Teaching Tropical Design Through Simulating Scale Models

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Abstract

The challenge of teaching a Tropical Design course to undergraduate students of an Architecture program of the University of the Philippines Diliman, College of Architecture is assisting students in visualizing the impact of heat gain in their design. This paper's objective is to illustrate that simulating scale models is an effective pedagogical tool.

Architecture students have high spatial intelligence. Effective spatial learning requires visual representations in communication and exploration. Two-dimensional graphics have its limitations, while three-dimensional models offer a richer presentation and development of design.

Application, as Washburn's fourth building block of learning, introduces practice as utilization of the lessons learned in the course. Thus, an effective exercise and application for the Tropical Design Course is the construction of a scale model exposed to direct sunlight and simulating the critical positions and angles of the sun for an entire year. It provides a sufficient conceptual understanding of heat gain. The advantages of scale models are providing learning through their physical creation and manipulation, and they offer immediacy and richness in conveying information and insights.

The scale model needs to be monochromatic, well-built, sturdy, lightweight, and able to withstand physical manipulation. The appropriate scale is from 1:50 m to 1:100 m, depending on the design brief, but small enough to carry around, and large enough to provide details, such as sunshade devices. The objective of the model is to demonstrate the ability of their design features to protect from heat gain. The instructor provides a shadow guide to assist the student in rotating the model under the sun. Successful testing entails prevention of direct sunlight from entering the interior of the scale model, which the students document extensively through photographs. The paper also presents student works as examples.

Success of the exercise is based on the grade given by the instructor as a component (sun-shading and heat-gain solution) of an evaluation rubric that covers also the other aspects of the plate. Out of 91 student works, over 93 percent were adjudged to have scored satisfactorily or better.

Keywords: tropical design, simulation, scale model, architectural education

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I. Introduction

A. Tropical Design Course

The Tropic Region characterized by climatic conditions that are hot, humid, and lacking in great thermal variability between seasons. Thus, Tropical Design is the architectural response to the tropical context reflecting a set of recognized climatic parameters (Riley, 2018). As explained in an Architecture undergraduate course in Tropical Design, the hot and humid climate has the following characteristics: relatively high and even temperature, high relative humidity, high amounts of rainfall, light winds with long periods of still air, and strong solar radiation (Fernandez, 2000). Each of these characteristics has their corresponding design interventions.

Testing proposed design solutions for these prevailing factors has been a challenge for the architecture student given the limitation of the duration of the semester. Proper testing of many of these factors requires large equipment and even prototypes to accurately gauge the effectiveness of the design. Some require expensive computer simulation software that requires long duration to be proficient. However, there is a feasible alternative that addresses the solar radiation problem that is within the accepted capabilities and limitations of the student. This aspect of the tropical climate is the easiest to physically simulate as opposed to the other characteristics. Direct sunlight carries with it not only daylight but heat as well. The absence of direct sunlight in interior spaces minimizes the heat gain of the space. Thus, the proof of effectiveness of design solutions is due to its visual nature - the presence or absence of light in interiors.

The University of the Philippines, College of Architecture offers its Tropical Design Course (Arch 55: Tropical Design) at the third-year level. For the final project or plate for the course, the common assessment tool is for the students to design a small building, usually a house for a single family, incorporating all the tropical design knowledge they gleaned during the semester. The challenge for the students is to test the viability and correctness of their design solution in a manner that is commensurate with their skill level, and also consider their and the school's limited resources and allotted time.

In the past, instructors would only require minimal shading computations, and sometimes, none at all, for the students' final plate. Instructors would rely on visual representations by students that can often be incorrect or misleading. Instructors would also look for the inclusion of specific design elements and features. Without proper testing, gauging their effectiveness would still be imprecise.

As part of the requirement of the course, each student must already construct an architectural scale model of the house. Thus, this paper has the following objectives:

- demonstrate a way to build scale models for simulation
- demonstrate the process to test these models effectively to show a building's capacity to protect from heat gain
- illustrate the efficacy of this teaching method in learning Tropical Design

B. Spatial Learning

Architecture students exhibit higher spatial abilities and generally learn more visually than the average student (Mostafa & Mostafa, 2010). Much of what is required in architectural education is spatial intelligence. It can be defined as intelligence that "represents the knowledge, intellectual predispositions and aptitudes which allow the human mind to comprehend and work with the concept of space" (Mitrache, 2013). Spatial thinking in architectural education can be construed as students mentally constructing spaces (through abstract manipulation of the three dimensions).

