CONTRIBUTION OF NUMERICAL SIMULATION WITH SOLENE* TO FIND OUT THE TRADITIONAL ARCHITECTURE TYPE OF CAYENNE – GUYANE FRANCE

E. Prianto, S. Houpert, P. Depecker and J-P. Peneau
CERMA Laboratory, Ecole d’Architecture de Nantes, Rue Massenet, BP 81931 - 44319 Nantes, France

(Received 2 August 2000; Accepted 3 November 2000)

ABSTRACT

In the ancient time, architectural design of dwelling was developed from accumulated observation from surrounding nature in order to apply human creation by considering environment aspect. This design without designer method passed on one generation to the other. It is contrary to contemporary style that tends to be more universal, individualistic and ignores the environmental aspect.

Environment constitutes source of life for human being. Therefore, a region and its climate give us data of architectural history.

This paper has two purposes, first, to classify traditional houses of Cayenne to determine the morphology of building exterior performance and its application on recent contemporary house. Second, to explain the contribution of numerical simulation with SOLENE on Cayenne house.

1. INTRODUCTION

A comfortable house is not only determined by building quality and the number of rooms required by occupant. One factor needs to consider is the influence of building microclimate (solar heat, temperature, humidity and rainfall).

Many obstacles could be found in designing residential house in tropical-humid region, some of them are economical obstacles. Conservation that uses local building material and specific architectural design of its region tends to use technology progress in order to meet the demand for comfort.

We are interested to investigate the problem of tropical-humid settlement, especially the aspect of ambient architecture by using numerical simulation that is being developed in the CERMA Laboratory – Ecole d’Architecture de Nantes, France. The discussion covers the problem of traditional houses in Cayenne City area – Guyana – France. Two purposes of this discussion are to find out the specific architecture style of Cayenne traditional house and its application on contemporary one and investigate the sun lighting phenomena with SOLENE software.

2. THE ARCHITECTURAL STYLE OF CREOLE HOUSE

Architectural design of traditional buildings was developed from accumulated observation from surrounding nature. Such design without designer method passed on one generation to the other. Environment constitutes source of life for human being and it is proved on residential design by considering microclimate and surrounding nature. The aspect of historical development, climate, and society culture form the background of architectural style of a region. Traditional dwelling of Cayenne is also influenced by those factors.

Fig. 1: The process of traditional architecture disappearance, a tendency of building design without respecting the phenomena of climate in the form of box architecture [1]

* SOLENE is a numerical simulation software for observing the sun rays’ behaviour in buildings and it is being developed in CERMA Laboratory – UMR CNRS 1563 (“Centre de Recherche Méthodologique d’Architecture”) - Ecole d’Architecture de Nantes, http://www.cerma.archi.fr.
2.1 Cayenne City – Guyana France (Fig. 2)

Guyana France is one of Outre Mer department of France government, located on Northeast of South America between Suriname (west side) and Brasilia (Southeast side) [7]. Guyana topography varies with 330 m of average altitude and 90,909 km² of area, whereas 95% of its territory is jungle [2]. The people variety shows the variety of culture and ethnic. The natives are Creoles and 50% of its population is arrivals. Guyana has three big cities. Cayenne city is one of the three big cities besides Remire-Montioly, and Kourou. Cayenne city is a plain located on Atlantic seashore and has various cultures. These aspects form the background of city and cause various residential building appearances [3]. The city’s characteristic is crocheted rectangle stretches. Each stretch is planted with agricultural plants and fruits [4]. Opening space with lines of vegetation can be found in “Place des Palmistes” [5]. Delouche [4] also explained that the characteristic of traditional house had the same schema along the side of the street. Wherein, transition space for public and private zone could be found horizontally and vertically.

Before analysing architectural type of house building in Cayenne, it is better to review the history of dwelling development and establishment.

In “d’Outre-Mer” magazine [6], it was classified into several groups based on its location: house building in urban and rural area.

2.2 The History of Cayenne House Development at a Glance

Until the end of 17th century, house building in Cayenne was very simple [6]. The main principal of building design was protective aspect from sun radiation and high rainfall. This building model was influenced by Indian style by using building material such as plaited foliage, and coconut tree trunk (like the word Guyana comes from Indian language means no name) [7]. House basic model was called “le Carbet”, having wood beam construction, and roof was made from coconut leaves. Carbet house did not have permanent wall and room partition because it functions only as a place for sleeping and taking a rest. Floating house was developed in the next decade and could be found in back country of Guyana France (this basic model is also found in other tropical humid countries, see Fig. 3 on Malaya floating house in Malaysia and Hmhong house in Guyana). This basic model constitutes the characteristic of tropical houses [8].

Fig. 2: The location and illustration of Cayenne city – Guyana France (left to right)
(a) The map of Guyana France [9], (b) “Place des Palmistes” in the centre of Cayenne city [5],
(c) the illustration of luxuriance in Cayenne with lines of vegetation [4]

Fig. 3: Floating house architecture as the characteristic and response of tropical humid climate (top left - clockwise), (a) Malaya floating house [10], (b) the construction of floating house [11], (c) Hmhong floating house in Guyana-France [16], (d) building classification that considers climate phenomena in the world [8]
By the end of 19th century and early 20th century in Guyana, there occurred a development of house on a large scale. It started from the arrival of immigrants and slaves from Africa. The slave brought about African culture and influenced house style that developed at that time. The existence of warehouse, square form buildings with oblique roof was the main house characteristic of that community. It constituted the main characteristic of Creole. The immigrants consisted of carpenters and soldiers who had brought new knowledge and technique of house development. Therefore, in the early 20th century, the development of residential buildings in Cayenne was based on providing comfort for occupants, it could be seen from the use of new building materials without neglecting the phenomena of climate and surrounding nature [6].

