NEW ASSEMBLES FOR LEARNING:
Flexible Construction Systems Aimed at
New Concepts of Learning Environments

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NEW ASSEMBLIES FOR LEARNING

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PREFACE

This thesis contains two distinct but interrelated works: a comprehensive research-based thesis and a design project, which seeks to translate research into physical design elements. This dual effort is an attempt to seek greater understanding of research-based practice as it is currently developing in architecture.

It is important to note that although the research and written portion of this thesis has been an individual effort, the design project has been collaborative. Georgia Tech Master of Architecture students Emily Finau, Megan Fagge, and I have worked equally to manifest individual research threads in a single design project. Again, a better understanding of evolving practice, here with regards to collaboration, group design and problem solving, is a primary goal of the entire work.

At the point of publication, the design project exists in a schematic state meant to begin to evidence key concepts from individual research as they inform and drive design. The design elements and ideas have been a collaborative effort, with drawings and diagrams completed by various team members at different stages in time. Although the ideas and drawings have been produced collaboratively, each of us has narrated these ideas in our writings through the lens of our specific individual research topics. Thus readers are encouraged to refer to the published thesis work of Emily Finau and Megan Fagge as well to further explore the design drivers of the collaborative design project.

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SUMMARY

The design and construction of American public high schools are forcibly and overwhelmingly influenced by ultra-cost effective techniques demanding simplicity in construction and durability of material. The inflexibility and banality of the architecture this paradigm typically delivers begs for exploration of the feasibility of innovative construction technologies. Such technologies influence both form and technique and include prefabrication of modular elements, utilization of computer-aided-design (CAD) and computer-aided-manufacturing (CAM) techniques to mill customized parts, and pliable materials (i.e., plastics) crafted to achieve dynamic forms. Through these new techniques, more engaging, flexible learning environments could be realized that significantly increase the performance of the architecture, both formally and ecologically, as well as ennobling students to higher levels of academic pride and performance.

Expanding on the potential of the Atlanta Public School's High School Transformation Initiative, which in 2006 began reopening schools that embraced a new model of campuses comprised of clusters of themed schools or academies, this thesis examines the possible physical manifestation of this new educational paradigm. By proposing a redesign of Daniel M. Therrell High School in Southwest Atlanta, at present the lowest performing high school in the district, to test new spatial possibilities offered by new fabrication and construction technologies to meet the demands of an evolving school typology and to propose further ideas for expanding and redefining the

contemporary American high school's learning environments.

Taking as a point of departure the existing program for Therrell High School, which includes three 400-student academies (School of Law, Government & Public Policy, School of Health Sciences & Research, School for Technology, Engineering, Math & Science), the thesis adopts a design-oriented methodology to identify and analyze the feasibility of computer-aided-manufacturing and innovation through construction techniques to meet the demands of a high school facility. The proposed system will be durable and able to support simple maintenance and replacement (recycling, deconstruction, reconstruction and reconfiguration) throughout its life. It will also feature scalar flexibility to meet shifting populations and flexible needs of the school staff.

Multiple techniques of mechanized assembly have existed for generations, although new equipment and systems reveal the potential to exploit complex geometries and a level of variability previously attempted only by hand-made craftsmanship. Widely explored processes include CNC mills capable of reductively shaping material or cutting sections of material along precise tool paths. Advanced CNC mills boast upwards of 7 axes of translation and a cadre of tools, offering such intricate tolerances as to come close to achieving some of the dynamic forms which can now be generated by even pedestrian 3D design software. Furthermore, pre-fabricated assembly techniques have held promise for decades, as they provide controlled quality and the ability to utilize machinery too cumbersome to haul to unique construction sites. How, where in the design and construction process, and to what ends a synthesis of these techniques might be realistically proposed to continue the evolution of the design of public high schools is the core of the investigation of this thesis.

CHAPTER 1: INTRODUCTION

Architectural history has issued countless editions of the notion of "the modular." From base constituent elements such as the easily made, easily manipulated module of the brick, small, uniform elements compiled to achieve monumentally scaled constructs in many ways forms the basis of this line of thought. In further evolution, the concept of the modular results in a more complex assembly of parts, as realized, for instance, in the example of a pre-fabricated roof truss whose elements can be created and joined off-site from the actual project and whose reproducibility and consistency of quality make it a desirable building element. Specific theoretical, cultural and intellectual movements in architecture have also contributed their own notions of the building module, such as the Modernist's machine produced machine for living. Even the mid-twentieth century's drive for utopian pre-fabricated housing for the masses took a standardized, built off-site module as its manifestation of the powerful idea of the repeatable, low cost, well designed module. Yet for all the areas in which architecture has attempted to utilize the module, there is one overlooked area begging for not only modularity, but also from a better modular concept than has yet been realized.

Every year in America public schools employ modular classrooms. "Portables", i.e., re-locatable classrooms or trailers, these elements have become a ubiquitous in the American schoolyard. Originally adopted as a temporary tactic to house overflowing, rapidly growing school populations, these transitory structures have since become the only option for the expansion of various classroom typologies as required by recent legislation.

The Bush administration's No Child Left Behind policy, for example, demanded schools take specific action to expand special learning programs for under performing students, but created no additional financing options thus demanding additional classrooms without providing financial means for expansion of existing facilities. Moreover the policy established new flexibility for parents who now have the option of moving their child out of a specific public school; should it fail to meet new Adequate Yearly Progress benchmarks. In such a situation the school district is responsible for diverting funds to follow these students and continuing to meet transportation obligations for them as well, thus siphoning funds away from poorly performing schools and further exacerbating the problems of classroom space and facilities needs.

Expansion of special needs education has also required schools to add space or displace traditional classrooms to make space for environments for students with special physical, mental and learning disabilities. Since the early 1980's this movement has witnessed significant continued growth in demand for specialized environments for unique students unable to learn effectively in traditional classroom settings. Requirements include more smaller rooms for instructors to be able to work with small groups in environments often tailored for specific disabilities, such as visual and auditory impairments, as well as wheelchair accessibility and settings attuned to other physical considerations.

All of these flexibility and expansion demands have forced cash strapped school districts to resort to the lowest common denominator of construction – that of the “temporary” classroom. What manufacturers of such buildings lack in quality of design and environment, they attractively offset by offering low cost and speed of installation. The average cost per square foot of a primary school facility typically ranges from $150-$200, whereas many manufacturers of temporary classrooms offer structures at or below $100 per square foot. Many also offer leasing options to further reduce acquisition costs to schools and address the impermanence of the materials and design of such facilities. Due to the mobile nature of these structures, installation is proclaimed to be as brief as a matter of days, as opposed to the average school construction project whose timeline typically spans 18 months or more.

Despite these apparent benefits a closer look reveals that initial installation of portable classrooms often demands extensive, costly additional construction of circulation and weather protection systems in the way of decks, stairs, ramps and canopies, often built of lumber that is wasted if/when the portable classrooms are removed. Furthermore, electric and plumbing systems must also be connected to these units, sometimes constituting a major undertaking of establishing expensive systems and networks only to be sacrificed once the facilities are relocated or removed.

Comparing such buildings to a primary facility typical of an American public school yields a most imbalanced duality. Primary facilities, as specified by most school districts, are required to meet the strictest fire code ratings and demand extreme durability in materiality. Portable classrooms offer neither of these. Not only are they more difficult to maintain, they also require much more maintenance due to the inherent impermanent nature of their construction. Yet it must be stated the problem does not solely reside in the impermanent nature of such portable classrooms per se, but rather in the extreme departure they embody when compared to what is typically considered a well appointed, well built school building.

The situation that is presented here is somewhat paradoxical – schools often need the flexibility modular building promises, yet the qualities otherwise demanded by schools are all but absent in current modular buildings available to meet this demand. Thus new concepts of modular architectural design and construction are required to better meet, and elevate, the demands of the built environment of the American public school. Such a new concept will require the expansion or contraction of current definitions of modular. It will require innovative building technologies capable of aiding in this redefinition. And, if successful, this new concept of the modular will lead to the realization of compelling new learning spaces capable of evolving with models of public education and the typical American student's school experience. First though, we must begin by understanding the module.

Many books on the subject will rewind the history of the modular back to dwellings like yurts or the stone and brick work of nomadic tribes around the globe. While these structures do evidence a particular notion of the modular, this thesis will pick up the trend much further down the road. Here it will be assumed that the concept of modular construction presupposes a building, or at least major parts of a building, produced off-site from its final delivery point, to be delivered upon completion, presumably with a high level of mechanized support in a specialized manufacturing facility. Such warehouses produce multiple copies of the same assembly and typically offer more consistent quality of construction than most on-site construction contingencies allow. In addition the factor of time is often displaced in such modular scenarios, as weather delays are largely removed from the equation, as are schedule limitations, such as a school waiting for students to vacate the site before construction can commence.

From an architectural standpoint, once a building design reaches this level of standardization, it would seem all hope for a unique built environment that responds in any meaningful way to person or site is lost. Thus architects have all but given up on the quixotic quest to make the modular, pre-fabricated building any semblance of “real architecture” save for a few limited explorations. Despite this surrender by mainstream architectural practice, this form of modular structures continue to meet the demands of residences and schools, and in fact each year more and more components that make up more and more buildings are produced under similar conditions of industrialized fabrication.

Oddly enough, this phenomenon, typically driven by economic efficiencies and disdained by so many architects, also has the potential to capitalize on a significant innovation in avant-garde and fringe architecture of the moment. Fast on the tail of digital design, and all the increasingly dynamic forms it promises, is the rapidly growing field known largely as "digital fabrication". So popular is this architectural niche that nearly all of the leading architecture schools in the country have devoted millions of dollars in funding to establish highly competitive research labs appointed with all the mechanical and digital manufacturing equipment they can muster. Rarely, if ever, in the history of formalized architectural education have so many dollars and resources been focused on such a phenomenon outside the traditional realm of architectural learning and practice.

Sci Arc, Ball State, University of Michigan, Georgia Tech, Harvard's GSD, Columbia, MIT and many others have established stand-alone digital fabrication labs in the last decade, most of which require cost investments exponentially higher than those of any previous lab typically found within an architecture school. Laser and Plasma cutters, CNC mills functioning on 5 or more axes, 3D printers of various materials and technologies, even advanced robotics have made their way into the current lexicon of architectural consideration. Whereas previous generations of architects relied on hand craft to model ideas to be built by another party, this new movement beckons a significant and fundamental shift in architectural thought with regards to the maker of architecture and the field's core technology and technique.

The fusion of digital conception with automated construction is now primed for testing and exploration. While this exploration has been occurring for several years now, it is clear that most attention has been paid to the realization of digitally driven constructs at very small scales – rapid prototypes and scaled down models. Far too little attention has been paid to how these techniques might be scaled up to full-sized building components. This thesis explores a linked conception of design and fabrication within the context of design for a public high school in the Atlanta Public School System. That the school system relies on the concept of modular, pre-fabricated structures and that the leading trends in this field promise wholly new possibilities of form, space and structure would seem to create conditions perfect for a marriage of these two ideas, resulting not only in more flexible school faculties but also in new spaces for more engaging learning to take place. Thus a new concept of modular construction is due.

CHAPTER 2: THE AMERICAN PUBLIC HIGH SCHOOL

2.1 ICONIC AND IMPORTANT

The notion of a nation expressing its ideals and beliefs through the architecture it creates is a common phenomenon throughout civilization. From European vernacular to Neoclassical, Federalist, Georgian, Neogothic, Palladian and a catalogue of dozens of others, American society has sought constantly to establish architecture that communicates its values, socially, politically, and culturally. Some have argued that, even more than text and sacred flags, architecture is the ultimate physical embodiment of a culture (Goldberger, 2009).

Surveying the breadth of government and publically funded architecture confirms this effort, with courthouses, government chambers, capitol buildings and civic monuments acquiring significant stature and meaning in the American landscape. Such works are even lauded as weathering time well, with age offering a building a yet stronger pedigree. In this way architecture reveals itself as a complicated icon, one that lends itself to the occupation, experience and interpretation of many users over time, all capable of inscribing their own reflections onto the icon (Goldberger, 2009).

The common American schoolhouse trailed most other monumental building in the country in that its role was early history of the somewhat removed from certain key functions of cultural representation and governance. Yet it was not long after the formation of the union that education did become a national priority and houses of learning became staple ingredients in a blossoming America.

Later American history witnessed the expansion and evolution of education into the ballooning, robust system now established through national, state and local authorities. The American public school system functions as one of the nation's leading employers and most costly programs, and bears the burden of educating U.S. and non U.S. citizens by the millions. No other federal initiative, including health care, military, governmental services, or law enforcement comes close to the size and scope required of the U.S. Department of Education.

The high school component of this system, typically encompassing grades 9 through 12, represents a critical final stage in the state-mandated educational process. Whereas elementary school (kindergarten through grade 5) addresses early childhood development and fundamental skill acquisition and middle school (typically grades 6 through 8) addresses adolescent development and advancing academic skills, high school serves as the gateway to adulthood, the workforce, and ideally college. As such it is poised to significantly affect the trajectory of the majority of the U.S. population, their depth of knowledge, and working habits.

As students mature through the grade levels and grow into productive members of society, the architecture of each successive school environment is also seen to develop. Early childhood education receives, by far, the most research attention, as scholars have now proven how early a child’s beliefs and core characteristics are formed. Truly the first few years of organized education set the trajectory for a life of learning, or not. Elementary education provides somewhat less materials than early childhood development research, as within its age brackets significant cognitive abilities and disorders begin to separate the performance levels of classmates. As more research emerges related to middle school aged children, the focus shifts to the phenomenon of puberty and emotional and social development in a large, social setting.

Once we reach high school age learning, research shifts to demographics, “professional” skill aptitudes and issues pertaining to college acceptance and performance. In many ways, it seems the high school stage of learning is assumed to be a linkage point between teenage life and the adult world, or in certain income level demographic sectors, to college life and ensuing professions beyond. At this stage, test scores, graduation rates and college admissions are the benchmarks for evaluating student learning. However these benchmarks often leave one wishing for more robust explorations of whether and how teenagers actively engage in learning processes. Culture and technology seem to be producing a message that all competent adults need to be capable life-long learners, and that completion of high school alone will not likely suffice to provide an adult with a profitable career for an entire life.

These evolving sociological points of view move a good deal faster than school design and construction. Thus schools whose facilities inhibit them from even attempting to modernize and evolve show their age not in a positive, trust-earning light, but are attributes of outdated relics serving as impediments to better arenas for effective learning.

Here we see revealed one of the many issues pertaining to the materiality, durability and longevity of a school building. Certainly by most standards, especially accepted building codes, school buildings are to be fire rated and built to a certain level so as to insure not just safe day to day operation, but also secondary functions as community shelters, with ample crime prevention measures and hearty weatherproofing. School systems spending significant amounts on construction projects also acknowledge they do not wish to repeat the process within short time frames, nor could they typically afford to do so; they therefore specify buildings that last decades.

These issues also often come into play with regards to the design of proposed facilities as well. For as the school is often a significant community icon representing many individual points of view, the design process is often openly accessible to stake holders such that the resultant architecture must mediate different perspectives within the communities, as opposed to providing a poignant, explicit message about educational or cultural absolutes. Because public schools exist in a highly charged political environment, decision makers often choose the path of least resistance when making choices as highly visible as a new school (Bogle, 2010).

2.2 HOLISTIC VIEW OF LEARNING ENVIRONMENTS

Above and beyond its role as a key source in the dissemination of academic knowledge, the typical American high school also serves to mold and establish critical social concepts. Thus the spaces for learning are balanced by non-programmed space and spaces for auxiliary activities, such as outdoor gathering places, circulatory avenues and interstitial space in and around the primary facility. Architecturally, spaces of this nature serve to allow the building as a whole to function. These spaces are often utilitarian in residential and commercial projects, though there are, at times, opportunities to use these conditions as focal points, intentionally designed elements and aspects of the architecture that enhance the overall environment and enrich the experience of the place. This is the lens through which such areas in schools should be designed, allowing greater expression, uniqueness of place, and valuable social learning to occur.

If social learning space may occur in any and all areas outside the formal classroom, there is a rich opportunity for exploration of programmed and un-programmed spatial designs. During the schematic design phase, where program requirements were overlaid on proposed plans, there was only a coarse address to un-programmed space: spaces were either dedicated for a specific usage or they were left over, residual space. Such spaces are often perceived as “wasted” and “optimized” out of final design proposals. However, one could easily imagine a new line of programmatic inquiry in which these spaces are brought to meet a range of unpredictable and loosely defined social interactions, facilitating positive growth and development of high school students in informal settings.

Loris Malaguzzi, the Italian educator in the 1940's who founded the forward-thinking Reggio Emilia technique of teaching, claimed children develop first through interaction with parents and peers and ultimately with the environment around them. If high school is the stage of development in which children are the furthest removed from their parents, then peer and environmental interaction become critical drivers in growth and development.

Philosopher, educator, and influential figure in the development of the contemporary American school environment, John Dewey also often expressed the need for effective learning environments to begin to better reflect community life and the many diverse cultural experiences of larger society (Dudek, 2000). They would then provide environments that are far more than mere collections of classroom boxes connected by corridors. To begin to emulate the complex cultural and physical fabric high school students are destined to encounter in subsequent stages of life, the currently accepted notion of institutionalized learning spaces is in need of expansion and redefinition. The classroom makes up only a portion of the critical constituent elements of a high school, and to design a facility to meet its multiple requirements, a more holistic approach to the creation of nuanced spatial configurations.

2.3 THE THEORY OF MULTIPLE INTELLIGENCES

The fact that not all children learn in the same way is a concept strongly promoted by Harvard psychologist Howard Gardner. His theory of multiple intelligences has earned widespread acceptance by educators and has served as a model for crafting learning environments more attuned to each of the various intelligences. Another influential educational figure, Maria Montessori further characterized Gardener's theory by saying:

> Howard Gardner argues that the concept of intelligence as traditionally defined in psychometrics (IQ tests) does not sufficiently describe the wide variety of cognitive abilities humans display. For example, the theory states that a child who learns to multiply easily is not necessarily more intelligent than a child who has stronger skills in another kind of intelligence. The child who takes more time to master simple multiplication 1) may best learn to multiply through a different approach, 2) may excel in a field outside of mathematics, or 3) may even be looking at and understand the multiplication process at a fundamentally deeper level. Such a fundamentally deeper understanding can result in what looks like slowness and can hide a mathematical intelligence potentially higher than that of a child who quickly memorizes the multiplication

table despite a less detailed understanding of the process of multiplication.

These notions of varying degrees of learning aptitude and differing kinds of cognitive usage of learned information may carry significant insight in the designing of schools to provide additional channels for multiple access points of information as well as multiple avenues through which students can utilize the information. Were we to take seriously the fact that there are differences between children, schools would be far more individualized than ever before (OWP/P Architects et all, 2010). More than adding variety for design or aesthetic intent alone, this line of thought significantly connects the task of the architect to that of the educator. If prosaic, mundane architecture impedes the effectiveness of individual instruction and learning, then perhaps a better, more attuned architecture can enhance it. The following chart begins to describe some of these potential implications for architecture.

TABLE 1: Architectural Implications of Multiple Intelligences. (Adapted from data from Taylor 2009.)

8 INTELLIGENCES IDENTIFIED BY GARDNER	CHARACTERIZED BY	ARCHITECTURAL IMPLICATIONS
VERBAL/LINGUISTIC	Thinks in words, is sensitive to language	Signage in multiple languages, a theater in every school, multimedia in communication centers
LOGICAL/ MATHEMATICAL	Approaches problems logically, discerns numerical patterns	Patterns built into the floor, walls and ceilings, structural features revealed, geometric form, spaces for technology
VISUAL/SPATIAL	Perceives visual world accurately, thinks three-dimensionally	Allow architecture to teach through a variety of spaces, sculpture and wall graphics;; galleries, museums, and views through windows inside and outside
BODY/KINESTHETIC	Uses one's body to sense the environment, communicate and solve problems, has manipulative skills	Fitness trails, outdoor areas, parks, gymnasiums, dance studios, tools and environments to manipulate
MUSICAL/RHYTHMIC	Is sensitive to nonverbal sounds in the environment, has ability to produce and appreciate music	Acoustics, music practice and performance rooms and spaces, public and private
INTERPERSONAL	Is sensitive to the moods and feelings of others	Deployable, movable furniture, places for team work, large, horizontal work surfaces instead of individualized task desks, gathering spaces indoor and outdoor, conference and meeting rooms
INTRAPERSONAL	Is sensitive to one's own feelings, knows self	Outdoor study and seating, alcoves, private areas, quiet spaces and comfortable rooms
NATURALISTIC	Is sensitive to natural world and natural cycles	Habitats, recycling venues, nature trails, green architecture

The wisdom of John Dewey's ordered diversity of the real world joins Gardener's communication of multiple intelligences to propose a learning environment full of variety and options that are absent in any meaningful way from most contemporary learning environments. Mere economy of space that groups large numbers of unlike learners into homogeneous spaces wastes valuable opportunities to affect students and allow their individual learning propensities to elevate their educational experience. Nevertheless it is this economy that typically drives the design of schools.

