UNIVERSITY of NOTRE DAME
School of Architecture

DESIGN VI/ ARCH 41121 (& AME 47431)

BUCCELLATO STUDIO SPRING 2016
Environmental Stewardship through Interdisciplinary Research and Design

PROJECT 1A:
CONTEXT, CLIMATE, AND ARCHITECTURAL FORM

ISSUED: JANUARY 13, 2016

The purpose of this exercise is to study and analyze specific ways that climate and context – or, more specifically, the simultaneous consideration of locality, function, resources, program, and culture – influence architectural form.

Each pair of students (ARCH and ENG) will select one* of the following traditional architectural prototypes in order to: 1) study, 2) analyze, and 3) describe how external forces, like climate and local resources, and internal forces, like function, building program, cultural traditions, etc. have (had) a profound influence on building form and disposition, including building location, orientation, massing, construction materials, methods, and detailing.

As you will discover in your forthcoming research and graphic analysis, these archetypes (among many) remain influential models of bio-climatic design and important examples of the relationship between architectural form and building performance.

1. Yemeni Tower House
2. Traditional Japanese House (*shoin sukiya*)
3. Native American Pueblo (or similar accretive dwelling type)
4. Iranian Atrium House
5. Baghdad Courtyard House
6. Spanish Colonial Plaza Type (or mission complex)
7. *Siheyuan* or Chinese Quadrangle
8. New Orleans Shotgun House
9. Inuit igloo & Traditional African or Turkish mud dwelling (in comparison)
10. Underground village type (China or Africa)
11. Croft Cottage (Ireland or Scotland)
12. Hakka Tulou (Fujian Province, China)

(Items 4–7: } regional variation of courtyard house)

* Another, similar prototype may be selected for study, with approval in advance from Prof. Buccellato

Simultaneous analysis (see ENG project brief) by your engineering colleagues will enhance your research and understanding of the actual performance of these structures for each of the prototypes studied.

Deliverables: your research and graphic analysis of the prototype(s) studied should include a thorough description of the *specific* and normative architectural "responses" that are demonstrated by the architecture either to amplify or mitigate the effects of the prevailing external and internal forces/ influences, like climate and context (as expanded above), and influence the performance of the building. These "responses" may include, but are not limited to the following:

- Building location
- Orientation

- Organization
- Materials
- Protective devices (wind, sun)
- Passive methods (heating, cooling, ventilation, and lighting)

Your successful completion and presentation of Project 1 requires the following (at minimum):

Documentation and Analysis Drawings:
Single Sheet (18 x 24) monochrome line drawing **on vellum or Mylar**
Analysis to include the following graphic components (minimum) **:
Building Plan(s)
Building Section
Building Elevation
Diagrams to illustrate climate/ context forces on form
Additional possible drawings:
Axonometric
Perspective

Bibliography

** Please refer to plate one of the case studies in Precedents in Architecture: Analytic Diagrams, Formative Ideas, and *Partis* (Roger H. Clark and Michael Pause) as a guide for the **layout** of your analysis drawing; in other words, as a guide for the orientation, organization, and clarity of your sheet (not necessarily content).

Prototype Selection: BEFORE Friday, January 15 at 1:30 pm

DEADLINE FOR PROJECT 1: Friday, January 22 at 1:30 pm

PROJECT 1 PIN-UP: Friday, January 22; 1:30-3:30 pm

PROJECT 1:
CONTEXT, CLIMATE, AND ARCHITECTURAL FORM

GENERAL ANALYSIS TIPS

- In general, this thermal model should be at the *engineering scale*, which means that it can be solved with pen and paper or a simple code (*e.g.*, Matlab) rather than requiring more complex numerical schemes. Thus, it is highly recommended that the approach be to use a lumped capacitance type approximation and energy balance as well as effects such as 1-D conduction. The limitations of these approximations must be pointed out (*e.g.*, if the body fails a Biot number analysis), but that does not mean that more complex approaches are required. Similarly, a steady state approximation may also be used, but also should be noted if not explained.