Auburtin [6] also stated that there are several types of dwellings in Cayenne based on its location. First, house type in urban area ("l'habitat urbain"), two storied houses (all stories were living areas). Second, individual house type in rural areas usually in the form of a floating house ("l'habitat rural"). Among those houses, there was communal house type ("habitat de commune") which constituted modern type of rural house.

2.2.1 Individual house type in urban area ("l'habitat urbain")

This type was developed in the early 20th century. Generally, it was private property and different from native house on building material usage, esthetical aspect and interior planning. The special characteristic of this building was massive wood construction (both on basement and upper floor) and designed according to classical style, the wall was made from brick plastered with wood layer in loud colour, ornamented roof, ventilated attic with meshes and gratings (called “la lucarnes” and “le chiens-assis”). The meticulousness design of opening was shown on doors, and window gratings and the proportion of windows. The permanent characteristic of this building type was symmetrical planning on building mass composition and appearance.

Interior planning: house located on urban area had several changes of living and transition room functions. Transition room means room between public and private zone. In the beginning, most of the traditional houses were signed by the existence of transition room both vertically and horizontally. Horizontal position was marked by a space in the form of small terrace between building and street, and gallery to connect to upper floor marked vertical one. Nowadays, the basement floor has a function as a garage or terrace for keeping flowers and plants. Gallery zone at the back of the house has a function as an office. The height of the ceiling depends on the upper floor, in several cases, the basement floor is used as a room for trading and the minimum height of the ceiling was 3 m [4].

House development occurs because of the change of room function. It is carried out with extending the main building or changing the function of the garden. Service rooms (kitchen and bathroom) are placed separate from the main building but they are still possible to be reached by occupants easily.

2.2.2 House type in urban area – communal house ("l'habitat de commune")

This type was different from the previous one. It did not emphasize building plan, volume, and orientation and use simple material. Building form was depended on society origin but principally, this type had characteristics as follows: symmetrical appearance, considering air movement in building, tackling sun radiation and rainfall entered into the building with oblique roof and overhang around building walls. Building structure and material were made from wood, both in building and roof constructions.

Fig. 4: The illustration of traditional house type of Guyana – France (left to right) (a) Creole traditional house, (b) the illustration of society life in traditional settlement [4], (c) Cayenne house [2]
Interior planning: all rooms in this building were living areas including the attic. Generally, oblique roof, roof opening, and windows placement famous for “la lucarnes” and “le chiens-assis” marked this house type. The basement floor was hiked up about 40 cm from the ground surface by using cement plaster as insulator between floor and ground. According to Delouche [4], besides those reasons, it also had function for anticipating flood that occurs regularly in that region.

2.2.3 House type in rural area (“l’habitat rural”)
In rural area, the dwelling is different from urban area especially in building material that uses wood in every construction. The interior planning is based on the building mass composition point of view. This type consists of the main building and annex. Building plan was related to farming, wherein building annex had a function as a warehouse for storing harvest but it was also possible to use it as a kitchen or bathroom.

The descriptions above are summarized in Table 1.

2.3 Seeking out the Plurality of Architectural Style [12]
The important role of space toward object can be analysed from harmonization between object and surrounding nature, because it gives certain perception to the observer. Space creates appearance quality of building performance because it enables a distance for the observer to observe the building, thereby, the image of the entire building can be performed.

There are three measurement criteria to observe building performance: first, measured/dimensional criterion is a qualitative criterion based on obvious form such as nature, physical performance of building, mass composition, etc. Second, unmeasured/non dimensional criterion is a qualitative criterion based on emotion and perception (e.g. the principal of harmonization, beauty, comfort, point of interest, etc.). Third, the combination of two criteria before, wherein it is always influenced by the recent tendency. Measurement to obtain the specific appearance of architectural plurality in a region or city is carried out with considerations on the classification, selectivity, adaptation, and repetition aspects.

2.4 Repetition Method - An effort to find out specific traditional architectural value of Cayenne
To find out the characteristics of architectural performance of Cayenne traditional house, the repetition method is used. Several houses that were found at random are classified and the qualitative repetition are analysed by using linear pattern.

Ching [13] stated that the simplest method of repetition is linear pattern. The framer elements are not necessarily identical but those models are classified in repetitive rhythm wherein each element is unique. Several physical treatments in repetition and architectural pattern are size, shape, and physical characters. The repetition aspect on Cayenne house can be analysed based on: vertical rhythm, horizontal rhythm, skyline shape, opening composition, facade decoration, and roof shape.

After classifying Cayenne traditional house in linear pattern, the analysis of repetition aspect is carried out. The result of visual analysis can be seen in Appendix A, and the recapitulation of the repetition method in Table 2.

