DESIGNING BETTER PORTABLE CLASSROOMS

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BACKGROUND

School classrooms, despite substantial changes in technology; economics; and educational, sociological and psychological theory, at some level have changed very little (with the ill-fated, but mercifully brief, exception of open-plan schools in the 1970's[2]) since the turn of the twentieth century.[3] In most schools during that time period we tend to find enclosed rooms, with a class size of something like twenty-five students and one teacher, writing surfaces on the walls, storage cabinets or shelves for books and supplies, and individual seating for each student. In that sense, this is why a typical school built say, fifty or sixty years ago, is still, today, perfectly adequate for instructional purposes. Classroom planning guidelines from that time period state, "A self-contained classroom is the ideal answer....yet devised for the on-the-job education of the teacher. It is a good answer to the enrichment of group life."[4]

Make a visit to an elementary school built in the early 1960's and you'll likely find a one-story school, organized along a double-loaded corridor, with substantial glazing on the outside wall providing daylight into the classroom. In some ways it's a simple model that's hard to beat, which accounts for its persistence. But at the same time, it's a model that, once-built, is hard to modify. If a particular classroom is well-designed, this may not be a problem. But if the original design is flawed in any way, the flaw persists for many years. If the school's needs change, remedies are expensive and potentially difficult to implement. Needs inevitably change over the life span of a school building: enrollments wax and wane, technologies come and go, special needs programs get implemented, and educational theories evolve.

NEED FOR FLEXIBILITY LEGITIMIZES PORTABLE CLASSROOMS

To accommodate change (particularly expanding and contracting enrollments) many—if not most—school districts employ the use of portable classrooms to introduce a degree of flexibility in their facility needs.[5] The Modular Building Institute estimates that there are 300,000 portable classrooms in use in the United States.[6] Lisa Heschong reports that 40% of all classrooms in Fresno, CA are portables, and that 200,000 children in California attend school in portable classrooms.[7] The portable classrooms have many advantages: they are readily available, relatively inexpensive (when compared to "bricks-and-mortar" classrooms), and can be quickly relocated as needs change. Though most districts consider them to be temporary solutions to temporary problems, the number of portable classrooms has seen continuous growth over the past fifty years. Despite school districts' claims that they're temporary, the fact is that many classrooms, once in place, remain for decades, and many questions linger about their adequacy as learning environments.[8] In one of our preliminary meetings Brian Hunter, of USD497 in Lawrence, Kansas, quipped, "There's nothing more permanent than a temporary classroom."

Figure 1. Existing portable classroom. Hillcrest Elementary School, Lawrence, KS.

PROBLEMS WITH PORTABLE CLASSROOMS

But even when truly intended for short-term occupancy, these buildings have a way of staying around much longer, and get used as classroom environments year after year.

It's not unfair to say that even the best of most of these units is sub-optimal, in the sense that they have not been designed for maximum educational effectiveness: they have, instead, been optimized for transportability, for minimum cost, for rapid deployment. These may be laudable goals for many school districts, but often at the expense of effective learning. Other potential liabilities include poor energy performance, high life-cycle costs, compromised safety and security, teacher dissatisfaction, and negative teacher, parent and community perceptions. The buildings are often installation and maintenance headaches for district staff, as they deal with failing roof systems, animal intrusions beneath the buildings, building leveling, access for the disabled, utility hookups and poor energy performance.[9]

THE "STANDARD" PORTABLE CLASSROOM MARKET

The portable classroom market is highly competitive, with several manufacturers offering buildings in most any given locale. Some manufacturers have a national presence, while others are more regionally-based. Manufacturers offer a range of procurement models, from outright purchase to short or long-term leasing, making it relatively easy for districts to acquire buildings under different funding scenarios. Some manufacturers offer financing services as well. In our research we discovered that the modular building industry is capable of producing a wide range of building qualities, from sophisticated, high-quality (expensive) buildings, to lower-quality, "cheap" construction. It all depends on what the customer wants and is willing to pay for. Our contention is that most districts see portable classrooms as temporary solutions to temporary problems, and there is little incentive to invest in a higher-quality—and thus more expensive—building. Many districts make their purchasing decisions based primarily on cost, leading to a "cheapest is best" approach to the buildings' design, detailing, construction, maintenance and materials choice.[10]

