngói âm*, are ultimately fixed on the top *Liet* tiles by traditional mortar within 2 or 3 layers to cover the intersection of two sloping roofs before finishing the roof ridges by traditional mortar (Fig.3.18).

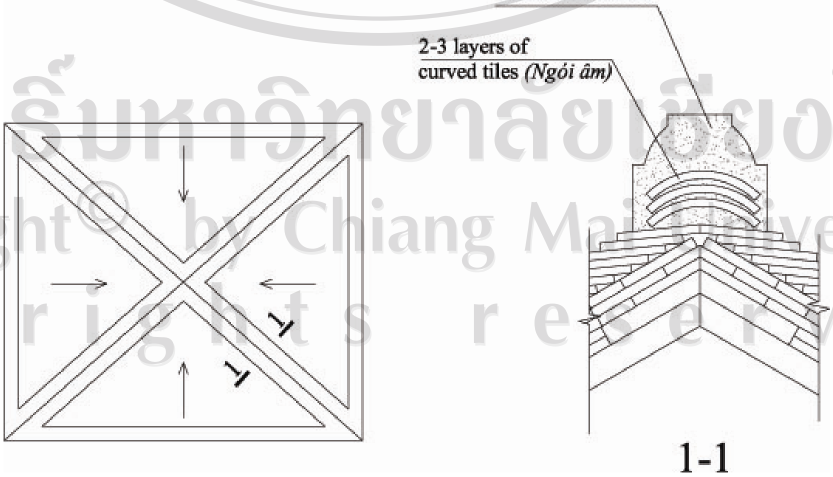


Fig.3.18 The curved tiles are used to cover to intersection of two sloping roof-planes.

The second traditional technique is to roof *Liet* tiles on the hip roof (*lợp ngói*). It is the work to arrange the tiles into straight lines precisely by hand which requires skillful roofers. Different from the direction of roofing current tiles from one side to another and from the bottom to the top in Hue today buildings, the direction of roofing *Liet* tiles on the hip roofs is from the both sides into the middle and, similarly, from the bottom to the top of the roof (Fig.3.19). But when roofers move to the center region of the hip roof, the direction is changed inversely from the top to the bottom, called *lợp lùi*. It is the work to finish the final *Liet* tiles flatly without mistake. Roofers must know how to tighten the tiles moderately in this stage. If stronger tightening, it is easy to break the tiles, or if weaker, the tiles will be loose. That needs the experiences from skillful roofers. To stabilize all *Liet* tiles, in *lợp lùi*, the locking by inserting more tiles after every 3-5 tile lines, called *khoá ngói*, is carried out to hold all *Liet* tiles firmly and keep the top-surfaces of hip roof stable.

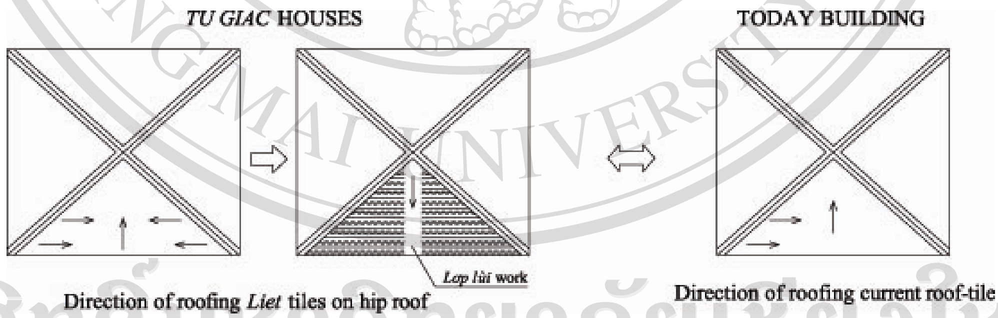


Fig.3.19 The direction of roofing *Liet* tiles in the hip roof.

3.1.5.c The traditional roof-composition of three tile-layers:

Different from the roofs of Hue today buildings with only one layer of current roof-tiles on the top, the covers of hip roofs by *Liet* tiles has contained the strong characteristic of Hue traditional architecture within three tile-layers (Fig.3.20).[7] The

[7] Hue Heritage House. *Guidelines for Conserving Hue Traditional Houses.* Hue., 2003., p. 34-35.

top layer (or *Ngói lợp*) is roofed carefully in which all horizontal lines of *Liet* tiles are overlapped each other with the distance 1.5-2cm in between to avoid water penetration. The middle layer (or *Ngói độn*) consists of 3-5 layers of *Liet* tiles to thicken the roof for its solidity and heat insulation. The bottom layer (or *Ngói chiếu*) is placed directly on timber rafters and be created by the better *Liet* tiles in their appearance such as having more equal sizes and similar color due to their displays into interior spaces.

The roofs of today buildings do not include heat-insulation layers in their roof-cover like hip roofs (Fig.3.20). Flexibly in today roofs, heat insulation is generally achieved by adding one layer of heat-insulated materials under the roof-tiles or by a ceiling. It leads to the simplicity in its composition and assembling, and makes the roof cover within three tile-layers as in the hip roofs become rare and unique. The composition of three *Liet* tile layers of hip roofs is the manifestation of Hue traditional architecture.

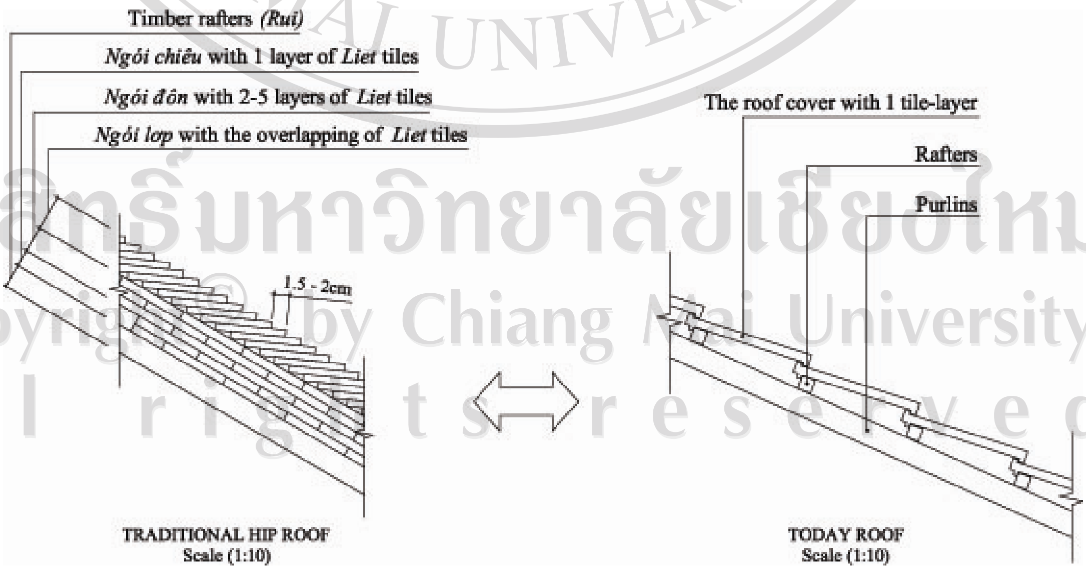


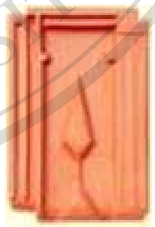
Fig.3.20 The composition of 3 *Liet* tile layers [8] distinguishable from the current 1 tile-layer.

[8] *Central Institute of Science, Technology, Construction.* 2007

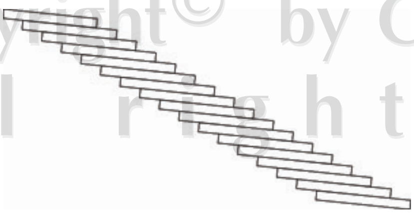
3.1.5.d The old traditional *Liet* tiles:

Liet tiles are the typical roof-tiles of Hue traditional architecture, appeared on the roofs of all *Ruong* houses and several royal buildings of Nguyen dynasty. They were made of clay and be produced in Hue local brick-kilns in form of flat square-tiles. Different from the clay roof-tiles of Hue today architecture with many details and be produced in factories, *Liet* tile unit is smaller in its sizes and has no any details. In addition, the stability on the sloping roof-planes of *Liet* tiles is dependent on the friction force among them while the stability of current tiles is based on the claw-connections (Fig.3.21). With the advantages of the current tiles in assembling more simply and quickly, it becomes popular in Hue today architecture and, of course, leads to the rareness of *Liet* tiles which only signify Hue traditional architecture. Similar to *Vo* bricks, *Liet* tiles are now produced in limited quantity only for the conservation work of historical buildings in Hue city.