2.5 Architectural Characteristics of Traditional Houses in Cayenne
Several researchers stated that nowadays people prefer to live in individual houses than storied buildings [2].

According to Rémi Auburtin, the director of CAUE (“Conseil d’Architecture, d’Urbanisme et d’Environnement de la Guyane”):

“...Life in storied building, far from ground surface is not comfortable for people from rural area”.
“...People used to park their cars in front of terrace, thus, the placement of kitchen is in the front of house that is possible for occupant to go out of home quickly. If the number of family members increases, they will modify the terrace to become a bedroom…”

In other words, native people were not used to live in storied buildings, so they prefer individual house type. The adaptation of microclimate is reflected from the room arrangement on building design.

“Natural ventilation is always needed”.

2.5.1 How is the performance of traditional architecture in Cayenne?
Delouche [4] stated that the perpetuation of this traditional house had many obstacles. Social, economic and even architectural aspects could not take important roles in rehabilitation effort. Most of the antique houses have been occupied, and they were developed according to occupant needs that tends to omit antique architectural elements. If financial support was not available, it evoked that these obstacles getting worse because the renovation needs fund. People in a certain social stratification prefer living in contemporary houses that have many rooms and are more comfortable in city periphery. This condition makes the antique architecture in Cayenne city being damaged [14].
Table 1: Characteristics of three traditional houses in Cayenne

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type 1 (l’habitat urbain)</th>
<th>Type 2 (l’habitat de commune)</th>
<th>Type 3 (l’habitat rural)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Function and Ownership</strong></td>
<td>• Individual dwelling</td>
<td>• Dwelling for community</td>
<td>• Dwelling and storing harvest/warehouse</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>• Urban</td>
<td>• Urban</td>
<td>• Rural</td>
</tr>
<tr>
<td><strong>Facade appearance</strong></td>
<td>• Existence of balcony, and canopy</td>
<td>• Balcony and canopy</td>
<td>• Balcony extending on second floor</td>
</tr>
<tr>
<td></td>
<td>• Two storied building (there was one floor on the top)</td>
<td>• Four storied building (included attic)</td>
<td>• Canopy</td>
</tr>
<tr>
<td></td>
<td>• Oblique roof with overhang around building walls</td>
<td>• Oblique roof with overhang around building walls</td>
<td>• Two storied building (there was one floor on the top)</td>
</tr>
<tr>
<td></td>
<td>• Symmetrical composition</td>
<td>• Symmetrical opening composition</td>
<td>• Oblique roof with overhang around building walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Building style depends on society origin</td>
<td>• Composition is not symmetry</td>
</tr>
<tr>
<td><strong>Roof shape</strong></td>
<td>• Oblique</td>
<td>• Oblique</td>
<td>• Oblique</td>
</tr>
<tr>
<td></td>
<td>• Using overhang as roof extension</td>
<td>• Using overhang as roof extension</td>
<td>• Using overhang as roof extension</td>
</tr>
<tr>
<td></td>
<td>• Using roof tile or wood as roof cover</td>
<td>• Using corrugated iron sheet as roof cover</td>
<td>• Using corrugated iron sheet as roof cover</td>
</tr>
<tr>
<td><strong>Wall opening shape</strong></td>
<td>• In the form of doors, windows, ventilation mesh, and ventilated attic</td>
<td>• In the form of doors, windows, ventilation mesh, and ventilated attic</td>
<td>• In the form of doors, windows, ventilation mesh, and ventilated attic</td>
</tr>
<tr>
<td></td>
<td>• Proportionally, windows composition is vertical</td>
<td>• Proportionally, windows composition is vertical</td>
<td>• Proportionally, windows composition is vertical</td>
</tr>
<tr>
<td></td>
<td>• Ventilation meshes above windows and doors</td>
<td>• Ventilation meshes above windows and doors</td>
<td>• Ventilation meshes above windows and doors</td>
</tr>
<tr>
<td></td>
<td>• Double doors and shutters</td>
<td>• Double doors and shutters</td>
<td>• Double doors and shutters</td>
</tr>
<tr>
<td></td>
<td>• Free ventilation mesh</td>
<td>• Free ventilation mesh</td>
<td>• Free ventilation mesh</td>
</tr>
<tr>
<td></td>
<td>• Wall porosity is 26%</td>
<td>• Wall porosity is 30%</td>
<td>• Wall porosity is 25%</td>
</tr>
<tr>
<td><strong>Building construction and material</strong></td>
<td>• Brick and wood</td>
<td>• Wood is the basic material of building cover</td>
<td>• Brick and wood</td>
</tr>
<tr>
<td></td>
<td>• First floor: massive wood</td>
<td>• Second floor used wood</td>
<td>• Floating house (building with stil)</td>
</tr>
<tr>
<td></td>
<td>• Second floor: wood with brick layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Room composition and its development</strong></td>
<td>• Having garage and room for trading</td>
<td>• All rooms in building has functions as living area including the attic</td>
<td>• It consists of main building and annex</td>
</tr>
<tr>
<td></td>
<td>• Terrace for keeping flowers and plants</td>
<td>• Floor was hiked up about 40 cm in order to avoid flood.</td>
<td>• Building annex has functions as a service room, warehouse, and bathroom/wc.</td>
</tr>
<tr>
<td></td>
<td>• Gallery room as office</td>
<td></td>
<td>• Floor was hiked up</td>
</tr>
<tr>
<td></td>
<td>• Service room is separated from main building</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Esthetical aspect</strong></td>
<td>• Having decoration and ornament in the front of house especially on the edge of roof and balcony fence</td>
<td>• Having ornament on ventilation mesh above doors and windows and balcony fence</td>
<td>• Decorated building column and textured wall (emphasising wood material)</td>
</tr>
<tr>
<td></td>
<td>• The wall was made from brick, plastered with wood layer in loud colour.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Specific characteristics of building appearance related to ventilation aspect</strong></td>
<td>• Opening roof</td>
<td>• Ventilation meshes on wall in the form of doors and windows</td>
<td>• Building volume development</td>
</tr>
<tr>
<td></td>
<td>• Ventilation meshes on wall in the form of doors and windows</td>
<td>• Opening roof</td>
<td>• Ventilation meshes above windows and doors</td>
</tr>
<tr>
<td></td>
<td>• Ventilated attic</td>
<td>• Ventilated and occupied attic</td>
<td></td>
</tr>
</tbody>
</table>