CONSEQUENCES OF "CHEAPEST-IS-BEST"

Cheap construction plays itself out in a variety of ways. Materials cost money; therefore simply reducing the amount and quality of materials in a building will typically reduce costs. The result is thinner wall assemblies, with less insulation value; less-efficient, noisier HVAC systems; lower-quality exterior finishes; fewer and smaller windows leading to decreased daylighting; lower-quality doors with less-effective weatherstripping. From a learning standpoint, inferior classroom environments can have detrimental consequences. Studies have shown that daylighting, for instance, is an important factor in student performance.[11] Cheap buildings, from an energy-usage standpoint, can be expected to perform poorly and studies have shown that significant increases in energy performance can be achieved through targeted improvements.[12] These same improvements from an energy-usage standpoint can also improve other environmental factors, including indoor air quality, acoustics and illumination levels, that have been shown to improve student learning outcomes.[13]

STUDIO PREMISES

A fourth-year undergraduate design studio to focus on missed opportunities in portable classroom design was taught at the University of Kansas in 2007 with the following premises: 1) Portable classrooms have many advantages to school districts. We can assume this to be true because of their prevalence in school districts all over the US, for many decades. 2) Portable classrooms also have many liabilities (as recounted above). 3) Even though many districts claim that portables are temporary, they are in fact permanent. 4) Given their permanence and ubiquity, why not just accept the fact that they are here to stay, and design proto-typical portable classrooms that minimize the liabilities, maximize the strengths, and are optimized for effective student learning? 5) To do so means that cheapness can't be the primary goal. USD497 facilities staff estimate that a portable classroom costs about 20% of the cost of a bricks-and-mortar permanent classroom. So there is a lot of room to play with. What would a portable unit that cost 50% be like? How about 75%? Even if the cost was equivalent to that of a permanent classroom, it still might be a desirable thing to do, given the advantages of portability.

Students were further encouraged to consider the entire life-cycle of the portable classrooms, from manufacture, transport, delivery, setup/installation, occupancy and de-commissioning. The idea was to see if re-consideration of the manufacturing scenario could lead to innovations that would have beneficial improvements to the learning environment.

PROJECT RESULTS

The studio started with visits to elementary and middle school classrooms in USD497 (Lawrence, KS) to understand the implications of environmental design decisions on learning. The buildings ranged in age from the 1920's Central Junior High School; to the 1960's Hillcrest Elementary School; to the just-completed South Junior High School. We met with both school administrators and teachers to understand some of the issues from their different points of view. Following those visits, we spent a morning with Tom Bracciano and Brian Hunter of the USD497 facilities staff to understand the issues from their points of view. For the students these efforts contextualized the project to include opinions of users (teachers and students) and of administrators (principals and facilities staff). The conversation unearthed several issues that would otherwise be hard to discover. (For instance, it was in one of these meetings that the facilities staff revealed how much difficulty they have in maintaining portable buildings; skunks, raccoons and other wildlife love to embed themselves in the below-floor insulation and cause other problems.)

