

The *Bundle-Up!* Game: a collaborative learning tool for net-zero energy design

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ABSTRACT

The purpose of the Bundle-Up! game is to make learning climatic design strategies and their complex interrelationships fun and easy. The project uses the concept of Bundles developed in the research project, “A New Knowledge Structure for Net-Zero Design.” The idea of design strategy bundles is to resolve conflicts and tensions among strategies by proposing related sets of design strategies that address recurring problems designers face. A Bundle identifies several discreet design ideas that apply in a particular situation across three scales. The game outlines a set of rules for users to create their own bundles specific to a particular project. Bundle-Up! is used with a set of instructions like a typical board game. It is designed to use design strategies from the book Sun, Wind & Light, 3rd edition. There is no one right solution, but some answers are better than others, and solutions that follow the rules are all acceptable. Bundle-Up! can be played by one person or several in collaboration. The game pieces (more than 100) each represent a climatic design strategy, each with a unique graphic and other identifying features and descriptions. A prototype was tested with peer teachers and feedback was very positive. The Bundle-Up! game has since been tested in fifth-year B. Arch design studios and with second-year technology course students. Feedback has helped refine the game and its instructions, along with the curricular exercises that accompany it.

Keywords: passive design, design process, knowledge structure, education, design strategies

1 INTRODUCTION: DESIGN STRATEGY BUNDLES

In the U.S., the American Institute of Architects has adopted ‘Architecture 2030’ goals for all new buildings to be carbon-neutral, operating free of fossil fuels by 2030. Carbon-neutral performance can either be achieved by a wasteful building with huge green power systems and purchase renewable energy or by efficient buildings lighted and conditioned by site-based resources, paired with small on-site green power systems. In other words, passive heating, cooling and lighting strategies reduce net loads, which reduce the need for expensive utility green power, photovoltaics and wind generation. To assist designers with this second more architectural and passive energy approach to carbon-neutral performance, this project uses the concept of *design strategy bundles* developed in the research project, “A New Knowledge Structure for Net-Zero Energy Design” and further developed and published in *Sun, Wind & Light: architectural design strategies*, 3rd edition (SWL) [1]. Bundles are theoretically a combination and development of Pattern Language theory and holarchic structure, particularly as developed in Integral Theory. The second edition of *Sun, Wind & Light* included 109 discreet analysis techniques and design strategies across a range of scales. These strategies addressed issues of heating, cooling, lighting and power. The strategy bundle was born in part as a result of finding three challenges that surfaced in over a decade of using the second edition in teaching and consulting:

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1. *Difficulty in knowing which strategies to use* for a particular design situation, such as designing the building envelope, especially for novice passive designers
2. *Challenges identifying how the strategies were related* to each other—or not related—was sometimes implied, but often opaque, and required substantial practical experience
3. *Difficulty in knowing how major variables, like climate type, changed which strategies to employ* or to emphasize.

The purpose of design strategy bundles is to resolve conflicts and tensions among strategies by proposing related sets of strategies across three scales. A bundle proposes a set of the almost-always-required strategies that come together to form solutions to design situations encountered repeatedly in buildings. Some design situations are recurring, such as the problem of how to bring in light through a roof or how to use the building to collect and store heat from the sun in a cold climate.

When one is able to generalize about these design situations, one can also generalize about the solutions and the characteristics of these solutions that seem to be workable across a variety of conditions. If a problem is encountered thousands of times in buildings, the building community develops particular solution types from which designers can learn.

