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AN INFORMATION MODEL FOR THE TRADITIONAL LONG-ROOF TYPED MALAY HOUSES

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ABSTRACT: *An information model has been developed for the study of traditional Malay houses (TMH) of the bumbung panjang type that is capable of being implemented in a computing environment. The information model consists of interpretive and generative sub-systems. The interpretive sub-system utilizes the formal approach of shape grammar in the analysis of the forms and spaces of the TMH while the generative sub-system utilizes the construction knowledge of the TMH to create the shapes of the TMH. This information model is implemented in a scene-graph modeling package which allow the users to modify design parameters such as type of spaces and length of timbers to either recreate an existing TMH or create a new TMH. The prototype implementation of the information model is currently limited to the timber-frame structure of the TMH.*

Introduction

In this paper, the approaches from computational design and modeling are combined in the modeling of information related to traditional Malay house (TMH). The computational design approach is based on the formalism of shape grammars while the computational modeling approach is based on the computer graphics representation that provides the platform for a prototype implementation. The combination of the two methods for representing the knowledge of the TMH results in a new approach for the study and analysis of the TMH.

The past decade has seen an explosive use of computers in architectural practice and research. The initial use is as drafting systems for producing architectural design. This was later followed by applications in layout designs, knowledge bases for architectural design practices, simulation of building performance, 3-D modeling and virtual reality of concept and historical buildings. Perhaps one of the best ways to experience historical architecture is to create virtual 3-D models. However, this task is tedious and time consuming and such attempts are typically one-off and have to be redone from scratch for each design, even for those that belong to the same style. An alternative approach is to capture the design principles that are common in the corpus of the historical buildings and develop a computational design and modeling system that implements this knowledge. In the case of the TMH, this approach is important especially from the point of historical preservation and restoration since the design process of the TMH by master builders and carpenters were never recorded or documented by the builders in a way that can facilitate preservation and reconstruction. In this respect, this paper offers a significant departure from previous approaches in the study of the TMH by using the computational approach as a foundation for the research.

In computational design approach, the process of generating design solutions can be captured using the shape grammar formalisms. Shape grammars (Stiny and Gips, 1972) are defined by a set of shape rules, which collectively define a language of shapes in which the logic of the form of the built environment can be captured. Shape grammars have been shown to be an effective design tool because of their ability to handle geometric reasoning and their ability to operate on parametric geometric representation (Agarwal and Cagan, 2000). Due to these desirable characteristics, shape grammar is chosen as the method of knowledge representation of TMH. It is one of the ideal ways of describing any built forms. As describe in the previous section, a grammar enable the generation of a built form using rules. The grammar also at the same time is able to generate new built forms that follow the same styles of the original forms. With this approach, designers are able to determine the sets of designs corresponding to the language of the grammar. Shape grammar does not only provide a mechanism for interaction between the user and the program through its visual formalisms, but also provide a formal apparatus for communication between the design models and the mathematical models. This requires complex data and variable management. Design models such as perspectives, proportional system, and other geometrical constructions are deeply rooted in mathematics and computation. Architectural styles can be explored visually and interactively with grammatical analysis due to its computational nature.

The main objective for this paper is to develop an information model for the analysis of the timber-frame structure of traditional Malay house (TMH) of the *bumbung-panjang* (long-roof) type. In particular, the research focuses on a general framework of sub-system representations and a computational environment that supports the representation of the form and style of TMH. The approach includes identifying the common structure and appearance of TMH and developing the compositional grammar to construct instances of the style. The compositional grammars of the TMH were developed by referring to the living spaces of the TMH and to the construction methods described in previous documentations of the TMH. The grammar however, does not necessarily follow the construction steps in building a TMH. The grammars formed the framework for the information model that is suitable for implementation in a computing platform. This would enable a user to investigate the various forms and style of the TMH and would allow the user to either recreate a particular TMH with data from documented sources or to create a new TMH base on user-defined data. A developed CAD tool would facilitate exploration within the architectural language of the TMH. In order for the implementation to be useful and practical, the implementation must support the level of geometric detail used to define the language.

This work focuses on the TMH of the *bumbung-panjang* type as a start. The *bumbung panjang* type is selected due to the fact that it is the original form of the TMH. While many of these houses are no longer habitable or have been destroyed, some have been well preserved and well documented. The *bumbung panjang* (long roof) type is also selected due to the fact that the key features of the houses were easily discernible from the side view. The developed framework allows for the variations to the built forms due to the differences in spaces and floor level as well as multi-unit houses. This work is currently limited to capturing the form and style of TMH as represented by the timber-frame structure. Further enhancement of the grammar could include the ornamental details of the TMH to capture a certain style from a certain region to distinguish it from another region. This however, would require specific grammar to be developed and would require an extensive graphical representation to be implemented. Examples would be a window grammar, a door grammar, a stair grammar, or a decoration grammar. This is recommended for further development in this area of research.

One of the earliest descriptions on traditional Malay houses was reported by Winsted (1929). Winsted (1929) described the Perak Malay house that was built entirely without any squared timber. The house has verandah attached to the core space on both sides and floor levels of the verandah are at a lower level than the core space. Noone (1948) described houses built by Malays of Patani descent living in Perak. His description includes the form and relative positions of the additional structures that could be added to the core space of the house. He characterised the houses as either a single-ridge roof house or a double-ridge roof house. The basic Malay house described by Hilton (1956) was a single-ridge long-roofed type house made of 3 x 4 posts with three spaces denoted by the *rumah ibu* (core space), the *serambi gantung* (hanging verandah) and the *kelek anak* or *serambi samanaik* (rear verandah). The floor level of the *kelek anak* is the same as the floor level of the *rumah ibu.* This description generalized the form of TMH found on the west coast of the peninsula of Malaysia. Sheppard (1969) continued the study of the built form of TMH by giving the description of TMH from the east coast region. Of particular significance in the study is the detailed description of *rumah bujang* (bachelor house) made up of six posts. *Rumah bujang* consists of only the core space under the single-ridge roof and is considered the most basic TMH. A detailed study on the physical, spatial and functional elements of TMH from the central and south regions of the Peninsula was given by Wan Burhanuddin (1981). The variations of styles of TMH from region to region of the whole Peninsula were described by Wardi (1981), Nasir (1985), Lim (1987), Nasir and Wan Teh (1994) and Mohd Tajuddin et al. (2004). Kamaruddin (1983), Lim (1987), Gips (1987) and Zulkifli (1996) provided details of construction and evolution of spaces of the TMH. A more detailed studies of TMH corresponding to the specific areas were conducted by Raja Bahrin Shah (1988) for the Terengganu houses, Mokhtar (1992) for the Malacca houses, Idrus (1996) for the Negeri Sembilan houses, Zulkifli (1999 and 2004) for Pulau Pinang and Perak houses, respectively. Recent studies of Malay vernacular architecture include not only traditional houses but also mosques, palaces, wakaf and other artefacts related to the Malay cultures (Nasir and Wan Teh, 1997; Mohd Tajuddin and Alice Sabrina, 2000; Zulkifli and Ahmad, 2005). Killmann et al. 1994 and Mohd Zambri (1997) detailed the reconstruction and preservation effort on traditional Malay houses.

Several institutions in Malaysia have conducted a concerted effort in documenting the measured drawings of the various traditional building structures including mosques, palaces, and houses. Among the prominent ones are the collections at Institute of the Malay World and Civilization (ATMA) in Universiti Kebangsaan Malaysia (UKM) and Pusat Kajian Alam Bina Melayu (KALAM) in Universiti Teknologi Malaysia (UTM). Universiti Teknologi MARA (UiTM), Universiti Sains Malaysia (USM) and Universiti Islam Antarabangsa (UIA) have also embarked on the documentation of the measured drawings. The combined collections of these universities along with KALAM have exceeded well over 200 sets of measured drawings [Zulkifli (2006) and Raja Nafida (2006)].

Recently, a more systematic data collection in the form of cataloguing of photographic collections and measured drawings has been undertaken. ATMA in particular has begun the digitalisation process by scanning some of the drawings and photos captured by the researchers in the field and making the scanned images available on-line. The Malay World Studies portal has been created which allow on-line access to images, scanned drawing plans and documents on Malay houses (Supyan, 2006). The collection of CAD drawings are yet to be done on a collective nature. Most of the CAD drawings are specific to the particular built structures that were studied and are part of the original documentation. As CAD drawing files are computing intensive requiring the availability of specific software and hardware to generate them, the efforts to make the CAD drawings easily available on the web are hampered by technological capability. A more simplified approach to represent the information regarding TMH built forms is required in order to recreate the TMH in a digital form. It is the objective of the research outlined in this paper to bring a new dimension to the study of TMH by developing an information model to accurately capture the architectural style of TMH in a computing environment. The propose generation approach is seen as a promising method in capturing the inherent forms of the TMH and representing the forms in a formal way (Said and Embi, 2007).