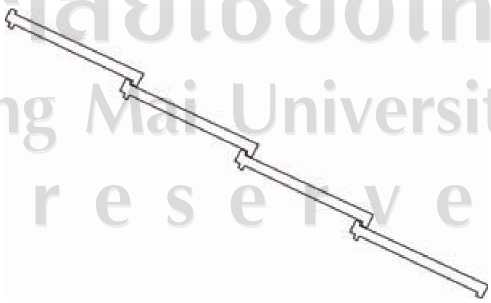
The traditional *Liet* tile 18 x 18 x 1cm



The current tile 34 x 20.5 x 1.3cm



Friction force from load-bearing helps to stabilize flat *Liet* tiles



Claw-connections or hooks for current roof tiles of today

Fig.3.21 The differences between *Liet* tiles and the currently roof-tiles.

3.1.5.e The usage of traditional mortar for roof ridges:

Four roof ridges on 4 diagonal sides of the hip roof are made from traditional mortar. It is the mixture of lime, sand, and treacle *(the dark and viscous liquid made from sugar-cane)* different from currently cement mortar without treacle. It has some advantages such as softer, capable of withstanding temperature changes and physical deformation, and longer life-expectancy.[9] Like *Vo* bricks and *Liet* tiles, the traditional mortar is now rare and be produced in limited quantity only for the conservation work of historical buildings in Hue city.

In short, the roofs of today buildings are diversity and be made from not only the current tiles but also many new materials like plastic, aluminum, or fiber-synthesized sheets accompanied by newly various technologies in roofing which contribute to the emergence and unique of the traditional *Liet* tile roofs as in the hip roofs at the present and in the future times.

3.1.6 The Entrance Doors using filled-in Horizontal Wooden Panels & The Slat Shutter Windows (A_6)

3.1.6.a The traditional characteristic of filled-in horizontal wooden panels door representing the historical street facing houses of the old towns in Central Vietnam:

The old towns in Central Vietnam were generally associated with their commercial development and their historical houses facing streets, specifically the Hoi An ancient town [10], the world heritage adopted in 1999. The type of door composed by slotting horizontal wooden panels from the top into 2 slots on both sides is the most common entrance-doors for the historic street facing houses of Hoi An and

[9] Hue Heritage House. *Guidelines for Conserving Hue Traditional Houses*. 2003.
[10] Hoi An flourished in the period from the late 16^{th} – early 20^{th} century and 150km far from Hue city.

becomes the outstanding architectural characteristic of this town required to be protected and conserved. In the old towns of Hue city like Chi Lang or Bach Dang, this type of door is also appeared in almost all the historical street facing houses (Fig.3.22). It can be inferred that the presence of this door in front of the historic *Tu Giac* street facing houses in Bao Vinh old town (former trading place of Hue city) is the reflection of historic street facing houses in the old towns of Central Vietnam.

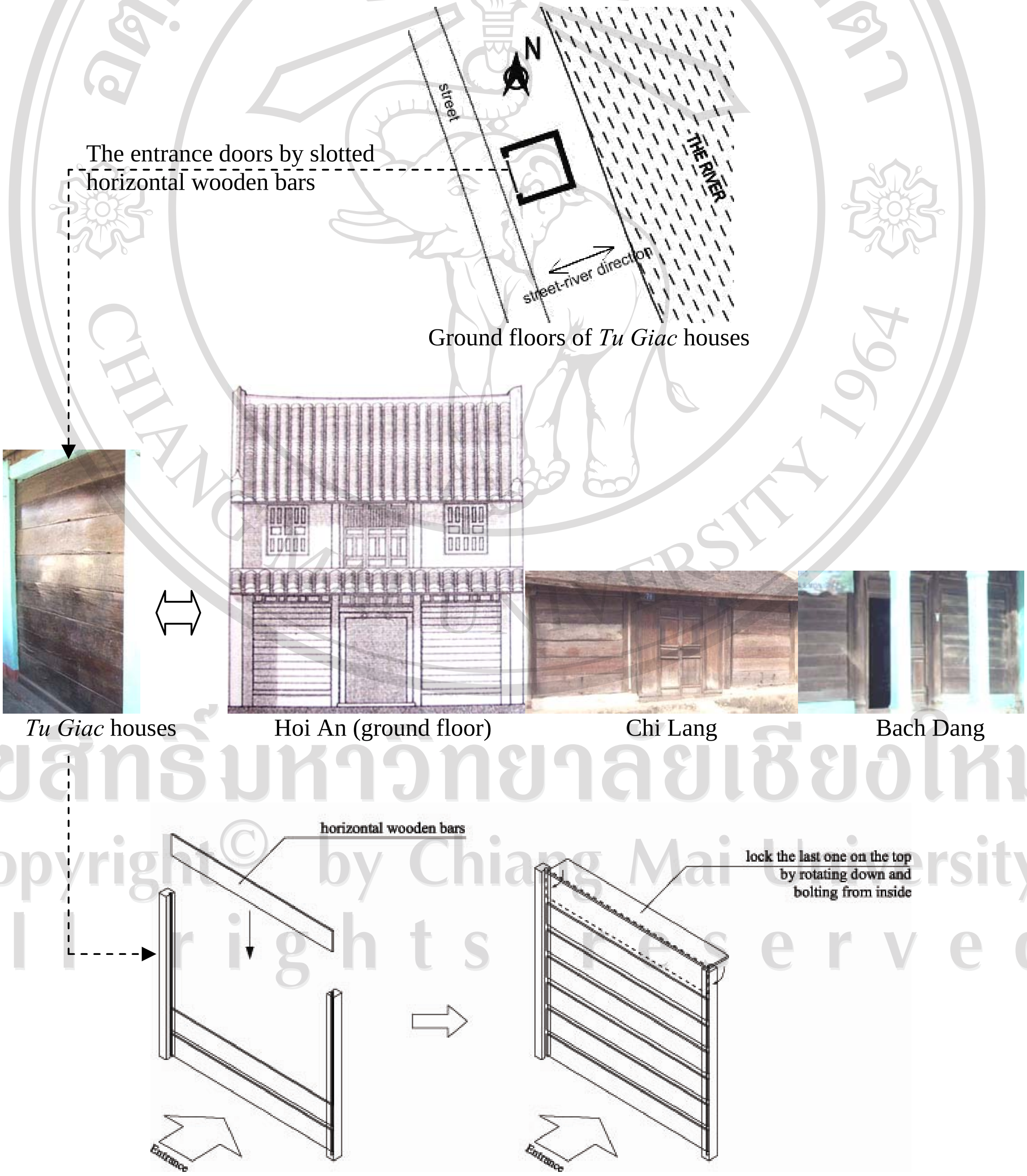


Fig.3.22 The entrance door using filled-in horizontal wooden panels in some old towns of Central Vietnam.

Comparing with the present doors of today buildings with numerous different types by steel, glass, U-PVC, or aluminum, the filled-in horizontal wooden panels in entrance door as in *Tu Giac* houses is very rare and typical only for the historical street facing houses of the old towns in Central Vietnam.

3.1.6.b The labor intensive but high strength filled-in horizontal wooden panels door:

The entrance door is made from two parts: 2 vertical slots on 2 wooden posts and the horizontal wooden panels. The horizontal wooden panels, within the width 25cm and the thickness 1- 1.5cm, are put in turn into two slots from the top by hand. The stability of the door is dependent on the last wooden panels on the top which is locked by rotating down and bolting from the inside (Fig.3.22). The time and labor spent to cover or uncover entrance is more than present doors but it allows the strength of the doors as the solid wooden-wall at front. It reflects the local intelligences to achieve the protective safety for the houses in the period without any new door-technologies.

3.1.6.c The response of the Slat Shutter Windows of the hot and humid region:

Along with the French arrival, the Shutter Windows as seen in *Tu Giac* houses were first introduced into Vietnamese and Hue traditional architecture and be used widely in the French-influenced buildings to response to the hot and humid region. It allows winds flow into the house through the opened-slits in-between the oblique wooden slats, bring the hot air and moisture out, and reduce temperature and humidity inside the house. It helps to improve the indoor microclimate of the house in hot seasons. In rainy seasons, the pitch of those wooden slats of the Shutter Window can prevent the rain-penetration but still enable air circulation inside the house (Fig.3.23).