A *Bundle* is defined here as a set of related strategies working together to resolve commonly occurring design problems. A bundle may address a single energy issue or it may address two or more energy topics (heating, cooling, daylighting, ventilation or power). In general, a bundle has the following four characteristic organizing principles, as illustrated in Figure 1:

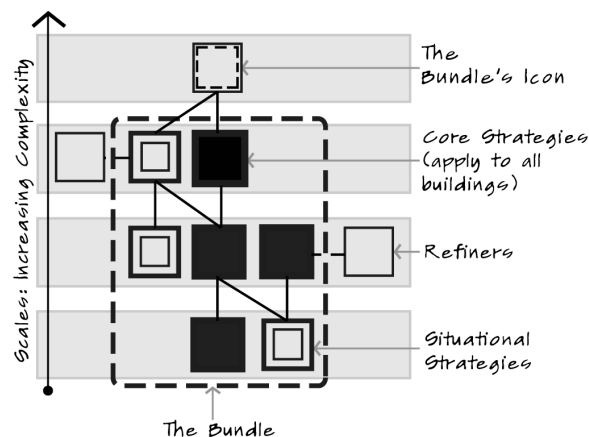


Figure 1: The structure of a bundle

1) *A Bundle covers two or more scales* in the hierarchical system for levels of complexity (*SWL* uses nine scales). Most of the fundamental bundles cover three levels (the gray bars). The black lines connecting the squares represent a particular kind of relationship among the strategies of lower and higher complexity. The levels function to make clear how less complex strategies help to build more complex strategies.

2) *A Bundle has 3–5 invariant core strategies* (the solid black squares) that are always workable in the given design situation. Core strategies are recognized as those that apply to all the bundle's variations.

3) *A Bundle has two or more situational variations*, each with its own bundle diagram. These variations adapt the bundle to a major variable commonly present (such as the difference between designing in a cool climate versus a hot-arid climate) by the addition of situational strategies (the hollow squares inside the dashed line) beyond the core strategies. Remember that core strategies are common to all of the situational variations, whereas situational strategies are more workable or important in one scenario than in the others.

4) *A Bundle may also identify refiner strategies* (the squares outside the dashed line), which are related to the bundle and are recommended to be considered as the design develops to greater levels of detail. These are most likely workable but are less critical strategies.

Because each strategy has a range of variables and can be adapted to variations in its context, the particular combination of strategies suggested for a bundle can yield thousands of formal outcomes. Similarly, the relationship of one strategy to another in a bundle will influence the way in which each strategy is applied. The designer fits one strategy to the others in the network of design strategies that forms the bundle. This network is a context of other more and less complex strategies.