- It is highly recommended that the students take a progressive analysis approach starting with the simplest analysis and adding subsequent complexity in order to refine the answer. For example, an initial analysis may simply *assume* reasonable values for all heat transfer coefficients, and subsequent iterations might improve on these estimates by using a correlation to arrive at the heat transfer coefficients. Another example may be a model that initially uses black body assumptions for the radiation analysis and then the subsequent model assumes gray bodies. One of the advantages of taking this approach to analysis is that it inherently helps dissect the relative roles of different heat transfer modes on overall thermal performance. An example of progressively more complex analyses is given below.

- The deliverables should be directed toward different audiences corresponding to your different 'bosses'. The pin-up drawing analysis should give a high level explanation of what were the primary driving forces on the thermal performance (wind conditions, sunlight, etc.) and focus more on the results and their interpretation. It should be organized in a way to effectively communicate the thermal performance of the prototype to your *non-engineering* boss – the overall project director. The technical memo should include the details not included in the pin-up drawing, such as the governing equations, important assumptions, estimates for various parameters (convection coefficients, radiation properties, conductivity, etc.), and interpretation of the results. It should be organized in a way to effectively communicate the thermal performance of the prototype to your *engineering* boss – your immediate supervisor who can effectively assess the quality of the work.

How might someone go about creating a thermal model to analyze something as complex as a building? As noted above, the simplest approach that can be used as a first step is to make a *lumped capacitance* type approximation. The following outlines a typical analysis that could be used to model a simple home.

1. Lumped, Steady State

Consider a simple home. A simplified lumped model will treat the entire interior of the house as a single volume at a single temperature. Thus we only need to model an *energy* balance to estimate the temperature of the house. We can start with a simple picture to recognize the different energy gains and losses:

The *steady state* energy balance is thus:

$$q_{in} = q_{out} \rightarrow q_{sun} + q_{window} = q_{wall} + q_{roof}. \tag{1}$$

The sun irradiation is a constant of G_{sun} ~1500 W/m^2 and the walls and roof may lose energy by both convection and radiation, or

$$q_{sun} + q_{window} = q_{wall} + q_{roof} \rightarrow$$
$$\left(\alpha_{house} A_{house} G_{sun}\right) + \left(\dot{m}_{window} c_p T_\infty\right) = \left(\frac{1}{R_{wall}}\left(T - T_\infty\right) + A_{wall}\varepsilon_{wall} T^4\right) + \left(\frac{1}{R_{roof}}\left(T - T_\infty\right) + A_{roof}\varepsilon_{roof} T^4\right). \tag{2}$$

The resistance of the wall and the roof can be written simply as a circuit of convection and conduction

$$R = R_{outside} + R_{conduction} + R_{inside} = \frac{1}{h_{outside}A} + \frac{L}{kA} + \frac{1}{h_{inside}A}. \tag{3}$$

We can plug Eq. (3) into Eq. (2) and this will give us a rough *estimate* of the steady state house temperature T (assuming suitable values for all the material and thermal coefficients are used). If the house has a heating unit or air conditioning unit, we can simple add a source or sink term to Eq. (2). Furthermore, if we specify the temperature, we can estimate the amount of heating/cooling needed to keep it at that temperature.

2. Lumped, Transient

Of course, no building is ever at steady state for long as the sun rises and falls each day. We can thus convert Eq. (2) into a *transient* problem by simply accounting for the thermal mass of the house:

$$\rho c_p V \frac{dT}{dt} = q_{sun}(t) + q_{window}(t) - q_{wall}(t) - q_{roof}(t) \rightarrow$$
$$\left(\rho c_p V\right)_{house} \frac{dT}{dt} = \left(\alpha A G_{sun}(t)\right) + \left(\dot{m}(t) c_p T_\infty(t)\right) - \left(\frac{1}{R}\left(T - T_\infty(t)\right) + A\varepsilon T^4\right). \tag{4}$$