The Interpretive Sub-system

This section details the approach of combining typological and topological analysis to develop the interpretive sub-system of the information model. In the topological analysis, the space development of the TMH is described. In this approach, only the spaces under the single-ridge gable roof and the skillion roofs are taken into consideration. These spaces are directly related to the typological (form and shape) description of the TMH that is shown through the side-view or section plan of the TMH. The objective of this study is to investigate the basic shapes that are possible in TMH.

In the following analysis, the spaces considered are those that are formed from the side view of the TMH. Internal spaces such the rooms that do not contribute to the external shape of the TMH are not considered. The purpose of this analysis is to determine the spaces that affect the form of the TMH when viewed from outside the houses. The reason for this is that in a large scale rendering of graphical objects in a computer environment, for example in animated computer images, internal structures or objects that are occluded from the view are not required to be rendered or drawn on the computer screen. The construction of the TMH is particularly known as a cladding system (Hilton, 1992) whereby the forms of the houses are determined by the timber-and-post structure of the houses and the roofs, walls and entrances are later affixed to the structure as coverings. The levels of the spaces, however, do contribute to a change in the external form of the houses.

From the analysis of the documented evidences, we arrive at the general compositional form of the TMH as shown in Figure 1. The form consists of a core space occupying the area under the gable roof above an elevated floor and additional spaces attached to the core space to its left or right. These additional spaces are roofed under the skillion roofs and are also above elevated floors. The levels of the floor of the additional spaces could either be below the level of the floor of the core space or at the same level. Due to social and functional constraints, the floor levels of the additional spaces are never above the level of the floor of the core space. The various forms of the TMH are due to the presence or absence of the additional spaces as well as the various possible floor level combinations. A fourth space could be added to be the house with three spaces. This space which is usually related to the additional entrance or rear features usually does not follow the width of the original three spaces and is not a part of the basic 4 x 3 or 3 x 3 or 3 x 2 post arrangement of the *rumah tiang* 12, *rumah tiang* 9 and *rumah tiang* 6, respectively.

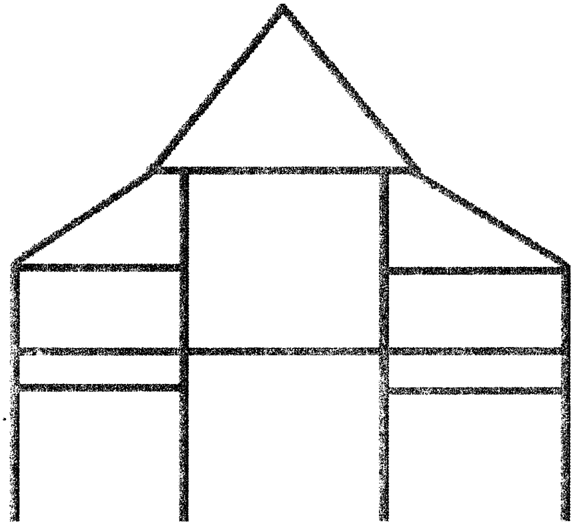


Figure 1: A general compositional form of a TMH

The main living spaces of the TMH comprise of the core space under the gable roof as well as the adjacent spaces to the left and right of this space, housed under the skillion roofs. For the purpose of studying the development of spaces in the TMH, we defined the TMH spaces as rectangles bounded by the main posts and the floor joist. The width of the rectangles is bounded by the distance between any adjacent two posts and the height of the rectangle is bounded by the height of the shortest post. Hence, the height of the space may be limited by the roof joist in the case of *rumah ibu* space and by the extent of the post for the *serambi samanaik* and *serambi gantung* areas. The spaces above the rectangles, denoting the roof spaces, are not considered during the space analysis but will be considered during the construction grammar phase. Also, supporting posts (called *tiang tongkat*) which extend from the ground level up to the floor joist are not considered as the demarcation of space in TMH.

Further to the above main living spaces, additional spaces may be defined for the TMH to represent the adjoining spaces to the *serambi gantung* or *serambi samanaik* or the *rumah ibu* space. These adjoining spaces are formed from the joining of several units for which the spaces are called a *selang* (an intermediary space) or a courtyard. The skillion roofs of the basic units are usually extended to provide some shade for these adjoining spaces, but rain would typically fall through. Towards the rear of the house, an open platform could be formed called the *pelantar* or *jemuran*. The *pelantar* serves as a place for washing and drying of kitchen utensils as well as a place for preparation of food. Towards the front, an entrance space called the *rumah tangga* (stair house) or *beranda* (verandah) could also be formed to serve as an entry space for the house. The *rumah tangga* space is typically smaller as it does not extend across the depth of the *serambi* spaces. The width of this space, however, could be larger than the width of the *serambi* spaces. Hence, these additional spaces are less consistent in their dimensions than the three major living spaces in TMH. In more recent development of the TMH houses, the *selang* space is roofed, sometimes forming another gabled roof by itself, or by joining the eaves of the opposing skillion roofs with a roof gutter (Figure 2).

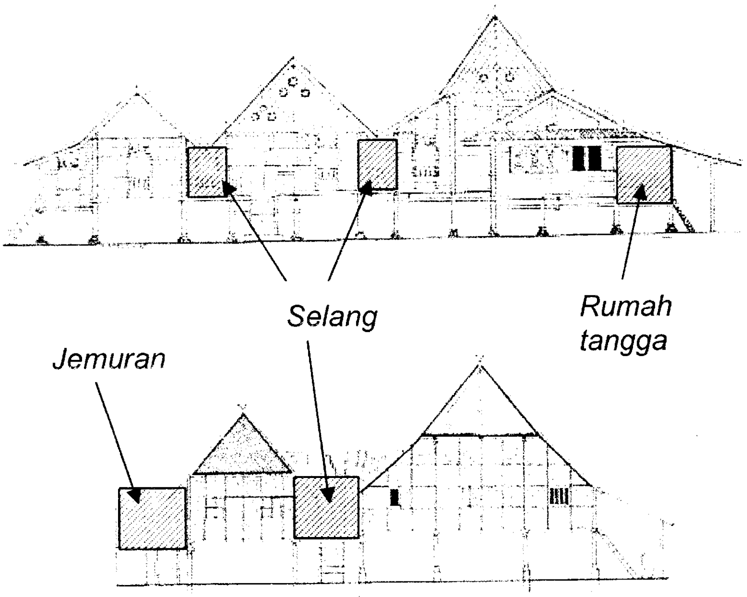


Figure 2: Additional spaces in TMH.

In Figure 3, the main living spaces of the TMH are represented by rectangles with heights and widths represented by symbols denoting the length of the sides. The dimensions of the spaces described above were measured from a sample of 13 TMH representatives obtained from the collections of measured drawings and the literatures on TMH from all the four regions of the peninsula of Malaysia. The average ratios of the main living spaces are shown in Table 1. It is assumed that this ratio is maintained as further spaces are added to the left or right of the main living spaces. This assumption is justified by the requirements on the angle of the skillion roof for the adjacent spaces of the *rumah ibu*. As further spaces are added, the angle of the skillion roof cannot be steeper than the previous angle and a gentler sloping of the skillion roof is expected. The limiting angle of the skillion roof is, however, near horizontal, as these would prevent a quick rain water runoff from the roof, defeating the strong environmental compatibility features of the house forms. Hence, the spaces of the TMH were observed to rarely extend beyond a fourth space. This understanding is used later to limit the rule applications and the space exploration of the TMH space grammar.

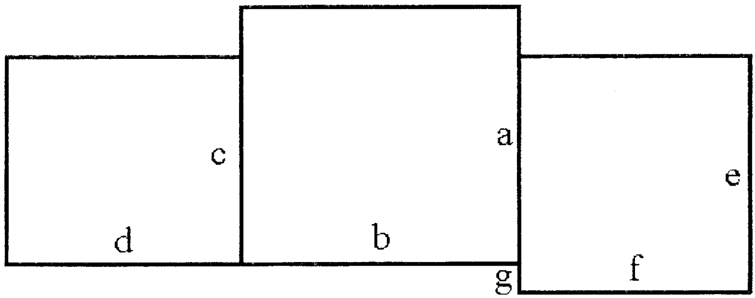


Figure 3: Key dimensions of the TMH spaces.

In addition to the ratio of the key dimensions, the ratios of the height of the *tunjuk langit* (kingpost) to the length of the *alang pendek* (roof joist) and that of the length of the *alang pendek* to the width of the *rumah ibu* (core space) are also tabulated. The arc tangent of the height of the king post to half of the length of the roof joist is 54.5 degrees, which is the average angle of the gable roof. If we let the height of the *rumah ibu* space, *a*, to be 1 unit length, then the value of the other symbols are as shown in Table 2. These values are used to construct the three main living spaces while the dimensions of the subsequent spaces are determined using the ratio in Table 1.

Table 1: Average ratios of the critical dimensions of TMH.