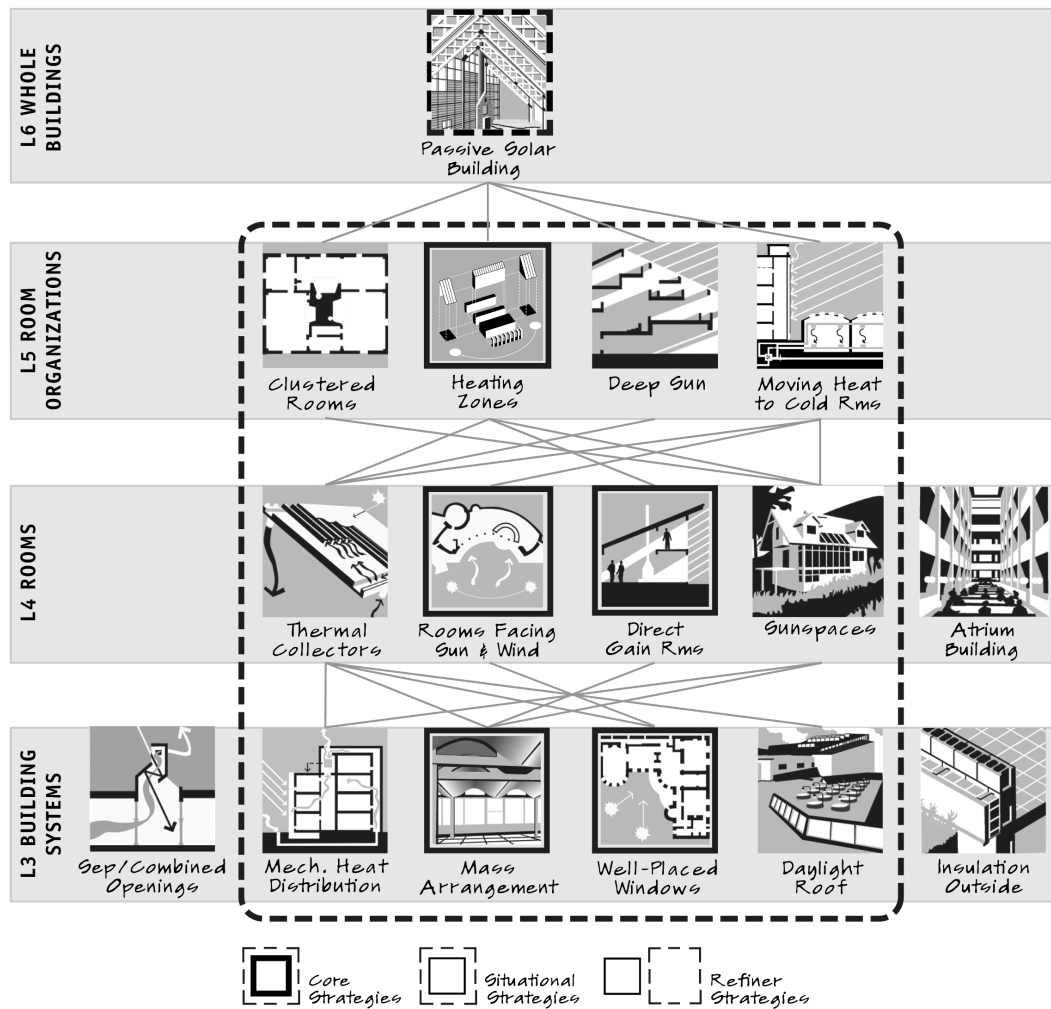


Figure 2: *Passive solar building bundle, thick plan variation*

2. EXAMPLE BUNDLE

The example bundle diagram in Figure 2 for a thick plan PASSIVE SOLAR BUILDING bundle, one of its two variations, illustrates the four organizational principles of a bundle.

1) *The bundle organizes design strategies at multiple scales*, covering three levels of complexity, from lower complexity level three (L3) Building Systems, to L4 Rooms, to higher complexity L5 Room Organizations. These are named in the range of grey bars on the left side of Figure 2. The scale of L6 Whole Buildings is the contextual scale for this bundle and is the level where its particular “emergent characteristics” are evident. The gray lines connecting the squares represent nesting relationships between strategies. For example, the less complex strategies of SUNSPACES, ROOMS FACING THE SUN AND WIND and THERMAL COLLECTORS are all strategies for designing at the L4 Rooms scale; they help to build the more complex strategy MOVING HEAT TO COLD ROOMS, which operates at the more complex scale of L5 Room Organizations to orchestrate heat distribution between rooms that collect heat and those that do not. SUNSPACES helps build MOVING HEAT TO COLD ROOMS, while the higher, deeper, larger strategy also depends on the lower strategy. Bear in mind that the bundles represent some important associations of strategies, and that many additional strategies may be used. Note that, for simplicity, the relationship lines for *refiner* strategies are not shown in the diagrams, but they can be seen on the design strategy maps in *SWL*’s chapter on “Navigation by Design Strategy Maps” [1].

2) *The bundle has five core strategies*. Each graphic icon represents an individual design strategy in *SWL*. Core strategies are shown in Figure 2 with a bold outline: HEATING ZONES, ROOMS FACING THE SUN AND WIND, DIRECT GAIN ROOMS, MASS ARRANGEMENT and WELL-PLACED WINDOWS. These will apply to almost all PASSIVE SOLAR BUILDINGS of both Thin Plan and Thick Plan variations.