2.4 CHARACTERIZING VARIETY AND FLEXIBILITY

As Gardener's theories began to gain traction, school architecture of the 1970's and 1980's began to manifest a device for flexibility of environments through open plan designs, no doubt grown from earlier Modernist theories of the free plan dwellings offering supposedly limitless possibilities thanks to unencumbered interiors which allowed users to configure space to their exact needs. Unfortunately, such large, nondescript volumes provided little or no scaffolding for established educational pedagogies and therefore were subjected to loud, chaotic use. Perhaps the most memorable effects of these attempts to evolve traditional learning space have instead fostered a fear of innovation in classroom design, despite the mounting data supporting the need to rethink the traditional classroom box. However as the highly influential architect of many schools and learning spaces, Herman Hertzberger commented:

> ...a thing exclusively made for one purpose
> suppresses the individual because it tells him exactly how to

> use it. If the object provokes a person to determine in what way he wants to use it, it will strengthen his self identity. Merely the act of discovery elicits greater awareness. Therefore a form must be interpretable-in the sense that it must be conditioned to play a changing role (Hertzberger, 1969).

Here we witness a different notion of flexible space, not defined as an open zone characterized by architecture that does nothing, but by an architecture that elicits behavior, discovery, and interaction of users. This is exactly the kind of architecture a promising school would offer to students of varying intelligences seeking out places where they can most effectively learn. In addition to this student discovery, there can also be exceptionally valuable opportunities for school administrators and educators to utilize spaces in different ways as well. Just as an inquisitive student may gravitate to a particular spot for an environment more conducive to the task at hand, an educator could also be freed to move about the school's various places to conduct lessons, lectures and forums that better match a specific place - rather than assuming that a classroom filled with desks suits the needs of many different lessons and scales of activity. Were a school designed in such a flexible manner, administrators could utilize the multitude of places provided by the architecture for gatherings, meetings, and diverse meaningful encounters with students.

2.5 SCALABILITY OF FACILITIES

A further critical issue pertaining to the design and construction of public high schools is that of scalability. When student populations fluctuate unpredictably and sometimes by hundreds of students over the course of a facility's lifespan, it is difficult for the facility to adequately respond. Thus ad hoc, temporary classrooms are often employed and additions, when conceived, often result in disjointed, awkward building appendages. In Fulton County alone, the student population has grown by over 12,000 new students since 2005 and schools have had to add hundreds of classrooms to house them. Classroom crowding and increased class size as a result of inability to adjust have in turn led many parents to move their children to other schools.

Here we see another argument for flexibility as it pertains to the design of the high school. In design "flexibility" is typically taken to entail a physical form that may be translated, folded, turned, or otherwise acted upon by an outside user or force to result in a different formation than the object's previous state. From a facility standpoint, flexibility may also describe a structure's ability to be partially deconstructed so that it may be modified, added on to or otherwise adjusted based on some pressing contingent need.

Physical flexibility may also pertain to certain scenarios in which it is beneficial to alter the character of a space rather than its overall geometry or physical structure. This might include motions such as the ability to change lighting levels in a classroom, open or close elements to induce or prevent the flow of air, or other means of modification that have an effect on the texture, material and perceptual reading of a space. Flexibly in this regards touches not just on the scalar issue faced by many high schools, but also on that of environmental flexibility.

2.6 FLEXIBILITY IN AND AROUND CLASSROOMS

Besides acknowledging different learning intelligences, two other key factors are involved in the issue of flexibility within the classroom itself. The first, most rapidly moving issue is that of technology use. Since the late 1980's and early 1990's computer use has fundamentally transformed the nature of commerce, business culture, and the ways people interact with data, information and learning. Clearly this information revolution was destined to affect the classroom in many ways. From dedicated computer labs to laptops for individual students, technology has quickly come to reformulate what it means for the average American student to conduct class work and learning on a day-to-day basis. Across nearly all demographic and economic bounds, computers have been prioritized by school districts, and installed in classrooms, and many instructional and homework interactions have migrated to digital formats providing a significant leap forward in customization and reception of learned material.

While it is not the aim of this thesis to focus on design for technology use in the classroom specifically, it is certain that no school facility could be conceived today without dedicated attention to the issue. Furthermore if the last 10-20 years of this trend has revealed anything, it is that technology use tomorrow may look quite different from what we imagine today. Computer labs were originally dedicated classrooms with large, unmovable desktop machines, where now tablet PCs and laptops are clearly preferred not only for their portability within a school, but also for their ease of maintenance and wireless network connectivity. Larger technology components have evolved alongside individual user machines as SmartBoards have become requisite in nearly all public high schools, and LCD projectors and various audio and visual equipment supplementing an educator's tool chest of effective means of communicating learning. All of these have significant implications for what the classroom looks like, how it is configured, and how it might be designed for as yet unimagined uses well within the lifespan of a facility.

The greater issue with digital technology is that it is not merely another subject to be covered in school, but both an explicit and implicit way of learning. It has infused its techniques and behaviors into nearly all other subjects and has successfully migrated far beyond the classroom. Students can be, and are, significant contributors to the evolution of how we use technology (Nair et all, 2009). Learning from the very ways they use digital methods to learn and communicate will only serve to better our understanding of such technologies' potential.

Designing for technology should thus be distanced from previous notions of dedicated computer labs, which presented technology as another item on the schedule to be mastered. Computer labs are rarely an acceptable arrangement for personal computer distribution (Nair et all, 2009) nor do they communicate any effort to motivate students to take ownership of their personal interaction with technology. Contemporary lesson planning and computer use displays a much richer set of spatial and physical demands. Computers are needed on desktops, but any single student may require a variety of desktops to work on before, during, and after normal class time. Desks in classrooms rarely facilitate this use, but need to, as does table space in media centers and other potential work spots in and around the school. Desks are also not the only viable workspaces in which students may interact with technology; seated on floors, on grass or outdoor seating, or even pausing momentarily in corridors students engage digital learning, group work, and communication even now.

In addition to new technologies, the other critical issue demanding a significantly heightened level of flexibility is that of the peer-to-peer collaboration many assignments and project-based learning scenarios encourage or require. This collaboration may very well run tandem with technology use, since groups are often assigned to research, write, and create presentation summaries all utilizing computers and digital methods. Thus much of the discussion of technology use in various spaces is relevant in thinking about what kinds of spaces inside and outside the typical classroom might be able to support group interaction at multiple scales. From partner work to small groups of three or four, and up to groups comprising multiple classes' worth of students, the ability to learn, function, and communicate across a group of fellow students is now integral in the high school curriculum.

As high school students are prepare to be, and indeed already serve as, functioning community members, their ability to coordinate and work in groups becomes more important at this stage of learning than most others. Teenagers posses a highly developed sense of social order and social hierarchy, and require much practice in leveraging these constructs for good and bad outcomes. In this context, both formal, in-class interactions as well as informal out-of-class interactions become valuable, relevant, and necessary components of a high school education. Therefore it is vitally important the architecture fosters many modes of group interaction and places for it to take place. As students and cultures evolve to embrace the notion of the global citizen and as many professions embrace tasks and jobs that rely on multiple parties' productive interaction, this evolution must manifest itself in the design of the school place.

Much contemporary school design has reached a point where rooms and spaces are intended to meet precise functional needs, and the function of the school is framed in neat periods of time, dedicated to specific subject areas (Dudek, 2000). Yet, as we've seen these functional needs shift over time into something much more flexible. Prakash Niar of the highly regarded DesignShare organization directing schools towards best practices and highly researched case studies puts this thinking into a more immediate frame of reference:

> It is clear that most schools' architecture tends to look at spaces in a linear way that means we first decide what a space would be used for and then we design the space for that activity. This kind of thinking ignores the complexity and research about the human brain and human experience, resulting in the design of static spaces that inhibit learning (Nair et all, 2009).

Clearly coming conceptions of school design must operate in full awareness of more rapidly developing educational paradigms and theories which entail fundamental changes in the way the classroom and the learning environment are conceived.

2.7 SMALL LEARNING COMMUNITIES

As the American high school grew to newer, larger than ever proportions, straining at the seams with exponentially larger populations of baby boomer children, school districts have struggled with how to finance large and expensive new high school facilities. With larger spatial requirements, more robust vocational labs and shops, and requiring the most advanced technologies, the typical high school cost per square foot is a great deal larger than that of a smaller middle school or an elementary school. The only feasible way to deal with such a cost burden seemed to be the consolidation and centralization of the high schools. By allowing multiple elementary schools to feed into a few middle schools that all powered a single, mammoth high school, numbers for a common grade 9-12 facility are typically greater than 1,000 students under one roof.

The complex task and negative implications of managing such a huge quantity of nearly adult students have clearly revealed themselves. Safety, security, and crowd control now are acknowledged as primary drivers of the facilities, trumping learning. High levels of cognitive achievement are impossible to meet in large classes and crowded schools (Achilles et. all, 1998) and when student performance levels drop to the widely unacceptable levels they are currently, coordinating efforts to turn them around is significantly more difficult, if not impossible, given thousands of students and educators in a single academy.

The Bill and Melinda Gates Foundation sponsored research that has significantly altered thinking about school size, proposing “Small Learning Communities” (SLCs). These academies have no more than 400 students each and are typically founded on a strong central theme in order to unite the student body under a single pre-professional concept, such as art and music or law and government. According to Dr. Sharif Shakrani, the Co-director of the Education Policy Center, "Recent studies suggest students in small public high schools perform better academically, have higher attendance rates, feel safer, experience fewer behavior problems and participate more frequently in extracurricular activities," (Shakarani, 2008). By the end of their first year of high school, 58.5 percent of SLC enrollees are on track to graduate in four years compared with 48.5 percent of their non-SLC counterparts. This positive effect is sustained over the next two years. By the fourth year of high school, SLCs increase overall graduation rates by 6.8 percentage points, which is roughly one-third the size of the gap in graduation rates between white students and students of color in New York City (Bloom et all, 2010).

The implications of designing a giant high school versus a campus of small learning communities are only now beginning to be explored. Related to the design task is a large set of issues such as possible of modulation of academy sizes, ability to change or modify an academy's theme over time, and how well a college campus-like site design transfers to a high school site of academies and shared program elements, such as cafeterias, gymnasiums and media centers.

Furthermore, evaluation is still being conducted on the true effectiveness of a school of small learning communities when compared to a large school facility. As recently as 2011, Bill Gates, one of the initial sponsors of the key research driving the SLC movement, has admitted only marginal improvements in graduation rates and standardized test scores. Yet SLCs positive effects are seen for a broad range of students, including male students of color, whose educational prospects have been difficult to improve (Bloom et all, 2010). Thus they offer hope for a better direction for high school design, at least with regards to limiting critical mass.

CHAPTER 3: PORTABLE / MODULAR CLASSROOMS

3.1 "PORTABLES"

One of the most common ways school systems attempt to address growth and provide flexibility for changing spatial needs is through the use of portable classrooms. Essentially constructed of the same materials and to the same standards as mass-produced mobile homes, these stand-alone shelters are often employed on a temporary basis initially, but have been known to remain in place long after their intended life spans have been exceeded. The use of such structures is prolific in the contemporary American school system at most levels. In fact, the education market accounts for nearly one quarter of all modular construction (Modular Building Institute, 2008) and it is not at all uncommon to see such structures being employed in a number of ways throughout school districts.

The primary driver behind the use of such buildings is clearly cost. The average cost per square foot of a primary school facility typically ranges from $150 to $200, whereas many manufacturers of temporary classrooms offer costs at or below $100 per square foot. Many also offer leasing options in five to ten year or greater lengths to further reduce acquisition cost to schools and address the impermanence of the materials and design of such facilities. Finally, due to the mobile nature of the structures, installation is boasted to be as brief as a matter of days, whereas the average school construction project whose timeline typically spans 18 months or more.

Such transient structures help schools grow incrementally over a period of years, allowing them the flexibility to add one or two classrooms at a time until enough growth is exhibited to warrant the construction of a new primary facility. Such flexibility in growth can be of great value to schools, as enrollment projections may fluctuate and initiating a new construction proposal is a costly effort.

As the speed of growth may also fluctuate, modular units also benefit from a relatively swift installation period requiring little or no significant site preparation. This not only reduces cost further, but allows schools the ability to adjust the size of its facility at many points throughout the school year. Whether it's the day before school is scheduled to start, a weekend mid year, or a school break, a school can arrange delivery and installation of most modular units within a matter of days, as many of the suppliers have built stock waiting.

For all their speed, ease of installation and low cost, however, this system also presents unique additional challenges schools must face. For instance, as a detached building, modular units force students outside throughout the day with no protection from the exposure to weather or security threats. Circulation systems of walkways or paths are similarly unaddressed. Constructing a connecting sidewalk and covering it with a simple roof structure can easily add significant cost to a "low cost" portable.

In addition to access, modules must be supplied with power and water and offer some climate control system. These infrastructure factors are rarely planned for in appropriate ways and can also lead to significant additional costs. When they are addressed, for instance with most air-conditioning units which are often module-specific wall-mounted units, control, service, and maintenance becomes an additional burden for school personnel. Compared to the centralized systems in main school buildings, a dispersed set of stand-alone units presents an exponential increase in equipment to monitor and maintain.

Given the materials and assemblies of which these units are commonly built, maintaining their enclosure and structure is also a formidable task. Portables are not built to be serviced in the same way more permanent structures are; therefore repairs can be difficult and parts and materials not easily available or simple to work with. For these reasons, long-term maintenance to keep such units in an acceptable condition can cost a significant percentage of the value of the unit.

Where this technique truly runs into trouble, though, is when it becomes overused and counted on as a permanent solution to growth and expansion. Portables are clearly not intended to remain on site for more than a few years, as is confirmed by manufacturer specifications and detailing. The fact that these units are utilized as long-term solutions, as acknowledged by the U.S. Department of Education and many school systems, points to a great need for more flexibility in the primary school structures so that they may adapt to changing needs and population sizes and provide more economical means of augmenting available spaces. A negative local example is Dacula

Middle School in Atlanta which at one point had over 100 portable units on site (Gertha, 2010). Managing such a quantity of units on a site not designed for such growth can easily erode a school's ability to feasibly add other needed elements, such as building expansions or even athletic fields or parking. Portables can even end up impeding existing site elements.

Beyond grappling with planning, architectural, and material shortcomings, current use of modular classrooms also struggles with the astoundingly poor health conditions of such units. In 2004 the Air Resource Board and Department of Health Services in the state of California conducted one of the largest inquiries comparing permanent school buildings with the ballooning number of portable classrooms on which its schools were relying. With regards to the health quality of these spaces and potential long-term damaging effects on students, the results pinpointed several issues (Air Resource Board and Department of Health Services, 2004):

- Inadequate **ventilation** with outdoor air. Substandard amounts of outdoor air were measured in classrooms during 40 percent of class hours, and seriously deficient ventilation was found 10 percent of the time. The causes included teachers turning off HVAC (heating, ventilating, and air-conditioning systems) because of excessive noise; closed or blocked outdoor air dampers; off-cycling of the HVAC; inadequate HVAC capacity; and other factors.

- Classroom **noise** too high. About one-half of the classrooms exceeded 55 decibels, the level used by many communities in the state for their outdoor nuisance regulations, and most exceeded the current “best practices” guideline of 45 decibels. Major noise sources are primarily noisy HVAC equipment, noisy lighting, and noise from nearby outdoor activties.
- Poor **thermal comfort**. Temperature and humidity levels were outside the range given by professional standards for thermal comfort in about one-fourth of the classrooms. Causes appeared to be related to improper HVAC system control and/or inadequate capacity.
- Indoor **formaldehyde** levels. In 4 percent of the classrooms, air concentrations of formaldehyde exceeded the guideline level for preventing acute eye, nose and throat irritation. Nearly all classrooms exceeded formaldehyde guidelines for preventing long-term health effects, including cancer. These findings are largely due to the widespread use of formaldehyde-containing building materials and furnishings, and inadequate ventilation.
- **Moisture** problems. Water stains, excess wall moisture, and other indicators of potential mold were found in about one-third of classrooms. Investigators found visible mold in about

3% of classrooms; and musty odors were reported by 69% of teachers. These conditions are often attributable to inadequate maintenance.

- **Toxic residues** in floor dust. Lead, arsenic, and numerous pesticide residues were measured in classroom floor dust. These residues are a concern because they can be inhaled, ingested, or absorbed through the skin by children, especially very young children who sit on the floor and put their hands in their mouths. The source is generally tracked in dirt from outside, and pesticides applied indoors or near the building.
- Inadequate **lighting**. In about one-third of the classrooms, room lighting was below the level given by professional guidelines. Properly installed daylighting can help.

Clearly the issue of healthy environments within the context of modular units should be a top priority when designing new systems. However, it is worth noting that the majority of current *permanent* school buildings have been cited in similar studies as exhibiting substandard health issues as well. Given both of these benchmarks, it becomes clear that designing healthier schools is imperative.

3.2 HEALTHY LEARNING ENVIRONMENTS

Leading the widespread effort to green American schools is the U.S. Green Building Council. As it's done with its LEED rating system for several specific building typologies, the latest (2007) version of LEED for Schools specifies matrices by which new construction and major renovation projects can be benchmarked. These address specific conditions critical to health learning environments as well as general environmental impact. Appropriate site development, material use, indoor air quality, and innovative design features are all significant factors within this system.

Adoption of any of these features has been shown to return significant dividends. Take, for example, day lighting. A comprehensive study by Nicklas and Baily in 1996 found:

- Students in full-spectrum light were healthier and attended school 3.2 to 3.8 days more per year.
- Libraries with superior light resulted in significantly lower noise levels.
- Full-spectrum lighting induced more positive moods in students.
- Because of the additional vitamin D received by the students in full-spectrum light, they had 9 times less dental decay and grew in height an average of 2.1 cm more than students attending schools with average light.

- Daylit schools in the study indicated energy cost reductions of between 22% to 64% over typical schools.

Recently, similar research has also been applied specifically to mobile classrooms. The California-based Collaborative for High Performance Schools has thoroughly studied best practices and published manuals with guidelines driving schools towards much needed solutions to substandard portable classroom units. Significant features of these recommendations include:

- Enhanced Daylighting
- Energy Efficient Indirect/Direct Lighting
- Energy Efficient Low Noise Title 24-compliant HVAC System
- Efficient Building Envelope
- Low VOC Interior Materials

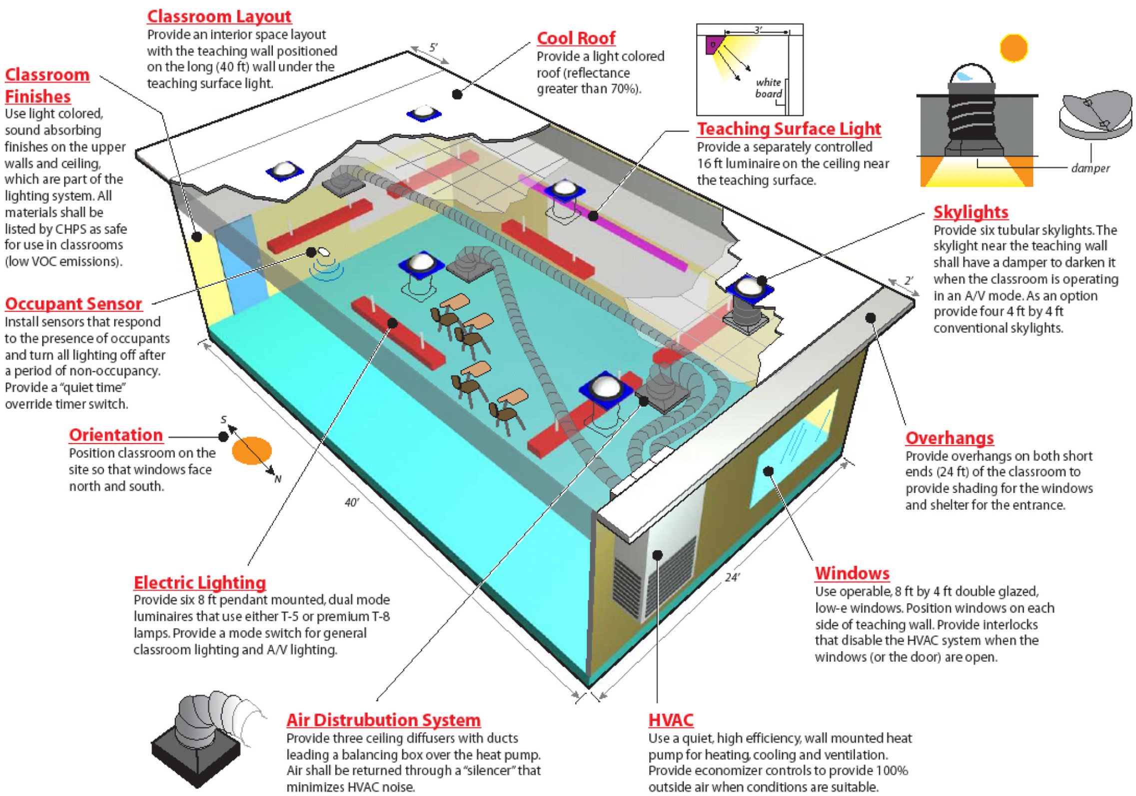


FIGURE 1: The CHPS Relocatable Classroom. (Collaborative for High Performance Classrooms. (2009). Best Practices Manual. Volume VI: Relocatable Classrooms. San Francisco, CA: Center for High Performance Schools. p.12)

With better lighting, air quality, and generally healthier environments displaying such large benefits for student health and performance, these factors should be design drivers at the forefront of new school design.