As part of Howard Gardner's Multiple Intelligences (Gardner, 2011), the presentation of ideas specific to spatial intelligence is through spatial organizations or visual representation (Washburn, 2010). The challenge for the students is the development and communication of these ideas, not only to the instructor, but more so to themselves. A 2-dimensional interpretation has its limitations. While a three-dimensional scale model, as a method of both exploration and communication, demonstrates design solutions that would be difficult to generate and develop using graphic methods (Dunn, 2007).

Kevin Washburn (2010) introduced the four building blocks of learning (Fig. 1). The fourth and highest level is application, often called practice, that allows students to demonstrate their understanding of the lessons within an instructional setting, in this case, the undergraduate course. This is, of course, in preparation for the application of what is learned in this course to other college courses and to the eventual professional practice. The application is essential in the mastery of the subject. Practice develops the ability to apply new skills accurately and efficiently. The knowledge gleaned from the lectures of the course is transformed into utilization.

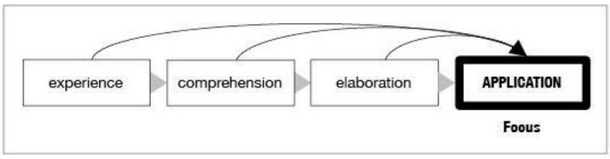


Figure 1: Core processes transforming knowledge into utilization

The practice connects the conceptual and the physical to promote understanding by creating physical relationships of how concepts are tied together (Washburn, 2010). An example of that physical act can be demonstrated by constructing physical models in architectural education.

Moreover, there are multiple ways to develop spatial intelligence. Gardner (2011) suggests experiencing graphic arts, solving spatial tasks, and doing exercises in imagery and active imagination. By using physical models, the students experience the graphic arts through 1) the construction and testing of the model itself, 2) solve spatial tasks by introducing design interventions and manipulation of the physical form, and 3) exercise their imagination by allowing the students to conceive in their mind the probable test results.

C. Scale Models

Architectural models for students have a dual function (Dunn, 2010). Not only do they act as a presentation tool, they also enable the student to explore and advance ideas. They are a tool for design. The models are both medium and mechanism through which concepts and designs are developed.

The particular type of model required is a secondary model, where a particular section or aspect is under focus, in this case, protection from direct sunlight (Mills, 2011) . It is also a qualitative model and its function is to study the essential attributes of a specific object (Smith, 2004). Moreover, this type of model is an evaluative model which purpose is to explore the properties and experiences that are not manifested in the model itself but are related to it (Dunn, 2010), particularly, the amount of direct sunlight entering the space.

One advantage of a physical model is immediacy - it communicates the design ideas of the student in a highly accessible manner (Dunn, 2010). Another advantage is having a rich source of information by its virtue of being in three dimensions. There is also a huge opportunity to mimic or simulate select properties from an actual structure, and generate design ideas from exploring, testing, and evaluating these parameters prior to actual construction. The language of the model is "dense," referring to the density of ideas and information it can potentially contain. At the same time, when a model is viewed, gaining and understanding information from it is faster.

Thus, the architectural model requirement is beyond a presentation tool for Arch 55 students, but also a learning and design tool.

D. Integration with Digital

Advanced CAD and 3D modeling softwares, such as Rhinoceros 3D and Trimble's Sketchup, have features that can precisely geo-locate the digital model anywhere in the world, and consequently simulate the sun path for that specific site. It can accurately project the shadows caused by the sun, thereby testing the effectiveness of any design intervention.

However, the significant advantage of a scale model is its tangibility (Stavric, 2013). Multiple viewers can have unobstructed simultaneous views without the need for an electronic equipment. The tactile qualities of constructing and manipulating a physical model gives the student contact with the real world (Dunn, 2010), and can only enrich and develop the design further.

Computer modeling and scale modeling are inter-related disciplines that may use different techniques to achieve the same goal (Stavric, 2013). The computer model may generate the initial permutations of design, due to its speed and convenience, and the scale model refines and validates the later stages. They complement each other.

E. Course Activities

The following table (Table 1) presents the multiple activities during the entire course and their corresponding learning objectives. Take note that the majority of the activities spur the development of spatial intelligence through mental and physical actions.