BUNDLE-UP

designing for net-zero energy

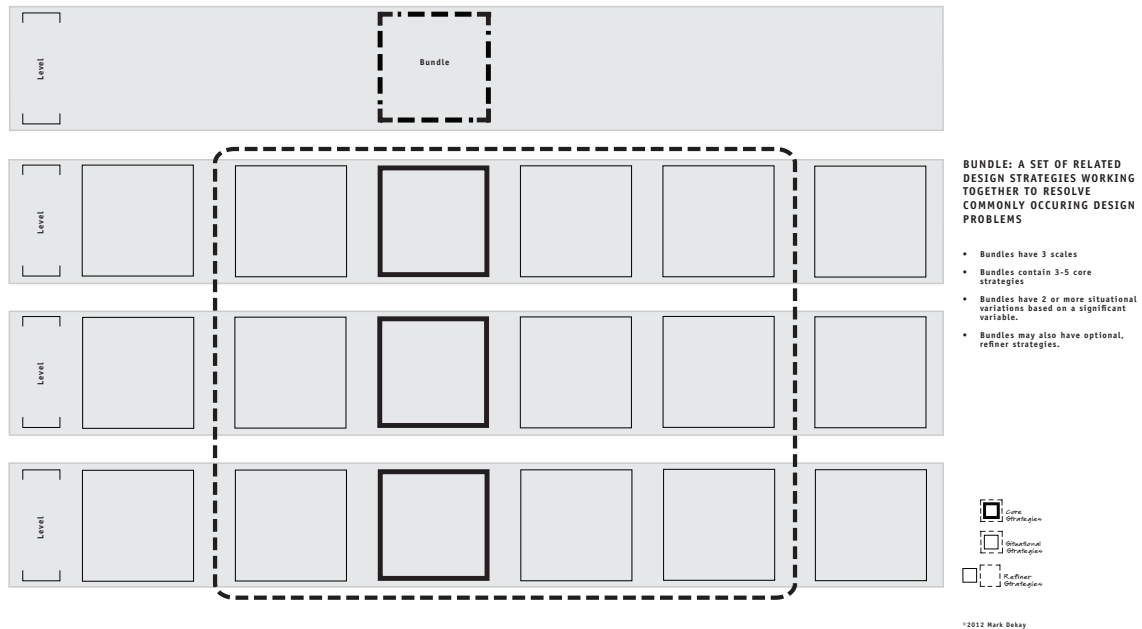


Figure 3: *Bundle-Up! game board*

3) *The bundle has two situational variations, one for a thick plan building* (shown in Figure 2), in which a significant portion of rooms do not face the sun, and one for a *thin plan building*, in which access to the sun by each room is easier. The *situational strategies* are located *within* the bundle boundary (bold dashed line); their icons have no border, for example: CLUSTERED ROOMS, SUNSPACES and MECHANICAL HEAT DISTRIBUTION. These design strategies will typically apply to one of the bundle variations, but not to all of the variations. The situational strategies are appropriate almost all of the time, yet not every strategy need be used in every project. For example, most Thick Plan Variation buildings will need MECHANICAL HEAT DISTRIBUTION to move heat from rooms or surfaces that collect solar heat to remote rooms that do not have direct access to solar heat, but a Thin Plan building can usually use passive radiation or local passive convective loops to distribute heat.

4) *Refiner strategies are less critical* to the bundle's success or have less impact on architectural form than core or situational strategies. However, they may still have a large impact on performance in Figure 2. The refiner strategies are located *outside* the bundle boundary (*bold dashed line*) and their icons have no borders: ATRIUM BUILDING, INSULATION OUTSIDE and SEPARATED OR COMBINED OPENINGS. For example, in a thick plan PASSIVE SOLAR BUILDING, a light court may be used in an ATRIUM BUILDING arrangement; the atrium may also double as a SUNSPACE to collect heat if its roof or one wall has SOLAR APERTURES oriented to the sun. This refiner strategy will not apply to all buildings, but if used, could improve the performance the bundle offers.