Parameters	**Variables**	**Values**
Height to width of *rumah ibu* space	*a:b*	1:1.1
Height to width of *serambi samanaik* space	*c:d*	1:1.3
Height to width of *serambi gantung* space	*e:f*	1:1.1
Floor level drop	*a:g*	1:0.1
Height of *rumah ibu* space to height of *serambi samanaik* space	*a:c*	1:0.6
Height of *rumah ibu* space to height of *serambi gantung* space	*a:e*	1:0.7
Length of *alang pendek* (roof joist) to height of *tunjuk langit* (king post)		1:0.7
Width of *rumah ibu* space to length of *alang pendek* (roof joist)		1:1.3

Table 2: Length of critical dimensions with respect to the height of the *rumah ibu* space as a unit length

Reference/Symbols	Length
b	1.1
c	0.6
d	0.78
e	0.7
f	0.77
g	0.1
Tunjuk langit (king post)	1.0
Alang pendek (roof joist)	1.43

It is interesting to note that in a restricted exploration of the spaces in TMH using only the three main living spaces as possible spaces, a total of nine basic forms are observable, as described in Said and Embi (2008). However, these basic shapes are derived from the typological approaches and did not take into consideration the fourth space as mentioned above. It is the intention of the authors to explore in the most general sense, the various possibilities of the spaces of the TMH by not limiting to the documented evidences but rather by allowing all possibilities of spaces using the simplistic rules of space additions as used in the previous investigations.

The approach considered in this section follows the classical shape grammar approach as outlined by Stiny (1980) and applied to the analysis of architectural objects by several researchers to generate spatial configurations such as floor plan arrangements of historical buildings. The space grammar for the TMH is outlined in Figure 4. Following the classical convention, the space grammar is comprised of the rectangles representing the spaces in TMH as the terminal symbols, a marker as the non-terminal symbols, and a set of four space addition rules with one terminating rule. The initial symbol is the rectangle with a marker, denoting the core space underneath the gable roof. The first rule in the grammar is to add a space to the right of the core space at the same level of the core space. From the construction point of view, it means that this space will use the same floor joist as the core space, the floor joist being extended to support both spaces and connected via mortise joints through the three posts. The second rule basically does the same operation as the first rule, but at the opposite side of the core space. In the third rule, a space is added to the right of the core space, but at a lower level. This means that the space is supported by an independent floor joist that rests on two mortise joints, one on the post of the core space and another on the post delineating the adjacent space. The fourth rule also accomplished the same results for the other side of the core space. The fifth rule terminates the space generation process by removing all markers. Overlapping spaces are not allowed during the generation process as this would result in creating a space that is not bounded by two posts.

As mentioned in the previous section, the spaces of the TMH rarely exceed a fourth space. Hence, by limiting the rules application to generating only four spaces, we are limiting the space exploration and this allows us to generate all the possible spaces of the TMH. To begin with the space generation, we apply each of the space addition rules to the initial shape. The result of these applications is a set of two new shapes that is comprised of two spaces, as shown in the first column of Figure 5. The space addition rules are then subsequently applied to each of these shapes. For each particular rule, new shapes are created. The rest of the shapes in Figure 5 are the results of applying the second, third and fourth rules to the shapes in the first column. For each of these shapes, a TMH unit can be created following the construction rules outlined in Said and Embi (2007a and 2008). In the investigations of the spaces and forms of the TMH using the approach of shape grammar above, we have shown that the exercise is significant in exploring the possible forms of TMH. The approach has allowed us to examine all the possible spaces of TMH and produce not only the common forms of the TMH, but also the less common and unknown forms of TMH.

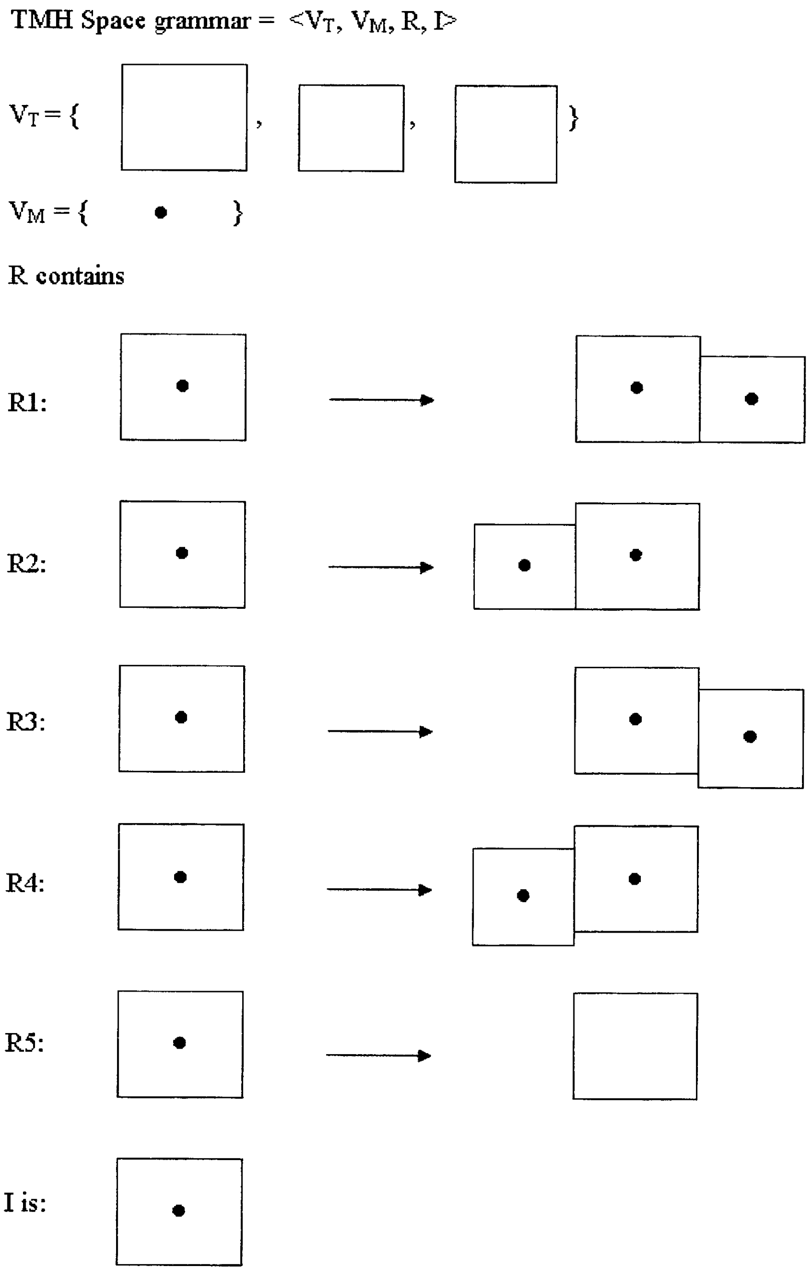


Figure 4: TMH Space Grammar

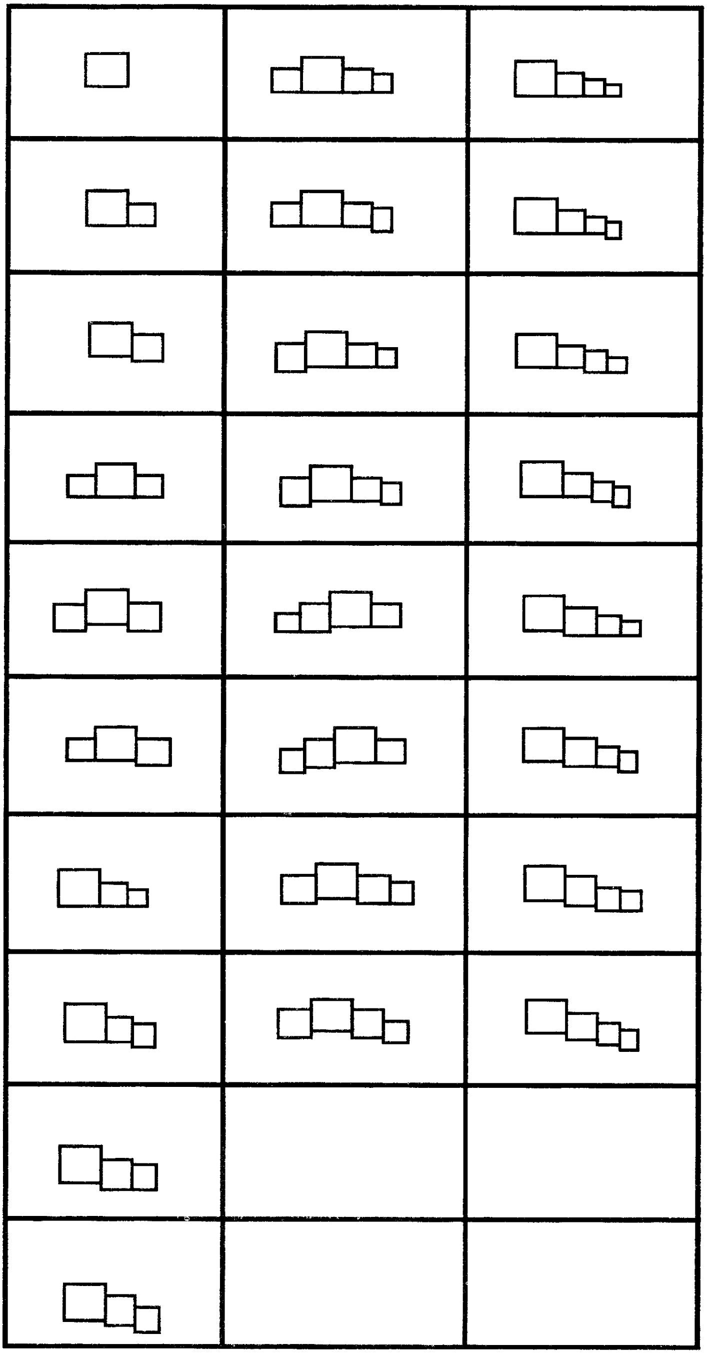


Figure 5: Basic TMH forms with 1,2, 3 and 4 space arrangements (in side view).