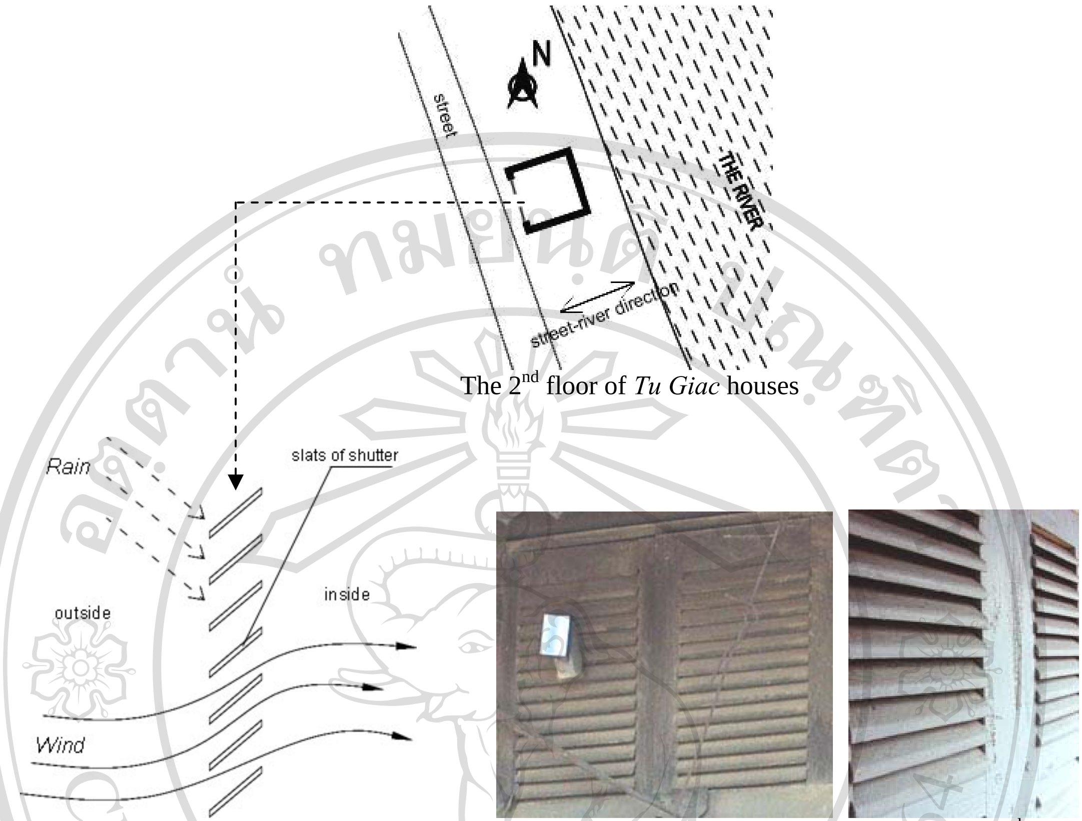
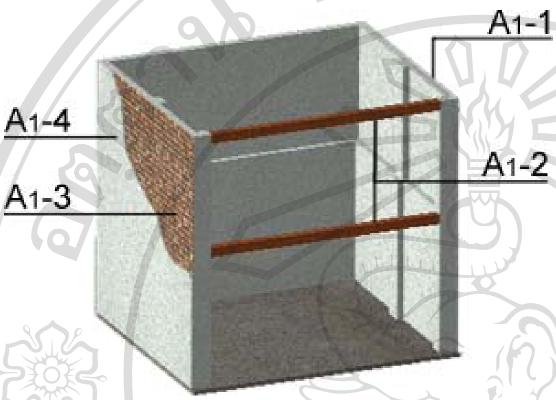
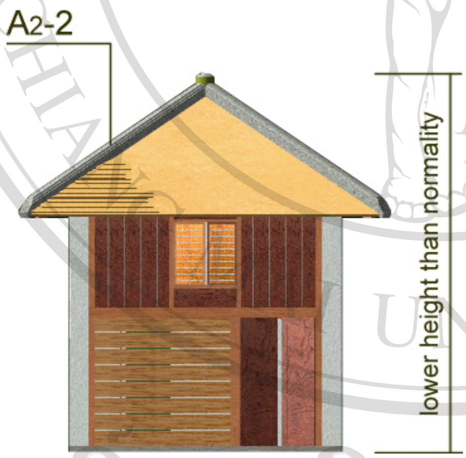
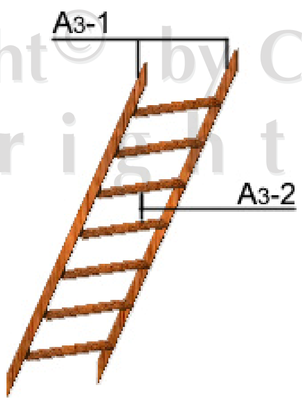


Fig.3.23 The shutter windows with its response to hot and humid climate are used for the 2nd floor spaces of the *Tu Giac* houses.

3.2 A typical *Tu Giac* House and Its Architectural Elements

Resulted from the analysis of six Outstanding Architectural Characteristics of the *Tu Giac* houses above, the typical *Tu Giac* House can be established which represent all 8 *Tu Giac* houses in Bao Vinh village. The provision of the Architectural Elements describing those six Characteristics is essential for the later actions of conservation and restoration. The typical *Tu Giac* House and its Elements is then shown as in Fig.3.24 on next page:

Fig.3.24 The conservation method-itemized model of *Tu Giac* House with its Architectural Elements representing 6 Outstanding Characteristics A_1- A_6

3D- Illustrations for the 6 characteristics A_1- A_6 of the typical *Tu Giac* House	Conservation Itemized – Architectural Elements for the 6 Characteristics A_1- A_6 of the typical *Tu Giac* House
	**The Load Bearing Walls (A_1):** ▪ A_1-1: Three walls on the north, south and west side ▪ A_1-2: Two timber beams on the missing load-bearing wall on the west ▪ A_1-3: The *Vo* bricks 25x13x5cm ▪ A_1-4: Lime-cement mortar
	**Two storey-Buildings (A_2):** ▪ A_2-1: The thicker wall downstairs and thinner wall upstairs ▪ A_2-2: The short two-storey buildings
	**The High-Pitch Timber Stair (A_3):** ▪ A_3-1: 2 high-pitch timber bars on both sides ▪ A_3-2: A set of horizontal timber stair-steps

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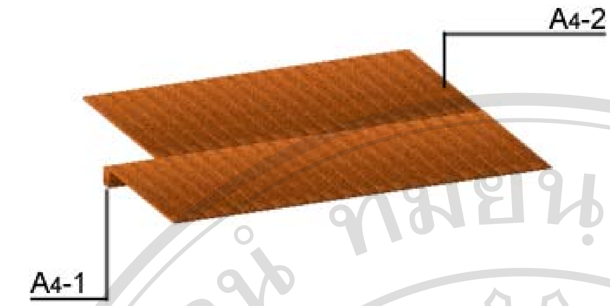

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The Timber Floor on the 2nd level (A_4):

- A_4-1: 1 timber beam in the middle
- A_4-2: A set of timber planks
- A_4-3: *Kien Kien* wood

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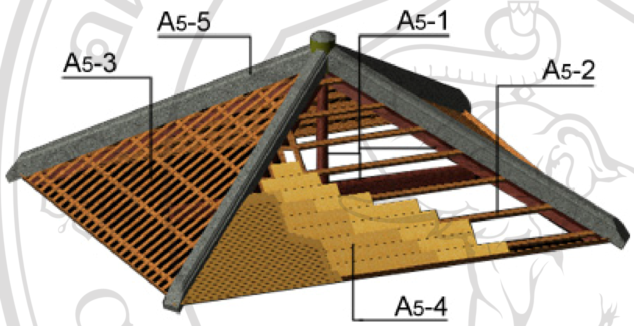

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The Hip Roof (A_5):

- A_5-1: Timber truss frames: 1 horizontal timber bar, 1 vertical timber bar standing on the horizontal timber bar, and 4 diagonal timber bars
- A_5-2: A set of timber purlins fixed on 4 diagonal timber bars
- A_5-3: A set of timber rafters fixed on timber purlins for putting *Liet* tiles
- A_5-4: 3 layers of *Liet* tiles arranged from the bottom to the top: *Ngói chiếu, Ngói độn, Ngói lợp*
- A_5-5: 4 diagonal roof ridges made from curved-tiles and traditional mortar

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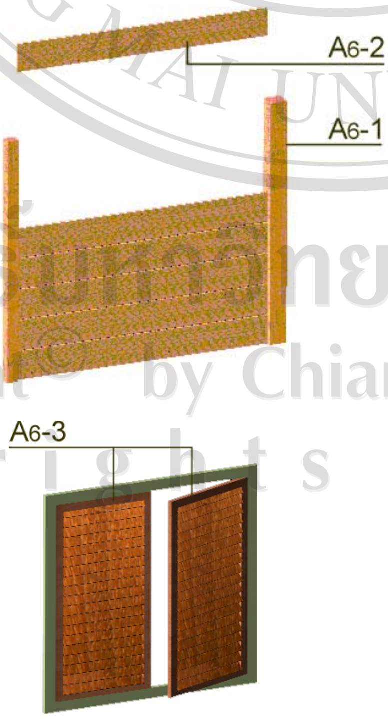

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The Entrance Door using filled-in Horizontal Wooden Panels and the Shutter Window (A_6):

- A_6-1: 2 wooden posts with 2 slots on both sides
- A_6-2: A set of horizontal wooden panels
- A_6-3: 2 revolving leaves created by the oblique wooden slats.