Table 1. Course activities and their corresponding objectives

Steps	Activity	Objective
1	Lectures on design interventions to minimize heat gain	Absorb and remember learned knowledge
2	Design according to plate parameters	Apply and synthesize learned knowledge of current and past courses; Exercise in spatial intelligence
3	Construction of scale model	Develop spatial intelligence through tactile activity
4	Simulation of scale model	Evaluate design and construct hypothesis; further develop spatial intelligence
5	Re-design based on test results of simulation	Analyze based on feedback and further iteration of proposed design solution

This is a general guide for the implementation of the course. The instructor can add activities that can be reflected in the syllabus handed out in the beginning of the semester.

Constant consultation sessions with the instructor are also recommended, particularly during the design phase and prior to simulation.

II. Methodology

A. Model Parameters

The challenge given to the student is to minimize the heat gain of their proposed structure. A design shows substantial protection if direct sunlight is minimized from entering any exterior opening and more so, falling on exterior walls.

The architectural scale model requirement is usually at a 1:50 m to 1:100 m scale, depending on the size of the given site. But for greater detail, the 1:50 m scale is preferred.

Figure 2: Student testing her model in sunlight.
Source: Project and Photo c/o Gilber Bercero and Carina Morente (submitted student work)

B. Design Process and Interventions

Students are taught several design interventions to minimize heat gain. Aside from specifying the appropriate building materials, they can manipulate the different building elements such as the roof, walls and openings. They can add additional elements such as sunshading devices to cover, not just openings, but also roofs, walls and other surfaces that are exposed to the sun. The students are taught how to design and compute the dimensions of sunshading devices through a graphical method.

First, they determine the location of the site and take note of its orientation. Then they determine the orientation of the walls or surfaces relative to the orientation of the site.

They need to generate the sun path diagram (Fig. 3) of the site using its coordinates, but this is usually done beforehand by the instructor. The latitude coordinates generally dictate the parameters of the diagram more than the longitudinal coordinates. There are multiple websites like *www.sunearthtools.com* that generates the sun path diagram if given the coordinates.

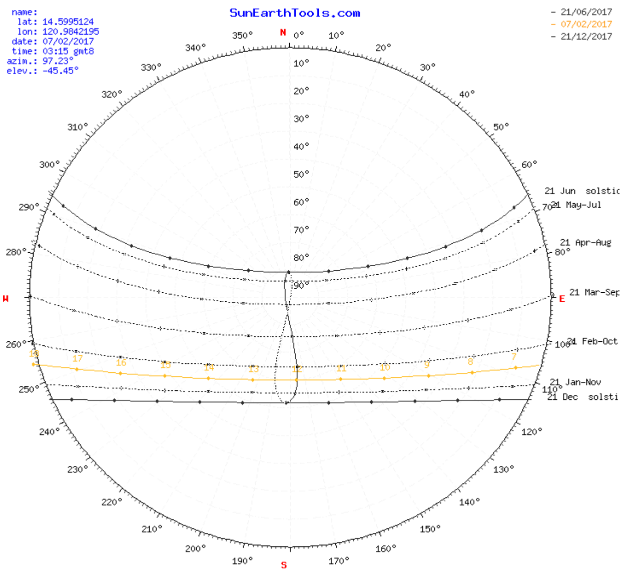


Figure 3. Sun path diagram for N 14.5° latitude (average coordinates for Metro Manila
Source: www.sunearthtools.com

A solar protractor or shadow-angle protractor (Fig. 4) is overlaid on top of the sun path diagram to generate the azimuth and altitude angles. (Baker, 1987) The base line on the protractor is parallel to the wall line where the sun angles are projecting (Fig. 5). The protractor faces where the sun is located.

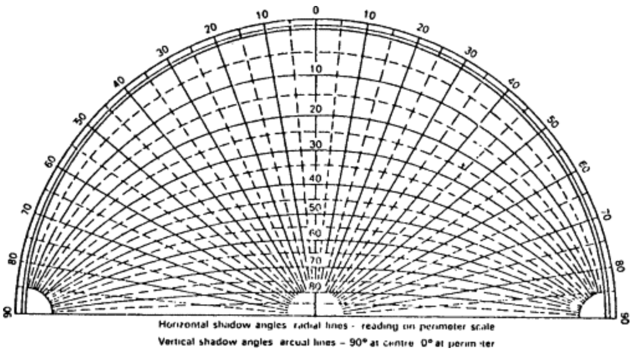


Figure 4. A solar protractor or shadow-angle protractor
Source: Dixon A and Leslie J. eds. (1979). Solar Energy Conversion: An Introductory Course. Ontario: Elsevier Ltd, p. 491.