In the second stage of the analysis, the unit addition rules are considered. In Figure 6, the various possibilities of unit arrangement are shown. Figure 6(a) and (b) are for the units with the centre line aligns along the same line. These arrangements are common in the eastern, central and southern regions. The unit additions of Figures 6(c) and (d) are only common in the central region. Another type of parallel addition is called the *gajah menyusu* where the lines of the roof ridges are aligned along a single axis. The addition of space shown in Figure 6(f) is sometimes called the *lepau* addition. This type of addition is only common in the northern region. Another type of addition is addition of a space with a single roof ridge attached to one of the spaces in a three-space TMH unit to create the entrance space called the *anjung* (entrance porch), see Figure 6(g). This addition which is common in the central and southern region is executed either on one side or on both sides of the *serambi gantung* (hanging veranda) area. In some TMH houses, an *anjung* is created at an angle perpendicular to the roof ridge (Figure 6(h)). There are also occurrences where a perpendicular addition is made to the rear of a unit to form the *rumah dapur* (kitchen house). Another type of unit addition with the roof ridge at perpendicular to the common roof ridge is shown in Figure 6(i). This addition is typically performed at a later stage of the house development as *rumah dapur* (kitchen house) and is not a common feature of the TMH.

As can be seen in Figures 6, the major addition type is of the parallel roof-ridge addition with *selang* or other type of separation being formed in between the units. The other types of addition serve to enrich the forms of the TMH. The *anjung* addition, in particular, is a very popular addition type in the central and northern region. In this approach, the addition of *anjung* is treated as the addition of the basic unit similar to the *rumah bujang* or the *rumah ibu* to the *serambi gantung* area either to the left or right or to both sides.

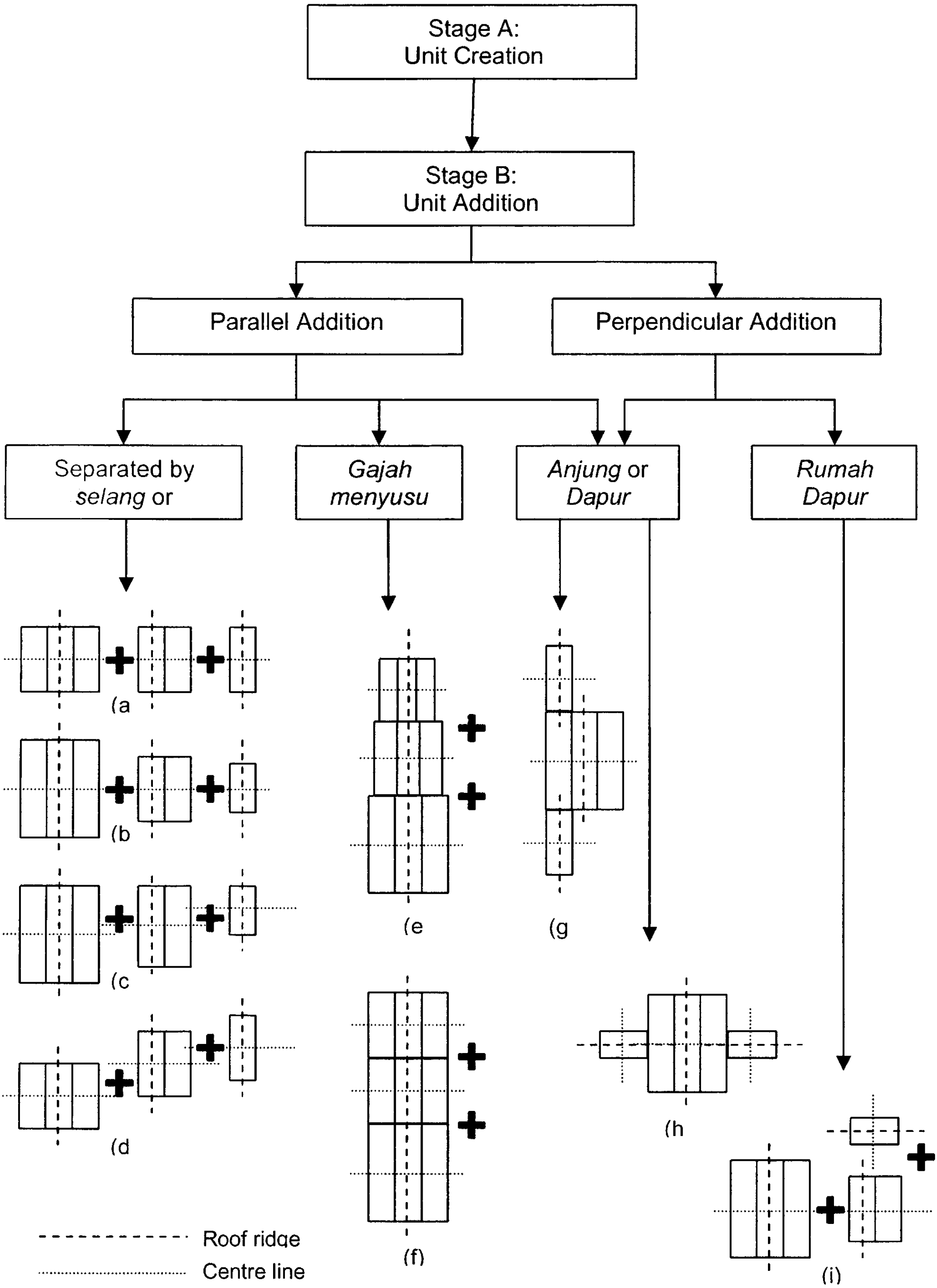


Figure 6: Types of unit addition (in plan view)

The Generative Sub-system

To enable fast generation of the skeleton of the TMH, a parametric shape grammar is used (Stiny, 1985). The parametric shape grammar follows the approach of shape grammar. A shape grammar approach is used due to the fact that the shapes of TMH can be easily described using simple polygons and lines. Rules in the grammar are based on the spaces of the TMH as well as the timber-and-post constructions of the TMH. The grammar uses the side-elevation approach as opposed to post plan to develop the initial 2D shape of the TMH and subsequently generate the 3D shape of the TMH by duplicating the 2D shapes across the width of the TMH according to the post plan. The parametric shape grammar begins with the description of the vocabulary of elements that compose the 2D shape of the TMH based on the TMH spaces and the spatial relationship among these elements. The generation rules are subsequently developed to recreate the basic shapes. The TMH parametric shape grammar consists of a set of parametric rules and sub-rules that create the 2-D timber-frame structure of the TMH as depicted from the side view or section plan. The rule applications and parameter values of the construction elements that characterize the TMH are constrained by the rules applications and ranges of values obtained from documented sources. The grammar continues with a 3D construct by duplicating the 2D form according to the desired post plan to form units. A limiting post plan is also specified. Hence, although this grammar is capable of generating a large number of instances of unique TMH construct, the forms are constrained to the style of TMH only.

The derivation on the vocabulary of elements for the TMH is obtained from the timber-frame structure of the TMH. In the following analysis, an example of TMH from one of the earliest sources is used to develop the vocabulary of elements. Figure 7 shows the timber-frame structure of the house showing the major columns and beams that form the shape of the house. As mentioned previously, though cladding is a vital part of the TMH, it is not a feature of value in distinguishing the TMH from other non-TMH houses (Hilton, 1992). Therefore, in the derivation of the grammar for the TMH, the various sorts of wall, window-opening, door-opening treatments as well as ornamental decorations are not taken into consideration.

In Figure 7, lines are drawn on top of the timber-frame structure to represent the posts and beams that made up the structure and the shape of the house. Figure 8 shows the 2D graphical representation of the house in a 2D Cartesian coordinate. An arrow with the symbol F is used to indicate the front direction of the house. In Figure 9, the points of interest that depict either the intersection of the columns and beams or the joint sections are highlighted with the marker that is represented by a cross within a circle. Each straight line has a minimum of two markers that indicate either the endpoints of the line or the intersection point with other lines. Other lines may have more than two markers, indicating that several other members of the timber-frame structures are either intersecting the member or are connected to it.