3.3 POTENTIAL HEALTH AND PERFORMANCE ADVANTAGES OF PORTABLE CLASSROOMS

The previous section discussed possibilities for modular classroom structures to overcome common health and performance barriers. Given more direct and holistic intent though, it is possible to conceive of modular classrooms that not only meet the health and performance standards of more permanent construction, but that also leverage advantages granted specifically by modular construction techniques to outperform the status quo.

One of the first advantages is reduction of materials and waste in construction processes. Pre-fabricated modular units in a controlled production environment allows for much greater optimization of raw material use. This environment also makes collection and recycling of unused materials much more feasible; therefore it is easier to close the material waste loop. Moreover, recycled and left-out material will not have been exposed to the elements. On a typical construction site, much of the raw material suffers rain, wind, and general damage due to on-site activity. Within a controlled environment, proper collection measures could insure materials are not lost due to such damage. This closed environment also means the left-over material will not rot, mildew, or mold due to over-exposure to moisture, causing quality and health issues.

Within a controlled construction environment, the health and safety of the construction site and crew may also be controlled. This means less risk to all parties involved as well as a better work environment for those constructing the project. On-site issues may vary wildly depending on site conditions, weather, and the surrounding areas. All of these variables may be controlled to insure the focus remains on delivering the ideal quality project, rather than dealing with site-specific issues.

A healthy construction environment also translates into a more health demolition – or deconstruction – later on. When a school needs to renovate or expand a portion of its facility, construction activity typically significantly reduces the quality of the learning environment near by. Construction crews, equipment, noise, dust, and debris can distract and endanger students. A modular classroom system, however, can be installed, modified, or removed with little or no significant impact on students and the surrounding environment. This means construction does not have to be limited to weekends or off-seasons, and schools therefore have the freedom to expand, contract, or develop their facilities throughout the year.

CHAPTER 4: CONSTRUCTION TECHNIQUES AND TECHNOLOGIES

4.1 TRADES AND TRADITION

As the largest industry, both globally and domestically, the building trades encompass a staggeringly complex and fragmented array of constituent elements. Since the very beginning of organized building efforts, acknowledgement that a major work of architecture must rely on a collection of tradesmen, craftsmen and laborers has manifested itself in specialization and guild formation. This pattern of fragmentation and subdivision continues today and is widely accepted in the building industry. Compartmentalization means specific duties get assigned to those with dedicated experience to address them; instead of setting unrealistic expectations on one person, or a few individuals to know all there is to know about a complex building project, those directing such efforts now coordinate appropriately skilled participants.

The notion of craftsmanship and specialization is a valuable concept in such trades. The ability of one generation to communicate to another the highly trained aptitudes and skills refined over lifetimes is a critical aspect of this phenomenon. For as seemingly banal as the act of laying a brick or joining lumber may seem to the untrained eye, such acts are not only of key importance to the quality, livelihood and performance of the resulting building, but inevitably require a highly attuned set of explicit and implicit skills learned best over a lifetime of repeated practice under direct tutelage of an accomplished predecessor. These critical acts often rely on the most delicate touches, the most attuned and nuanced tactile dispositions, and the cognitive road maps that describe countless scenarios and resulting outcomes, thus allowing one to accurately determine the outcome of complex situations.

This aptitude, so often verbally and physically attained, is the very currency building trade groups rely on; experiences that cannot be effectively communicated via the printed word or the formal academic institute. Thus these “trade secrets” quite appropriately are “guarded” by those who practice them regularly.

It may also be worth noting that the cultural benefit of such skills has directly elevated several classes of people throughout history. One’s ability to demonstrate competency in a specified building trade is a skill that can often be exported and imported as a worker travels, thus issuing a transferable livelihood across multiple localities.

Finally, the fact that critical building tasks, when not carried out by skilled professionals, often lead to disastrous outcomes insures the skilled trades a high level of value in the industry. This respect not only secures their economic place but also solidifies the notion that there is a certain way in which things must be done when it comes to construction.

That participants in the building trades are typically hyper-specialized with a very narrowly focused field of vision actually does present problems, however. Coordination of parties who have divergent understandings of the other’s work to be done on a construction site can often lead to scheduling, logistical, territorial and interference problems. Multiple sub-contractors are counted upon to occupy the same space on site and often to install critically important building components within the same location within a short period of time. Common errors, as well as clashes or damage to work of one party by the next party to work in the space are expected realities of this system.

Nevertheless, disturbing these established combinations of building systems and skills often leads to significant friction and collapses of intention. Since the respective trades are conditioned to work in certain spaces in certain sequences, for the architect to selectively remove and replace any single kind of work can yield less than favorable results. For example, an electrician used to running wiring through wooden stud framing may not know how to approach a project constructed of structurally insulated panels, and thus would claim the need to charge more than normal, the net effect of which is the motivation for the client to fall back on wooden stud framing or more conventional techniques suited to the sub-contractor’s realm of knowledge.

In this way, the large cast of characters involved in the building process work to insure themselves a future yet subvert much forward progress in the development of building technology. The attitude of a “right” and “wrong” way to build becomes the benchmark for feasibility and any attempt to elevate the performance or design of a building are weighed under this scrutiny. Innovative proposals are therefore overpriced, leaving clients and financers to retreat and buildings to continue to be built the way they have been for generations.

At the forefront of contemporary building technology, however, we find a new collective of tradesmen. Those equipped not with secret skills and tools of the trade handed down for generations, but rather with complex digital instruments capable of making informed predictions of building outcomes far beyond the grasp of even the most experienced craftsmen. Not only has the world of computer-aided-design (CAD) allowed the industry to work more rapidly and efficiently than ever before, intelligent applications that model the visual aspects of a building design as well as the data-driven performance aspects are now allowing teams of clients, architects, financiers, engineers, and construction professionals to push the envelope of the “known” way of building.

4.2 PARAMETRIC MODELING

At the heart of the current technological development is the phenomenon known as parametric modeling which is garnishing much attention within architecture at present. Parametric modeling is rooted in a digital application’s ability to simultaneously formulate complex geometries, architectural forms, and proposed building components according to a host of variables that can be adjusted and altered with the aim of evaluating and optimizing the end result. A single change in a façade louver, for example, could be seen visually as propagating across the exterior skin of a building while also providing data as to the system's ability to provide differing degrees of solar shading. The true power of these applications is in their ability to control hundreds, if not thousands, of variables that make up exceptionally complicated building projects. In fact, the greater the project complexity the more beneficial such systems are in optimizing the end result to explicitly stated goals and benchmarks.

Prior to such systems, "value engineering" sought to optimize design proposals through post-rationalized cost saving measures and predictive calculations relying on wildly complex dynamic engineering tests. These were some of the only means by which control of a building proposal could be exercised by someone other than the architect. However, this system fails to deliver good architecture because it does not balance the input or create group consensus needed to move forward building projects.

Above and beyond cost and logistical control, a huge benefit of preconstruction digitization of this nature is the ability to optimize a building design to respond to environmental performance benchmarks. For example, solar radiation control is of critical importance to a building's heating and cooling loads as well as occupant comfort yet there are many complex elements that determine a building's ability to respond to solar radiation. These may include placement, various options for glazing and façade assemblies, roof design internal and external shading devices, material choices, and the proportion and spacing of windows and doors. Within the context of a modern parametric design application, all these variables and more (including scheduled availability of materials, cost, phasing, etc.) can be input to a digital model and adjusted, changed, and “designed” to achieve the perfect blend of variables as specified by the project team.

This power to design a project in a more informed way not only results in clearer outcomes and more accurate expectations of environmental characteristics, and also empowers teams to speculate on new processes and techniques. A digital application knows little of a “right” or “wrong” technique or traditional construction convention, but merely operates within the parameters and processes the design team authors. In such a context, engineers, architects, and construction professionals can collaborate more actively and productively not just to design not just final buildings, but also to model the processes by which they are realized.

In their seminal text *Refabricating Architecture*, Kieran and Timberlake emphasize architecture’s widespread failure to acknowledge that which engineering so intentionally embraces: the notion that a process sets the stage for outcomes. (Kieran & Timberlake, 2004). Whereas traditionally the architect relies on the construction professional to determine the order and nature of execution of a given design, here it is argued that much can be gained from the ability to *craft a process* resulting in the end design. In fact, more than merely informing design, a specific process methodology can test and optimize design that can lead to a highly cost effective end result that also balances highly designed aesthetics.

Such are the roots of “design for assembly” or “design for manufacturing” concepts. Both of these paradigms have far reaching implications for the computer-aided-manufacturing (CAM) process that will be discussed shortly. Suffice it to say that even for manual fabrication and construction techniques, the ability of the author to design a building through the explicit filter of how it will be made, at what location, and in what sequence could be of great value. Parametric design applications enable such approaches through their ability to allow multiple contributors to the design process to *co-author* a project while also allowing the adjustment of production variables with the goal of iteratively evaluating modeled outcomes and effects on the end design proposal. Thus the qualified parties responsible for various segments of fabrication and construction can influence the design process much earlier.

In addition to directing the assembly and construction of a building, parametric design techniques make the creation of menus of customizable components an easy addition to any project. Here we see great potential to bridge the long-standing divide between standardization and customization.

4.3 STANDARD VS. CUSTOM

Standardized building components have existed since the origin of construction. Regularized dimensions of lumber, masonry units and complex assemblies of façade panels and key building components are all common at present. Such consistency makes easier the job of designing and building.

Yet for all this standardization, there exists much room for custom design exploration – thus the role of the architect is to orchestrate known ingredients into a previously unimagined vision uniquely addressing the needs of a particular client within the constraints of a particular site. Such a dialectical operation in fact works at multiple points on a running continuum. The nuances of what constitutes “custom” versus “standardized” exist on several perceptible and imperceptible scales.

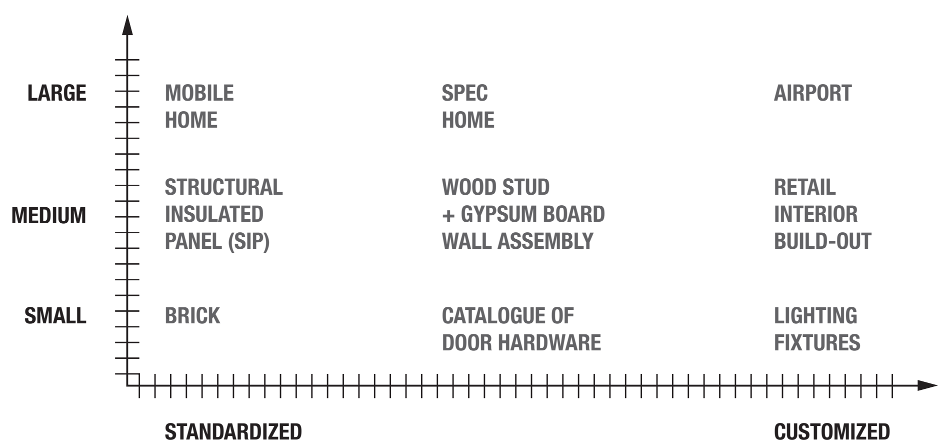


FIGURE 2: Continuum of Standard vs. Custom at Varying Scales

At one end, that which may be replicated consistently with the quality of an original is typically deemed a standardized construct. A custom object, by contrast, is typically referred to as that which is designed specifically for an individual purpose, person, or place and intended for only one final production. While traditional architectural and product design discourse relies on these divergent fundamental concepts, contemporary design presents a complicated scenario when one introduces the multiple scales such elements exist at. For example, the standardized module of a 2x4 piece of sawn timber is a blatantly repeatable item, yet using these items to produce a custom designed house presents a dilemma of codification. Namely, is the house a collection of standard elements, or is it a unique custom construct? Or perhaps let us consider the case of an office park featuring multiple copies of a single, standardized building design wherein a lessee has employed the aid of a custom furniture and cabinetry maker to build an entire interior environment based on the unique concepts, specifications and desires of this client. Is the resultant architecture standardized or custom?

Much academic discourse shies away from these paradoxical dilemmas and mainstream culture passes them over in favor of more coarse-grained distinctions. Yet confronting them head on is exactly what will allow adequate discussion of standardized and custom construction to evolve. For each paradigm is associated with much cultural, professional, and cost-driven decision-making.

4.4 PRE-FABRICATION

The term “fabrication” is common in the construction industry to describe acts involved with preparing materials and pieces of a building to arrive to the project site and be installed. While this notion typically involves raw materials being cut and sized into basic building blocks (i.e. 2x4 sawn lumber, standard w-section steel members, etc.) it is also rapidly evolving to capture some of the modular assembly characteristics of automotive and nautical construction. This newer paradigm of a standardized module represents an orchestration of construction techniques not merely by a selected craftsman's skill set, but within a specific manufacturing facility as well. Within such a context more elaborate assemblies may be engineered, tested and constructed to higher tolerances than could be achieved on a building site. Architecture's seduction by this string of possibilities reach far back into the profession's history, and typically the end results have failed due to over-bearing idealism and stylistic reasons, among a host of other economic, cultural, financial and logistical problems. Yet emerging practices in architecture are utilizing a broader definition of pre-fabrication as well as new sets of digital and mechanical tools to realize them.

Just as the continuum of standard and custom offers large expanses of overlap, a similar overlapping concepts cloud what might otherwise explicitly define a pre-fabricated piece of architecture. Building elements fabricated off site may also exist at greatly varying scales. Common elements such as doors and windows are often fabricated to meet a specific design's size requirements. Yet in other more extreme cases, an entire building may be transported to a site and simply set into place with little or construction occurring on site.

Such issues are foregrounded here to illustrate the growing complexity of common notions of "standardized" and "pre-fabricated" as they pertain to architecture. Only by scrutinizing such paradigms can we begin to surmount cultural disdain for standardized architecture as well for the perceived danger such concepts are believed to present to skilled craftsmen and trade workers within the construction industry.

4.5 COMPUTER-AIDED-MANUFACTURING

The ability to redefine standardized and custom building components (and buildings) combined with the ability to design in rich digital environments empowering informed design decisions driven by modeled results brings us to a point in architectural and construction research at which new tools are in fact leading to viable new evidence-based design and production. Namely this phenomenon is known as computer-aided-manufacturing (CAM). Here it should be acknowledged that the majority of manufacturing and fabrication processes - cutting, bending, molding/casting, forming, pressing, drilling, laminating, etc. – remain to this day quite close to their ancient origins. However, the great recent advancement lies in the ability to exert the highest level of control over such processes by means of computer numerically controlled (CNC) equipment, as well as to generate highly accurate replicated pieces many times over. Via simple codes communicating Cartesian axes in two-dimensional and three-dimensional space, such machines are capable of turning a digitally modeled geometry into physical form via a host of means. Whether by subtractive removal of material, bending or forming of material, extrusion or “printing”, or casting and molding, CNC fabrication offers a wide variety of flexible, intelligent options for contemporary explorations in design and construction.

Besides the basic characteristic of accurate automated physical construction of digitally conceived forms, CAM also takes fabrication a huge step forward in its ability to create not just duplicate copies of single parts, but great numbers of unique parts within the same time and cost structures. This additional layer of potential introduces not just higher quality and complexity in making components, but begins to also introduce concepts of "mass customization." Such customization could be advantageous in many ways. Site-specific ecological and environmental factors that significantly effect the health, comfort, and performance of the building could be factored into the design and the resulting façade (or entire building) could adjust accordingly. Unique class environments could also be fabricated to deliver a rich palette of textures, finishes, and experiences throughout a school project. Also, as prototype designs are rolled out across an entire school system, alterations could be tailored to each facility in order to provide a unique environment, as opposed to a completely duplicated and mass produced building.

Schodek et all (2005). go into great lengths to classify and outline emerging workflows and industrial methodologies relevant to CAD/CAM in Digital Design Manufacturing. Here we see how industrial manufacturing and fabrication techniques are not merely being appropriated by architects and builders, but evolved and empowered to new levels thanks to software development and focused analysis of workflows and systematic thought processes. Through these channels, design processes are collapsed and integrated into multiple streams of production and analysis simultaneously. For example, the previous notion of "reverse engineering" a product is a remnant of linear design process in which design, fabrication and analysis existed in different spheres at different times. However with the ability to rapidly manufacture iterative prototypes via the very output processes the final outcome will be produced through as well as feeding specific design and performance parameters into these systems at the time of design and fabrication, there is no need for post-rationalized reverse engineering to optimize or determine the success of a project, as these benchmarks can reached much further upstream.

4.6 MODULAR DESIGN

At this point, modular classrooms, or "portables," have been discussed at length, as have their advantages and disadvantages with regard to health and safety and their risks and benefits for schools. Assuming a better modular system can be achieved, it becomes important to consider how to design for a modular system, as compared to more conventional construction methods.

The first assumption with regards to modular design is that the "module" be identified and conceived in such a way as that it may be replicated as many times as needed while retaining the quality and integrity of the original. Given the current state of computer-aided-manufacturing, however, it should be considered possible that a module may not be replicated exactly, but rather be redefined as a set of parameters which could be fabricated in different permutations delivering a set of modules that are different, as opposed to a set of modules that are duplicates.

Under such a premise, one must not only define modules, but what the key variables could and should be. Again, environmental factors become obvious design drivers. Material opacity, density, and even the size and proportion of a modular component may all be tuned according to specified inputs. Patterning, texture, and finishes may also be a key output variables.

Thus given the variability of contemporary modular design, one is freed to redefine “modular” according to essential components based on ideas and input parameters and prioritized and optimized assemblies, not merely on what overall construct might be easiest to produce off-site. This is in distinct comparison to on-site construction, or custom design, where every piece is free to vary under multiple input parameters making it difficult, or impossible to optimize construction or performance of building components or assemblies.

4.7 MATERIALS

Within the realm of traditional and contemporary construction it becomes important to note the manner and nature of the materials utilized. Material choice is impacted by several factors, not the least of which are fire ratings, building codes, energy guidelines, availability, structural ability, workability, and aesthetic judgments. Materials are the channels through which design ideas become reality when translated through these various filters. The opportunities here lie in both the quantity of new materials now available to the architect and also the new means and methods by which traditional materials may be worked.

The growing field of material science encompasses many disciplines, from nanotechnology to large-scale material applications. Driven by chemistry, physics, environmental impact and performance assessments, many new materials become available to the construction industry annually. These include plastics, resins, polymers, adhesives, finishes, and a host of other sub-materials. Along with these come new hybrids, composite amalgamations synthesizing multiple known elements in and around new ingredients, or using a new ingredient to result in a new combination of known elements. The glue laminated wooden beam, or glulam, is a perfect example of this phenomenon. Utilizing high strength adhesive, multiple laminates of structural, sawn lumber are affixed to deliver larger, better performing elements capable of competing with large, heavy timber of similar size, yet composed of significantly smaller pieces. Many engineered wood products fall into this category and represent a line of material thinking that continues to evolve and influence design.

Above and beyond engineered wood products, however, it is also worth taking note of the other developments material science has granted to architecture in recent years. From dyes affecting the finish of environments in whole new ways to polymers capable of carrying structural loads or serving as façade components, new materials are developing more rapidly than ever and therefore warrant much exploration by architects. The following figure illustrates the rapid acceleration of such material innovation.