Following visits to understand the problem from a school point of view, we visited Kan Build, Inc., a modular building manufacturer located in Osage City, KS. Kan Build has been in operation for over twenty-five years and employed 275 people at the Osage City location.[14] In 2001, Kan Build's best year, they reached $20 million in sales. Kan Build's primary market was for modular housing and commercial buildings. They were not typically a regular manufacturer of classroom buildings.[15] The primary purpose of this visit was to understand the differences and opportunities between site-built and factory-built buildings. These differences are significant, in the sense that there is the potential for greater control in the factory, and the visit caused students to understand that they could harness this potential in their own design proposals. Another potential lies in the approach to construction advocated by Kieran and Timberlake in *Refabricating Architecture:* the development of a sub-assemblies approach to building construction similar to that used in the automotive industry.[16] At the Kan Build factory this is how the factory's production is organized and optimized. For instance, one of the first "stations" early in the production line is the place where walls get framed. The surface on which the framing lumber gets laid out is a waist-high steel table with slots for the studs, perfectly spaced at on 16" centers, and perfectly squared to the top and bottom plates. Worker comfort is maximized, and error is minimized at the same time that squareness is maintained. The roof/ceiling assembly manages to avoid the problems of an uneven ceiling surface (due to less-than-perfectly-straight ceiling joists) by the following: 1) The sheets of gypsum board are laid out face-down on a perfectly flat waist-high table. 2) A quick-cure expanding foam adhesive is applied to the lines where the trusses will attach. 3) The ceiling truss sub-assembly is lowered down until the trusses touch the gypsum board. 4) The adhesive expands and cures, and the entire assembly is hoisted from above to allow workers—at a convenient working height—underneath the assembly so they can then install screws from below and mud it in a conventional fashion. The result is a perfectly-flat ceiling assembly, installed by workers on their own feet (not on ladders or stilts), that then gets hoisted up and set atop the wall assemblies that have been assembled in a different station. Water supply lines are done in continuous runs of flexible, cross-linked polyethylene (pex) tubing and installed in floor and wall cavities with large-radius sweeps at changes of direction, rather than with elbows and couplings in hidden cavities, to minimize installation time and the potential for leaks—leaks in plumbing typically occur at joints. These are just a few examples of individual moments in the construction process where innovation could occur to the advantage of better classrooms.

A parallel precedent study consisted of examining recent developments in portable classroom design, including the well-known Montgomery County, MD school competition and Project Frog's prefabricated classroom system.[17]

INNOVATION AND IMPROVEMENT

The studio divided itself into 4 teams, each developing its own proposal for classroom prototypes. Though they differed in their details, several common themes emerged that can be discussed in general.

Configurability: One of the problems of conventional portable classroom buildings is the fixed size and proportions of the classrooms. A single-wide configuration leads to a narrow aspect ratio for the classroom; a double-wide configuration may lead to a more desirable aspect ratio, but still a limited set of arrangements. By developing a finer-grained module, a greater number of configurations can be achieved. For instance, in one proposal, we find classroom bays of 8' x 40', allowing configurations in 320sf modules. They propose 3 module types: 1) an entrance/utility module, containing the entrance, bathroom, HVAC closet, and a multi-function support space; The entrance is an enclosed vestibule providing a thermal barrier and giving the classroom a less-temporary feel. Placing the functions in the core allows the other bays to have more configurability. The support space can be used as a place for coats and book bags, a reading area, or resource room for private study. The wall that separates the support space from the rest of the classroom is six feet tall (the ceiling height is ten feet) to provide a divide in space but allows the teacher the ability to hear students from the classroom. The entrance module is always placed on one end of the building. 2) A center module, which is the "expandable" portion of the building. A district chooses as many bays as necessary to meet its needs in that particular building. 3) An end module that caps the end of the building opposite the entrance module. With these three modules classroom size could range from a minimum of about 1000sf to an unlimited size. A well-proportioned, "typical" classroom of about 1700sf can be achieved with three center modules and the two end modules. (Figure 1). For this team, the seam between the modules presented an opportunity for daylighting, and a linear skylight system was proposed to equalize daylighting within the classroom.

Other teams proposed different configuration concepts. For instance one team proposed a basic configuration of two classrooms arranged so they create a shared common space between them for mutual use. In general, all four teams proposed that configurability, in the interest of maximizing opportunities for learning, was a concept that should be pursued in portable classrooms.

Structure: The four teams in this studio all ended up with three-dimensional modules as the basic structural unit. ("Flat pack" construction was considered, but all teams ultimately decided that a box-type module made more sense in the interest of speed of installation.) The modules need to be strong enough to withstand the loads applied during transportation and installation. For a center module, as described above, this means that longitudinal shear needs to be incorporated into the basic module. For this team, steel construction for the superstructure is the means by which to introduce adequate strength to the system. Steel is inherently strong, has a high strength-to-weight ratio, can be welded for moment resistance, and is industrially fabricated for uniformity and universality. An example that illustrates such utility is the proposal to use castellated beams for the floor system. Castellated beams have the qualities listed above for steel-in-general, and allow for convenient distribution of plumbing, electrical and environmental systems. (Figure 2). The vertical structure can be welded to the floor structure for longitudinal shear, and secondary and tertiary structural components of say, wood, can be easily attached for the installation of conventional finishes.