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The above outcomes of all Architectural Elements of the typical *Tu Giac* House help to compare the existing architectural elements of each *Tu Giac* house with those in the typical. It allows the study to define which houses have all architectural elements, and which houses are lacked of the architectural elements as in the typical *Tu Giac* houses, summarized in Fig.3.25 below:

Fig.3.25 The defining of 8 existing *Tu Giac* houses which contain or lack of Architectural Elements in comparison with the typical *Tu Giac* House

Architectural Elements of the *Tu Giac* House	House No.1	House No.2	House No.3	House No.4	House No.6	House No.7	House No.8	House No.9	Total	**P_1 (%)**
A_1-1	V	V	V	V	V	V	V	V	8V	**100**
A_1-2	O	O	O	V- O	V- O	V- O	O	V	4O, 3V-O, 1V	**31.2**
A_1-3	V	V	V	V	V	V	V	V	8V	**100**
A_1-4	V	V	V	V	V	V	V	V	8V	**100**
A_2-1	V	V	V	V	V	V	V	V	8V	**100**
A_2-2	V	V	V	V	V	V	V	V	8V	**100**
A_3-1	V	O	V	V	V	O	V	V	6V, 2O	**75**
A_3-2	V	O	V	V	V	O	V	V	6V, 2O	**75**
A_4-1	V	V	V	O	V	O	V	V	6V, 2O	**75**
A_4-2	V	V	V	V	V	V	V	V	8V	**100**
A_4-3	V	V	V	V	V	V	V	V	8V	**100**
A_5-1	V	V	V	V	V	V	V	V	8V	**100**
A_5-2	V	V	V	V	V	V	V	V	8V	**100**
A_5-3	V	V	V	V	V	V	V	V	8V	**100**
A_5-4	V	V	V	V	V	V	V	V	8V	**100**
A_5-5	V	V	V	V	V	V	V	V	8V	**100**

A_5-6	V	V	V	V	V	O	V	V	7V, 10	**87.5**
A_5-7	V	V	V	V	V	O	V	V	7V, 10	**87.5**
A_6-1	O	O	O	O	O	O	O	V	1V, 70	**12.5**
A_6-2	O	O	O	V	O	O	O	O	1V, 70	**12.5**
A_6-3	O	V	V	O	O	O	O	V	3V, 50	**37.5**
Total	16V, 50	18V, 30	16V, 50	17V, 1V-O, 30	17V, 1V-O, 30	12V, 1V-O, 80	17V, 40	19V, 20		
P_2 (%)	**76.1**	**85.7**	**76.1**	**84.2**	**84.2**	**59.5**	**80.9**	**90.4**		

(<u>Notes:</u> **V**: *have* **O**: *not have* **V- O**: *1 original beam existed and 1 original beam missed*
***P_1**: Percentage of keeping the architectural elements of the typical Tu Giac House in all 8 houses*
***P_2**: Percentage of keeping the original architectural elements in each Tu Giac house)*

From the percentages of retaining the architectural elements of the typical *Tu Giac* House (P_1) in relation to 6 characteristics A_1- A_6 in all 8 houses, it can be inferred that:

- The architectural elements of load bearing walls (A_1) are still intact in all 8 houses (100%) except for the two timber beams (A_1-2) on the missing load bearing wall which are removed, totally, in 4 houses and, partially, in 3 houses (31.2%).
- The architectural elements of two-storey buildings (A_2) are completely intact in all 8 houses (100%).
- The architectural elements of the high-pitch timber stair (A_3) are kept in six houses No.1, 3, 4, 6, 8, 9 and removed in two houses No.2, 7 (75%).

- The architectural elements of the timber floor on the 2^{nd} level (A_4) is retained in all 8 houses (100%) except the middle timber beam of the 2^{nd} floor (A_4-1) in two houses No.4 and 7 are removed (75%) for steel and concrete beams.
- The architectural elements of the hip roof (A_5) are still retained in all 8 houses except the *Liet* tiles (A_5-6) and 4 roof ridges (A_5-7) are only removed in the house No.7 (87.5%).
- The architectural elements of the entrance door using filled-in horizontal wooden panels and the shutter window (A_6) are greatly changed in all 8 houses (12.5% and 37.5%).

From the percentages of keeping the original architectural elements in each *Tu Giac* house (P_2), it shows that the *Tu Giac* house No.9 has kept the most original parts (90.4%) in all 8 houses while the *Tu Giac* house No.7 has contained the least original parts (59.5%). It means the replacing of missing original parts in the conservation of the house No.7 is more than in the house No.9, and the conservation techniques applied for decayed original parts in the house No.7 is less than the house No.9.

3.3 Deteriorations & Destructions of *Tu Giac* House (B)

3.3.1 The Load Bearing Walls (A_1-B)

3.3.1.1 Crack:

Cracks occurring in the load bearing walls come from two sources: thermal movement and the subsidence of the house.

- All building materials expand when heated and contract when cooled which is called thermal movement. It is the absolute dimensional change in material caused by temperature changes and known as the major cause of decay in buildings. The inner core of the walls made of bricks has lower Thermal Expansion Coefficient than the outer plaster made of lime mortar (Fig.3.26), which consequently cause the thermal movement of brick lower than plaster when seasonal temperature changes. This uneven movement between those two adjacent layers has caused cracks in plaster of the walls, especially when the physical properties of mortar like the cohesion and elasticity of material in plaster are reduced by adverse climatic impacts. The cracks usually appear in the plaster layer (Fig.3.27). It does not affect directly to the structural strength of the walls but, indirectly, its openings allow water or moisture to penetrate into the bricks, the main structural materials for the load bearing walls, deteriorate them and lessen the strength of the walls. The accumulation of that phenomenon in the passing of time has widened old cracks and created new cracks which quicken the destructive process of the load bearing walls.

Fig.3.26 The difference of thermal expansion coefficients of brick and mortar[11] leads to the cracks on the plaster.

Material	*Thermal Expansion Coefficient (m/m^oC)*
Lime mortar	$8\text{-}10 \times 10^{-6}$
Brick	5×10^{-6}

[11] Bernard M Feilden. *Conservation of Historic Buildings*. Architectural Press., 2003, p.96.