This is a differential equation where we can estimate $G_{sun}(t)$ based on its angle and other transient parameters in a similar manner. Sometimes we can solve this analytically can be integrated using something like ODE45 in Matlab, Wolfram Alpha, or similar. Alternatively, we can write a very simple code to integrate this with 1st order accuracy where we approximate

$$\frac{dT}{dt} \approx \frac{T_{n+1} - T_n}{\Delta t}$$

We can rewrite the problem as

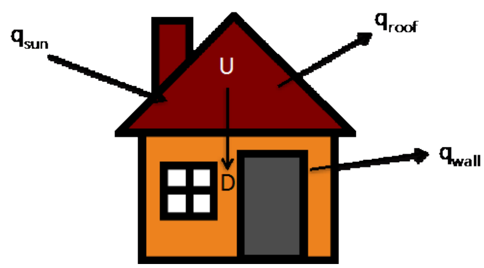
$$\rho c V\left(\frac{T_{n+1} - T_n}{\Delta t}\right) = \left(\alpha A G_{sun}(t)\right) + \left(\dot{m}(t) c_p T_\infty(t)\right) - \left(\frac{1}{R}\left(T - T_\infty(t)\right) + A\varepsilon T^4\right) \rightarrow$$

$$T_{n+1} = T_n + \frac{\Delta t}{\rho c V}\left[\left(\alpha A G_{sun}(t)\right) + \left(\dot{m}(t) c_p T_\infty(t)\right) - \left(\frac{1}{R}\left(T_n - T_\infty(t)\right) + A\varepsilon T_n^4\right)\right] \quad (5)$$

We can thus march in time and solve the transient problem using a simple code.

3. Two-Body Lumped, Transient – Multiple Stories

One natural question arises when there are multiple stories. We all know that the top story is usually hotter than the bottom story in the summer because 'heat rises'. So how might we capture this effect? In short, we split our single lumped body into two lumped bodies, the upstairs (U) and downstairs (D), respectively.



Let's assume all windows are closed and there's no air conditioning/heating on. We can then write *two* differential equations for each body as:

$$\left(\rho c_p V\right)_U \frac{dT_U}{dt} = \left(\alpha A_U G_{sun}(t)\right) - \left(\frac{1}{R}\left(T_U - T_\infty(t)\right) + A_U \varepsilon T_U^4\right) - \frac{1}{R_{U/D}}\left(T_U - T_D\right); \quad (6a)$$

$$\left(\rho c_p V\right)_D \frac{dT_D}{dt} = \left(\frac{1}{R}\left(T_D - T_\infty(t)\right) + A_D \varepsilon T_D^4\right) + \frac{1}{R_{U/D}}\left(T_U - T_D\right). \quad (6b)$$

Notice that I've assumed that the sun only irradiates on the *upstairs* portion of the house. Further, I've assumed that there is some heat transfer between the upstairs and downstairs. I've *assumed* that the upstairs is hotter than the downstairs such that this floor-to-floor heat transfer is a *heat loss* in Eq. (6a) and a *heat gain* in Eq. (6b). The resistance between the two floors ($R_{U/D}$) can be conduction through the floor or airflow through a stairwell. Regardless, Eqs. (6a) and (6b) can be solved simultaneously to provide the temperature of each floor of the house.

4. Two-Body Lumped, Transient – Energy Storing Walls

In some cases, the walls of a home can be great places to store energy – during the day the wall 'heats up' in the sun and at night this stored heat is released into the home. How might one capture this effect? Using a similar two-body approximation where one body if the wall (W - treating it as lumped) and the other body is the interior of the house (IN). We could write

$$\left(\rho c_p V\right)_W \frac{dT_W}{dt} = \alpha A_W G_{sun}(t) - A_W \varepsilon T_W^4 + h_{out} A_W \left(T_\infty(t) - T_W\right) - h_{in} A_W \left(T_W - T_{IN}\right) -; \quad (7a)$$

$$\left(\rho c_p V\right)_{IN} \frac{dT_{IN}}{dt} = h_{in} A_W \left(T_W - T_{IN}\right). \quad (7b)$$

Note that the only source of energy into the house now comes from the temperature of the walls. The radiation and convection all occurs on the *outside* of the house, so it only interacts with the walls and not directly inside the house. Again, we have two equations and two unknowns that can be solved to obtain the transient temperature of the wall and interior.