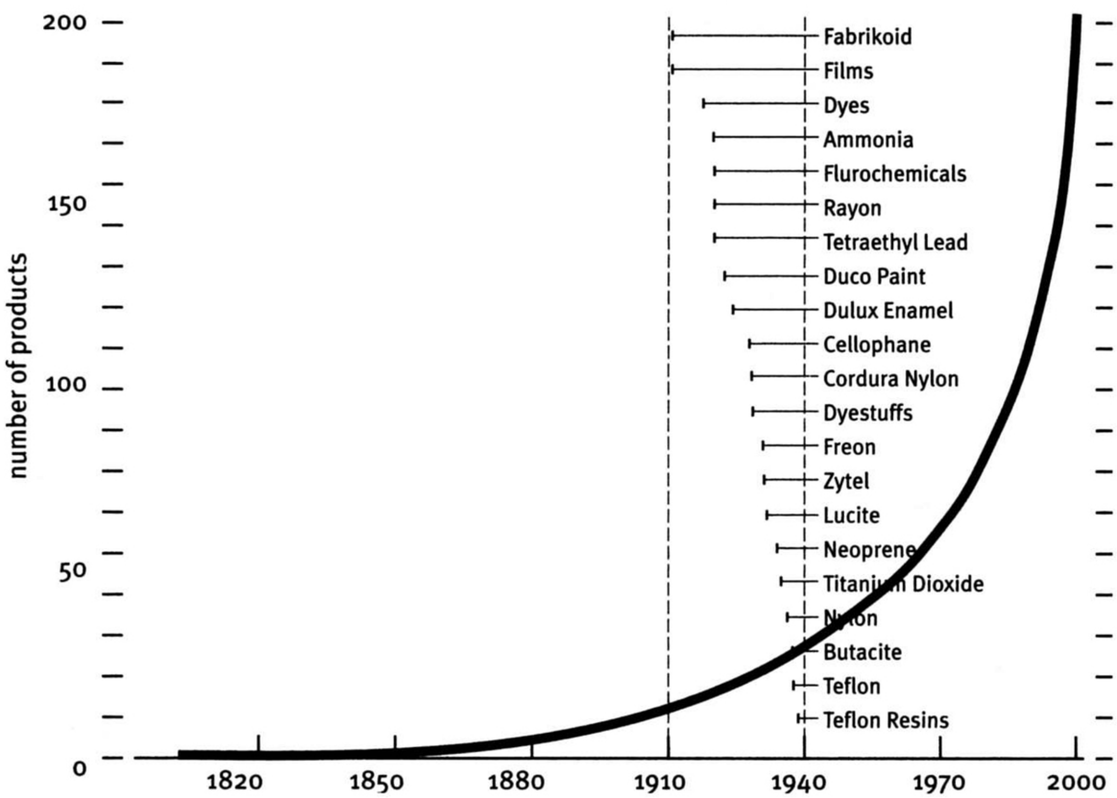


FIGURE 3: Explosion of New Materials. (Kieran, S., & Timberlake, J. (2004). Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction. New York: McGraw-Hill. Pg. 120.)

The other compelling material aspect to foreground here is the use of traditional materials in new ways thanks to innovative fabrication technologies. Some of the first examples were developed by the lumber and steel industries to aid and speed up production of pre-cut or standardized sizes of processed raw materials. CNC mills, welders, and cutters were set to produce these standardized elements in factories receiving or making (in the case of steel) the raw materials. This stage has now developed to include the process of non-standard elements, as CNC technology has evolved. Wood provides a particularly compelling example of this continuing evolution. As one of civilization’s earliest construction materials, wood has long been a base constituent element used by carpenters to build some of the world’s greatest architectural legacies. Today, thanks to CNC mills that can cut exact parts, customize parts, and carve wood stock into an infinite array of geometries and parts, innovative uses of wood are still being pursued.

4.8 ASSEMBLIES

As construction technology utilizes and embraces new methodologies and techniques, it becomes necessary to migrate from the paradigm of raw materials constructed on site to something more flexible, such as the concept of “assemblies” pre-fabricated off-site, then “assembled” on-site. Here the term “assembly” serves multiple purposes at multiple scales, as is necessary within this frame of reference.

An “assembly” is a manufacturing term used to indicate a set of parts, or “chunk” of parts that is joined with other assemblies to result in a final product. That the assemblies of a final product can be subdivided and broken down into smaller constituent pieces is critical to pre-fabrication or optimized manufacturing processes. This freedom allows smaller assemblies to be built simultaneously, as opposed to the singular process of construction from the ground up that is typical. Simultaneous construction of such assemblies significantly reduces the time required to prepare the assemblies for final installation as well as the time and effort required for the actual final installation. This methodology is widely utilized by automotive and nautical manufacturing and is only now beginning to be realized in architecture. While many modern curtain wall systems feature such sub-assemblies, there are possibilities for translation of this methodology to larger components of the building, especially those where performance must be highly regulated and tolerances are critical.

The second notion of “assembly” is in the combining of multiple assemblies into the final product. This action takes place where parts are brought together and connected. It is typically engineered to be a rapid set of operations easily executed with few or no tools. Lock-in-place seams, click-together joints and other simple connections are all innovative techniques allowing construction crews to quickly and easily assemble several sub-assemblies, resulting in amazingly rapid production of an entire building. Such techniques are ideally suited for building typologies where maintenance, speed of installation, and customization of parts are required.

CHAPTER 5: SELECTED PRECEDENTS AND CASE STUDIES

5.1 INTRODUCTION

Throughout the course of this study, multiple precedents and case studies have been considered, to various ends. Initially, it carried out an overview of positive and negative examples of contemporary high school buildings. This survey attempted to highlight trends and common issues. It was followed by a more in-depth examination of award-winning school designs. Using Architectural Record's annual Schools of the 21st Century data base as a source, exemplary designs were catalogued and studied for material applications, construction technology, and design innovation.

The final three projects illustrated below, the PeaPoD, Rogers IB Environmental Magnet School, and High Tech High were selected for further in-depth examination of unique, relevant features: portable modularity, green construction, and modular construction systems respectively.

5.2 SCHOOLS - SURVEY

Blythewood High School

Columbia, South Carolina
Perkins + Will
2005

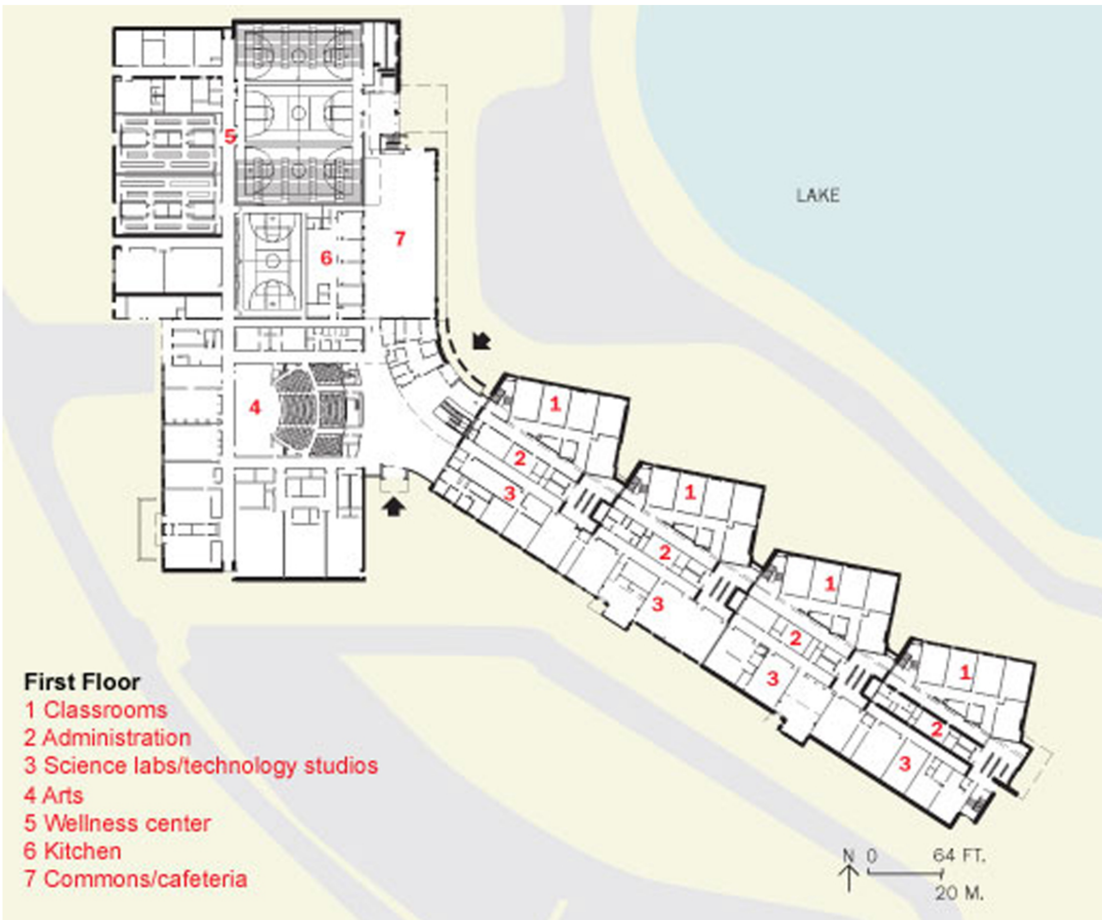
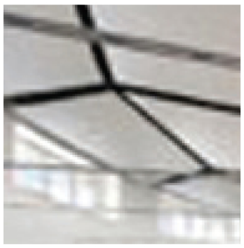


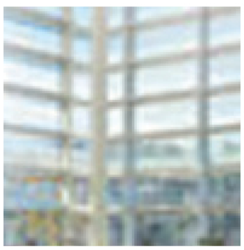
FIGURE 4: Blythwood High School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 5: Blythwood High School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Premanufactured Building System by VP Buildings



Variable system ceiling by USG allows for acoustic control as well as dynamic space



Vista Walls by Old Castle introduce intense connections with outdoors

FIGURE 6: Blythwood High School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Brunswick Upper School

Greenwich, Connecticut
Skidmore, Owings & Merrill LLP
2008

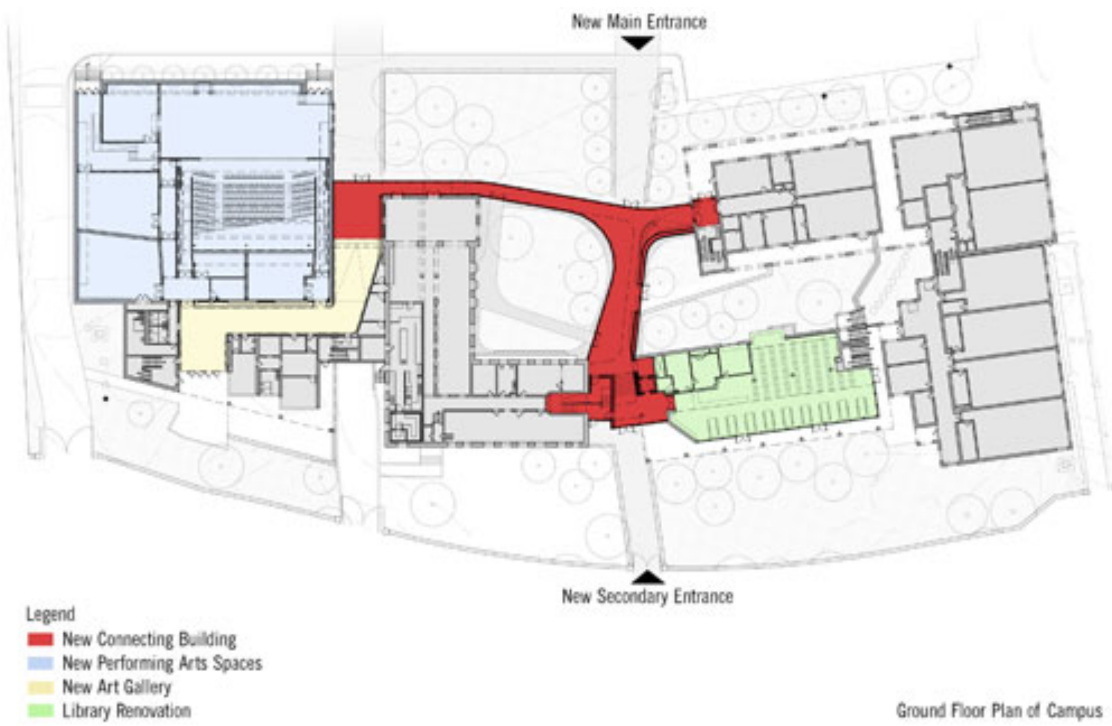
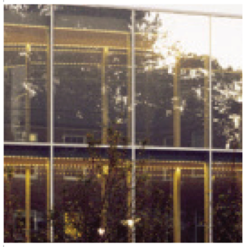
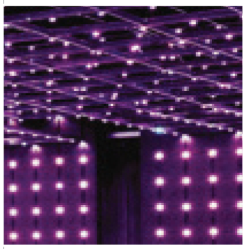


FIGURE 7: Brunswick Upper School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

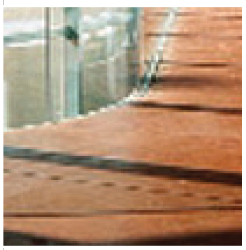
FIGURE 8: Brunswick Upper School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)



High performance insulated glass



Theater utilizes dynamic ceiling and wall assemblies by Armstrong



Retroplate Polished Concrete

FIGURE 9: Brunswick Upper School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Betty H. Fairfax High School

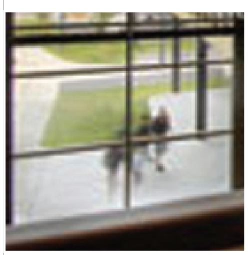
Phoenix, Arizona
DLR Group
2007

FIGURE 10: Betty H. Fairfax High School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 11: Betty H. Fairfax High School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Quincy Joist steel structural system

Metal Panels on Exterior: Kovach Metals / AEP Span

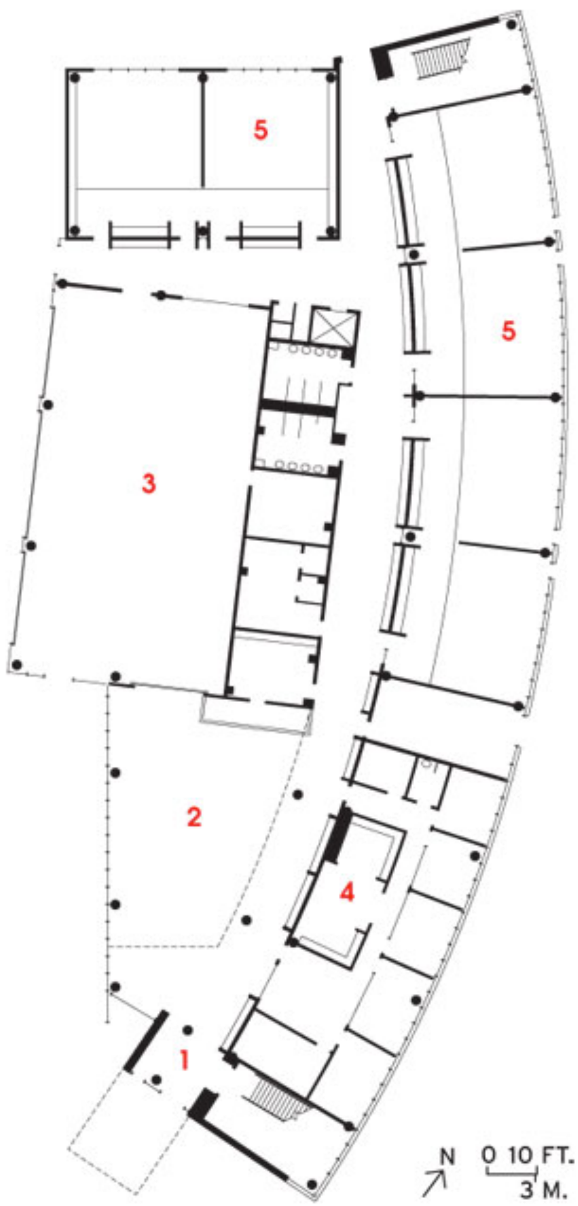


Aluminum glazed curtain wall: Vista Wall

FIGURE 12: Betty H. Fairfax High School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Concordia International School

Shanghai, China
Perkins Eastman
2007

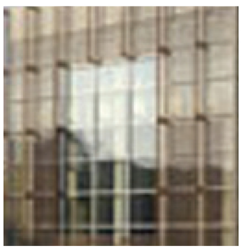


Elementary School, First Floor Plan: 1) Entrance 2) Commons 3) Motor skills 4) Administration 5) Classroom

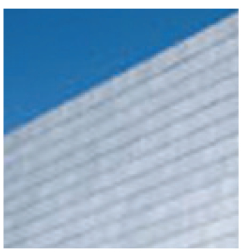
FIGURE 13: Concordia International School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 14: Concordia International School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Extruded aluminum solar shading devices



Exterior solar shading assemblies comprised of elevated rods above facade



Exterior facade utilizing modular zinc cladding panels to provide reflective defense against solar heat gain

FIGURE 15: Concordia International School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Booker T. Washington

Dallas, TX
Allied Works Architecture
2008

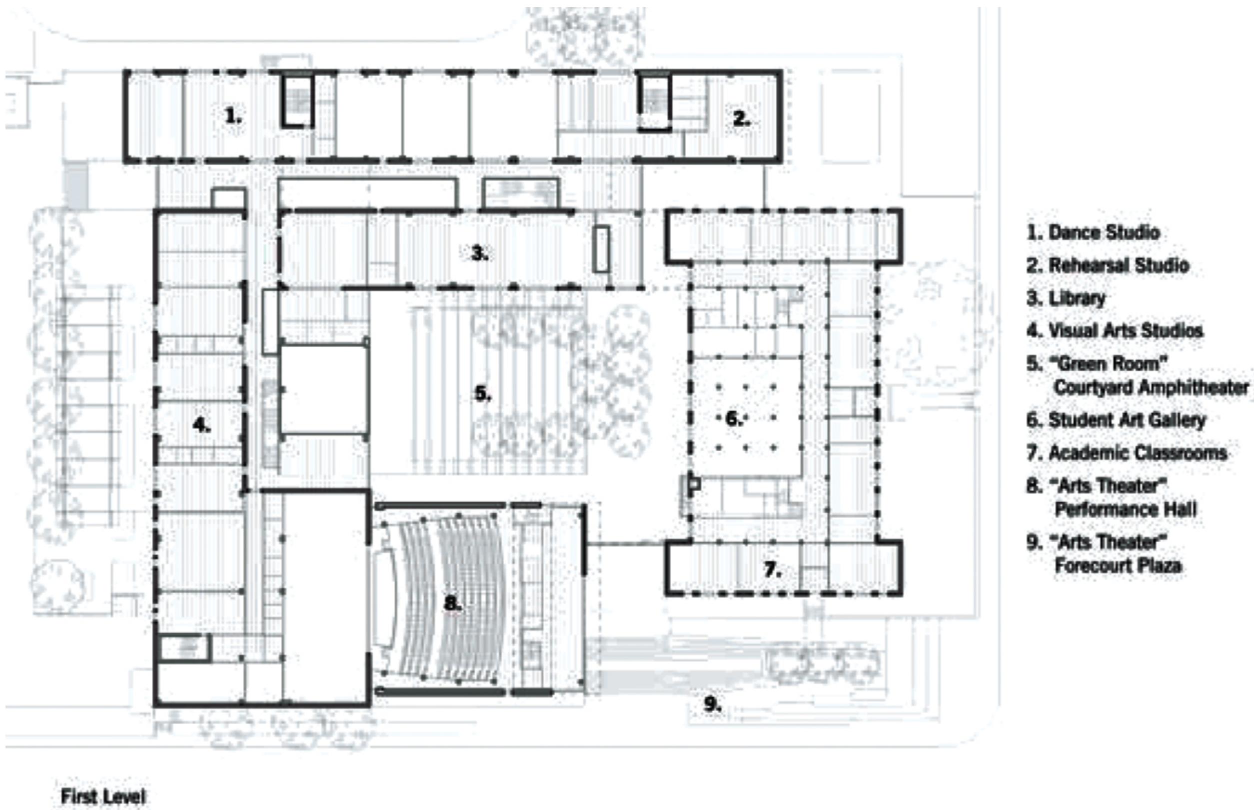
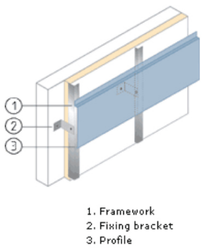


FIGURE 16: Booker T. Washington School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 17: Booker T. Washington School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)



Umicor Self Supporting Interlocking Zinc Panel System

Despite use of dark masonry facade system, much attention was given to piercing the exterior wall with numerous windows to allow for high levels of natural day lighting

FIGURE 18: Booker T. Washington School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Denver School of Science & Technology