### Table 2: Recapitulation of architectural performance analysis of Cayenne house

<table>
<thead>
<tr>
<th>Building reference</th>
<th>Indication obtained from visual analysis of building performance of Cayenne house in Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical rhythm</strong></td>
<td>• It is indicated by horizontal line stacked on the other&lt;br&gt;• Vertical line is started from main door, balcony and windows until the edge of roof (for storied building)</td>
</tr>
<tr>
<td><strong>Horizontal rhythm</strong></td>
<td>• Consists of 2-3 floors&lt;br&gt;• First floor is dominated by opening in the form of doors and windows&lt;br&gt;• Second floor is dominated by the composition of window lines, doors and balcony&lt;br&gt;• It is indicated by opening rhythm on each floor</td>
</tr>
<tr>
<td><strong>Skyline</strong></td>
<td>• Pointed and the edge of roof shape is indicated by steep declivity</td>
</tr>
<tr>
<td><strong>Facade composition and opening</strong></td>
<td>• Symmetrical, it is shown on opening composition and placement on each floor&lt;br&gt;• Repetition of windows and doors patterns&lt;br&gt;• The axis is usually started from balcony&lt;br&gt;• Having similar opening on each floor&lt;br&gt;• Opening creates horizontal line on each floor and vertical line toward upper floor&lt;br&gt;• The average porosity of all building facades is 35%</td>
</tr>
<tr>
<td><strong>Facade decoration</strong></td>
<td>• Overhang, balcony with fence&lt;br&gt;• Having ornament on windows and door&lt;br&gt;• Roof with opening</td>
</tr>
<tr>
<td><strong>Opening shape</strong></td>
<td>• Symmetrical position both on horizontal and vertical side&lt;br&gt;• First floor is dominated by doors&lt;br&gt;• Second floor is dominated by windows&lt;br&gt;• Having vertical proportion of windows shape&lt;br&gt;• Double doors (cowboy door)</td>
</tr>
<tr>
<td><strong>Roof shape</strong></td>
<td>• Roof with opening&lt;br&gt;• On the second floor, there is overhang around the wall and balcony extending (as efforts to tackle direct sun radiation and rainfall)</td>
</tr>
</tbody>
</table>

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**Fig. 5: The tendency of individual house in urban area**<br>(a) line of traditional houses in urban area, (b) modern house with traditional architecture, (c) traditional house besides modern storied building [6]
To seek out the specific type of traditional architecture in a region does not mean finding out the static style of architecture, but creating new buildings and urban elements that consider traditional elements and society’s demand in accordance with time evolution.

The architectural characteristics of building and urban planning are shown on building or urban performance, which have the wealth of architectural heritage and perpetuate very carefully [1]. It means we should not be trapped in the glory of the past but the spirit of traditional architecture must be accommodated on new building performance.

2.5.2 Is the value of traditional architecture of Cayenne applied on contemporary building?

By reviewing the tendency of building style that is being developed nowadays in Cayenne at a glance, traditional elements are still applied on contemporary design. It could be found by comparing two building models representing traditional house (left) and contemporary house (right) on Figs. 6 and 7. Briefly, the repetition pattern of traditional architecture that is applied on contemporary house could be analysed based on:

**Vertical rhythm aspect:**
- Vertical tendency is still applied on contemporary building. Symmetrical layers or the use of building column on building facade marks it.
- Opening composition on all building facade forms vertical line.

**Horizontal rhythm aspect:**
- Both in traditional and contemporary buildings, horizontal rhythm is indicated by the existence of terrace and balcony with decorated fence in loud colour.
- The first floor is dominated by door placement and building column element (like on floating house) and on the second floor, horizontal tendency is indicated by terrace placement and opening composition. On multi-storied building, this tendency is repeated on the upper floor.

Fig. 6: The application of symmetrical aspect and the use of ornamented balcony on contemporary building

Fig. 7: Kind of ventilated roof shape constructions
Facade and opening composition aspect:
- Symmetrical tendency on these two building performances constitute dominant characteristics of building exterior performance.
- The symmetrical composition is formed by the repetition of windows and doors pattern horizontally and vertically.
- On multi-storied building, the placement of the balcony and public stairs become the vertical axis of its facade and are supported by the roof shape.
- On individual house, both of building performance (roof shape) and opening placement on each floor form symmetrical performance.