In the derivation of the spatial elements above, the joint formations are not discussed as the elements are treated as a one-dimensional line. There is no common type of joints in TMH as each region's master carpenters and builders would adopt individual style of joints. Zulkifli (2000) has documented several types of joint according to the various regions within the peninsula of Malaysia. However, adding types of joint to the derivation of the grammar would result in more complexities and would require a more extensive graphics representation. In the prototype graphical environment of the digital TMH developed, the line elements will be represented by 3D solids and simple joints between the 3D solid elements are adopted, as described in Hilton (1959).

In Figure 10, the structural elements that form the 3D spaces are shown. The structural members that connect the 2D frame are highlighted with lines and markers depicting the elements' representations and connections. The structural members are the *gelegar* (floor tie beam), *alang panjang* (roof girt), *tumpu kasau* or *alang muda* (rafter end beam) and *tulang perabong* (roof beam).

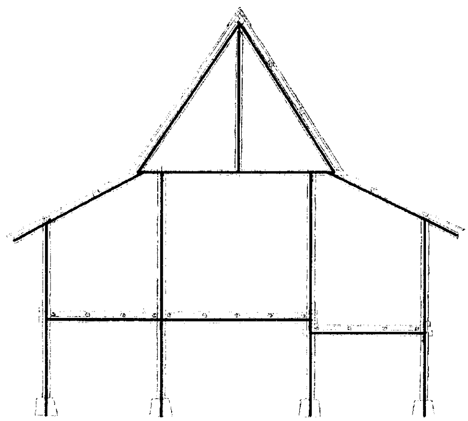


Figure 7: The timber-frame structure of the basic TMH. A simple line drawing is overlaid on the structure.

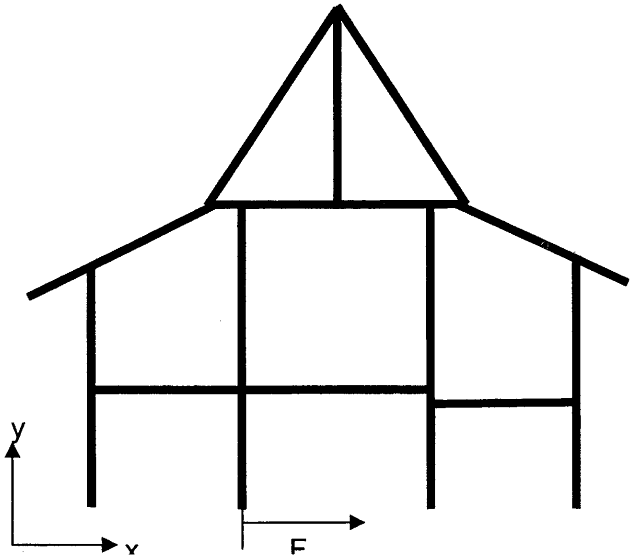


Figure 8: The 2D graphical representation of the timber-frame structure

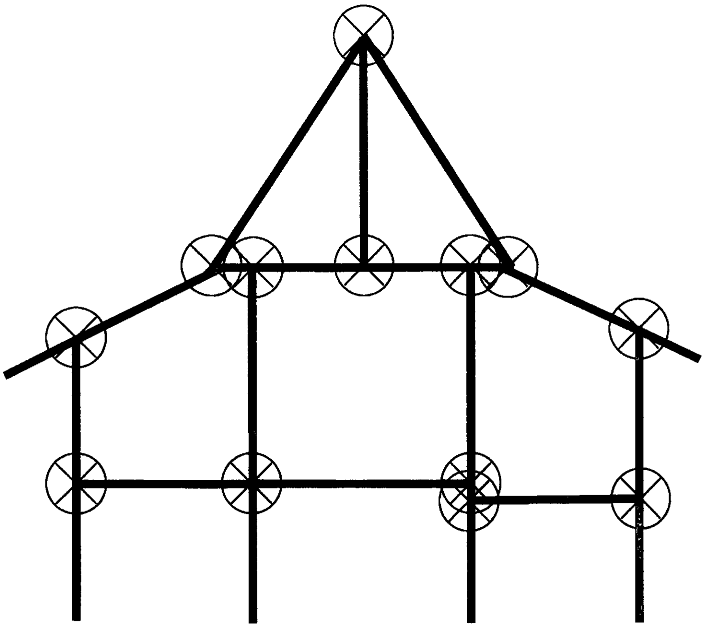
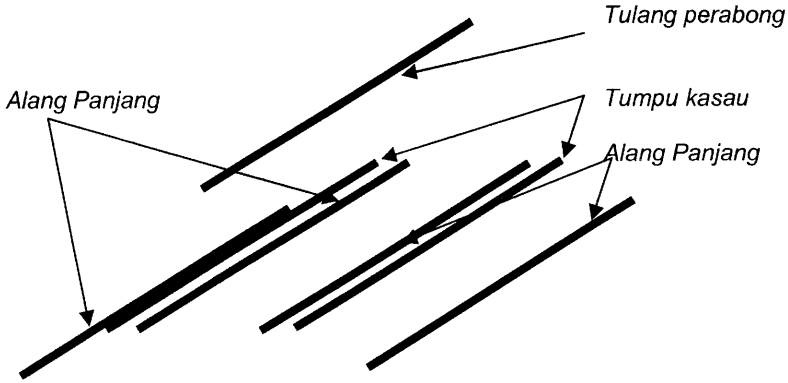
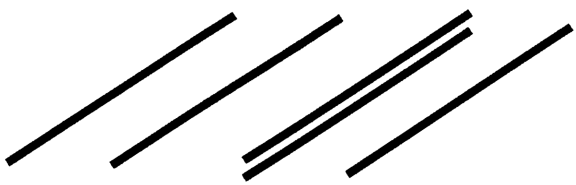


Figure 9: The graphical representation with connection and intersection points highlighted.



(a)



(b)

Figure 10: Horizontal elements forming the 3D shape of TMH (a) *tulang perabong, tumpu kasau* and *alang panjang* (b) *gelegar*.

The result of the space grammar in Figure 5 shows a total of 26 basic shapes of the TMH. All the nine basic shapes are reproduced as expected. However, several new shapes are generated. In the following paragraphs, the nine basic shapes are first analyzed in the light of the new adjoining space that could be part of the final space configurations. In Figure 11, only six of the nine basic shapes are reproduced, after taking into account the symmetry of the shapes and assuming that the shapes are not directional dependent. The most basic shape that forms a unit with only a core space has only one possible form. The two subsequent shapes with two spaces (Figures 11(b) and (c)) may have up to six possible forms. The first two forms are the common forms with both the spaces are under the roof system of the TMH. The other four forms assumed that the adjoining space is either an open platform or a *selang*, connecting the basic unit to another unit. The unit with an open platform is typically either a standalone unit or an end unit of a multi-unit TMH. The subsequent three shapes with three spaces have up to 14 form interpretations. The standalone units are the common forms of the three-space TMH. However, the three spaces could also be interpreted as a two-space unit with either an open platform attached to it or a *selang* forming an intermediary space. It could also form the spaces of a middle unit with a core space with the *selang* spaces on both of its side. The last shape (Figure 11(f)) has a possible of six form interpretations due to its unsymmetrical spaces. In Figure 11(d) and (f), the units with the *serambi* space (the space next to the core space) which is at the same level as the core space is typically more relevant as an end unit as opposed to a front unit, as it is uncommon to find such a space being used as an entrance space due to its low wall height.

In addition to the above six basic shapes, four new basic shapes have also been generated, as shown in Figure 12. These new shapes however, introduced a smaller space as the third space. There are 12 possible interpretations of the four shapes, either as a standalone unit, a unit with an open platform or a unit with a *selang* space. The unit with the *selang* space could either be a front or an end unit. In Figure 12(a), the third space is the smallest space and is too small for a living space with full covered wall. Hence, it is more suitable to be interpreted as either an open platform or as an intermediary adjoining space. In Figure 12(b) and (d), the third space could also be interpreted as the entrance space called the *rumah tangga* (stair house) that forms the landing space of a stair.