Denver, Colorado
Klipp
2005

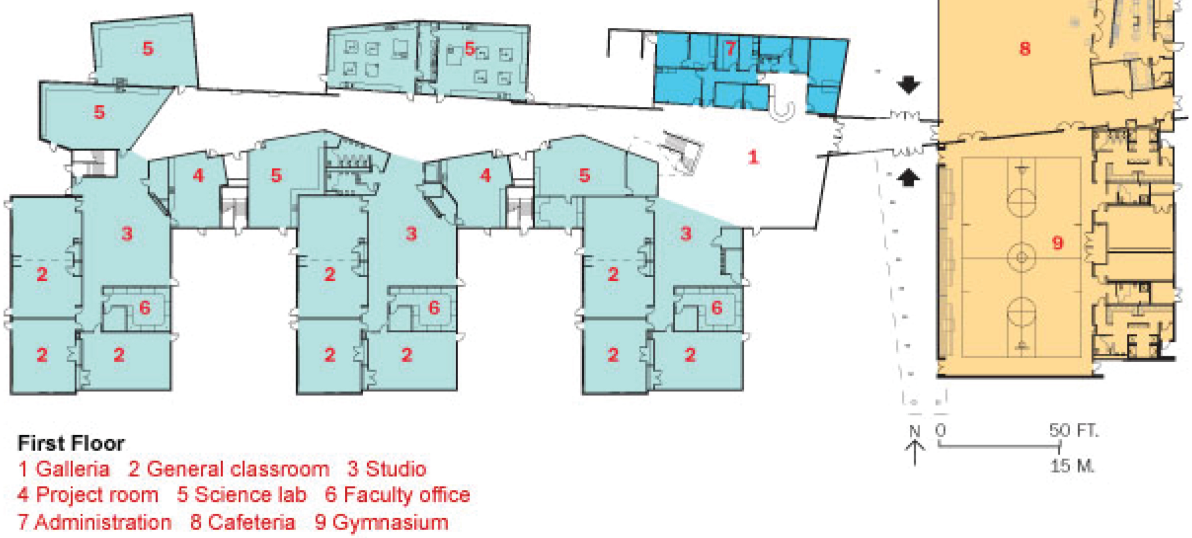
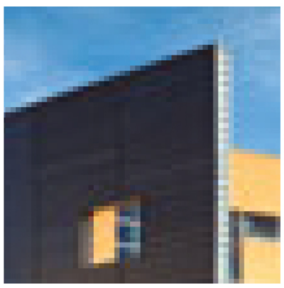


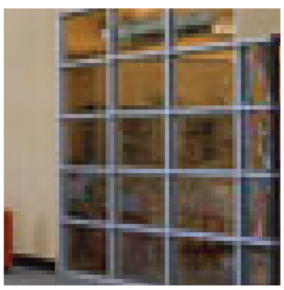
FIGURE 19: Denver Science & Technology Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 20: Denver Science & Technology. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Exposed steel truss structure
on interior



Zinc cladding facade



Grazed facade used in interior
applications

FIGURE 21: Denver Science & Technology Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Jeremiah E. Burke High School

Boston, Massachusetts
Schwartz/Silver Architects
2009

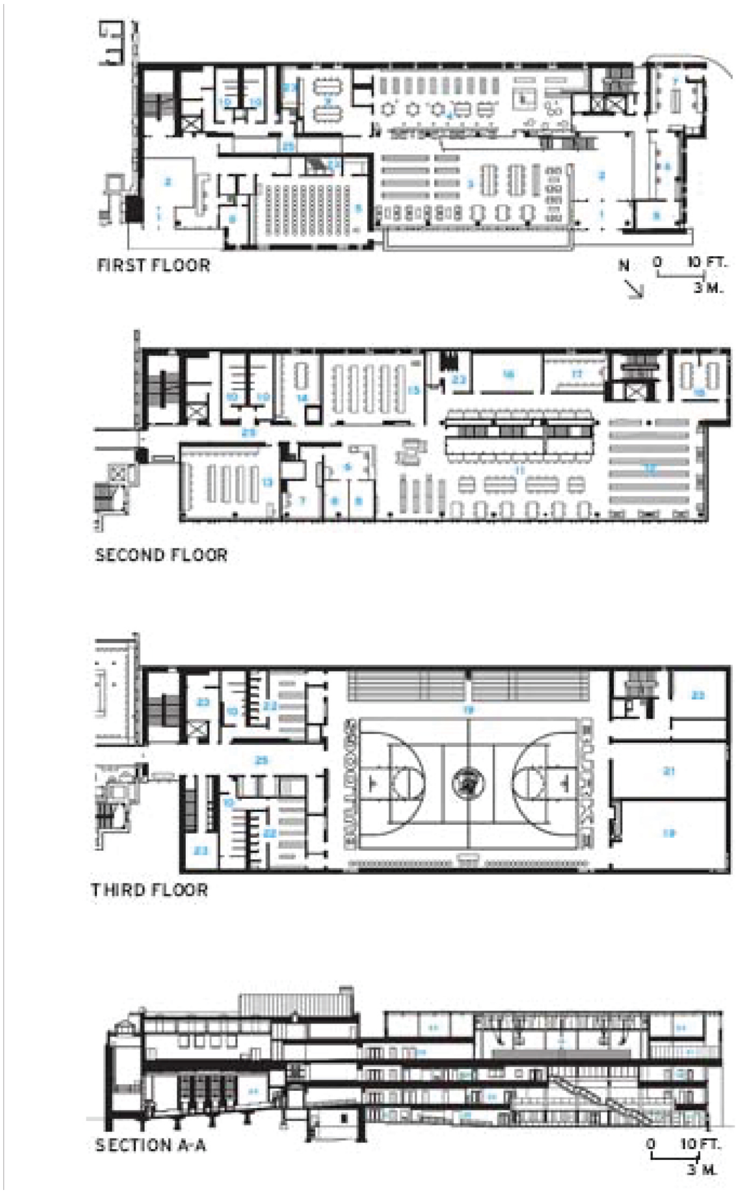
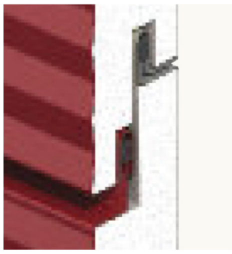


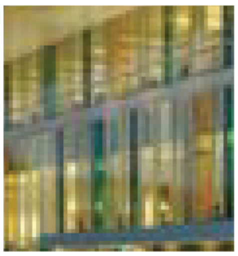
FIGURE 22: Jeremiah E. Burke Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 23: Jeremiah E. Burke. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Morin interlocking panel systems were utilized for texture



Insulated, textured panels interlock for assembly



Vanceva® Color Interlayers were installed in facade glazing to provide colored tinting to curtain wall elements

FIGURE 24: Jeremiah E. Burke Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Oslo International School

Bekkestua, Norway
Jarmund/Vignæs AS Architects MNAL
2008

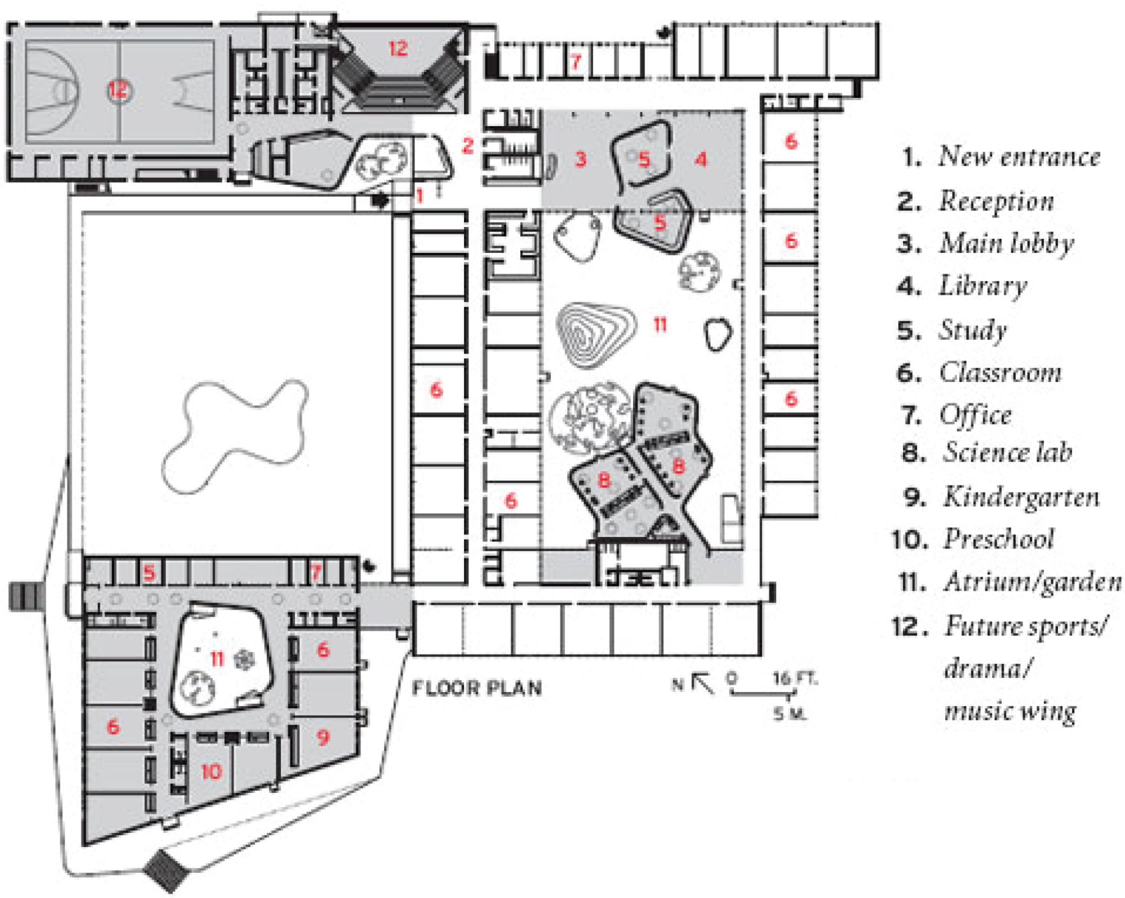
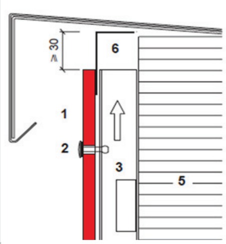


FIGURE 25: Oslo International School Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 26: Oslo International School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Multi colored fiber cement facade panels (EIFS) by SwissPearl



SwissPearl panel systems feature extremely diagrammatic installation instructions for assembly

Materialbanken AS exterior wood cladding system

FIGURE 27: Oslo International School Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Phoenix Union Bioscience

Phoenix, AZ
Orcutt | Winslow
2007

FIGURE 28: Phoenix Union Bioscience Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 29: Phoenix Union Bioscience. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

Tilt-up concrete
with form liner and
integral color panels.

FIGURE 30: Phoenix Union Bioscience Material Analysis. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

5.3 SCHOOLS – CASE STUDIES

PeaPoD
Perkins + Will
2009

Winner of the 2009 Open Architecture Network's Challenge in the Relocatable Classroom Design category, the PeaPoD offers a new approach to modular learning environments through its explicit prioritization of healthy, sustainable design and material use. Encouraging ample day lighting and connection to the outdoors, this precedent delivers clues to what a more viable modular classroom might look like were to it embrace its environment.

FIGURE 31: PeaPoD Exterior. (Images: Perkins + Will)

FIGURE 32: PeaPoD Exterior. (Images: Perkins + Will)

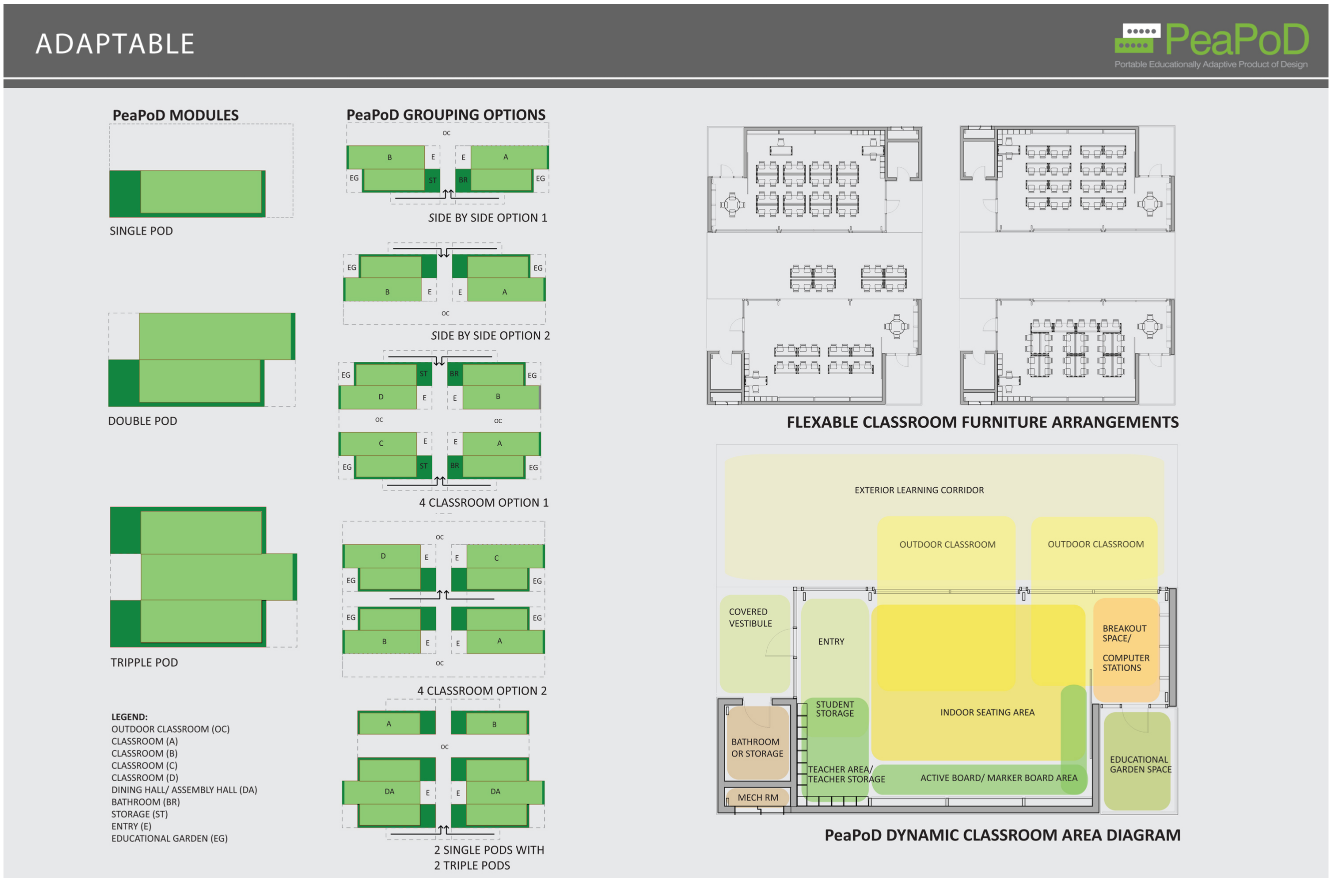


FIGURE 33: PeaPoD Configurations. (Images: Perkins + Will)

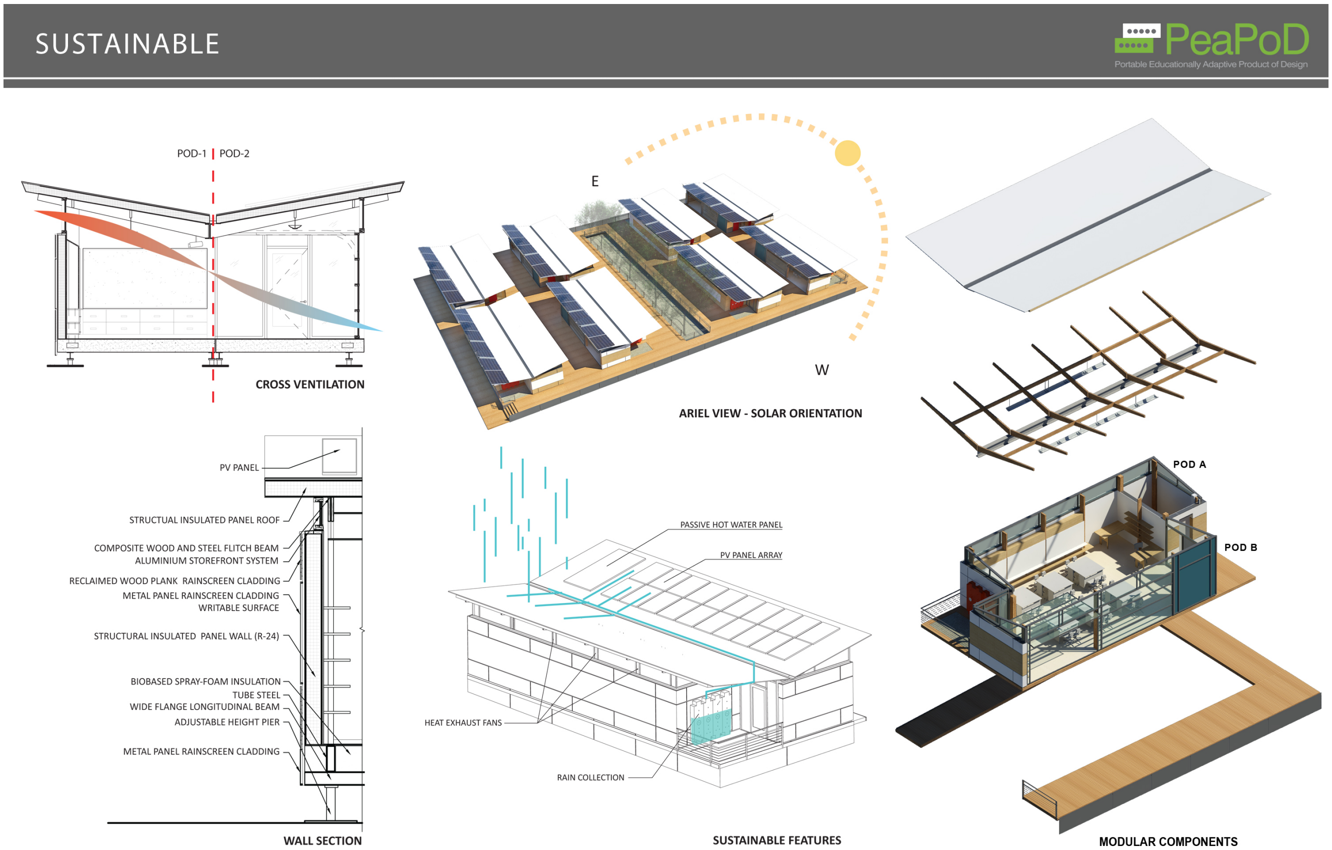


FIGURE 34: PeaPoD Environmental Diagrams. (Images: Perkins + Will)

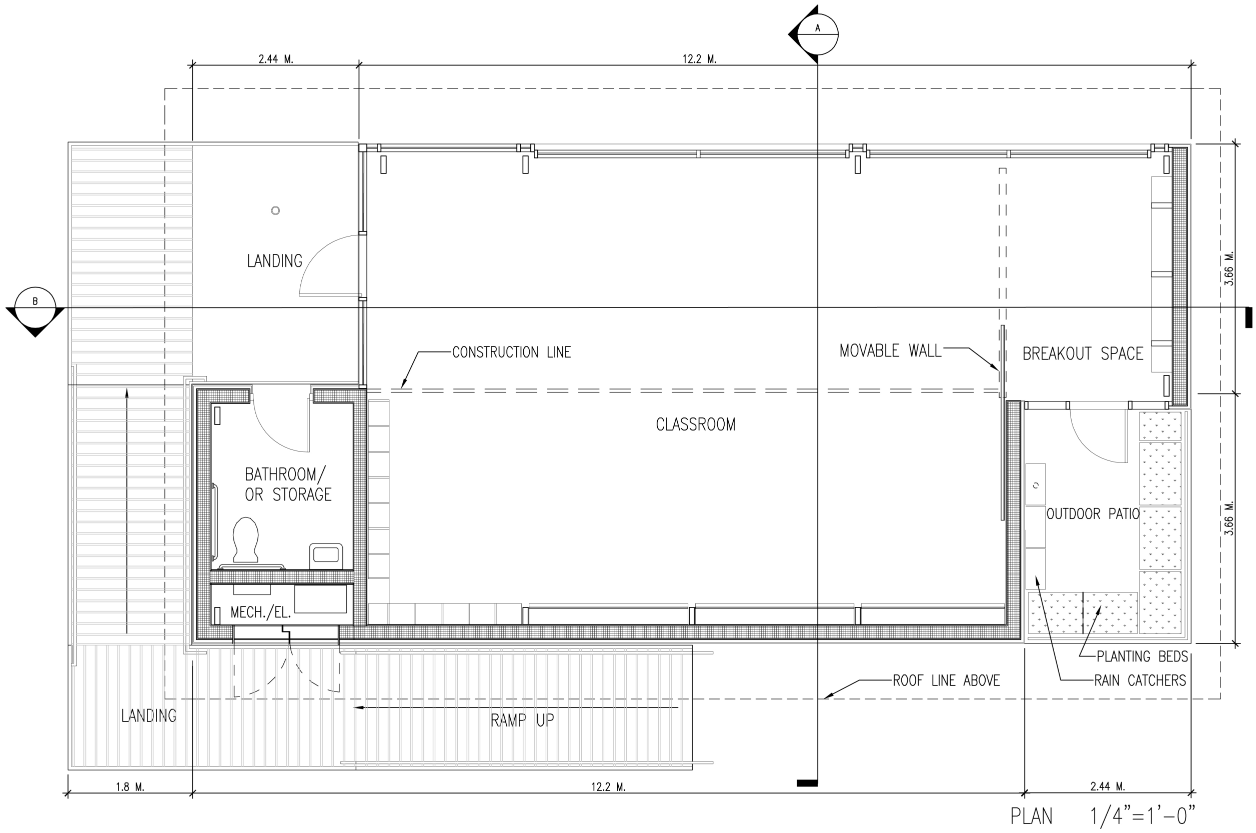


FIGURE 35: PeaPoD Module Plan. (Images: Perkins + Will)