Facade decoration aspect:
- The most dominant aspect of facade decoration on traditional and contemporary houses is balcony fence design, opening shape decoration and the ornament of public stairs.

Opening shape aspect:
- On those two building types, the symmetrical tendency on building performance is indicated by opening placement, shape and quantity. It constitutes the response of climate in order to provide natural ventilation in building and tackle direct sun radiation.

Roof shape aspect:
- If the attic had a function to serve as a living area, roof opening is needed and if not, the roof shape is usually in the form of a floating roof (has cavity – with transparent and floating structures especially on building structure from iron material).

2.6 Conclusion
Based on the analysis of historical development or the evolution of traditional house in Cayenne, the classification of traditional building, and the analysis of repetition pattern on several architectural elements above, the specific traditional performance of architectural style of Cayenne is found. But, the function and role of each exterior element must be investigated further.

3. THE CONTRIBUTION OF NUMERICAL SIMULATION WITH SOLENE SOFTWARE

3.1 What is SOLENE?
Solene is a software that simulates sun lighting and day lighting for buildings and urban. It has been being developed in CERMA Laboratory since 1990 [15]. There are two techniques to operate this software [16]:

First, the technique of “Héliodon” is a geometrical method to illustrate sun lighting on building and its surrounding (Fig. 8 is an example of heliodon form of balcony). It is started from axonometric view in observed time produces polygonal shape that constitutes numerical calculation result of geometrical building and environment toward sun direction (see Fig. 9b). The simulation result in various time periods will be performed depending on building type and its site (see Fig. 14).

Second, the technique of mask is to define the type and position of shading device in overheated period. Mask can be illustrated as a complex geometric shading device. Olgay stated that there are three kinds of masks [17]: (a) Horizontal overhangs: their typical mask characteristics are segmental area, (b) Vertical louvers: radial lines bound their typical shading mask. (c) Eggcrate types: basically combination of horizontal and vertical devices; their mask characteristics are, accordingly, a combination of these.

![Fig. 8: A simple illustration of heliodon view of shading device (balcony) in each time period](image-url)
In Solene, the technique of mask uses reversed method, meaning that the effect of shadow between mask and a plane (wall or floor) depends on the angle between the plane and sun direction. This simulation observes a point in a space by using spherical projection to obtain the sun radiation period. The simulation result is formed by combined points of grid (both triangle or rectangle grid). Begun by this step, architects can make a creation on building model based on sun radiation data and observed time period [16]. Solene enables the building of geometrical data of architecture, building site, and other aspects corresponding to sun radiation [18-20]. This visual presentation makes it easier to analyse the phenomena of building shape, room, and time to solve related problem (see Figs. 9 and 10).

3.1.1 SOLENE operation at a glance

This software is distributed for PC’s with a standard Microsoft environment with Open Inventor for the visualization functions. To operate this software, it needs several parameters that are related to one another: ‘le projet’, ‘les géométries’, ‘les ciels’, ‘les descripteurs’ and ‘les matériaux’.

- “Le projet” constitutes a unity of wall, window, roof establishments used as working media of this simulation (see column a of Fig. 9).
- “Les géométries” is a unity of orders to form a volume (3D object for example to form horizontal plane, circle, rotation, etc). Each side of this geometrical building can be formed based on the material, colour, etc. (see column a of Fig. 9).
- “Les ciels” is a special geometrical building formed by hemisphere of triangles plane on sky vault (see column b of Fig. 9).
- “Les descripteurs” is a function of time in a geometrical building. Generally, it presents the simulation difference on geometrical plane, for example the intensity of solar radiation, shadow area, the amount of lighting, etc.
- “Les matériaux” is a physical character presentation of a building material that gives certain effect toward sun radiation (see column c of Fig. 9).

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Fig. 9: The series of technical process in SOLENE program
3.1.2 The facility of SOLENE software

Technically, the presentation corresponded to sun radiation aspect on building and urban is formed by three components. The first component is the observer (someone who observes the evaluated point); second, the observed object in 3 dimensions; and the third component is other objects such as sun radiation, sky vault, and other elements in observed location.

Nowadays, there are several results of this simulation, and the principals of SOLENE software are:

a. Shadow area presentation (Fig. 10a)
b. Duration of radiation (Fig. 10b)
c. Calculation and evaluation of direct solar radiation (Fig. 10c)
d. Modelisation of sky vault and its energy (Fig. 10d) [21]
e. Evaluation of framer factor (Fig. 10e) [22]
f. Prediction of artificial lighting (Fig. 10f) [23]

3.2 Numerical Simulation with SOLENE: the evaluation and development of specific architectural design of Cayenne house

3.2.1 Building model establishment

a. Antique and modern models

Started from two architectural styles of Cayenne house (traditional and contemporary models), we can establish a simple building model that represents the real condition and enables us to obtain the concepts of architectural developments of tropical house and carry it out with the numerical simulation experiment by connecting each building element.