4 THE BUNDLE-UP! GAME

The *Bundle-Up!* game was developed as a fun way to learn about designing with bundles. It allows players to build their own bundles of design strategies that are more specific to their design's program, site, and climate than the more generic "fundamental bundles" in *SWL*. The game board (Figure 3) follows the structure of bundles as described above. Users select "Scale Cards" from among nine options (Figure 4a). Scales must be sequential from smaller to larger. A colored "Bundle Tile" from among nine current options (Figure 4b) is placed in the top position, or, alternatively, a blank tile may be selected and given any original name by players who wish to create a custom bundle for a new problem type. Each fundamental bundle and design strategy (currently 115 total) from *Sun, Wind & Light* [1] is represented by a "Strategy Tile" (Figure 5). The front of the tile shows its *SWL* strategy icon, abstracted

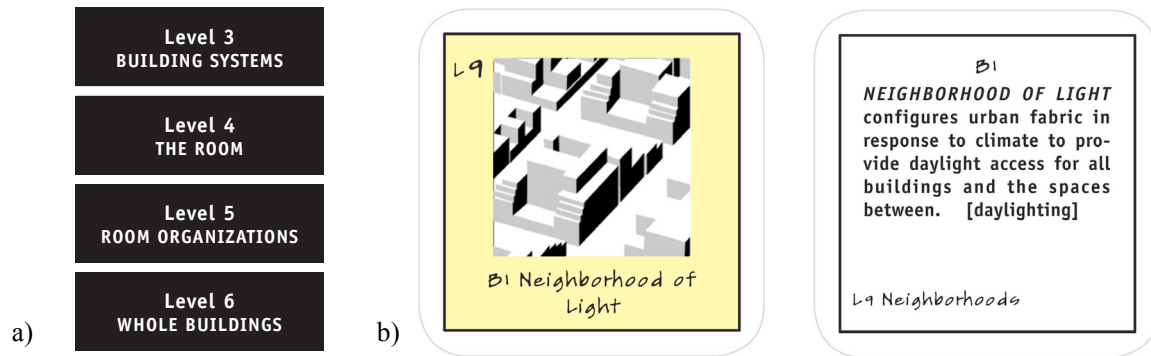


Figure 4: (a) Cards for scale/level of complexity (b) Bundle tile example

from a built example, along with its name, strategy number, and level of complexity designation (L1, L2, etc.). The back side gives more information: the strategy or bundle number, its defining “strategy statement,” the energy issues it addresses (heating, cooling, daylighting, etc.), and its level name.

5 OUTLINE OF INSTRUCTIONS FOR PLAYING *BUNDLE-UP!*

The game can be played by one person (as solitaire) or several people in collaboration. It can also be played by having different teams create variations on the same bundle. This is a good way to arrive at *core* strategies (ones that have workability in all of a bundle’s variations). Instructions for play:

- 1) Place your colored Bundle Tile (or create one) in the dashed bundle square on the top.
- 2) Each strategy has a scale and can only be used at that scale.
- 3) Choose critical strategies (or your best guess for candidates) from the deck of Strategy Tiles and place them inside dashed bundle “wrapper.” These will become either core or situational strategies. You may start with any strategy that you think would be very important to the design scheme.
- 4) Place less critical refiner strategies at their designated scale, but outside the bundle wrapper.
- 5) Examine your set of strategies for their interactions and add, subtract or substitute strategies to create greater synergy between strategies to solve the bundle’s energy issue(s). Debate the importance of different strategies, moving them inside or outside the bundle wrapper.

6) Now identify the strategies that are the three most critical—at least one at each scale—that are critical to “almost every building” in your situation. Place these in the bold core squares. If desired, you may add up to 2 more core strategies.

7) To test your choice of core strategies, think about whether or not each would still be effective in the other situation(s) of the bundle problem. If playing in teams, debate with the other team. If playing in one group, it is useful to assign different players to advocate for the needs of a particular bundle variation.

8) There is no one right solution, but some are better than others, and solutions that follow the rules are all acceptable. When satisfied with your solution, or your group has reached consensus, record it on the Bundle Capture Form (a reduced version of the game board).

9) HAVE FUN!!! Design. Repeat.