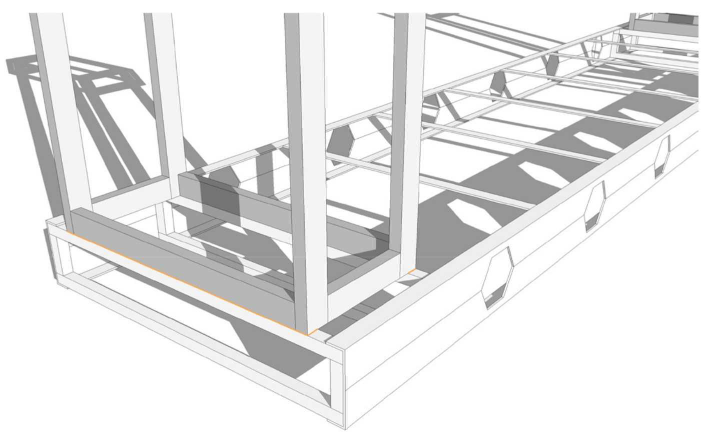

Figure 2. Castellated floor structure.

Foundation systems: Foundations of typical portable classrooms consist largely of tie-downs for wind loading. In our scenarios, several foundation systems were proposed, including slab-on-grade, site-cast piers and pre-fabricated, quickly-installed systems such as Diamond Pier.[18] Prefab foundation systems are an emerging technology that provide opportunities for further speculation. The Diamond Pier is a proprietary system consisting of a precast concrete head with steel bearing pins. The pins are driven into the ground through the concrete head and create a solid foundation without needing to pour concrete. It is a bearing system, and performs in the soil much like any flat bottom footing. In plan, this head has a base square footage area that can be applied to a given soil's bearing capacity just like a conventional concrete footing. Pier spacing, size and pin length depend on the soils, the weight of the structure itself and the live loads the structure is meant to carry. The pier may also be set completely below-grade or recessed from the outer edge of framing members in order to allow perimeter skirting to be constructed. According to the manufacturer, the system, once fixed in the ground, has the added benefit of uplift and lateral resistance. Though Diamond Pier is an existing product, the relevance to this project is that it is readily available, has wide applicability on different kinds of sites, can be quickly installed and is removable.

Transportation: Regulations for transport are set on a state-by-state basis. The Federal Motor Carrier Safety Administration has established rules that mandate "no State shall impose a width limitation of less than 8.5 feet and no State shall impose a length limitation of less than 48 feet." [19] In the prototype referenced above, the classroom bays are 8 foot by 40 foot. These bays are able to meet the minimum width and length requirements that can be imposed by any state and therefore should work anywhere in the US. Box-type modules that don't have their own wheel systems need to have additional equipment, like cranes, for placement on site, but wouldn't require "wide load" accommodations when in transit, so there may be a trade-off in that sense.

Other bay designs were considered to make shipping more efficient. The idea of a flat-pack system was deliberated. This involved making the floors, walls, and roof separate panels that could be stacked flat for transportation. The advantages to this were that the panels were easy to ship, store, and replace when needed. Several attachment connections, column styles, and floor and roofing structures were examined, but all of them seemed to be a better idea in theory than in practice. Flat-pack designs do not have a lot of precedent so not many pre-existing connections and details were available for study. As mentioned above, setup time was deemed to be critical, so that inclement weather problems could be minimized.

Daylighting: Ecotect was used to model and analyze design proposals from a daylighting point of view. To give perspective to the classroom lighting analysis, daylight levels for night-lit parking lot would be around 30 lux, a computer lab around 300 lux, a hotel room around 450 lux, a classroom around 600 lux, a grocery store around 750 lux, and outdoors around 1200 lux and greater.

In Ecotect, lux measurements are calculated in the worst case scenario under an overcast sky design sky. Designing a lighting system based on the brightest day of the year is inaccurate as it may only occur once or twice during the year and people are very likely to close the blinds anyway to protect themselves from heat and glare. Analyzing from worst-case scenario produces the best results for understanding the lighting in a room and should be understood from that frame of reference. Also, materials, their reflectivity, and local conditions were considered to make an accurate representation. Figure 3 shows an analysis of a proposed classroom prototype, with linear skylights, compared to an analysis done of an existing classroom with small punched openings. The skylit version is clearly superior.