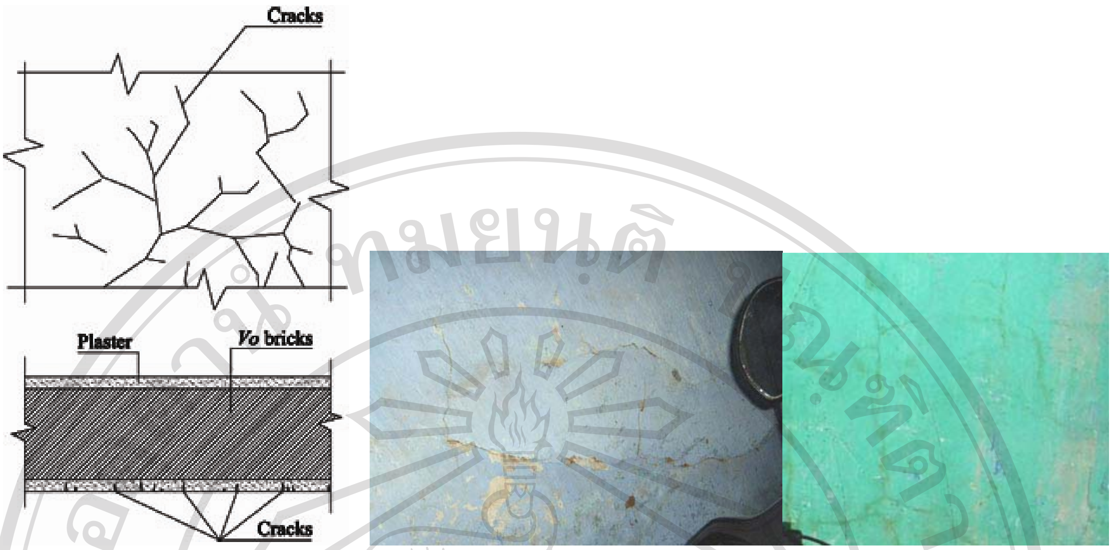
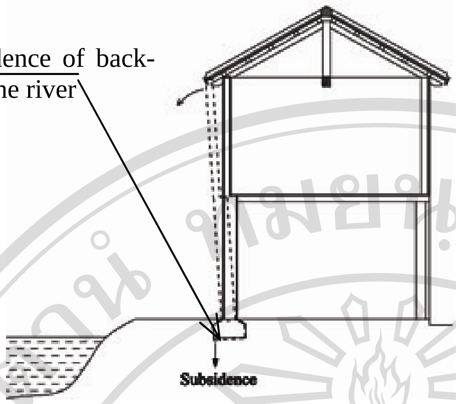


Fig.3.27 The cracks on the walls caused by uneven thermal movement between plaster and brick.

- The subsidence of *Tu Giac* houses, generally happened on the back side closely to the river (Fig.3.28), is the other cause of cracking in the load bearing walls. The extra weights added to the original *Tu Giac* houses by the later spatial expansions have led to the subsidence of their footings. The load bearing walls placed directly on them are moved out of their initial positions. This happening has created the shear and tension forces apart from the only compression forces the walls have to withstand. As a consequence, cracks have been created on the walls in both the plaster and the bricks. The cracks caused by the subsidence usually tend to separate the wall into many pieces. They are much wider and deeper than by thermal movement (Fig.3.28& 3.29). They are more harmful to the house because they affects directly to the strength of the walls.

The subsidence of back-wall near the river



The device based on the water-drop balance shows the declination of back-wall caused by subsidence

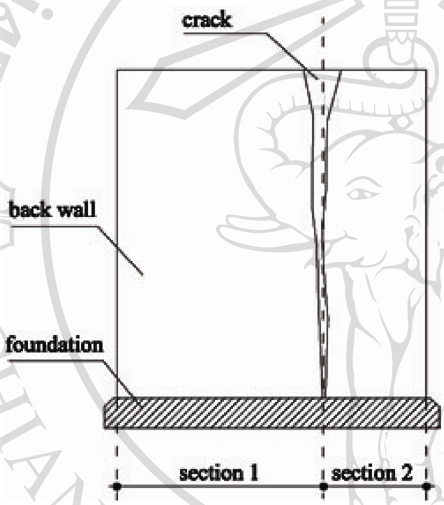


Fig.3.28 The uneven subsidence of two vertical sections (1 & 2) of a single back-wall causes the vertical crack which tends to separate the wall into 2 vertical parts.

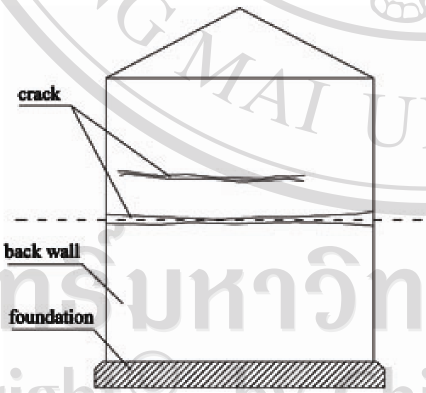


Fig.3.29 The subsidence of the whole foundation backwards creates shear forces in walls. It results in the horizontal cracks which are liable to divide the wall into 2 horizontal parts.

3.3.1.2 Moss:

Moss appears on the places where there is the dampness with the soil or dirt[12]. The lower parts of the walls on the ground floor soaked with annual floods with mud and dirt. The lower parts of the walls on the 2nd floor is wet by daily washing clothes are vulnerable to the growth of moss (Fig.3.30). It affects the physical properties of mortar in the plaster, reduces the adhesive nature of mortar and finishing material, and contributes, in other ways, to the deterioration process of the load bearing walls.

On 2nd floor *On ground floor*

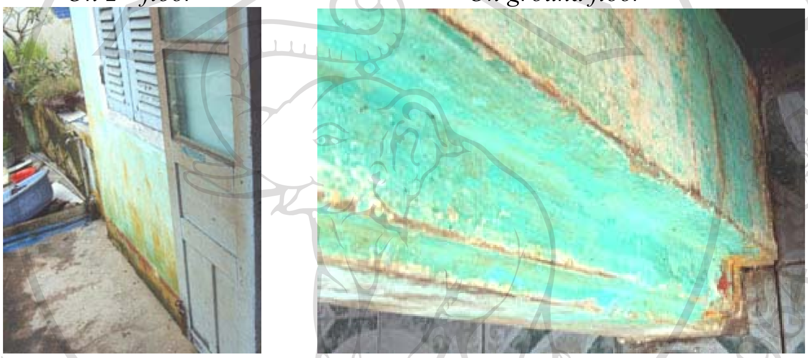


Fig.3.30 Moss appears on the lower parts of the load bearing walls on the 2nd floor (left side) and on the ground floor (right side).

3.3.1.3 Fungi and moulds:

They grow on the surfaces of the walls which supply enough water and oxygen without sunlight for their survival[13]. In the hot and humid region as Hue city with the humidity over 80% in year, the moist interior spaces without air circulation in some *Tu Giac* houses is the good condition for their rapid growth. Similar to moss, it has damaged the physical properties of mortar and then intensifies the destruction of the plaster in the load bearing walls (Fig.3.31).

[12] Bernard M Feilden. *Conservation of Historic Buildings*. Architectural Press., 2003.
[13] Ibid.

Fig.3.31 Fungi and moulds have grown on the below part of the walls on the ground floor (left side) and on the 2^{nd} floor (right side).

3.3.1.4 The flakiness of plaster and finishing:

- The flood water is the major stimulant for the flakiness of the plaster and finishing layers on the below parts of the walls (Fig.3.32). In Hue city, there are annual floods which soak the below parts of *Tu Giac* houses into flood water for 2 or 3 days[14]. Physically, flood water drenches the interior and exterior of the walls and penetrates into the *Vo* bricks. The adhesive nature of mortar in plaster has been lessened and made the plaster peeled off. The *Vo* bricks inside are wetted then. Because their evaporation rate is uneven, the *Vo* bricks are saturated and have become friable. Year by year, this problem leads to the flakiness of all plaster in the below walls and cause deteriorations to the *Vo* bricks.

Fig.3.32 The flooding in Bao Vinh (in 2008) and the flakiness of the plaster and finishing on the below parts of the load bearing walls caused by flood.

[14] Hue Heritage House. *Renovation Guidelines on Traditional Houses.* Hue., 2003., p. 47 – 49.

- The development of cracks has created the isolated regions of mortar which tend to fall down (Fig.3.33). The plaster and finishing are thus easy to be flaked off accordingly. In addition, the climatic impacts from high fluctuation of temperature and humidity of Hue weather have quickened the aging process of mortar. In time, mortar has been disintegrated and turned to powder before falling down. It also results in the flakiness of the plaster in load bearing walls.

Fig.3.33 The flakiness of isolated regions of plaster caused by the development of cracks (left) and by the aging process of mortar (right) has made *Vo* bricks exposed to outside.

- The growth of moss, mould, and fungi on the finishing layers, made from calcium-originated whitewash, together with the thermal movement of finishing layers due to seasonal temperature changes has promoted their disintegration (Fig.3.34). Those actions has reduced the cohesion of material in the finishing layers and, as a result, resulted in their flakiness.

Fig.3.34 The flakiness of finishing layers, the calcium-originated whitewash, on the load bearing walls.

3.3.1.5 Man-made destructions:

- The load bearing walls have been used for hanging things or objects by iron bars or nails. Drilling holes disorderedly on the walls for fixing them have damaged the surfaces of load bearing walls (Fig.3.35).