There are several considerations to establish the interior of a building model, namely:

- Symmetrical and opening dimension aspects. Generally, the opening is in the form of a window and door. The opening on building facade is in the form of a wide door between the living area and balcony. Whereas, at the back of the house (in service room), the opening is in the form of a window with 1.00 m of height. There are no openings on building sides because it constitutes the living room of neighbour houses. The proportion of opening on building wall is 35% with symmetrical placement.

- The aspect of overhang (its form and placement). Overhang can be in the form of roof extending or a shading device around building wall with 1-2 m of width.

- Besides overhang, the other main element of building facade is balcony, with various widths (1-2 m). Balcony has a function as intervening space or an overhang [24]. In this case, we assume a balcony as an intervening space with 2 m of width.

- The placement and height of room on the second floor from ground surface. Usually, building in Cayenne has two stories or more.
Fig. 11: The schema of building model establishment based on traditional and contemporary houses
b. Building orientation

Orientation means positioning a building in such a manner that it is insulated either against heat or cold depending on the climate. The two most important factors that influence building orientation are the behavioural pattern of sun and local wind. After finding the best orientation for sun and wind, it is easy to find the right combination for sun and wind. In tropical humid country, building orientation should be such that the heat impact of the sun is mitigated as far as possible. Orientation for wind is aimed for evaluating the effect of wind on human comfort [25].

In designing building model with specific architectural style of Cayenne, we limit on building orientation for sun. Generally, the orientation of tropical houses is North and South.

3.2.2 Sun lighting and shadow area on Cayenne house

a. Sun orbit and GIRASOL diagram CERMA

Because of the earth rotation, the direction and angle in which the sun rays’ strike the earth’s surface vary from day to day. In the northern hemisphere, the sun reaches the lowest point on 22 December, which is known as the winter solstice. The summer solstice occurs on 21 June, while the equinoxes, where the sun is directly overhead at the equator, fall on 21 March and 21 September. In this simulation, we observed the behaviour of sun on all dates above. The position of the sun at any particular point is determined by the angle of azimuth and the altitude. The latitude determines these angles, the date, and the hour. The azimuth is the horizontal angle measured from the north meridian. In the morning, it is measured in an easterly direction and the afternoon in a westerly direction. Altitude is the angle between the vertical plane of the sun and the horizontal plane of the horizon [25].

With a diagram to manipulate the sun orbit (a kind of sun diagram) which is developing in CERMA laboratory, called GIRASOL diagram, we can find out all phenomena of sun orbit such as altitude, the duration of sun radiation per day, the times of sun rise and set, etc. This medium is also possible to use and find in Audience programme-CERMA [26].

b. Shadow area establishment with SOLENE

To determine the best protection for sun in tropical region, we should pay attention to shadow on building facade or room through openings. According to Olgay [17], there are four steps in order to use shading mask for design purposes. It is necessary first to define the times – hours and season. The second step is to define the direction – orientation and altitude – where shading is needed. The third step is to determine the type and position of a shading device for overheated period and the last step is to evaluate the shading device.

Whereas the meaning of shading mask of sun radiation with SOLENE is the visual presentation of this numerical simulation that illustrates how far the sun rays strike the wall or floor surface because the existence of obstacles; and the intensity of sun rays. The illustrations below show the lines of the sun rays in every hour a day. That enables us to provide an animation in observed time [27, 28]. Started from this animation, we will analyse the phenomena in Cayenne house by establishing building model with overhang and balcony.

![Fig. 12: (a) GIRASOL medium, (b) sun diagram with GIRASOL, (c) horizontal sun diagram of Cayenne](image)
Fig. 13: An example of formed shading masks in every hour on building exterior of Cayenne house with SOLENE simulation

Fig. 14: An example of formed shading masks in every hour on building interior of Cayenne house with SOLENE simulation
c. The altitude and overhang width of Cayenne house

Cayenne that is situated on latitude 4.8 of north and longitude 52.5 of East has altitude characteristics as follows (Table 3):

- On east and west oriented buildings, the altitude is 0°00’ in March, 23°33’ in June, and 27°41’ in December. The maximum height of altitude 76°15’ occurs in June and December. The lowest altitude of east oriented buildings occurs when the sun rises and for west oriented buildings, it occurs when sunset.

- On north oriented building, the lowest altitude 66°30’ occurs in June and the highest is 71°25’.

- On south oriented building, the lowest altitude is 85°00’ and the highest is 90°00’ which occurs in March. Whereas, in December, the lowest altitude is 61°25’ and the highest is 65°14’, and in June there is no direct radiation.

Besides sun altitude, it is also important to calculate the intensity of sun radiation. The following are the factors which determine the amount of sun’s radiation received at any point on earth: the position of the sun according to the time of day, the position of the sun according to the season, clouds and atmospheric obstruction, the direction of slope of the station, the angle of slope of the station, the height of the station and the situation of the station with regard to its surrounding [25].

The observation of sun behaviour and its radiation constitute is of great importance to the architect. He must understand the effect of sun not only on architecture but also on the environment where he is building, for example, to determine the slope and placement of overhang as an effort to tackle sun rays entering into buildings.

d. The minimal width of overhang for Cayenne house

SOLENE simulation, GIRASOL medium, and the altitude data of a region are needed to compare the shading device (in the form of overhang) to building height, in order to obtain the shadow mask on the building facade. For Cayenne house, the proportion is:

- For north oriented overhang, wherein the lowest altitude is 66°30’ in June, the proportion between overhang width and building height is 0.4.