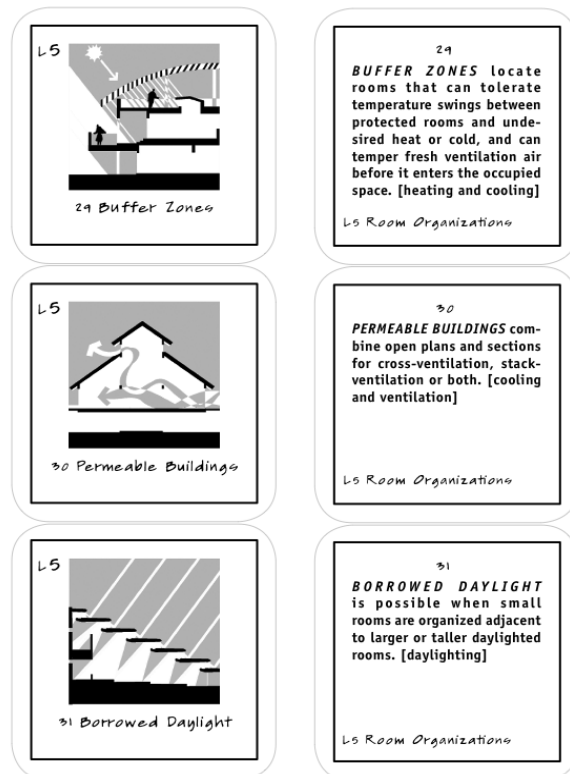


Figure 5: Strategy tile examples

6 PROTOTYPES AND TESTING

A rough, limited scope prototype with one bundle and only cooling strategies was created, and an initial test was run with peer teachers at the 2012 annual curriculum meeting of the Society of Building Science Educators. Two teams of architects and design professors debated over and created bundles for hot-humid and hot-arid variations of a PASSIVELY-COOLED BUILDING bundle. Feedback was very positive. The members offered suggestions for improvement, mainly to the instructions and options given to users. Overall, they agreed that the game was a good learning tool and that they had actually learned something themselves in the process of playing. The teachers enjoyed learning in a group together and saw possibilities for transforming the typical architectural technology class that primarily uses individual learning approaches and also noted the potential as a design tool in design studio classes.



Figure 6: Testing Bundle-Up! with the Society of Building Science Educators

The next prototype, with a complete set of bundles and strategies, along with revised instructions, was then tested in two classroom settings: fifth-year undergraduate design studios in Spring and Fall terms of 2013 and a second-year “Introduction to Architectural Technology” course in Spring of 2013 and 2014. The lower level instruction in a class of 65 students made use of an instructional video created by the author with two advanced students. In one semester, upper level students designed housing for a village in Gujarat India, collaborating with Professor Sharad Sheth’s fourth-year students from Sardar Vallabhbhai Patel Institute of Technology, Vasad. University of Tennessee students are shown playing *Bundle-Up!* in Figure 7a. A team working on housing design for the village of Wagnagar developed a composite bundle for a PASSIVELY-COOLED BUILDING and an OUTDOOR MICROCLIMATE, shown in simplified form in Figure 7b. Their scheme for two variations on low-energy climate-responsive courtyard houses built with local materials and labor skills is shown in Figure 8.