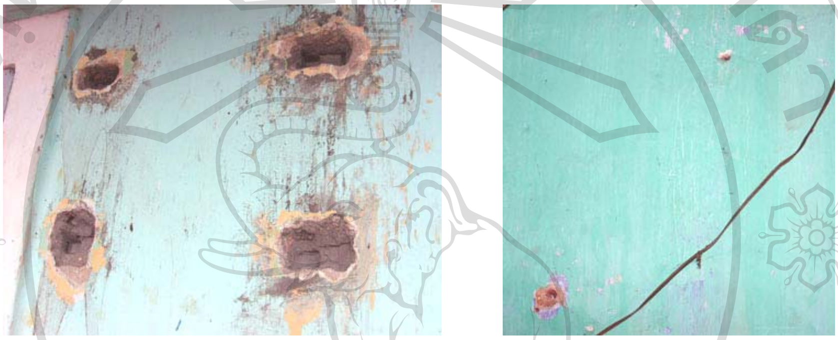


Fig.3.35 The holes created on the walls for hanging things or objects have been destroying the surfaces of the load bearing walls.

3.3.2 Two-storey Buildings (A_2-B)

3.3.2.1 The encroachment of additional parts

The additional parts like walls or roofs built recently for enlarging living spaces on the 2nd floor have the approximately equal height to the original two-storey fabric of *Tu Giac* houses, especially their conflicts with the heights of the hip roofs. Therefore, the special scales in façade defined by the dimensional relationships of the original two-storey fabric of *Tu Giac* houses has been destroyed by the presence of those additional parts (Fig.3.36).

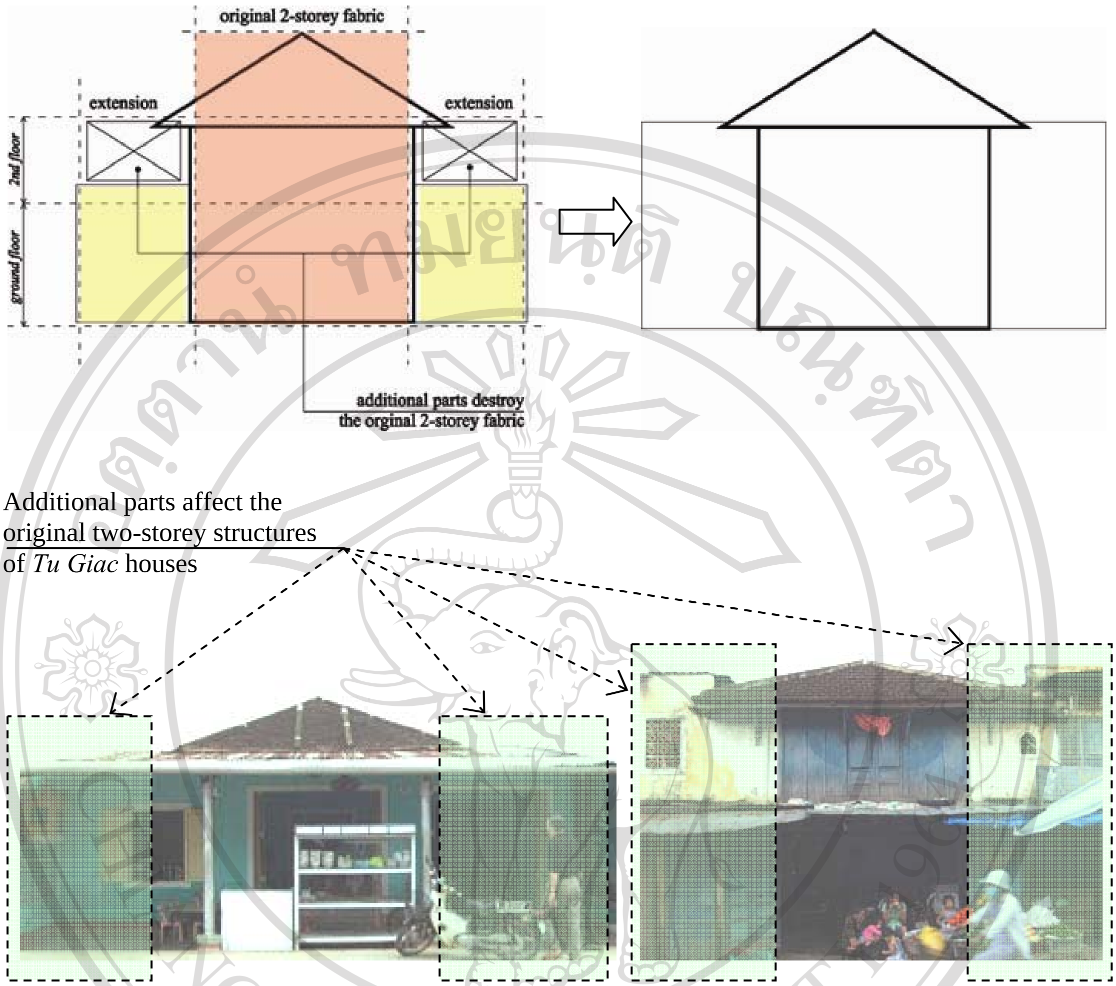


Fig.3.36 The additional parts on the 2nd floor conflicting with the hip roofs have destroyed the special scales in façades of the *Tu Giac* original two-storey fabric, shown clearly in the façade analysis *(above)* and the real photos *(below)*.

3.3.3 The high pitch Timber Stair (A_3-B)

3.3.3.1 Cracks:

Cracks occurring on wood surface of the stair are induced by thermal movement. Wood is the anisotropic and not identical material that leads to the uneven expansion and contraction when seasonal temperature changes.[15] It has resulted in cracks on wood surfaces and contributed to the destruction process of high-pitch timber stairs (Fig.3.37).

[15] Hue Heritage House. *Renovation Guidelines on Traditional Houses.* Hue., 2003., p. 47.

Fig.3.37 The cracks on the wood surface of the stairs caused by thermal movement.

3.3.3.2 The aging of wood and fungal and pest attacks:

Wood is the organic material affected by time, especially under the impacts of temperature and humidity changes, the aging process of wood escalates and lead to the reduction of physical properties and the cohesion of wood material. The wood surfaces, which are contacting environmental changes, have turned to powder and been vulnerable to fungal and pest attacks (Fig.3.38). Through time, the timber elements of the stair have deteriorated and reduced the values of the high pitch timber stair.

Fig.3.38 The aging process of wood and fungal attacks on their surfaces.

3.3.3.3 The damages of endpoints:

Due to located on the ground floor which suffers flooding every year, the ends of the high pitch timber stairs has been soaked into flood water for several days. Moisture, mud, and soil left on the below parts of them after flooding has destroyed the endpoints of the stairs and caused rots, cracks, or even broken (Fig.3.39).

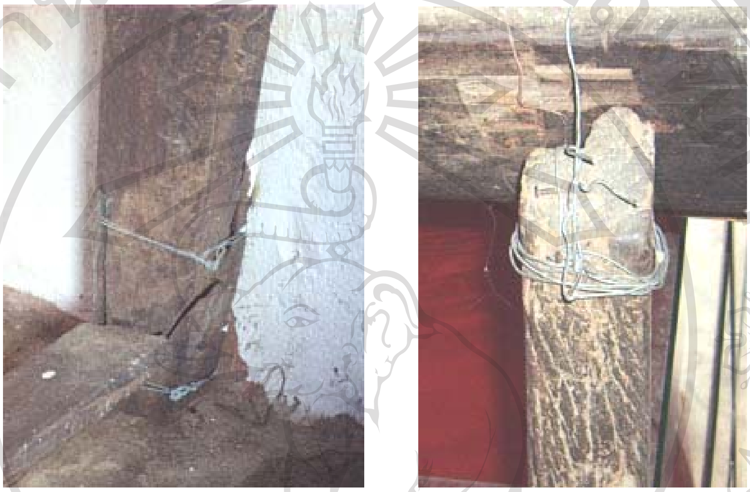


Fig.3.39 The damaged endpoints of the stairs.

3.3.3.4 The movement out of its original position:

Since the *Tu Giac* houses were expanded for living purpose, their original ground floors have been used for main activities of both living and shop. In some specific cases, the stair was moved out of its original position to another place for freeing and making use of the ground floor area (Fig.3.40). Particularly in the house No.2, the timber stair was not only shifted out of its original position but also rebuilt by the new material of concrete. Therefore, the architectural values of the stair associated with the historical and architectural values of the house have been removed totally.

Fig.3.40 The moving to the other place outside the original structure of *Tu Giac* house and its stair hole left with the new wooden planks *(2 photos on left sides).* The changing into new material of concrete of the timber stair *(right side)*.