FIGURE 36: PeaPoD Elevation Drawing C. (Images: Perkins + Will)

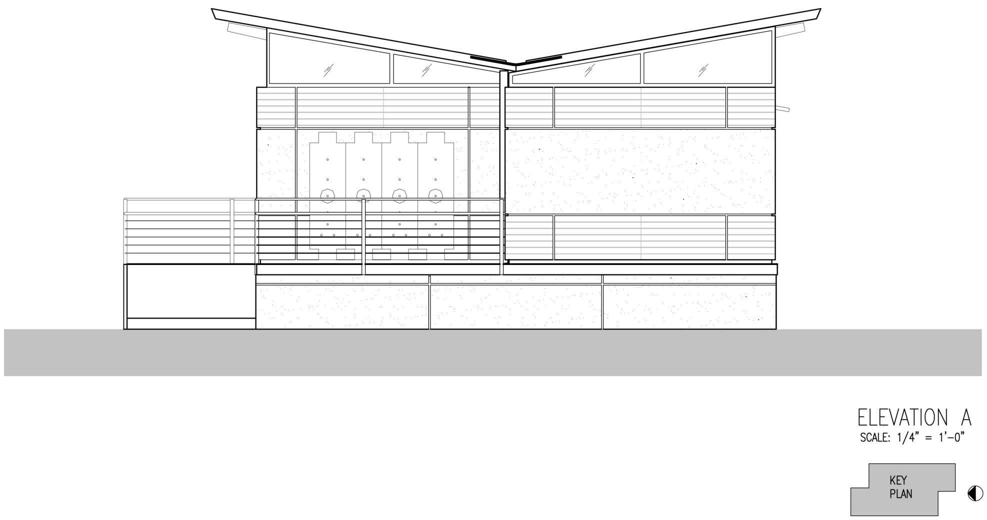


FIGURE 37: PeaPoD Elevation Drawing A. (Images: Perkins + Will)

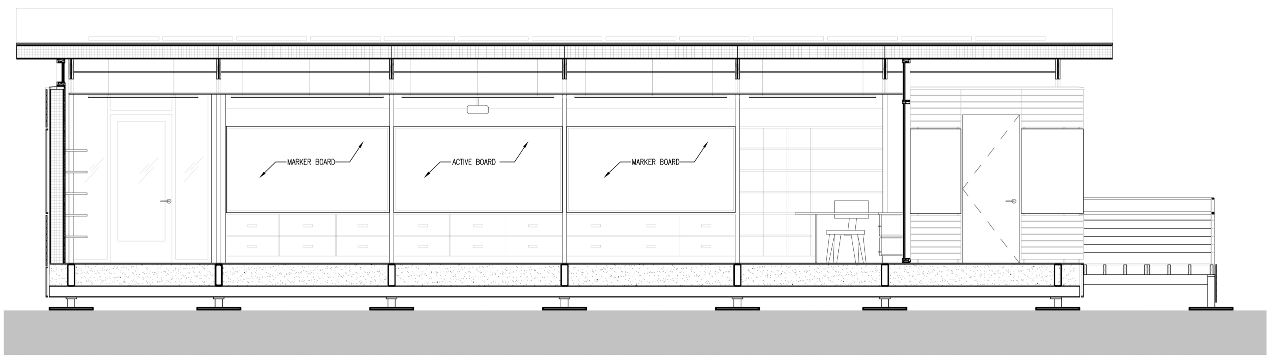


FIGURE 38: PeaPoD Section Drawing B. (Images: Perkins + Will)

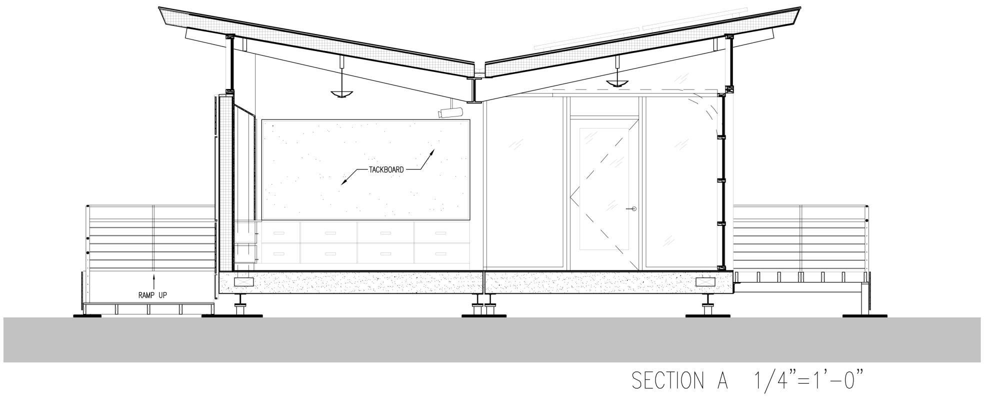


FIGURE 39: PeaPoD Section Drawing A. (Images: Perkins + Will)

Rogers IB Environmental Magnet School

Stamford, Connecticut
Tai Soo Kim Partners
2009

Roders IB Environmental Magnet School offers not only an example of a school connected with nature, it pulls the natural environment into learning areas in truly meaningful ways, such as gardens, parks and green roofs. Here plant life, water use and great potential for outdoor activity are evidenced.

FIGURE 40: Rogers IB Environmental Magnet School. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

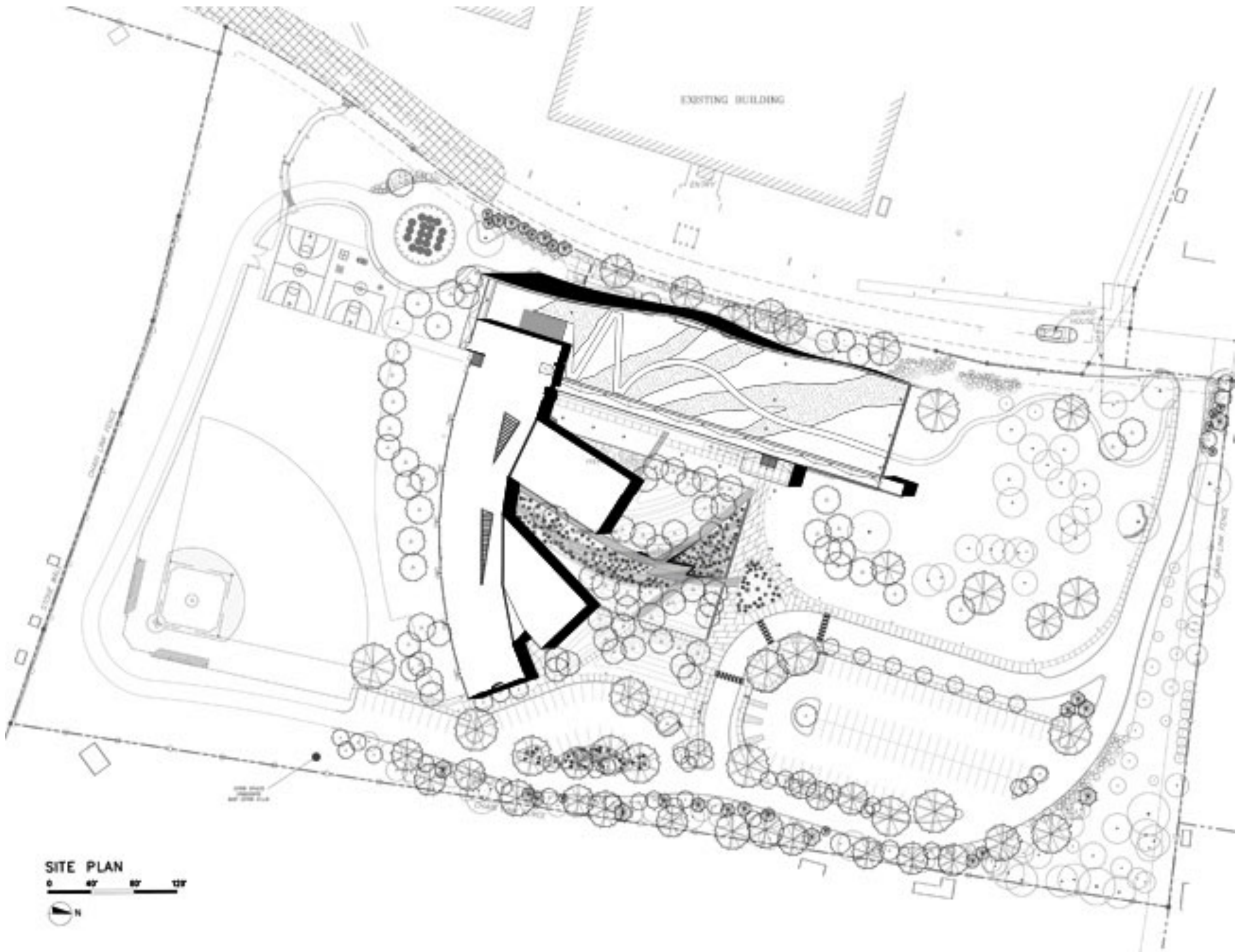


FIGURE 41: Rogers IB Environmental Magnet School Roof Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

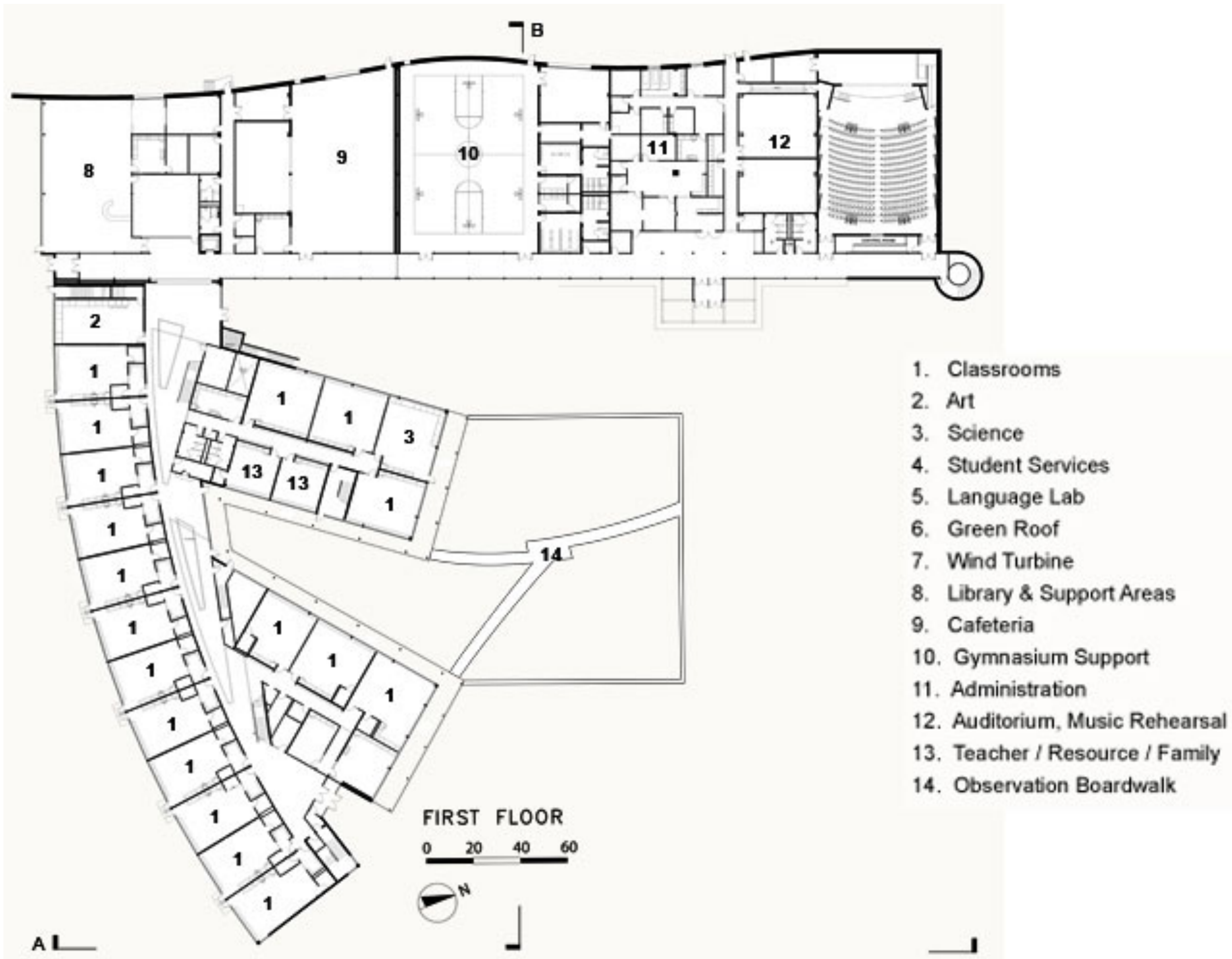


FIGURE 42: Rogers IB Environmental Magnet School Ground Floor Plan. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

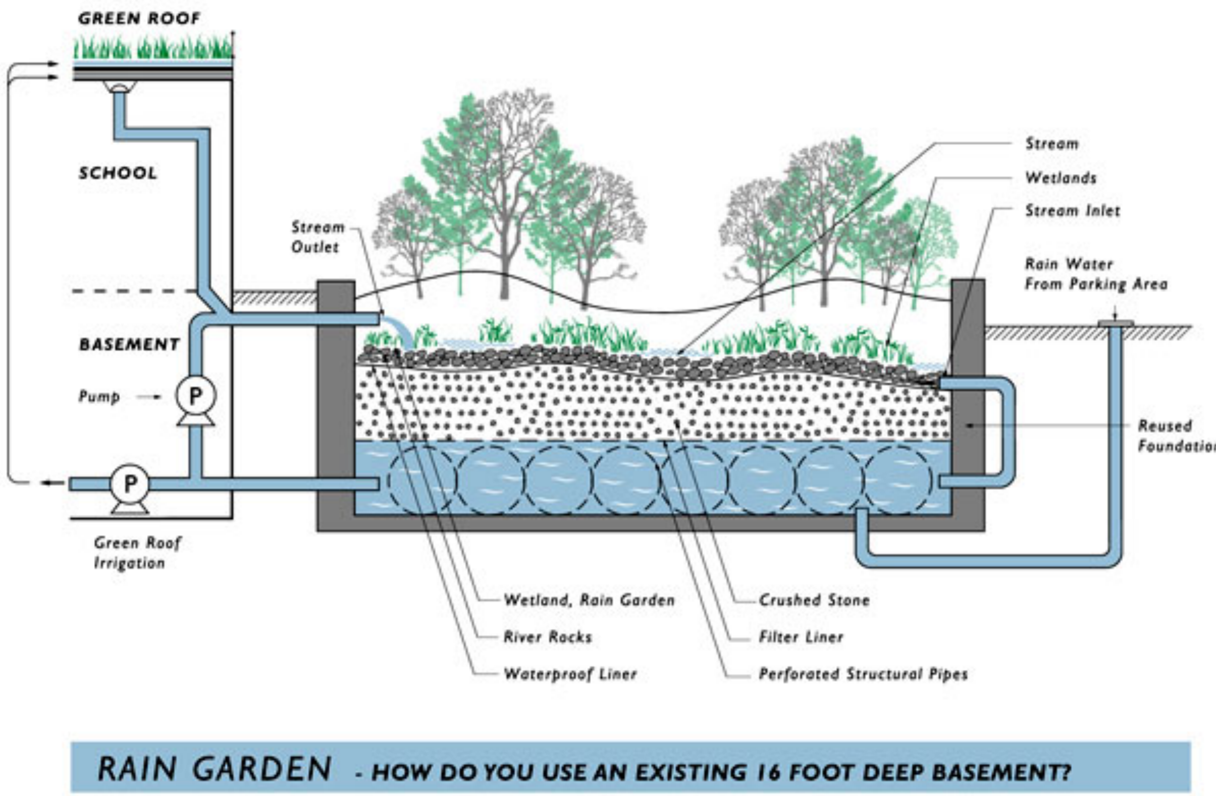


FIGURE 43: Rogers IB Environmental Magnet School Detail Drawing. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

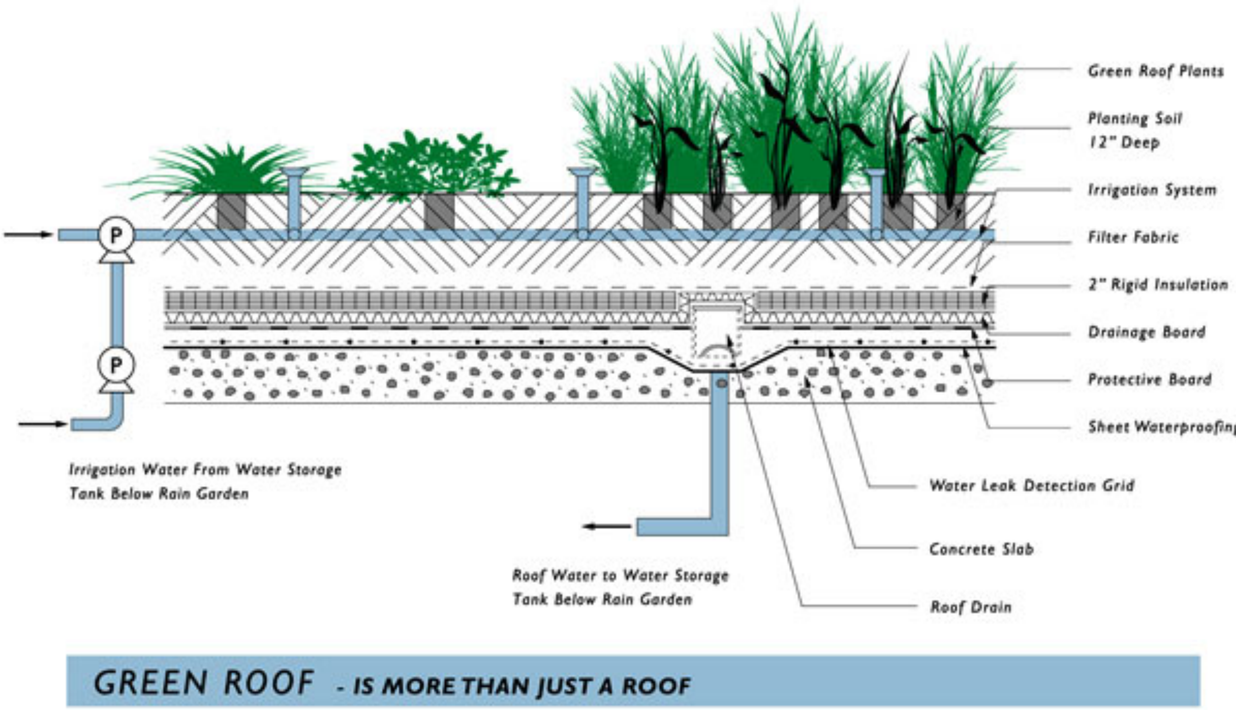


FIGURE 44: Rogers IB Environmental Magnet School Detail Drawing. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

High Tech High Charter Schools

Chula Vista and San Diego, CA
Various architects
Launched 2000

The High Tech High and High Tech Middle School charter system in California represents a systemic application of evolving paradigms of educational environments. By mediating technological and environmental priorities, most schools within this system offer expansive, open-air spaces and ample opportunity to students to utilize technology via multiple access points. Much of the construction has also been approached through an intentionally pre-fabricated process to allow expansion and growth of the system while retaining many of the prototypical aspects of these optimized learning environments.