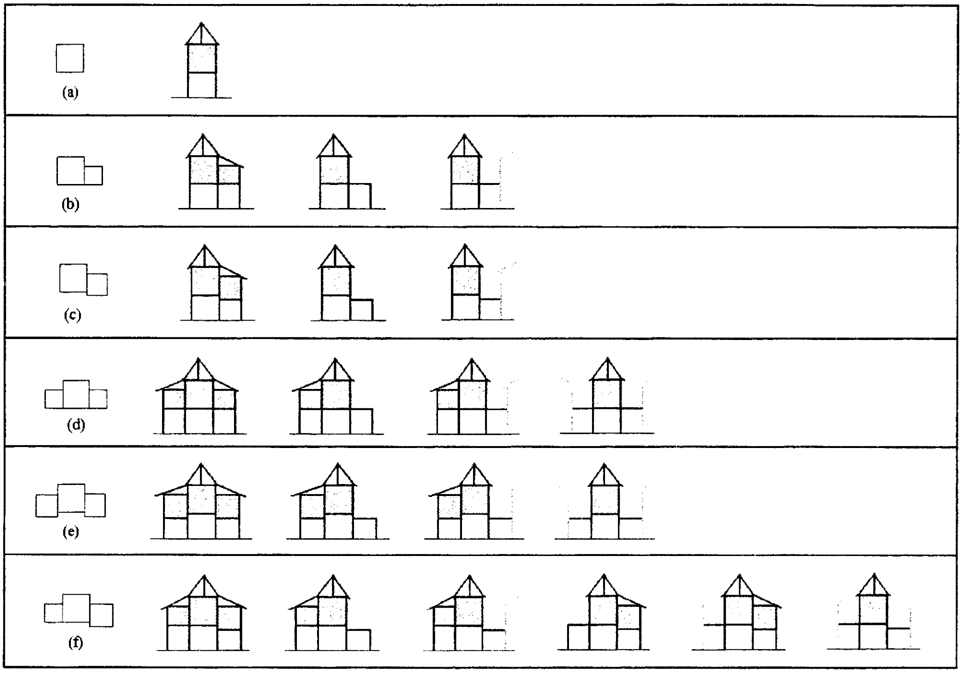


Figure 11: The six basic spaces of TMH and the possible unit shapes.

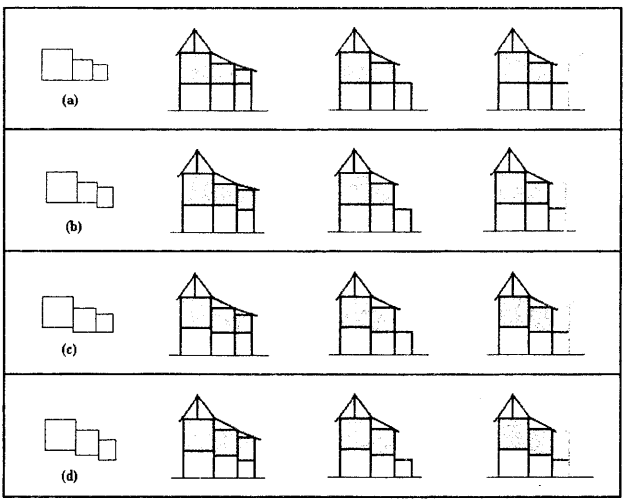


Figure 12: New TMH with 3 spaces and the possible unit shapes.

Further analysis of the shapes produced by the space grammar in Figures 5 resulted in two sets of 8 distinct shapes with four spaces. These sets are obtained after combining shapes that are symmetrical and similar in forms after the applications of the space addition rules. The first set of 8 distinct shapes is comprised of the core space with a space attached to both of its sides. A further adjoining space is attached to either end of the three spaces. Each of the 8 distinct shapes has six possible forms. It can either be interpreted as a standalone 4-space unit, or a standalone 3-space unit with open platform to the left or right of the core space, or a 3-space unit with a *selang* space separating the unit from other unit or an intermediate 2-space unit with two *selang* spaces on its sides. The 3-unit space with the core space and two adjacent spaces to its left and right couple with a *selang* space is the most common form of a front unit of a multi-unit TMH.

In the second set of 8 distinct shapes, the shapes are comprised of the core space with the additional 3 spaces added to only one of its side. This resulted in some of the spaces considered to be too small for a living space with covered walls. It is more probable that the fourth space is interpreted as either an open platform space or a *selang* space. The forms of the standalone units, have not been observed in any documented sources before, but have the critical features of the TMH in terms of the gable and skillion roof systems as well as the presence of a core space with adjoining spaces.

In the multi-unit forms of the TMH, the two-unit TMH is the most common form constructed. A three- or four-unit TMH are typically constructed by more affluent owners and the third and fourth unit additions are a more recent addition to the original built form of the TMH. Hence, it is interesting to study the various possible formation of the two-unit TMH. Referring back to the original nine basic shapes of the TMH, the parallel unit addition rules allow the combination of any of these basic shapes. A total of 81 combinations of the nine basic shapes are possible, as shown in Figure 13. These combinations are unique if they are directional dependent. In other words, if the direction to the front of the houses is fixed in the direction to the left of the figures, then each combination is a unique two-unit TMH. The smallest of the units is composed of two core spaces separated by a *selang* while the largest is composed of two 3-space units. A non-typical form in these combinations would be the *serambi gantung* (hanging verandah) space facing another *serambi gantung* space with an intermediary *selang* space in between. The *serambi gantung* space is more suited to facing the front of the house, acting as a public space. The rear facing space could either be the *serambi gantung* (hanging verandah) or the *serambi samanaik* (rear verandah). For the two-unit house, the additional unit will form the *rumah dapur* (kitchen house). In a three-unit house, the middle unit is called the *rumah tengah* (middle house). Both units may assume the shape of any one of the nine basic shapes.

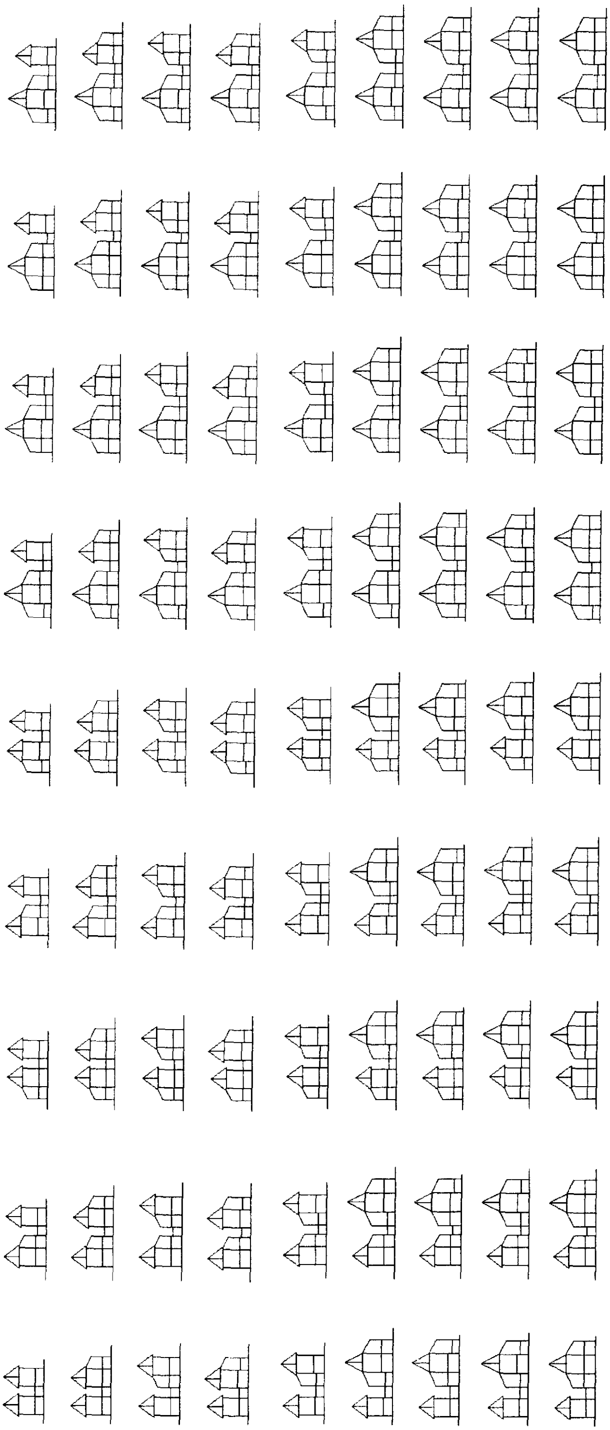
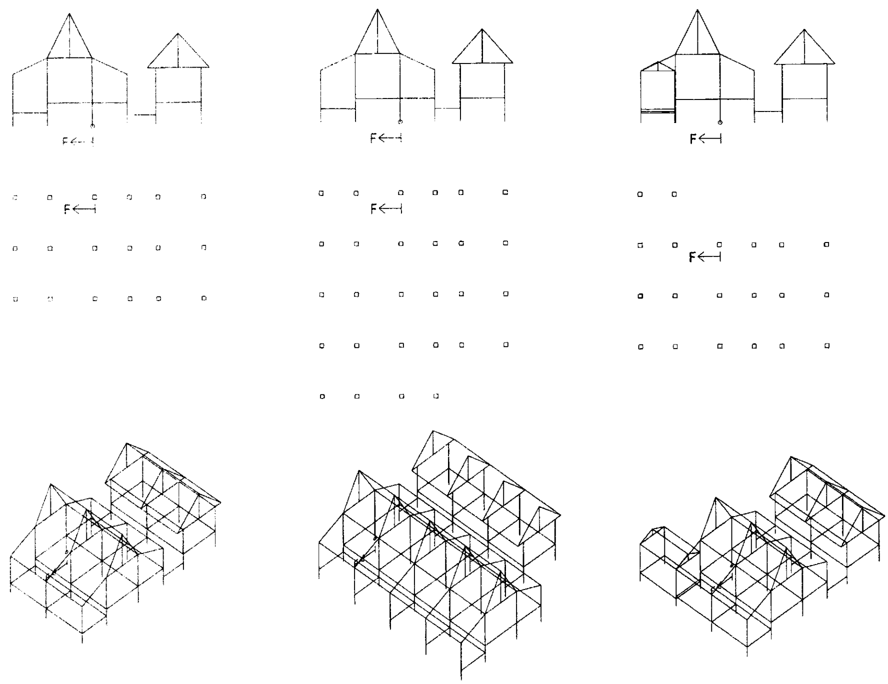


Figure 13: Examples of 2-unit TMH formed by the combination of the 9 basic units.