3.3.3.5 The encroachment on the original narrow access:

To make use of the 2nd floor area, owners have used new wooden planks to cover one part of the access-hole to enlarge using area despite its inherent narrowness (Fig.3.41). The low quality wooden planks together with their covering on the original narrow access have diminished one of the outstanding characteristics of the high-pitch timber stair in *Tu Giac* houses.

Fig.3.41 The encroachment of the stair-holes by disordered wooden planks has affected the outstanding characteristic of the timber stair.

3.3.4 The Timber Floor on the 2nd level (A_4-B)

3.3.4.1 Cracks on the floor beams and planks:

Cracks occurring on the timber planks and beams of the 2nd floor are caused by two reasons: thermal movement and the reduction of strength (Fig.3.43 & 3.44). The uneven expansion and contraction of wood induced by seasonal temperature changes is liable to cracks on the wooden surfaces of floor beams and planks. Through time, the physical properties and the cohesion of wood to withstand compression and tension stresses are reduced gradually. It makes the elements of the timer floor weaker and results in the cracks on them.

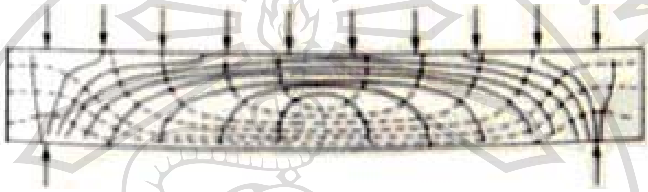
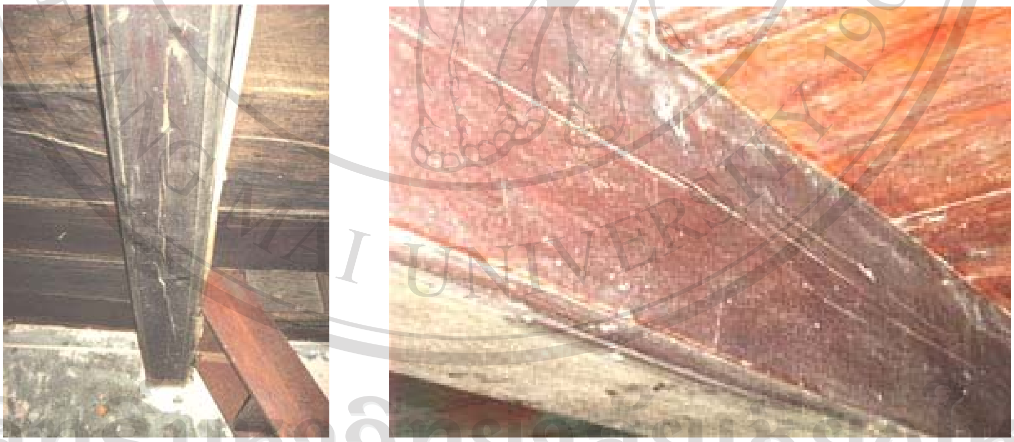


Fig.3.42 Isostatics are contour lines of tension *(dotted lines)* and compression *(solid lines)*. The intersection of lines shows shear. The closeness of the contours expresses the intensity of stress. It indicates that tension is greatest at the bottom and compression is biggest on the top of the beam at mid-span. Shear is greatest at the ends[16]. It accounts for the appearance of cracks along the below half of the beam due to excessive tensions.



Grain direction   Horizontal shear against bend between grains

Fig.3.43 The structural cracks along the below half of the floor beams caused by their weakness in withstanding the tension stresses.

[16] Bernard M Feilden. *Conservation of Historic Buildings.* 2003.


Fig.3.44 Cracks appeared on the wooden surfaces of the floor beam (left) and planks (right) caused by thermal movement.

3.3.4.2 The change of the original timber planks:

Due to suffering flooding on the ground floor every year, some original timber planks of the 2nd floor have been removed to enlarge the access hole for moving big objects or goods upstairs (Fig.3.45). To assemble or disassemble them easily and quickly, the new timber planks without *groove and tongue* joints have been used as the substitutes. It leads to the looseness among those new planks and enable dusts to fall downstairs through the open slits in between. To avoid this problem, some owners have utilized sticking-plasters to close the slits. In addition, the poor-quality planks are used for changing the original ones. All the above things have disfigured and affected seriously the outstanding characteristics of the original 2nd floor in *Tu Giac* houses.


Fig.3.45 The poor-quality planks used as the substitutes for the original ones with the covering of sticking-plasters on opening slits in between (left).

3.3.4.3 The fungal and pest attacks:

Through time of using under climatic impacts, the adhesive nature of wood has been reduced gradually, wood become dry and soft. The poisonous substance against fungi and pests inside wood has been reduced and thus vulnerable to their attacks, especially in the good conditions of hot and humid region as Hue city. Additionally, the cellulose and lignin in wood is the food sources of them.

- The attack of fungi in the 2nd timber floor can be detected by the whitish discoloration of wood and by, through paintwork, the whitish flecks on the darker background (Fig.3.46). These kinds of fungi can destroy the lignin[17] of wooden planks and beams. The wooden planks and beams that are embedded in masonry like load bearing walls of *Tu Giac* houses have high moisture content and thus are destroyed by fungi. The wood-staining fungi grow on wood surface and produce stains. It induces the flakiness of painted surfaces.

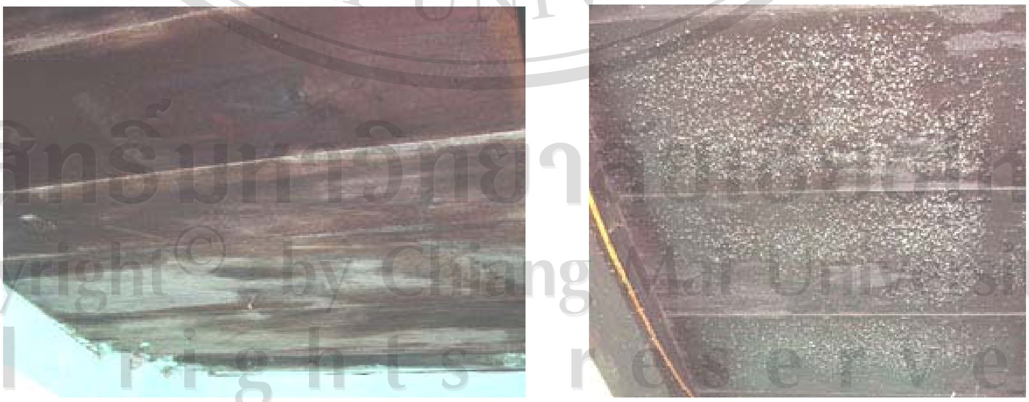


Fig.3.46 Fungal attacks with white flecks on the wooden surfaces of the floor planks.

[17] Bernard M Feilden. *Conservation of Historic Buildings*. Architectural Press., 2003, p. 135.

- In the tropical regions like Hue city, termites are considered as the main pests of destroying the timber elements. [18] Due to its separation from the ground, the 2nd timber floor is only vulnerable to the dry-wood termites which require no access to the soil. They live in small colonies and feed on seasoned wood (dry-wood). They eat sapwood. They dig holes on wood surfaces and produce granular dusts when feeding. They continue their feeding until there is no nutrition left or the timber is totally destroyed (Fig.3.47).

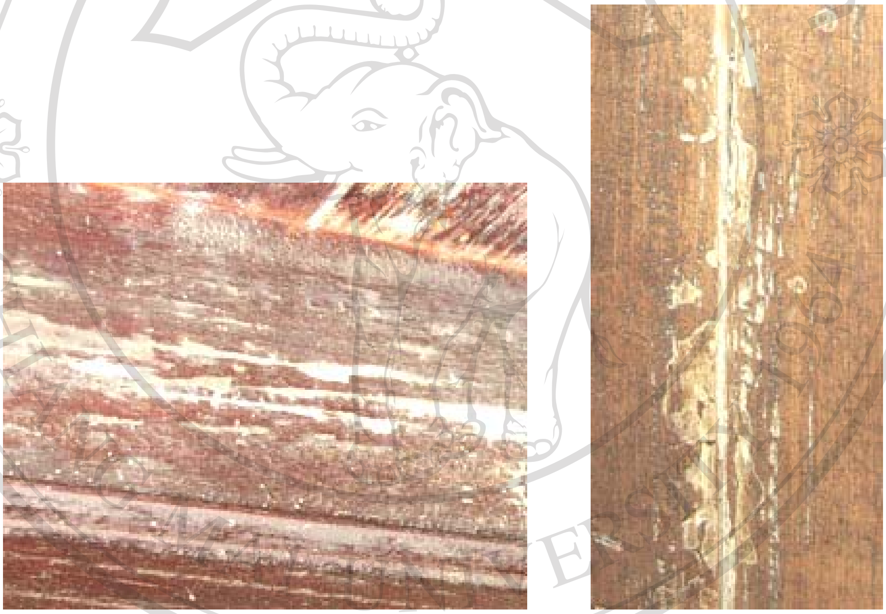


Fig.3.47 Floor beams and planks are attacked by termites.