- For south oriented overhang, the lowest altitude is 61°25’ in December and the proportion is 0.6.

By the same way, we can calculate the proportion of overhang and altitude in tropical region (see Fig. 15).

- For tropical dwelling in northern equator, the ideal proportion for north oriented overhang is 0.3 or 3:1 for the ratio between building height (H) and overhang width (T).

- The proportion for south oriented overhang is 0.5 or 2:1 for the ratio between building height (H) and overhang width (T).

- Whereas, in southern equator, the ratio is 0.3 for south oriented overhang and 0.5 for north oriented building.

Table 3: Sun altitude in Cayenne: a simulation result with GIRASOL program in CERMA Laboratory
3.2.3 Analysis of overhang and balcony effects

There are some architectural elements of exterior performance of Cayenne house observed with SOLENE. These elements must have direct contact with sun radiation both in order to form shadow mask or obstruct the sun rays entering into the building directly. They are overhang, opening, and balcony.

- **Overhang:** the placement of overhang around building wall to protect wall opening is observed with SOLENE simulation to find out the function of overhang to obstruct the sun rays entering into buildings. It is carried out with modifying the dimension and shape of the overhang.

- **Balcony:** the placement of balcony is on the building facade, as room extending which has the same dimension with overhang width. The existence of balcony constitutes the main observation of this discussion and also the connection between balcony and overhang functions.

- **Opening:** in this discussion, we assume the dimension of opening is 30% with symmetrical placement.

### a. Aspect of overhang dimension

The initial step of this numerical simulation is to observe the sun rays’ behaviour on north and south oriented building models by considering the use of overhang and the position of sun on 21 March, 21 June, and 21 December. This model emphasises on kitchen room with 30% of opening (the placement is contrary to balcony). The building models we choose have criteria as follows: the first model is building without overhang, and the second one is building with horizontal overhang (overhang is roof extending), the overhang’s width is 1.00 m. The third model is building with horizontal overhang, and the width is 2.00 m. The figure in Appendix B gives the illustration of the sun’s behaviour with SOLENE from 6 a.m. until 6 p.m. with intervals of 60 minutes.

Based on the visual presentation of SOLENE simulation (see Appendix B), we know in detail that buildings with south oriented overhang, the sun rays enter into buildings in December (with 65°14’ and 61°25’ of altitude) and in March (with 85° and 90° of altitude), wherein the sun rays intensity in December is greater than in March. And on buildings with north oriented overhang, it is found that overhang with 2.00 m of width obstructs the sun rays entering into buildings effectively in June, wherein the altitude are 66°30’ and 71°35’. Based on the descriptions above, we can make a conclusion for the case of Cayenne house as follows: overhang obstructs the sun rays entering into buildings, and the effect of overhang is more effective for south oriented overhangs in December and March, and in June for north oriented ones.

### b. Aspect of overhang shape

In the second step, we compare the visual presentation by emphasising the effect of overhang. Three overhang shapes are chosen: horizontal...
overhang with 1.00 m of width, overhang with 45° and 60° of angles. The placement of overhang is above the kitchen in order to protect the opening which has 30% proportion of wall area.

Based on the result of simulation (see Appendix C - in column a), the different effect of overhang shape will be observed by comparing horizontal overhangs to overhangs with 45° of angle in December. The difference intensity of sun radiation that obstructed by overhangs with 45° and 60° of angles is very small in December and March.

There are two follow up of this simulation experiment: first, to compare the sun rays intensity ("flux solaire") that enter into buildings in each time period between buildings with overhang that has 45° of angle ("Flux direct incident avec masque") and building without overhang ("Flux direct incident sans masque"). Second, to calculate the intensity of sun rays on protected area. (It is assumed that the percentage of protected area is 100%). It can be seen in Table 4.

In Table 4, the left side shows the comparison of the sun rays intensity in buildings between buildings without and with overhang that has 45° of angle in December. All buildings are south oriented. With SOLENE simulation, we can find that the use of overhang protects building totally between 10.00 am until 2 pm, or it can be said that the protection percentage is 100% and the percentage of the sun rays intensity that enters into buildings is 19.37%. (The sun rays intensity of buildings with overhang is 753 Whm⁻² and building without overhang is 3887 Whm⁻²).

Table 5 shows the situation in March, wherein the sun rays are obstructed between 11.00 am and 1.00 pm, and the intensity of buildings with overhang is 17.9% of the total intensity. (Wherein, the sun rays intensity on buildings with overhang is 104 Whm⁻² and building without overhang is 588 Whm⁻²).

On north oriented building (see Appendix C - column b), the use of overhang both horizontally or with 45° of angle only has a little effect on buildings especially in June. Table 6 shows the detail visualisation of simulation results on building models without and with overhang that has 45° of angle. In June, sun radiation is obstructed between 11.00 am and 1.00 pm; and the intensity percentage of sun radiation that enters into buildings is 24.5% of total intensity without shading device (in buildings with overhang the intensity is 755 Whm⁻² and building without overhang is 3081 Whm⁻²).