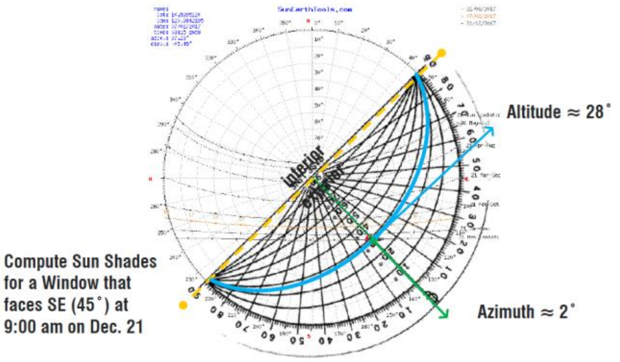


Figure 5. Teaching slide showing the solar protractor overlaid on sun path diagram to derive the azimuth and altitude angles

The derived azimuth and altitude angles determine the size, depth and spacing of a sunshading device (Fig. 6). It also determines the ideal configuration, whether vertical, horizontal or a combination of both.

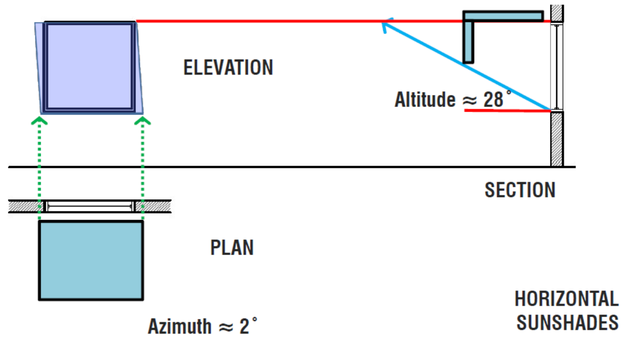


Figure 6. Teaching slide showing how to use the derived azimuth and altitude angles for sunshade design

Students are required as part of their submission to do these calculations for each instance of date and time, and reflect them in their design, particularly in their sunshade devices (Fig. 7). Once the model is made, further modifications can be done, if the initial computations are proven inaccurate.

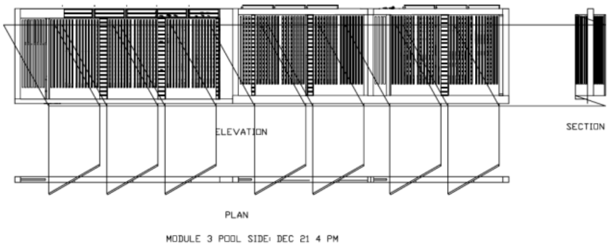


Figure 7. Student calculation of the design of vertical louvers
Source: Project and diagram c/o Fracesca Catipon, Alysza Carballo and Tristan Naag (submitted student work)

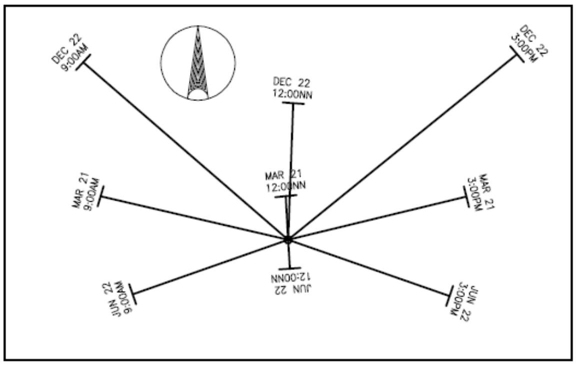
C. Criteria for a Successful Design

One criteria of a successful design is the students to demonstrate the ability to calculate the sizes of the building elements, whether they are roof or sunshade devices for the protection against the direct sunlight. The student should also appropriately specify the type of design intervention required, particularly sunshade devices, based on orientation and sun path.

Moreover, the student should show through photographs the minimization of direct sunlight falling on two aspects of their design - first, the interior space, and second, the exterior elements such as walls, fenestrations, and roof that has the problem of the building material's tendency to absorb and radiate heat.