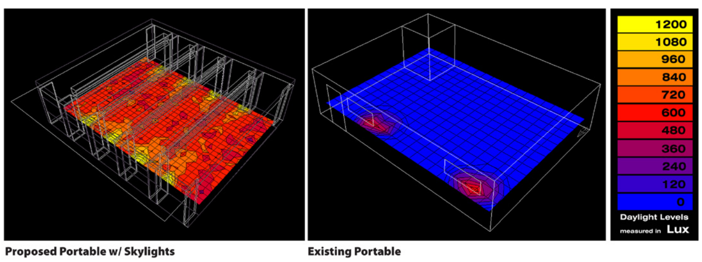

Figure 3. Daylight levels. New prototype on left and existing portable unit on right. Blue represents low light levels, yellow represents high light levels.s

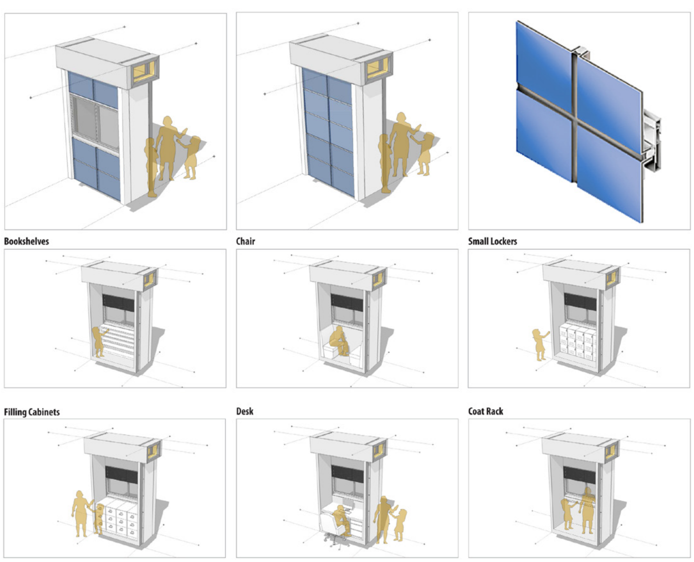

Figure 4. Subassembly options at the exterior wall.

Sub-assemblies: Investigations regarding the utility of a sub-assemblies approach to construction concluded that there could be some merit to this approach. For instance, one project demonstrated that a wall sub-assembly could be developed that would have different finishing options based on its ultimate use. It might include windows, or not; it might have alternate interior and exterior finishes; it might be outfitted with interior components according to curricular needs (i.e., cubbies for kindergartners, science labs for high-schoolers, etc.). (See figures 4 & 5).

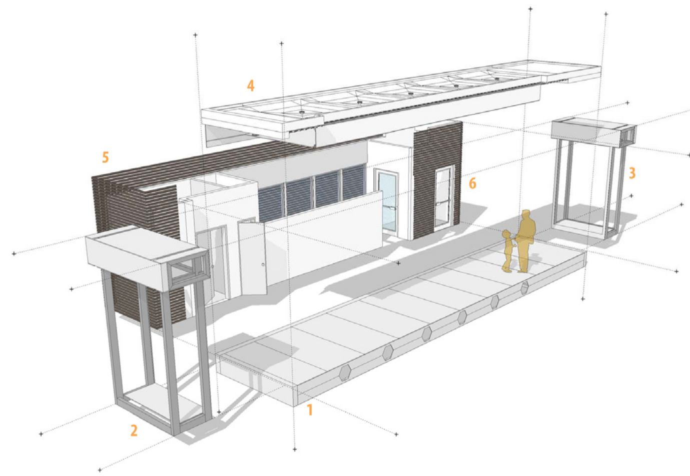

Figure 5. Subassemblies.

CONCLUSIONS

This studio was a good experiment with excellent outcomes. Students embraced the "R&D" spirit of the studio and were able to advance more artistic design considerations at the same time. The time gap between now and then—and the recent economic crisis—has renewed our our interest in the subject from both a design and research point of view. Another studio, building on the knowledge produced here, and in the years since, by others, is in order. External funding from the manufacturing community is also plausible.

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ENDNOTES

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