FIGURE 45: High Tech High. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 46: High Tech High. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

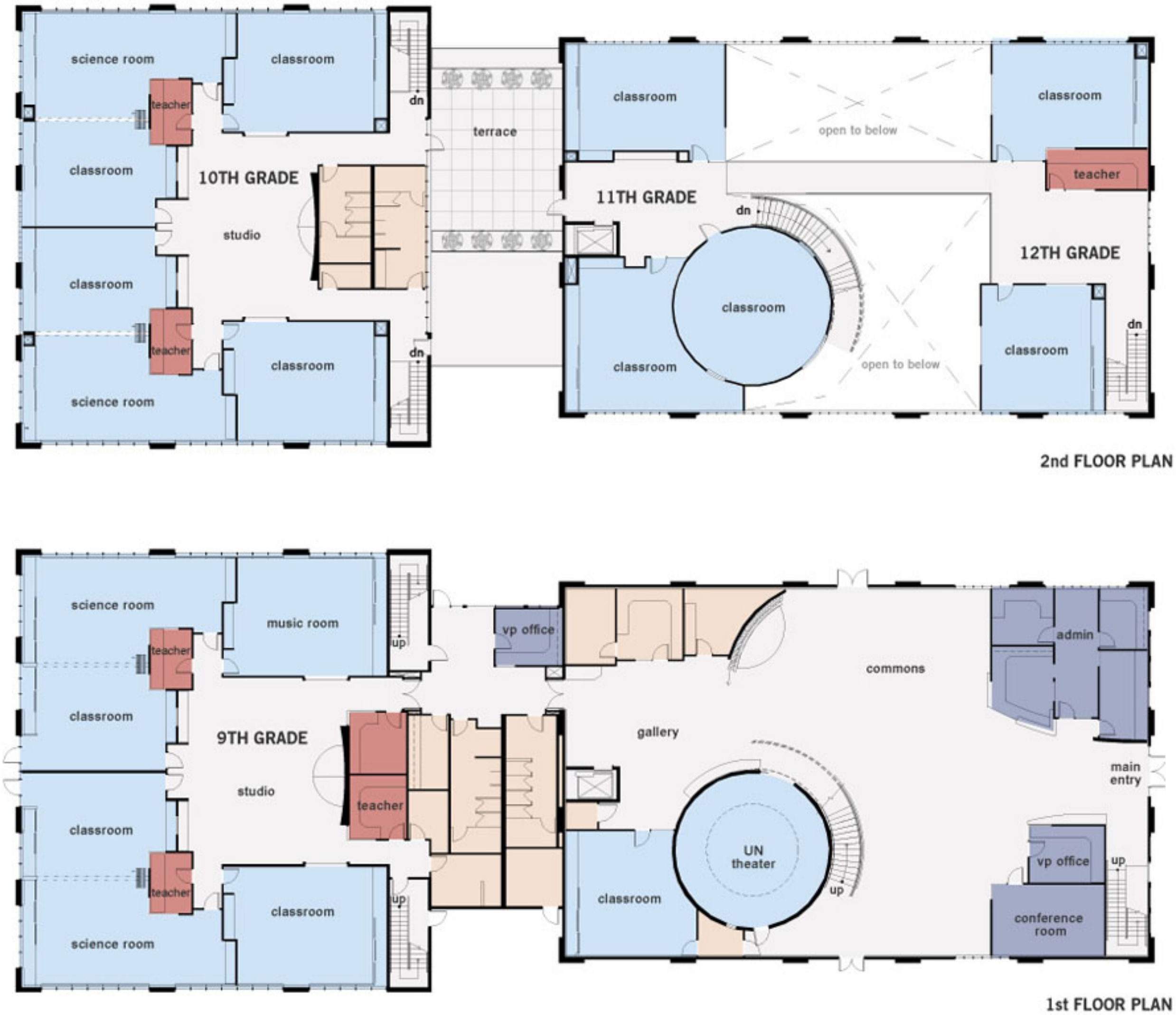


FIGURE 47: High Tech High Plans. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

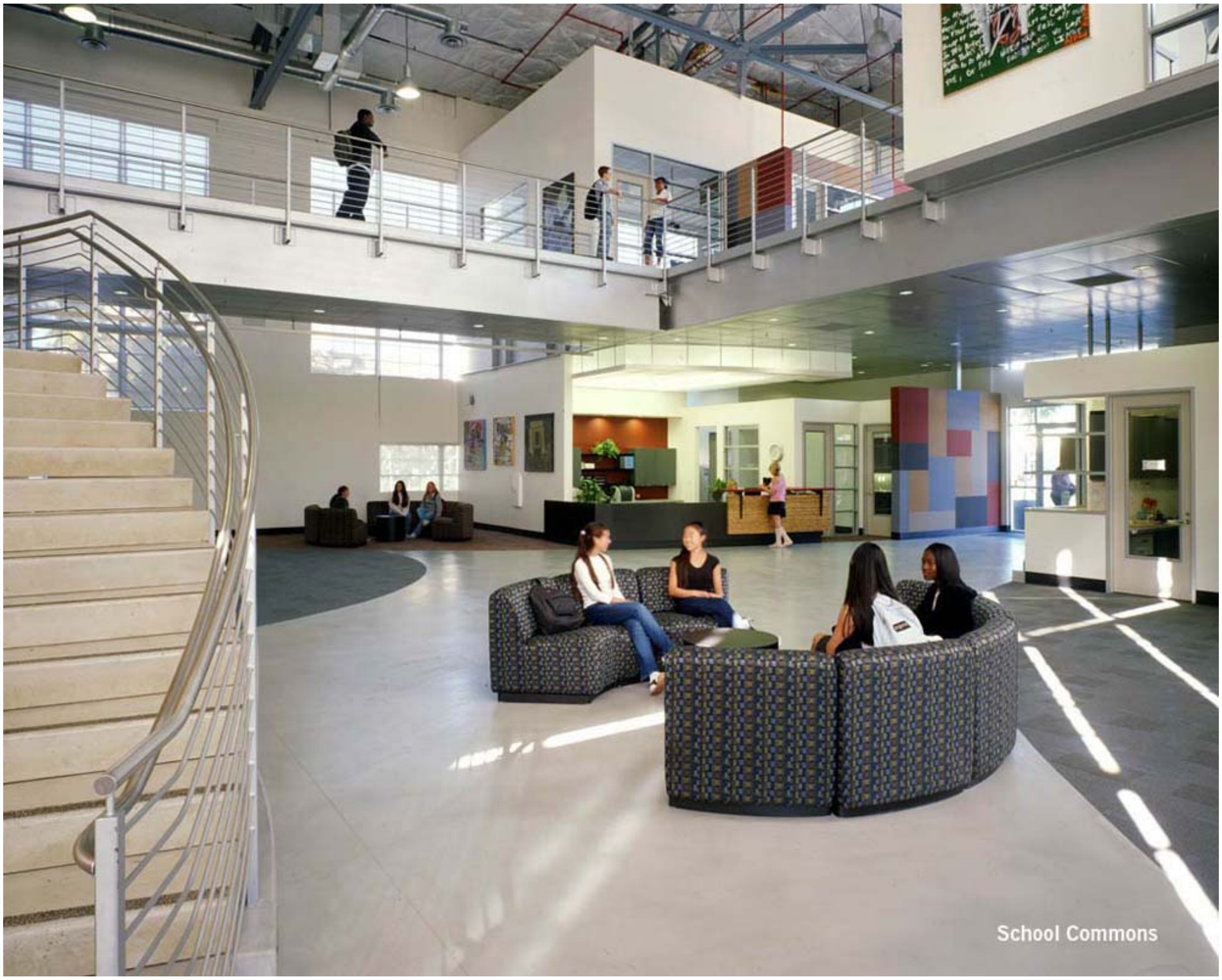


FIGURE 48: High Tech High. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

FIGURE 49: High Tech High. (Images: Architectural Record. (2010). Schools of the 21st Century. http://archrecord.construction.com/projects/building_types_study/TypeIndex.aspx?bts=K12)

CHAPTER 6: DEFINING THE PROJECT

6.1 PROJECT BRIEF

Therrell High School, in the Atlanta Public School System, is one of the district's poorest performing schools. It is being reconceived, under the High School Improvement Initiative, as three small learning academies: Science, Technology, Engineering and Math; Health and Biotechnology, and Public Safety and Government.

Each academy requires a large amount of standardized programming (20 typical classrooms and 4 science labs) but also unique labs, workshops, and learning spaces geared toward its own themes. Each academy will hold 300-400 students and will house its own administrative body (principal and key administrators). Classes will average 26-28 students and will continue to follow conventional grade level segments of 9th, 10th, 11^{th}, and 12th grades.

Parking, Physical Education, Fine Arts (including Performing Arts), Media Center, Health Center, and Cafeteria will be large programmatic needs shared by all academies. A central administration office will also be shared by all academies and will serve as a main entry point to the school as well as housing Records, the Registrar's Office, Conference Rooms, etc.

Situated just inside I-285 in suburban Southwest Atlanta, the site features heavily wooded areas to the north and rolling topography with significant elevation changes. Panther Drive, on the south edge of the site, currently serves as the main entrance. A secondary road to the east and a small, utility road to the west border the edges of the site but do not provide entry access to the property at present.

6.2 PROGRAM

The given program for Therrell High School is as follows, as stipulated by the Atlanta Public School System. It reflects not only the three Small Learning Communities specific to the school, but also all other programmatic areas that will need to be addressed by the design proposal.

TABLE 2A: Program (Pg 1 of 2).

#	Space	Sq Footage (per space)
	CLASSROOMS	
41	**Typ Multipurpose Classrooms**	**750**
17	Language Arts	
13	Mathematics	
1	Math Lab	
13	Social Sciences	
8	Foreign Language Classrooms	
2	ESOL	
1	Foreign Language Lab	
1	Hearing Impaired (w/add mech + office)	750
1	ISS Classroom	750
3	Itinerant Teacher Classrooms	750
3	PEC Classrooms	750
	SCIENCE	
12	**Science Labs**	**1000**
4	Biology Labs	
2	Chemistry Labs	
1	Physics Lab	
5	Science Prep/Stock Rms (shared between 2 labs)	260 each
1	Additional Mechanical Space	
	HEALTH OCCUPATIONS	
1	**Main Space (seats 28)**	**840**
1	Classroom (seats 25)	750
1	Teacher Work Room	400
1	Office	140
1	Restroom Men	50
1	Restroom Women	50
1	Kitchen	Comply with GDOE rqrmnts
1	Patient Beds (x3)	
	Exam/sick room	100 each
1	Additional Mechanical Space	
	CULINARY ARTS	
1	**Kitchen (for industrial kitchen equip)**	Comply with GDOE rqrmnts
1	Pantry	200
1	Linen	150
1	Prep Space	(part of kitchen)
2	Offices	150 each
	BIOTECHNOLOGY	
1	**Main Space (for 46; central demo table, counter/sinks)**	**1000**
3	Computer Workstations	140
	PUBLIC SAFETY	
	Main Space (seating for 37)	**1110**
	Jury Box (seating for 12)	170
	Judges Stand	
	Witness Stand	
	Classroom for 25	**750**
	Office	150
	Storage	250
	Teacher Work Space	400
	FINE ARTS	
1	**Main Space for art work stations**	**1000**
1	Kiln Room	350
1	Supply Room	250
1	Office	150
1	Storage	250
2	Restrooms Men	60
2	Restrooms Women	60
1	Teacher Work Area	150
1	Spray Booth	100
1	**Photo Lab (dark room)**	**750**
1	Chemical Storage	100
1	**Multi-Purpose Classroom/Film Processing**	**750**
2	Flm Loading	50
1	Gallery	500
	STUDIOS	
2	**Multi Purpose Studios**	**1000**
1	Office	150
1	Storage	250
	ENGINEERING	
1	**Main Space (seating for 24)**	**1000**
1	**Stage**	**1200**
1	**Lecture Classroom (seating for 25)**	**750**
1	Robotics Lab	1000
1	Tool Storage	250
1	Additional Storage	
1	Office	150
1	Teacher Work Space	150
1	Additional Mechanical Space	
	TECHNOLOGY ENERGY LAB	
1	**Main Space (seating for 28)**	**840**
1	**Computer Workstations (x25)**	**1200**
2	Offices	150 each
1	Storage	250
	THEATER	
1	Theater (seating for 300)	
1	Audience Seating	
1	Stage	800
1	Control Room	100
1	Ticket Booth	200
1	Stage Shop/Storage	800
1	Costume Room	150
1	Dressing Rooms Men	100
1	Dressing Rooms Women	100
1	Additional Mechanical Space	
1	Dance Room	750

TABLE 2B: Program (Pg 2 of 2).

	ADMIN	
3	Principal Office	200-350 each
3	Graduation Coach Office	120 each
3	Admin Office	180-200 each
3	Connselor Office	150 Each
3	Misc. Office	
1	Waiing Area	400
1	Receiptionist	150
3	Secreterial Workspaces	120 each
1	Registrar's Office	180
1	Records Storage/Storage/Supplies	300
1	General Storage/Supply Room	200
2	Conference Rooms	400
2	Staff Restrooms	40 each
2	Public Restrooms	60 each
1	Parent Center	750 each
1	In School Suspension Room	120
1	Vault Room	75
1	Archives	based on school need
1	Records Storage	130
	RESTROOMS	
1 per floor	Public Men and Women (8)	60 each
1 per floor	Admin/Educator Men and Women (2)	40 each
	MEDIA CENTER	
1	**Main Room**	**2000**
	x36 10' book shelves	
	x5 tables for 4	
	x2 tables for 6	
	x12 double tables for individual work	
	x10 soft seats	
	x24 work stations	
1	**Computer Classroom**	**1200**
1	Work Room	240
1	Restroom Men	60
1	Restroom Women	60
2	Group Work Rooms	120
1	Circulation Desk	200
1	Office	150
1	Storage	170
	BAND ROOM	
1	**Main Room (to seat 60)**	**2000**
1	Equipment Storage	300
1	Uniform Storage	300
1	Office	150
2	Practice Rooms	80
1	**Choral Room**	**2000**
1	**Orchestra Room**	**2000**
1	General Classroom	750
1	Music Storage	250
	GYM	
1	**Main Gym (seating for 500)**	**8000**
1	**Practice Gym**	**5000**
1	**Weight Room**	**1000**
1	**Locker Rooms (M+W, Home+Visitors)**	**2000 each**
1	Team Storage	TBD based on need
1	General Storage	750
6	Offices	150
1	Trainer	200
1	Laundry	150
2	Health Classrooms	750 each
1	Restrooms Men (8)	60 each
1	Restroms Women (8)	60 each
1	Tickets/Box Office	200
1	Concessions/Spirit Store	300
1	Athletic Director Office/Shower/Toilet	230
1	P.E. Coaches' Office/Shower/Toilet	350 each
1	Visiting Team Room	500
1	Staff/Coach Showers	250
1	Vending	100
	DINING HALL	
1	**Main Space (seating for 330)**	**4000**
1	**Kitchen**	**3000**
1	Office	150
1	Storage	200
1	Pantry	200
	Additional Mechanical Space	
1	Food Court Servery Stations	1000
	HEALTH CLINIC	
1	Main Clinic	140
2	Exam Rooms	100 each
2	Offices	150
1	Restrooms Men	50
1	Restrooms Women	50
	OTHER	
	Parent Center	750
	Career Center	120 each
	General Meeting Room	400 each
	School Store	300
	Lobby	400
	FACILITY SUPPORT	
1	Building Mechanical Office	150
6	Custodial Closets	35
2	Custodial Storage	300

6.3 SITE

The site for Therrell High School sits in a low density, suburban context on the southwest side of Atlanta, GA. Neighboring subdivisions and wooded areas surround the school with strip-mall retail close by but not on the same street as the primary school entrance.

The site features rolling topography with several feet of grade change. It borders, on the north end, an elementary school also within the Atlanta Public School system.

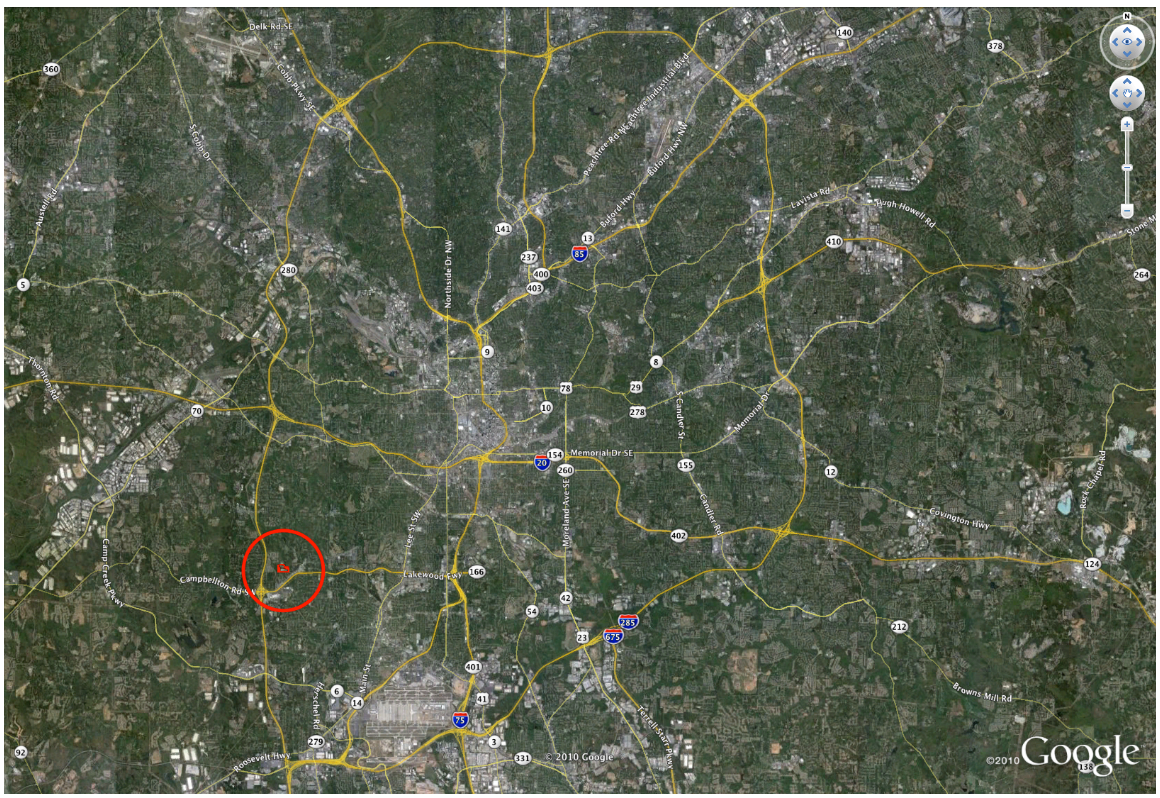


FIGURE 50: Site (within red circle) in relation to the greater metropolitan Atlanta area. (Google Earth, 2010).

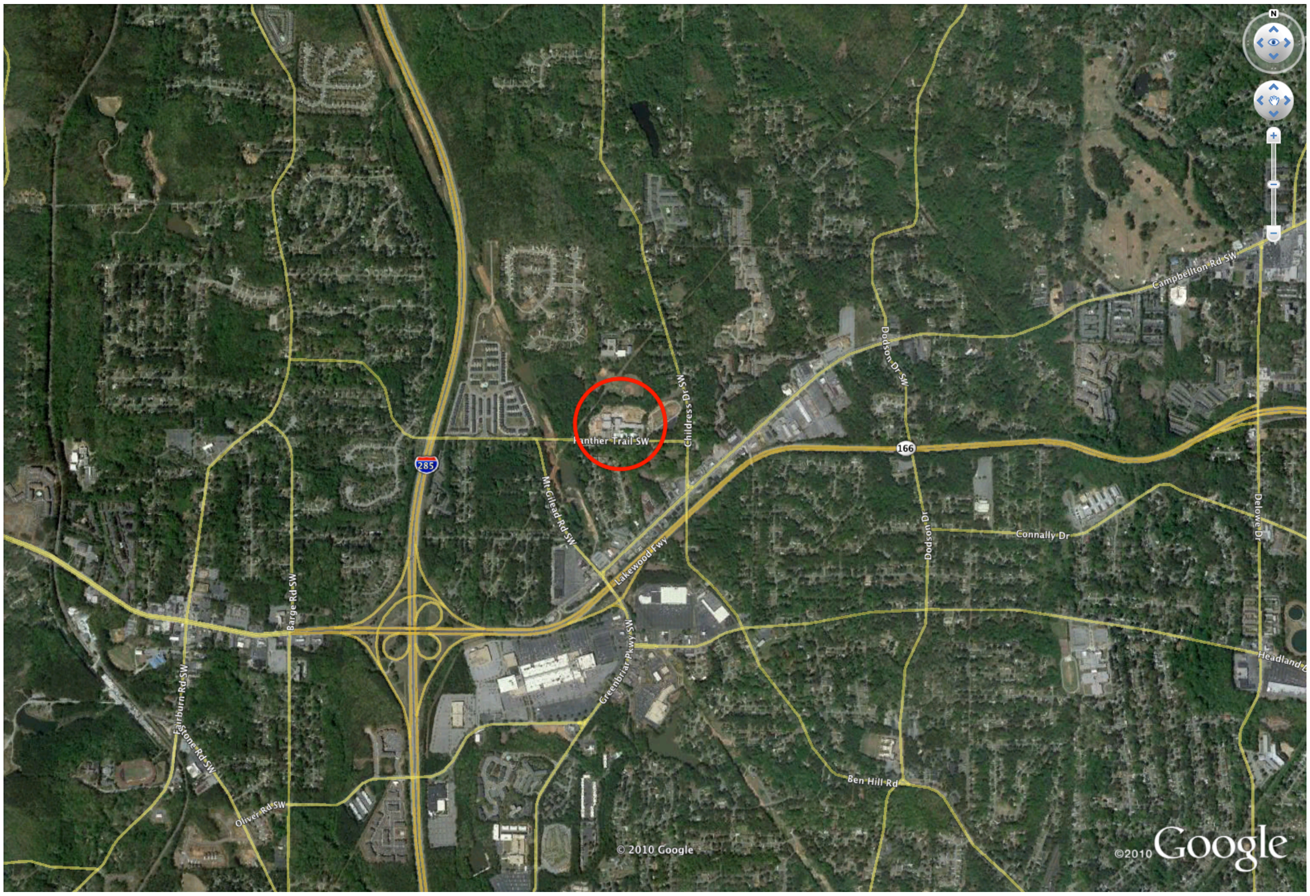


FIGURE 51: Site (within red circle) in relation to nearby major highways. (Google Earth, 2010).