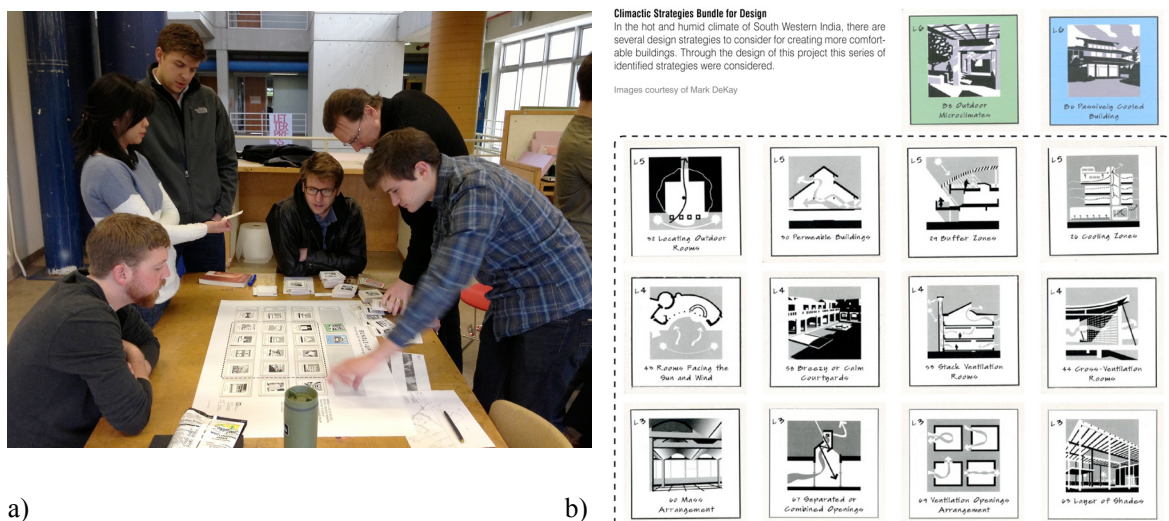


Figure 7: (a) Bundle-Up! in design studio (b) Hybrid custom bundle for Gujarat housing design

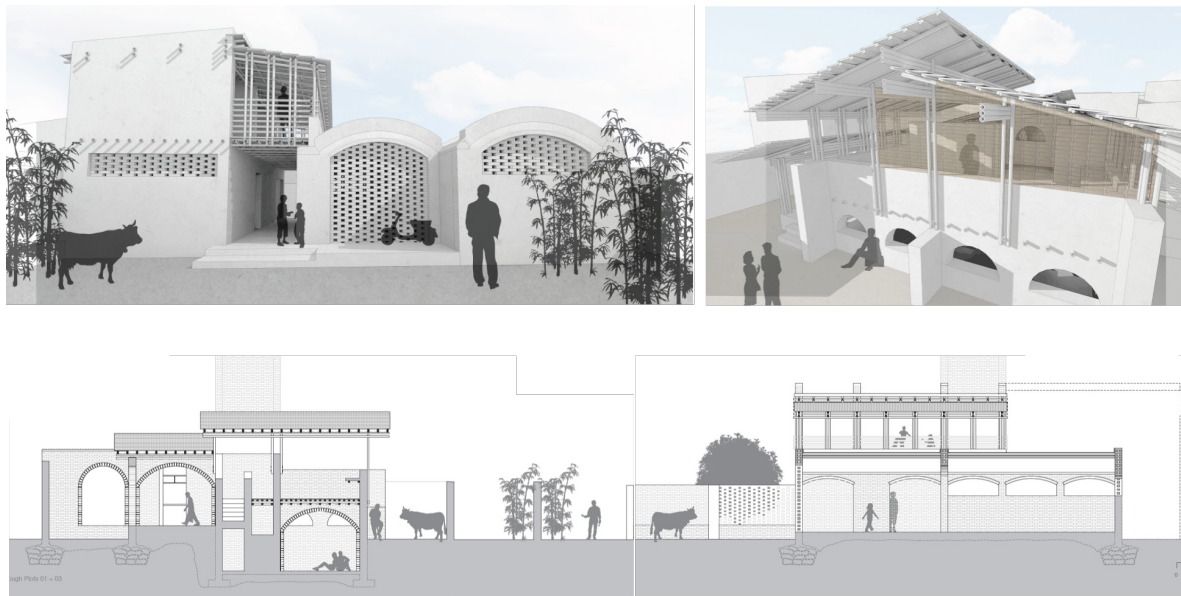


Figure 8: 5th-yr studio project, housing in Wagh Nagar, Gujarat, designed using SWL bundles



Figure 9: 5th-yr studio project, brewpub in Marfa, Texas, designed using SWL bundles

In another semester, fifth-year students used *Bundle-Up!* to help design a net-zero energy brewpub and beer garden in seven different U.S. cities, each set in a different climate. One team's design for warm-dry Marfa, Texas is shown in Figure 9. It includes passive cooling, heating, and daylighting strategies from *Sun, Wind & Light*, 3rd edition [1]. They also used the new *SWL Tools* spreadsheets to calculate energy demand and size photovoltaics to become a plus-energy project.