A 3D form modelling of the TMH begins with generation of the basic forms using the grammars outlined above. To create a 3-dimensional unit of the house, the generated structure is duplicated along the z-axis to make up the 2 x 3-, 3 x 3-, 4 x 3-, or 4 x 4-post structures. The *rumah bujang*, for example, can be constructed as the smallest 2 x 2-post structures and the common 2 x 3-post structures as well. *Rumah Melaka tiang dua-belas*, which is a common form of the TMH can also be constructed as a 3 x 4-post structure and could be as large as 5 x 4-post structure. The many possibilities of arrangement in the post plan in a multi-unit TMH will give flexibility to the grammar to form the traditional houses documented in the current measured drawing database.

The 3D constructions with unit additions resulted in a variety of forms as each unit may be made up of different post plan. In Figure 14, examples of two-unit additions are shown to show a few possibilities of the built forms. The most common form is shown in the left of Figure 14 while a combination of a large first unit with a smaller second unit is shown in the middle of Figure 14. In the right of Figure 14, an addition system to the side, as elucidated in the unit addition rules, is illustrated. This type of addition is a common feature to houses of the Melaka type, or the southern region type. It forms a new space called the *anjung* (entrance). A stair is commonly attached to this space. The *anjung*, however, has the same form at *rumah bujang.* Hence, the form can be built by using the same function that built the core space, but with a different set of dimensions. The prototype 3D form modelling program with the underlying grammar is currently being implemented in C++ programming language with OpenGL graphics engine that supports scene graphs. The nodes in the lowest level of the scene graphs contain the parametric elements whose values are within certain limits and whose relationship with other elements are defined by the grammar. This will be further illustrated in the following section.



(a) (b) (c)

Figure 14: Complexities of post arrangement in several unit additions (a) A typical post plan (b) A post plan where the first unit is larger than the second unit (c) A common unit addition to the side to form an entrance space.

In the investigations of the forms of the TMH using the approach of shape grammar above, we have shown that the exercise is significant in exploring the possible forms of TMH. The approach has allowed us to examine all the possible forms of TMH and produce not only the common forms of the TMH, but also the less common and unknown forms of TMH. The results also show that the nine basic shapes of the TMH are the main vocabulary of the grammar of TMH and the basic shapes and the combinations of these shapes are able to describe the language of TMH of the *bumbung panjang* (long-roof) type.

The Graphical Model Sub-system

One of the goals of this research is to develop a prototype computational design and modeling environment that can produce in 3D the structure of the TMH. The objective of the modeling environment is to be able to build a TMH in a digital media with the flexibility to generate different designs of TMH that correspond to the different level of complexity of the houses. The complexity of the houses here means the various combinations of spaces or units. The form of the TMH will differ from region to region as each house is unique in terms of its dimensions, post plan, floor levels and spaces. To accomplish this goal, the modeling environment must address the issues of architectural form together with construction. This paper explores the compositional grammar of the TMH as the basis for the information model and uses this knowledge to develop the modeling environment for the creation of the TMH computer models. The shape grammar formalisms were used to develop the information model that captures the essence of the form of the TMH. The shape grammar formalisms represent the design knowledge of the TMH in terms of geometrical elements and the relationship between the elements. A modeling environment with the model generation engine and a user interface is developed for creating the modeling environment and generating the models of the TMH.

It is important that the design representation of the TMH be captured in such a way that allows the reproduction of the TMH. The geometric model based on the space and construction grammars is the vehicle for this representation. The modeling environment was required to produce the representations that were more detailed than purely abstract geometric forms but less detailed than a typical working drawing requirements. The desired level visualization is to have the ability to display the forms of the TMH and be as near as possible to an actual construction of the TMH. The goal of incorporating the construction knowledge into the design representation is to highlight the relationship between the forms and the construction. Sufficient level of construction knowledge is applied for the construction of the models. However, the level of the construction knowledge would not include details about variations of joint formations in different regions. By locking into a specific construction methodology such as that described by Hilton (1956), the task of developing a joint detail for a specific region could be re-looked at a later stage.

The TMH modeling environment was implemented using the scene graph technology. A scene graph is a data structure that holds the geometry of all objects in the scene as well as their appearance such as color, transparency, and textures, along with other information such as light sources, camera position, and more. The data structure used is a hierarchical treelike structure. The treelike structure is a collection of nodes in a graph. A node may have many children but often only a single parent. The effect of a parent is apparent to all its child nodes. An operation applied to a parent node automatically propagates its effect to all of its child notes. A common feature in a scene graph, for instance, is the ability to group related shapes/objects into a compound object which can then be moved, transformed, selected, etc. as easily as a single object.

The set of software tools that are used to build and interact with the scene graph is called a scene graph applications programming interface (API). The combination of the API and the scene graph structure are collectively known as scene graph systems. The graphics application first creates and loads data into the scene graph, than the system renders the contents of the scene graph into an image. The objects to be drawn must be stored somewhere, and must be dispatched to a rendering program in a more or less sequential fashion. The data storage, management and access machinery is fundamental part of scene graph systems. Scene graph performs many other tasks related to the display of the scene objects. These tasks are however related to enhancing the performance of the system.

One of the key benefits of a scene graph is the level of abstraction it provides when compared to a low-level API programming. The scene graph allows the programmer to concentrate on *what* is to be drawn, rather than *how* it is to be drawn. A scene graph provides the programmer with a convenient framework for managing objects in a scene, and also makes it easy to express the relationship between those objects. For instance, it is useful to group related objects in a common coordinate system so that even when an object is moved or rotated, the relationship with related objects is not disturbed. A partial scene graph representation of the TMH is shown in Figure 15. Note that some of the nodes in the scene graph describe grouping of related objects in the scene, and that the leaf nodes at the bottom of the scene graph contain the actual geometry and appearance of the shapes that constitute the scene objects.

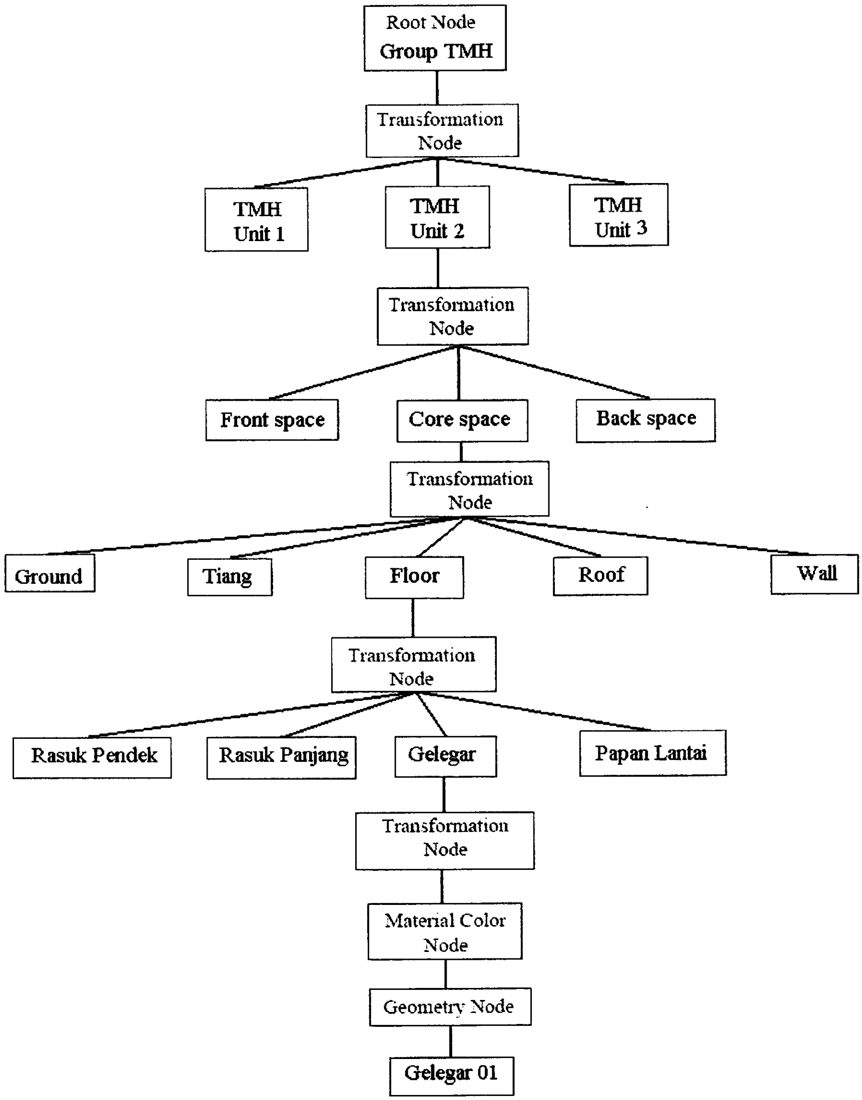


Figure 15: A partial scene graph of the TMH.