Finally, the student should consider the integration of all these building elements into a cohesive design, responsive to the climate of the potential site.

ARCH 55 SHADOW GUIDE FOR NUVALI, CALAMBA, LAGUNA



INSTRUCTIONS:

PLACE A 2.5CM STICK AT THE CENTER. MAKE SURE THE STICK IS PERFECTLY PERPENDICULAR TO THE PLANE.

ATTACH THIS SHADOW GUIDE TO YOUR MODEL. MAKE SURE THE GUIDE IS LEVEL AND IS ORIENTED PROPERLY ACCORDING TO THE MODEL'S NORTH.

BY TILTING THE MODEL AND LETTING THE SHADOW OF THE STICK MATCH THE EDGE OF THE LINES, THE SUN WILL BE SIMULATED ON THE CORRESPONDING DATES.

Figure 8. Shadow guide for Nuvali, Calamba, one of the chosen sites) with instructions on how to use it.

D. Testing

To test the design, the model is simulated underneath the direct sun. A shadow guide is produced by the instructor (Fig. 8). This guide is dependent on the location of the proposed site and can only be used for that site or any sites that have similar latitude coordinates.

To make the guide, first determine the azimuth and altitude angles for the following specific dates and times for the chosen site: December 21, 9am, 12nn and 3pm (winter solstice); March 21, 9am, 12nn and 3pm (vernal equinox); and June 21, 9am, 12nn and 3pm (summer solstice). If the site is within the Philippines, the winter solstice has the sun at its most southern direction and produces the lowest angles relative to the plane. The equinox is at the midpoint mark. The summer solstice has the sun at the northern route, affecting the north-facing surfaces.

These dates and times are the simulated sun positions where the model is being tested.

Data for these angles can be found on the same websites that produced the sun path diagram. Using a small vertical piece of stick placed at the center, plot the possible shade casted at the specific dates and times using the angles.

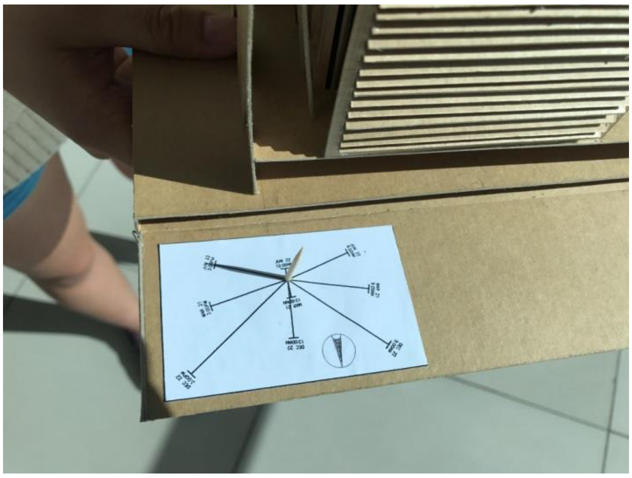


Figure 9. Shadow guide on a model under the sun for Jun 21, 3pm.
Source: Project and photo c/o of Alleli Balboa and Joana Tibayan *(submitted student work)*

This shadow guide is mounted on the model (Fig. 9). The guide must be level with the ground and have the same orientation as the site. By manipulating the model underneath any concentrated light source, the model can simulate the lighting conditions based on the shadow casted by the small vertical stick placed at the center. The concentrated light source can be from a heliodon, a lamp, or preferably direct sunlight (Mills, 2011).

Since, the model is going to be physically carried and rotated, it is essential that the construction is sturdy to prevent any loosely joined elements to fall off (Fig. 10). The base of the model should be stiff and strong to prevent the entire structure from deforming and bending in the middle when carried. It is also recommended that the weight is minimized, particularly at the base of the model where most of the weight is concentrated. Lightweight construction materials such as cardboard or thick paper are recommended. Specific details and embellishments, such as window jambs and frames, are unnecessary. A monochromatic color scheme is preferred. Added color and extraneous textures or finishes can sometimes distort the results of testing by blurring the line between lighted and shaded areas.