The lower-level students used *Bundle-Up!* as a part of a sequence of passive design exercises that design a net-zero energy bioclimatic residence, again in multiple climates. In all of these cases, students developed their designs in collaborative teams of two to four students. Figure 10 shows an example a PASSIVELY-COOLED BUILDING bundle developed in the exercise, a student team using *Bundle-Up!* in the design process, and a second-year scheme for a net-zero energy residence in the mixed-humid St. Louis climate. As a result of these and other classroom innovations, the instructor/author was awarded the Chancellor's Award for Teaching Excellence 2014 at the University of Tennessee.

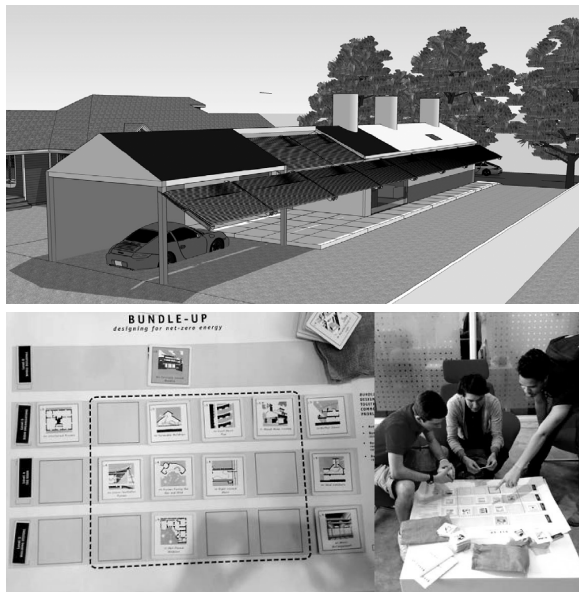


Figure 10: Student net-zero residence designed using *Bundle-Up!* in technology class; example exercise bundle; game in student design process

CONCLUSIONS AND FUTURE PLANS

The next step in testing and revision will be a workshop for practicing architects in October 2014. In theoretical terms, observing users playing *Bundle-Up!* many times and applying their results in designing buildings have suggested the need to expand the *Sun, Wind & Light* knowledge structure. Bundles, as defined in *SWL*, cross a limited range of three scales in the nine-scale system of *SWL* that ranges from materials to neighborhoods. The development question is, “Can the bundle concept and the *Bundle-Up!* game be expanded to include mapping the full range of design strategies employed in a specific design?”

While the game is clear and useful as a learning or design activity, it is important to place it for students within a clear design process context. Students need assistance in knowing when to employ the bundle concepts and more specific

guidance about what to do with the game results. To this end, future class exercises will guide a more explicit design process that involves multiple uses of the game in a sequence of different problem variations. Examples might include generating building design bundles for passive heating, cooling, and lighting, or using *Bundle-Up!* to explore a responsive envelope that addresses multiple energy issues.

Perhaps the most common request is for an iPad app or other electronic version of the game tied to its *SWL* knowledge base. The author is currently seeking technical collaborators and funding.

Through application and feedback in different settings and class types over a two-year period, several conclusions may be drawn. Students have found the *Bundle-Up!* game useful as a step in the process of designing passive and net-zero buildings. It requires them to choose carefully and to narrow their design options strategically. Via the game, the relatively complex *SWL* knowledge structure becomes more accessible to both beginning and advanced students. Playing *Bundle-Up!* seems intuitive and fun. Making more fun of understanding climatic design was the game’s real purpose. One peer teacher found, “It teaches systems thinking across multiple scales with none of the systems thinking jargon.” Another reported, “This really supports integrative ecological thinking in a very concrete architectural way.” Students’ responses from feedback surveys are consistent in their appreciation of learning in collaborative dialogue and the teamwork required by *Bundle-Up!*, in contrast to many of their other classes. They enjoy learning in a hands-on, project-based setting, working together with their peers, rather than working in competition with them.

Digital files for printing and making *Bundle-Up!* are available from the author.

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