The graphical user interface (GUI) for the TMH modeling environment is shown in Figure 16. The GUI is comprised of a pull-down menu area and several interaction windows. The top-left window is the scene-graph window that displays the scene-graph tree. All the graphical elements drawn by the scene graph is listed in the scene-graph tree. Element selection can be done in this window. Directly under the scene-graph window is the property window that displays the property of the selected element (or node) in the scene-graph tree. Operations on the properties of the element such as changing the visibility state of the element, modifying the dimensions of the elements, etc. can be performed in this window. To the right of the property and scene-graph windows is the rendering window where the elements in the scene-graph tree are drawn and rendered. Direct graphical manipulation of the rendered elements, such rotation and zooming in and out, can be performed in this window. A command window provided at the bottom of the main window for entering text command. The GUI allows the following actions to be performed:

i. Type selection – the user can select the type of TMH to be drawn. Any of the nine basic TMH can be drawn at one time.
ii. Coordinate of the TMH – the default coordinate of the centre of the TMH is (0, 0, 0) to designate the ground level. The user, however, may specify any other coordinate.
iii. Space selection and dimension specification – in addition to the selection of type above, the user may also specify the type of the TMH through the space selection. For the front and back spaces, the information on the depth and height of the spaces need to be specified. For the core space, in addition to the above information, additional information required are the width of the core space and the level of the floor height. The level of the floor for the front and back space will depend on the type of TMH selected. Changes to the floor levels could be changed after the creation of the elements through the scene-graph and property windows.
iv. Post-plan specification – for the core space, additional information regarding the post plan is required. The user may either select a post plan or specify a new post plan.

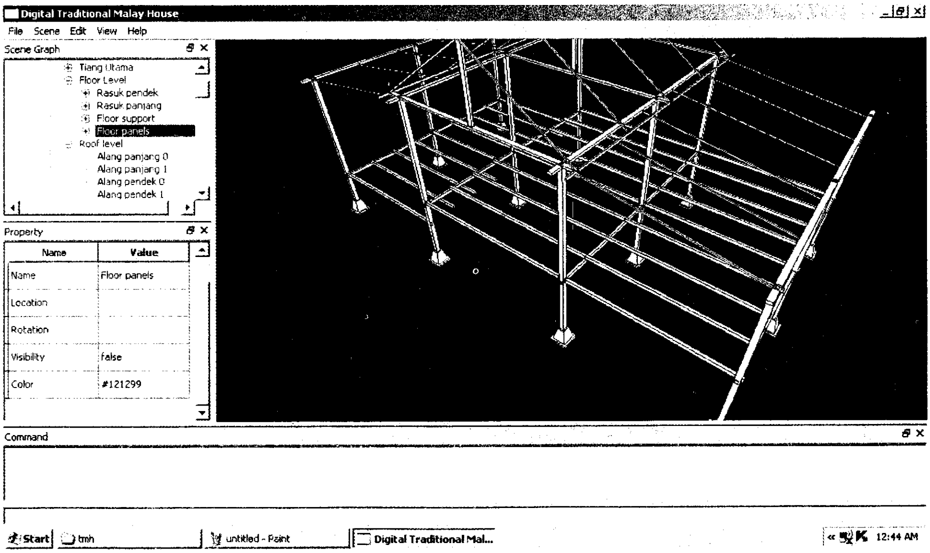


Figure 16: The GUI of the prototype TMH modeling environment.

As explained in the previous section, the purpose of the current approach is to capture the forms of the TMH. This is achievable through modeling of the structural elements that follow the spaces of the TMH. The shape of the specific TMH would be dictated by the length of the structural members that bound the living spaces in TMH. The roof angle, for example, is formed from the length of the *tunjuk langit* (king post) and the *alang pendek* (roof joist). The length of the *alang pendek* is proportional to the width of the *rumah ibu* (core space). The user would be able to examine various forms of the TMH that are formed by varying the width of the core space. In the following section, some examples produced by the prototype modeling environment are discussed. In Figure 16, the rotated view of the TMH model is shown. To add additional units, the user simply repeats the process mentioned from the beginning of this section and specifies a new coordinate for the new TMH. Outputs from the modelling environment that reflects its capability in modifying the spaces and form of the TMH are shown in Figures 17, 18 and 19. Changes to the TMH models in terms of space size, roof angle, etc., can readily be investigated in the environment.

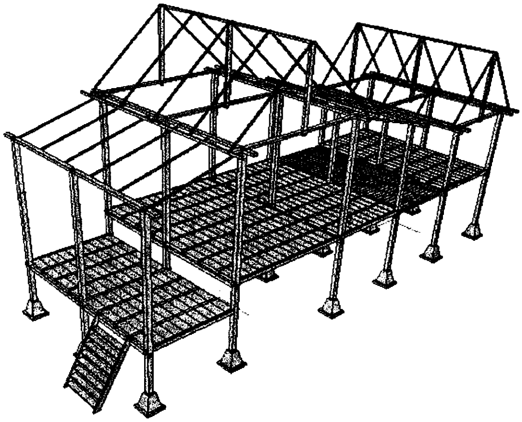


Figure 17: An example of a two-unit TMH.

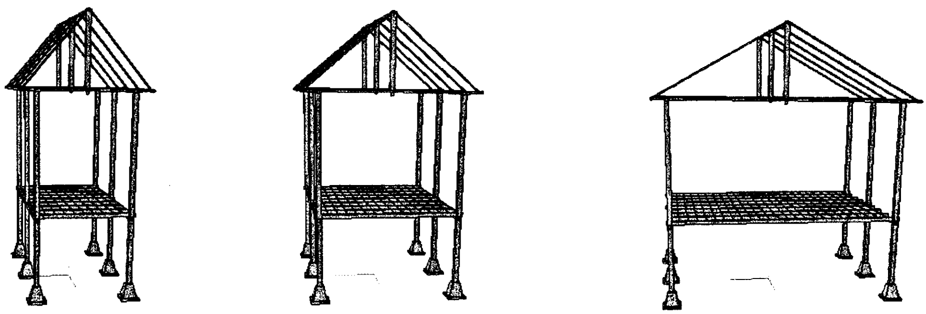


Figure 18: Variation of the roof angles due to the width of the core space.

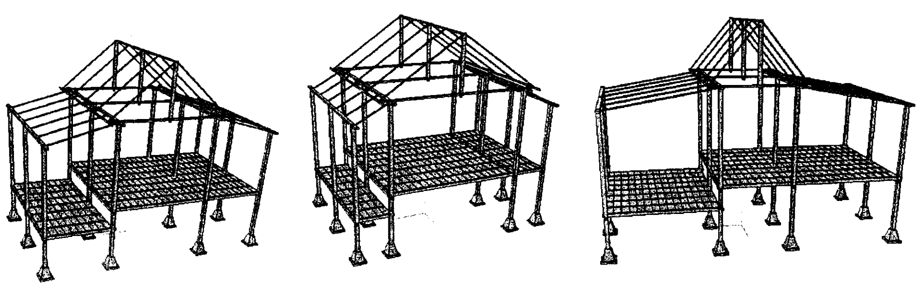


Figure 19: Variations on width of the front and rear spaces

Conclusions

In this paper, the information model for the TMH is developed. The purpose of the information model is to provide the knowledge for the recreation of TMH in a digital environment and for the exploration of the TMH forms and spaces. The prototype modeling environment is by no means complete. More features and functions need to be added in order for the prototype to be successfully distributed to the general public, either as public-domain or commercial software. However, the objective of developing a framework for the software has been achieved and a working prototype has been demonstrated.

The objectives of this paper are to represent the knowledge of the TMH for a computational design and modeling environment and to develop the framework for creating the TMH models in a computer environment. A combined computational design and modeling approach has been adopted for the development of the modeling environment for the TMH. The computational design approach is used to capture the design knowledge of the TMH while the computational modeling approach is used to represent the design in the form of digital models. The former gives us the knowledge on the relationship between the physical elements of the TMH with its spatial and functional elements, while the latter gives us a digital representation of the physical elements of the TMH.

The TMH from the four regions share some common generic features such as the structure and form of the TMH and differ in terms of the additional features such as the roof and opening structures as well as ornamental decorations of the houses. The information model captures these common features based on a computational design approach so as to enable the generations of the built forms, independent of the regions. The digital representations of the houses are in the form of graphical elements with construction and addition rules to recreate the style of the various *bumbung panjang* (long roof) built forms. With this systematic programming approach, a digital representation of the TMH could be created with ease.

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