3.3.4.4 The damage of the endpoints of timber planks:

The endpoints of the timber floor planks which are enclosed in masonry walls are threatened by rot and termites due to the high moisture content inside walls. It increases the deterioration process of their endpoints (Fig.3.48).

[18] Bernard M Feilden. *Conservation of Historic Buildings*. Architectural Press., 2003, p. 146.

Fig.3.48 Deterioration of the endpoints of the timber floor planks.

3.3.5 The Hip Roof (A_5-B)

3.3.5.1 Crack of the roof ridges:

At the positions of the roof ridges 30-50cm from the peak, the only connection of four ridges, cracks normally happen due to their tendency of sliding down. It creates openings on the top liable to water-leaking inside the houses (Fig.3.49).

Fig.3.49 The cracks of the roof ridges on the top.

3.3.5.2 The aging of wood and the fungal and pest attacks:

Similar to the timber floor on the 2nd level, the timber frame system of the hip roof with timber trusses, purlins, and rafters have been attacked by fungi and pests, especially the dry-wood termites. In addition, the rain-water penetration from the top through decayed *Liet* tiles has increased the growth of them and deteriorated the timber frame system. It also contributes to the aging process of wood (Fig.3.50).

Fig.3.50 Fungal attacks (left and middle) and termite attacks (right) on the elements of the timber frame system of hip roof.

3.3.5.3 Cracks of the timber truss frames:

Similar to the timber stair and 2nd floor, thermal movement occurring inside wood has caused cracks on the wood surfaces of the elements of timber frame system of the hip roof (Fig.3.51).

Fig.3.51 Cracks caused by thermal movement appear on the horizontal (left) and vertical trusses (right) of the timber frame system.

3.3.5.4 Destructions of *Liet* tiles:

▪ In the condition of heavy rain and high humidity of Hue city, mosses have grown rapidly on the top surfaces of *Liet* tiles, the organic material, slowed down the drying process of their surfaces and therefore rotted them gradually (Fig.3.52). After a definite time, *Liet* tiles turn to powder and are liable to water-seeping down to below *Liet* tiles before leaking into the interior spaces.

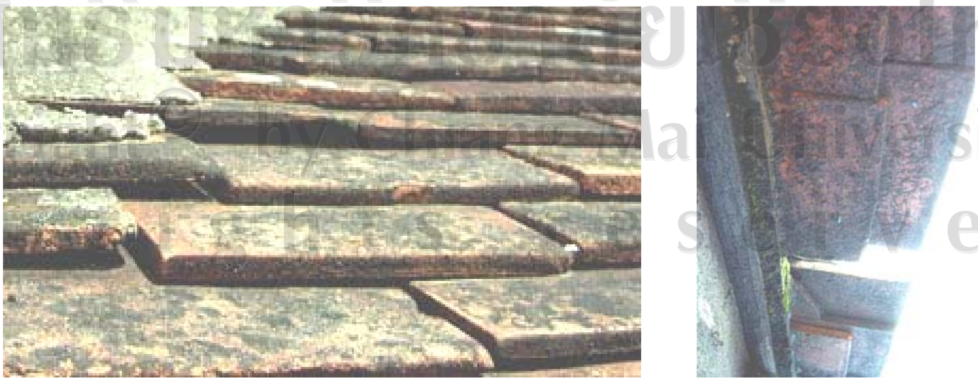


Fig.3.52 Mosses grow on the top surfaces of *Liet* tiles.

▪ The high moisture content inside the house due to the high humidity of Hue city and no air circulation is a good condition for the rapid growth of fungi and mould. They has caused blackish moulds on the tile surfaces and contributed to the deterioration process of *Liet* tiles (Fig.3.53). Rain water can seep and leak through those decayed *Liet* tiles easily and causes damages of timber frame system of the hip roof below.

Fig.3.53 Mould and fungi on the surfaces of *Liet* tiles due to high moisture content inside the house.

3.3.5.5 Man-made destructions:

▪ The iron plates are used in between the decayed *Liet* tiles to seal the holes in the hip roof where rain water can leak downwards (Fig.3.54). The presence of them in front of *Liet* tiles has disfigured and affected to the internal appearance of *Liet* tiles in the 2nd floor. Besides, in heavy rains, these iron plates function not well due to the possibility of water-leaking into interior spaces through them.

Fig.3.54 Iron plate is used to seal the holes on the roof for water-proof.

▪ Spontaneously refilling mortar on the top to prevent water penetration has destroyed the traditional original *Liet* tiles of the hip roof (Fig..3.55). It affected seriously the architectural values of the hip roof.

Fig.3.55 The filling of mortar on the roof to prevent water-penetration.

▪ In order to fix lights and electric lines on the hip roof, iron nails were hammered on the vertical timber trusses and purlins (Fig.3.56). It leaves disordered holes unable to fix after removing nails. Rusts from decayed iron nails can destroy wood surrounding. The presence of iron nails and messy electric wires on the timber frame system have contributed to the destruction of the hip roof.

Fig.3.56 Iron nails fixed on timber elements cause rots of them.

3.3.6 The Entrance Doors using filled-in Horizontal Wooden Panels & The Slat Shutter Windows (A_6-B)

3.3.6.1 The aging of wood and fungal and pest attacks:

Similar to the 2^{nd} timber floor and the timber frame system of the hip roof, the wooden doors and windows of *Tu Giac* houses have been attacked by fungi and pests. Furthermore, rain water possible to hit them from outside has increased the aging process of wood as well as the growth of fungi and pests. Rots, holes, and cracks appeared on the wood surfaces of the doors and windows as a result (Fig.3.57).

Fig.3.57 Holes, cracks and rottenness are created on the surfaces of wooden doors and windows by pest and fungal attacks and the aging process of wood.

In brief, the *Tu Giac* Housing Type which represents the genuine Vietnamese-French architecture of all *Tu Giac* houses are already established though the analysis on their six Outstanding Architectural Characteristics (A_1-A_6) as in section 3.1 in this chapter. The provision of all Architectural Elements symbolizing those 6 Characteristics of the *Tu Giac* houses as in section 3.2 is necessary for the consideration to their physical decays and destructions as in section 3.3 and the application of appropriate conservation methods and techniques in Chapter 4.

3.4 Conclusions of Chapter 3

The total of 6 outstanding characteristics of *Tu Giac* houses are identified as follow:

1) the significant 3-sided load- bearing wall, making the load-bearing incompleted on one side but utilized a horizontal wooden beam to hold the 3 walls together and to support the load of the second floor, a talented and strange construction technique,

2) the 2-storey buildings had been very rare in Nguyen Dynasty (1802-1945) especially for 2-storey-load- bearing walls, the 8 *Tu Giac* houses together with the 11 of 2-storey *Ruong* houses (out of > 1000 houses), make them truly a significant group of architecture,

3) the space-savings high-pitch staircase which required exceptional skill to load and unload goods and commodities up and down between the 1st and 2nd levels, resembling the high pitch stairs of a Citadel Palace

4) the old and long lasting 70-80 year-old *Kien Kien* wood-floor are still fully today,

5) the hip-roof which was a strange type of roof in Hue City, functioning (French-influenced architecture) in contrast with the traditional gable roofs of the *Ruong* traditional houses,

6) the traditional two wood slots filled-in with *Kien Kien* wood panels one on the top another to fill up as a high strength wooden door to protect valuable commodities inside *Tu Giac* houses.

Fig.3.3 illustrates the correlation of all 6 significant characteristics of *Tu Giac* houses in Column A, then study the possible decays, deterioration, and destructions of the 6 items shown in Column B, the refer to the related charters and principles for conservation in Column C, and finally, determine the possible conservation methods and techniques shown in Column D. The methods and techniques found in Column D are transferred to Chapter 4 to define a ‘prototype’ of conservation methods that can be applied to conserve the 8 *Tu Giac* houses.