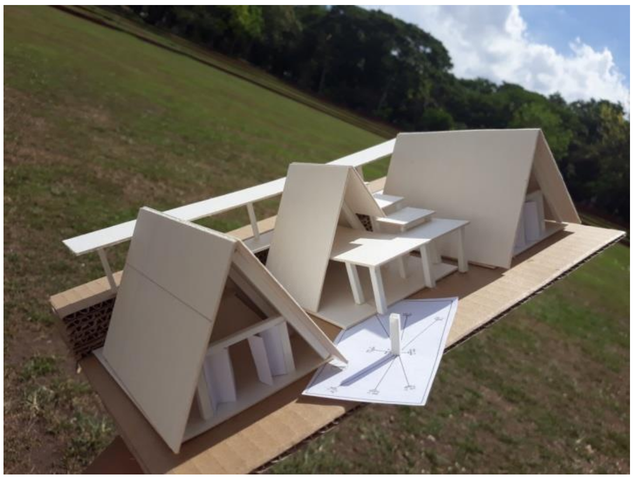


Figure 10. Student simulating the lightweight model under the sun with a steep angle rotation.
Source: Project and photo c/o Ysabelle Coelyn Bacila (submitted student work)

In essence, the model can also be described as a quasi-lighting model, with a different purpose. Where lighting models perceive the effects of daylight throughout the space modeled (Dunn, 2010), the tropical design model seeks the absence of direct sunlight from entering the space.

During testing, students are required to take photographs of their model, particularly the sides where there are sun exposure. They are asked to take close-up and interior shots, focusing on the effectiveness of their design interventions.

III. Results

A. Student Output

The following are sample works of students from 2013 to 2018 showing their application of tropical design concepts in their projects.

This project (Fig.11) shows the preciseness of the calculations done by the students of the depth of their roof eaves. The sunlight is allowed only on the exterior veranda but prevented from touching the exterior wall, thus minimizing heat gain for the interiors.

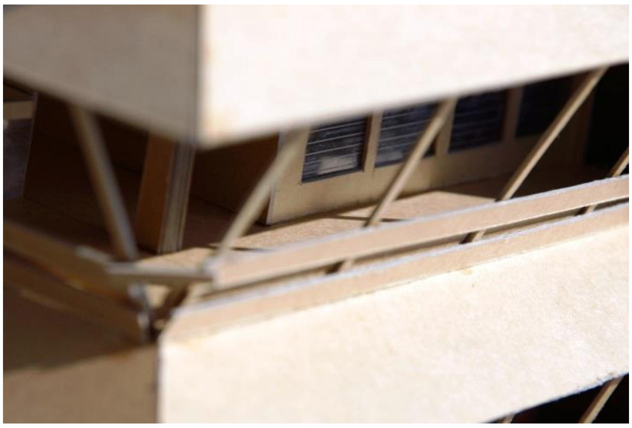


Figure 11. Eave depth calculated to prevent sunlight from reaching the walls.
Source: Project and photo c/o Timothy Ong and Sharmaine Go (submitted student work)

Horizontal sunshades are taught to the students to prevent direct sunlight from the Southern orientation. The students tested (Fig. 12) the effectiveness of their louver design for the second floor rooms and stairs under a simulated noontime condition.

Figure 12. Testing the effectiveness of the horizontal sunshade devices of a monochromatic model.
Source: Project and photos c/o Gilbert Bercero and Carina Morente (submitted student work)

Vertical louvers acts as significant design elements of the front facade of this project. (Fig. 13). The model was simulated for March 21, 9am. The results (Fig. 14) showed significant reduction of direct sunlight entering the interior.

Figure 13: Front facade of house model.

Source: Project and photo c/o Kirby Manuel and Kyle Chua (submitted student work)

Figure 14: Close up of vertical louvers.
Source: Project and photo c/o Kirby Manuel and Kyle Chua (submitted student work)

The students are also taught to protect covered exterior spaces. The project (Fig. 15) displays the light and shadow effect of glass blocks and egg-crate sunshades at the house's entrance vestibule.