Based on two visual analysis above, we can make a conclusion that in Cayenne house, the effect of overhang angle in order to obstruct sun radiation entering into building is more effective for south oriented buildings than north oriented ones.
c. Aspect of balcony usage

Balcony constitutes the specific character of traditional Cayenne house. Its placement tends to be central or has symmetrical position on building facade. Usually, balcony is used instead of overhang. The phenomena of sun radiation on building model with balcony can be seen in Fig. 16.

To find out the role of balcony usage on building in order to obstruct sun radiation entering into buildings, it can be detected by sun trace in buildings. By observing the comparison of simulation result of balcony position on north and south oriented buildings with the same dimension, it is shown that the balcony position on north oriented buildings in June and south oriented buildings in December are very effective in obstructing sun radiation from entering into buildings (the intensity of sun radiation in the building is 4 Whm^{-2} between 9.00 am and 3.00 pm but the intensity on balcony is 3887 Whm^{-2}) (see Tables 7 and 8).

d. Balcony or Overhang?

How is the role of balcony and overhang to obstruct sun’s rays entering into building effectively? It can be detected from the simulation result by comparing the horizontal building model with overhang that has 2 meters of width to building model with balcony (the width is 2 m) and building model with overhang that has 45° of angle (see Appendix D).
Table 8: The intensity of direct sun rays on balcony (for south oriented buildings) and the respective percentage of protected area in March (above) and December (below)

By observing the phenomena of simulation result on north oriented building model (in June - see column b in Appendix D), and south oriented building model (in December - see column a in Appendix C), it can be said that the use of balcony is more effective than overhang with the same width (2 m) to obstruct sun radiation entering into buildings. It is found that the use of overhang with 1 m of width and 45° of angle is more effective than horizontal overhang with 2 m of width.

4. CONCLUSION

- The description of specific architecture elements of Cayenne house both in traditional and contemporary houses constitute the investigation result that takes a long time and the application of those element based on natural and climate condition.
- The investigation on residential development shows the perpetuation of traditional element especially the aspect of symmetrical placement, opening placement and dimension, shading device, vertical rhythm, and balcony usage.
- There are some concepts to develop tropical architecture with SOLENE numerical simulation based on shading mask or sun radiation aspect (especially for the case of Cayenne):
  - For south oriented buildings:
    - It needs to consider the dimension and angle of overhang in order to obstruct sun radiation entering into the building directly in June and December.
    - In December, the use of overhang with 1.00 m of width and 45° of angle reduces the sun rays intensity in room to 19.37% of total sun radiation intensity.
without overhang (the total intensity is 3887 Whm$^{-2}$). Between 10 am and 2 pm; the building is totally protected/ the percentage of shading mask is 100%. Whereas in March, the intensity is 17.9% of 588 Whm$^{-2}$, and the building is totally protected by shading mask between 11 am and 1 pm.

- Shading mask is formed as much as 99.9%-100% in the living area. It occurs in March and December if the building has balcony.
- South oriented buildings have shading mask along the year if the proportion between overhang width and the building height is 0.6.
  - For north oriented buildings:
    - The use of overhang (its dimension and angle) is effective in June.
    - In June, the use of overhang with 1.00 m of width and 45° of angle reduces the sun rays intensity in room to 24.5% of the total sun radiation intensity without overhang (the total intensity is 3081 Whm$^{-2}$). Shading mask occurs between 11 am and 1 pm.
    - If the building has balcony, there is no shading mask in the building.
    - North oriented buildings have shading mask along the year if the proportion between the overhang width and the building height is 0.4.

The minimum overhang dimension for tropical building:
- In northern equator, the proportion is 0.3 between overhang width and building height for overhang in north direction and 0.5 for south direction.
- In southern equator, the proportion is 0.3 between overhang width and building height for overhang in south direction and 0.5 for north direction.

- What is the advantage of balcony and overhang usage with the same dimension on the two buildings above? Apparently, the use of balcony is more effective than overhang with the same width, and balcony also has a function as intervening room between outdoor and indoor spaces (the function of veranda)[24].

- With SOLENE simulation program that is developing in CERMA Laboratory, the aspect of sun radiation in buildings and urban plots is investigated in order to find the specific character of tropical building types and develop the new design concept for recent buildings. The result of SOLENE simulation on Cayenne house shows that the use of slope and short overhang (not horizontal overhang) and balcony constitute efforts to obstruct sun radiation entering into buildings directly. These shading devices are more effective for north and south oriented buildings.

ACKNOWLEDGMENT

Authors are grateful to give thanks to CERMA Laboratory’s Director Mr. Gerard Hegron and Mr. Dominique Groleau as the experts of SOLENE program for supporting this research.

REFERENCES


Appendix A: The analysis of architectural performance of Cayenne house

<table>
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<th>Horizontal rhythm</th>
<th>Silhouette</th>
<th>Building composition and appearance</th>
<th>Appearance decoration</th>
<th>Opening composition</th>
<th>Roof shape</th>
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<table>
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### Appendix B: The simulation on south and north-oriented overhangs with different dimension

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Appendix C: The simulation on south and north-oriented overhangs with different shape

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### Appendix D: The simulation on south and north-orientated balconies and overhangs

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