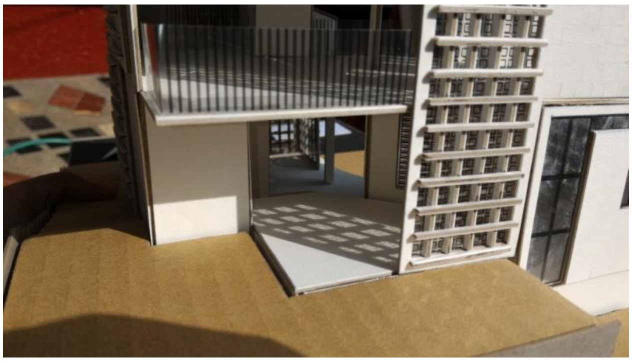


Figure 15. Light and shadow effect of an egg-crate wall.
Source: Project and photo c/o Aira Leung and Lance Lim (submitted student work)

Exterior hallways can double as buffer zones from direct sunlight and heat gain, so added protection is needed for these areas such as perforated screens (Fig. 16) and horizontal sunshades (Fig. 17). The gaps between louver blades promotes natural ventilation to enter any windows facing the corridor. The depth of the roof eaves facing west are calculated to prevent direct sunlight from reaching the exterior walls.

Figure 16: Exterior hallways protected by perforate screens
Source: Project and photo c/o Carlo Llanto and Rafael Rulloda (submitted student work)

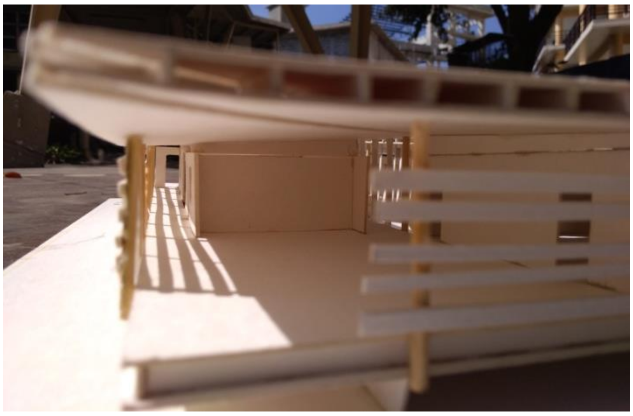


Figure 17. Eave and sunshade detail simulating Dec 21, 4pm.
Source: Project and photo c/o Marc Carbon ad Rafael Sta. Maria (submitted student work)

Another potential and creative design solution is to have a double roof (Fig. 18) and wall system where the outer layer or skin acts as a buffer and protection from direct sunlight over the interior roof and spaces underneath. The air space between the outer and inner layers also provides insulation, trapping heat and preventing the transfer to the interiors. This model (Fig. 19) demonstrates the protection from the December sun at 4pm.

Figure 18: Double roof system design draped over the interior spaces
Source: Project and photo c/o Fracesca Catipon, Alysza Carballo and Tristan Naag (submitted student work)

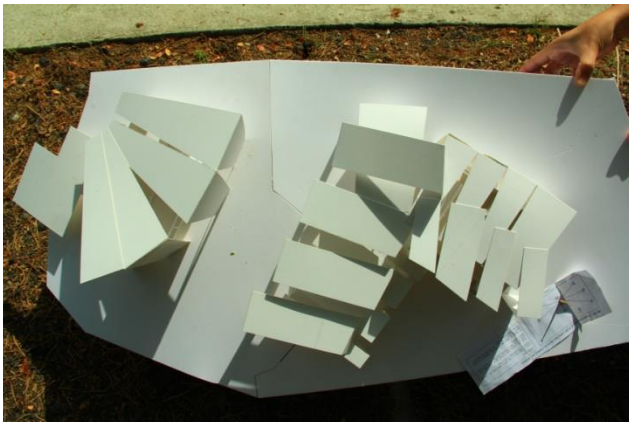


Figure 19: Double roof and wall system
Source: Project and photo c/o Jarelle Abario and Ciphia Molina (submitted student work)

Simulations may also be done using other sources of light such as adjustable table and reading lamps (Fig. 20). The light is usually softer than sunlight, and produces a more diffused shadow. These are taken by the student above the requirement of those simulated under the sun to produce a controlled creative shot of their models.

Figure 20. Simulation under lamp light.

Source: Project and photo c/o Jed Capistrano (submitted student work)

One project (Fig. 21) tests the effect of translucent windows and the amount of direct sunlight entering the space.

Figure 21. Interior shot showing amount of lamp light entering the space.
Source: Project and photo c/o Ishka Mejia and Dominik Rusiana (submitted student work)

The process of simulating scale models has been taught to the third-year students who take up the Tropical Design course of the UP College of Architecture for six years (2013-2018).

IV. Evaluation

The students' works were graded using a rubric divided into different categories (Table 2). Passing grade for the entire plate is 70 percent. Since Tropical Design is considered partially as a design course, the College has a policy of prescribing 70 percent as the passing mark for design courses.

The success of the simulation was graded under "Sun-Shading and Heat Gain Solution." In order to pass under this category, the instructor visually judged, based on the students' submitted photographs, the amount of light entering the interior of the model, thus categorized into Fail (more than 30 percent of light passed through), Pass (about 30 percent), Satisfactory (about 22.5 percent), Good (about 15 percent), Very Good (about 7.5 percent), and Excellent (almost zero percent).

Table 2. Rubric used for grading the plate

	Pass	Satis-factory	Good	Very Good	Excellent	Grade
Site Analysis and Orientation	7	7.75	8.5	9.25	10	
Programming of Spaces	7	7.75	8.5	9.25	10	
Sunshading and Heat Gain Solution	10.5	11.6	12.75	13.87	15	
Computations for Sunshades	7	7.75	8.5	9.25	10	
Ventilation Solution	10.5	11.6	12.75	13.87	15	
Overall Design Translation	10.5	11.6	12.75	13.87	15	
Drawings and Presentation	10.5	11.6	12.75	13.87	15	
Model	7	7.75	8.5	9.25	10	
TOTAL	**70**	**77.5**	**85**	**92.5**	**100**	

Eight sections of Arch 55 and a total of 91 student works had undergone the simulation process (Table 3). Around 93 percent or more of the projects had scored satisfactory or better in this aspect. Over 40 percent had successfully fully minimized the entry of direct sunlight in their interiors (Fig. 23). This meant that the students grasped the lessons of the course and purpose of the simulation, and had consequently reflected these in their final design

Table 3. Sun-shading and Heat Gain Solution grades for 91 student works

Course	Fail	Pass	Satis-factory	Good	Very Good	Excel	Total
2015 Th		1		2	4	8	15
2016 W		1		1	10	1	13
2016 F			1	2	7	4	14
2017 W1	1	1		3	1	3	9
2017 W2		1		1	1	8	11
2017 F			2	4	2	5	13
2018 T				1	3	4	8
2018 Th		1		1	2	4	8
Total	1	5	3	15	30	37	91
%	1.1%	5.5%	3.3%	16.5%	33.0%	40.7%	100.0%

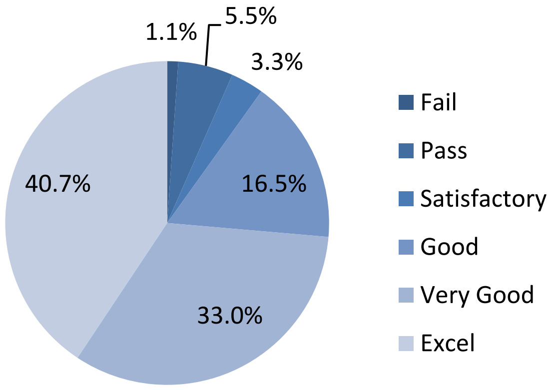


Figure 22. Percentage of grade for student works under Sun-shading and Heat Gain Solution

V. Conclusion

Based on the examples shown, the scale model is one possible instrument in teaching Tropical Design to BS Architecture students. However, there are some limitations to this teaching tool. The simulation covers only three specific times (9am, 12noon and 3pm), thus does not cover early morning (6-7am) and late afternoon (5pm - onwards). Furthermore, poor construction of the model can lead to poor simulations too. If small details, such as louvers, are imprecise in size, spacing and placement according to their calculated design, unwanted light will distort their visual results. Other design interventions that require minute details such as screens and closely spaced *brise soliel* are difficult to construct manually, and consequently hard to test. Any physical errors too in simulating the model under the light source can produce different results based on their intended design. Also, the instructor is reliant on the photographs taken by the student, where negative results can simply be omitted during submission.

Overall, the benefits of a scale model outweigh its limitations. The physical aspect of constructing and handling the model, as well as seeing instantaneously and in real time, the effectiveness of their design under similar climate conditions make it a potent tool for teaching Tropical Design.

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Aira Leung and Lance Lim

Carlo Llanto and Rafael Rullo**da**

Marc Carbon ad Rafael Sta. Maria
Jarelle Abario and Ciphia Molina
Ishka Mejia and Dominik Rusiana
Jed Capistrano

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