FIGURE 52: Site (within red circle) in relation to nearby neighborhoods. (Google Earth, 2010).

FIGURE 53: Site, including existing facility and athletic fields. (Google Earth, 2010).

FIGURE 54: Surrounding context. (Photos by author).

FIGURE 55: Surrounding context. (Photos by author).

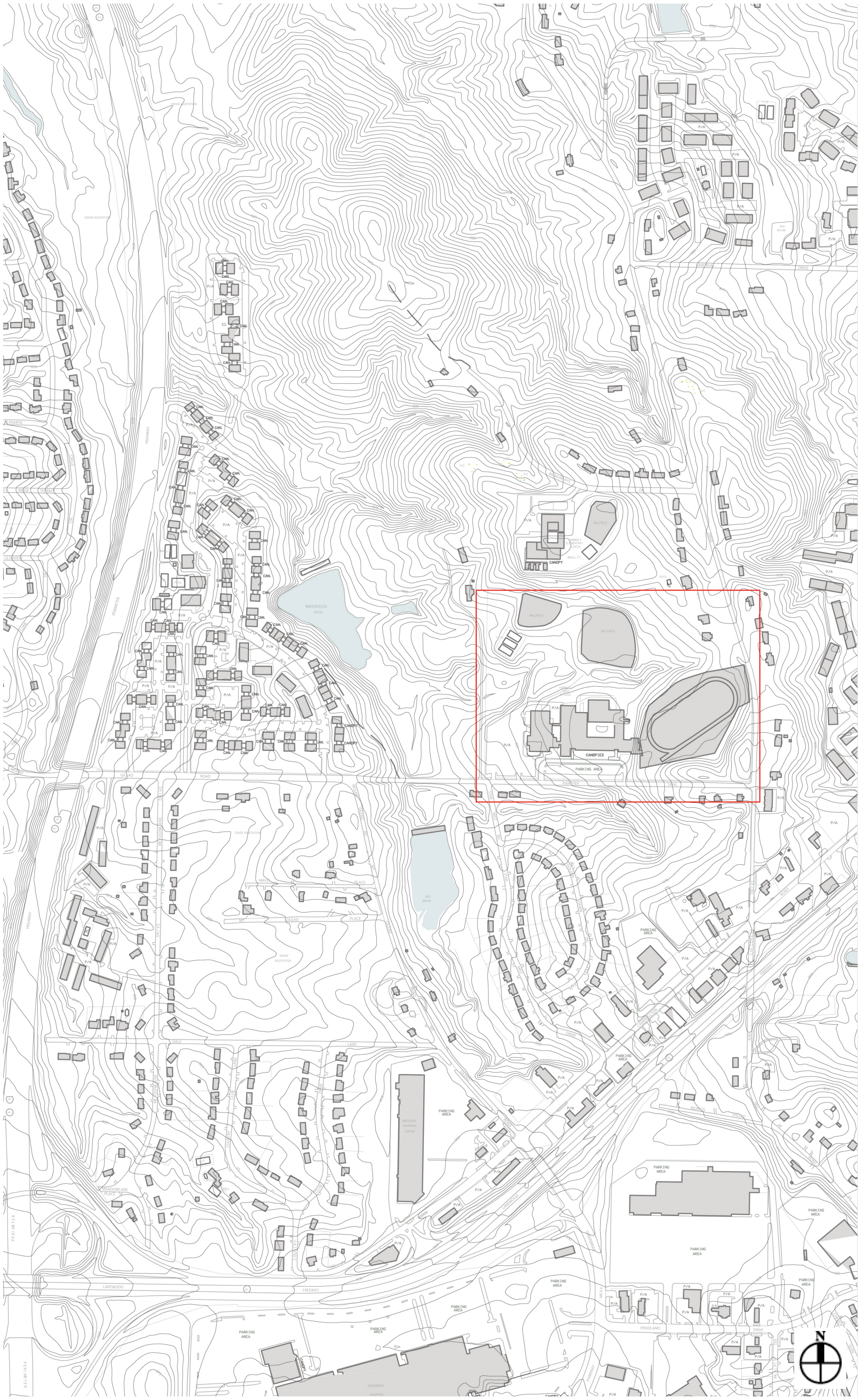


FIGURE 56: Site (within red box) showing Therrell High School in relation to surrounding context.

6.4 DESIGN GOALS

Small Learning Communities

Taking the idea of the SLC initiative that inspired three 300-400 student academies, this project seeks to cultivate even smaller communities within each academy. The environments for these take the form of family-sized spaces, clusters of locker spaces, and break-out spaces throughout the school that can be appropriated by both students and teachers to make places for small groups to socialize, teach/learn, and otherwise share the school experience in their own, non-programmed ways. This concept of flexibility, adaptability and spontaneous social and educational use is also taken to the scale of the individual classroom and including several sizes of spaces including: small (individual student), medium (4-6 student group), and large (26-28 student class).

Connection to Outdoors

As lighting and air quality are two of the most significant environmental drivers of student performance, connections to the outdoors (particularly in classrooms) are prioritized in this project. Each classroom will connect to a secure courtyard space that acts as a viable auxiliary teaching space while serving rooms with light and air. These spaces may be fully open-air or covered, shaded or partially enclosed to address seasonally use.

Flexibility of Facilities

School buildings are typically not built to expand easily and therefore temporary ("portable") units are utilized to address additional classroom needs year to year. This project proposes a modular system that allows for yearly expansion without the significant demolition, reconstruction, or reorganization of the main facility.

CHAPTER 7: THE DESIGN PROPOSAL

7.1 PROPOSED PLAN

As a component of this thesis project, the following design proposal has been collaboratively conceived with fellow Georgia Tech MArch students Emily Finau and Megan Fagge. It represents a collective effort by all three students to infuse individual research into a single design proposal. The following discussion and diagrammatic explanations, however, will remain focused on the research topics proposed by this thesis.

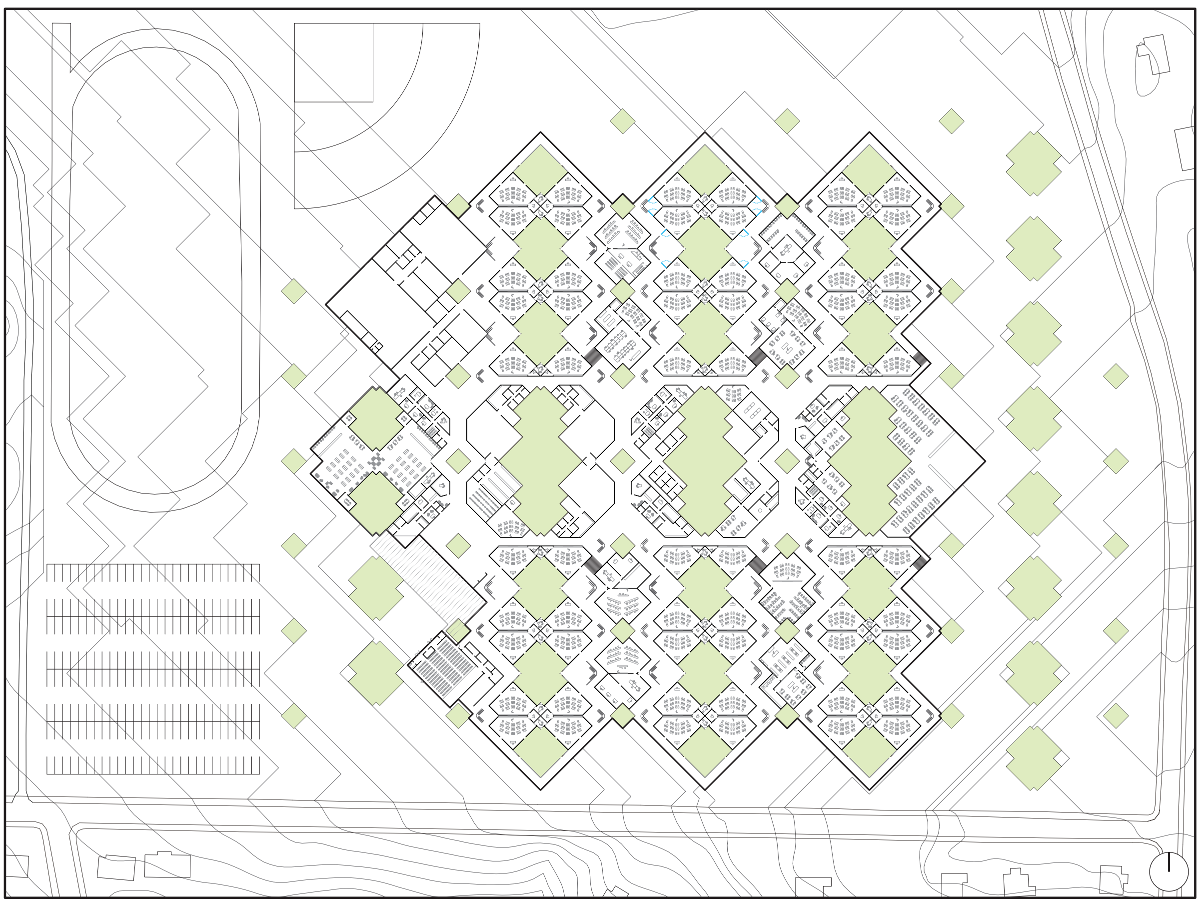
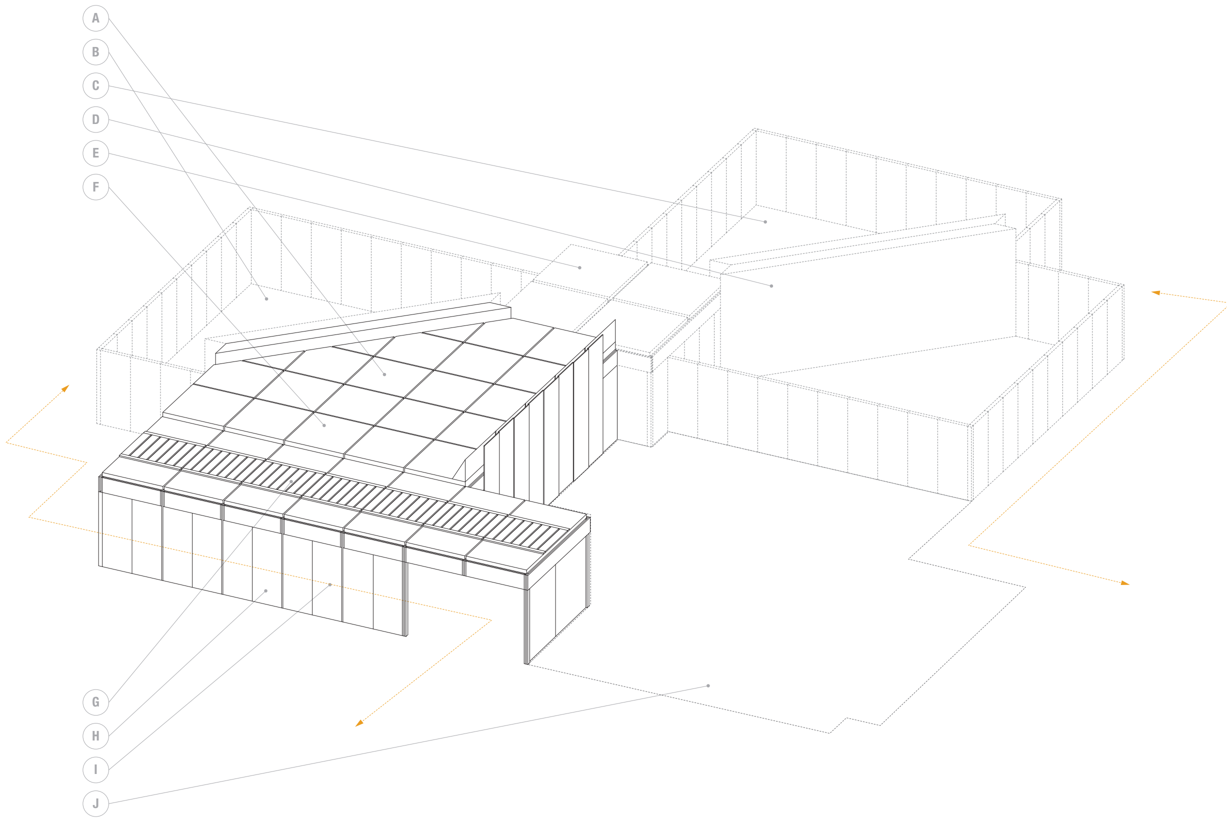


FIGURE 57: Proposed Site Plan.

7.2 MODULAR SYSTEM

Given the need for expansion, flexibility and variety of materials and spaces, sets of modules are created at multiple scales. The smallest construction element of the system is based on modular **panels** used for wall and roof conditions. A full menu of panel assemblies includes and tilt-up concrete primary wall that serves as a main “teaching wall” supporting a SmartBoard®, bulletin boards, and containing embedded systems, such as electrical and HVAC. It also includes wood and steel framed interior wall panels filled with a selection of transparent and translucent polycarbonate panels and opaque wood panels.

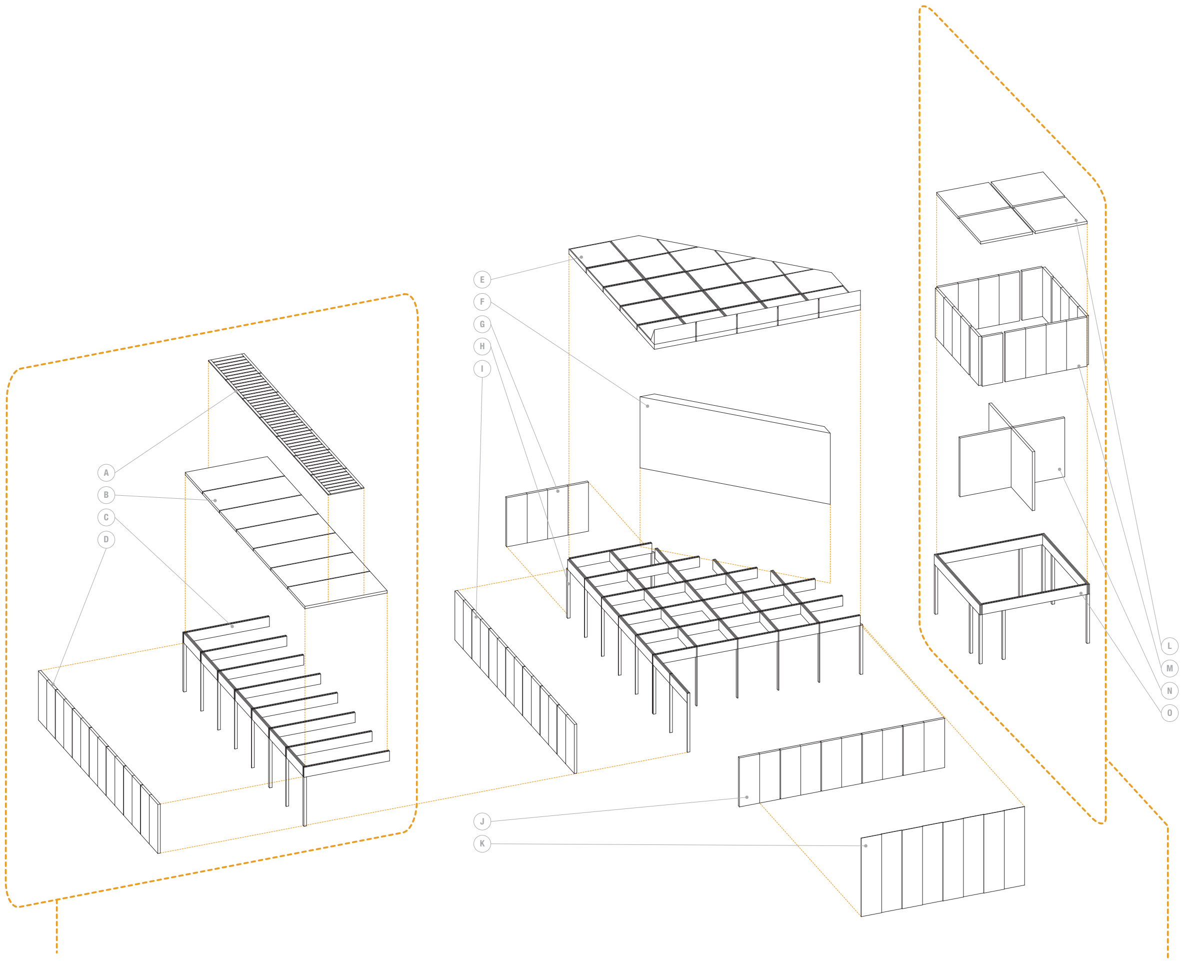
As these modular assemblies aggregate and form larger building parts, pentagram **classroom modules** are established that can easily be nested into a four-classroom cluster joined by a modular set of four **break-out spaces** (two for individual student work and two for small group work). By placing one set of four modules next to another set, the resulting space forms a courtyard, providing bounded learning space in an open-air setting. Space surrounding the classroom modules can then be connected by an expandable **circulation module** serving as corridor and exterior façade.



NESTED CLASSROOM MODULES

A.) Classroom #1
B.) Classroom #2
C.) Classroom #3
D.) Classroom #4
E.) Brea-out Spaces (x4)
F.) Green Roof
G.) Walkable Roof Path (Wood Decking)
H.) Exterior Facade Panels
I.) Circulation
J.) Courtyard Space

FIGURE 58: Axon Drawing: Nested Classroom Modules.



CORRIDOR

A.) Wood Decking Pathway
B.) Translucent Roof Panels
C.) Wood Structure
D.) Glass Facade Panels

CLASSROOM

E.) Green Roof Panels
F.) Tilt-up Wall
G.) Glass Facade Panels
H.) Wood Structure
I.) Interior Panel System
J.) Glass Facade Panels
K.) Exterior Shading Panels

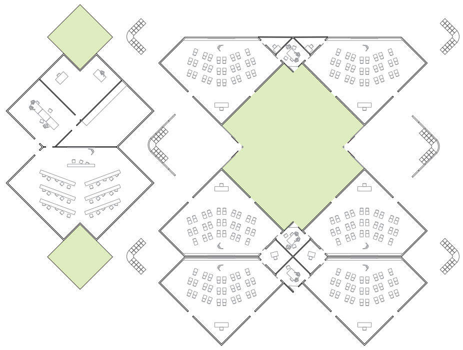
BREAK-OUT

L.) Translucent Roof Panels
M.) Interior/Exterior Panels
N.) Tilt-up Wall Panels
O.) Wood Structure

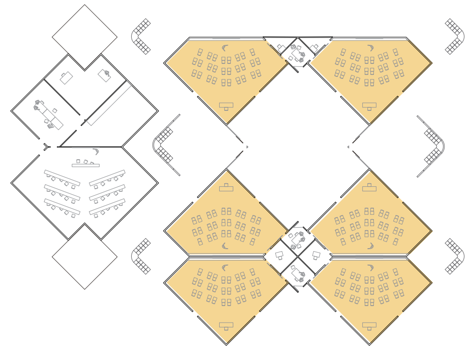
FIGURE 59: Exploded Axon Drawing: Modular Elements.

7.3 MULTIPLE LEARNING ENVIRONMENTS

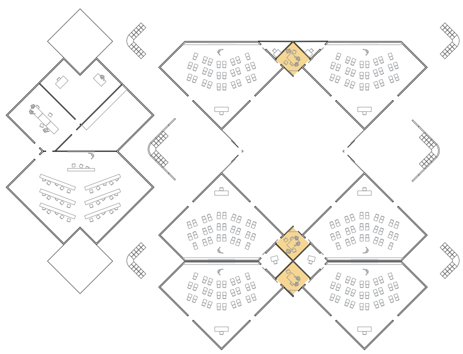
Prioritizing the need for many environments capable of facilitating learning, this proposal offers a menu of potential teaching and social areas. Within the classroom, formal lectures may be held, small groups may utilize break-out spaces, and individuals may work in solitude. Additionally the interior walls of the classroom pivot out into the corridor allowing the circulation space to be used as class space during class periods. Finally, each classroom is connected to a courtyard, allowing both fresh air and daylight to enter the room as well as granting the educator access to an enclosed outdoor area that can also be used for class.



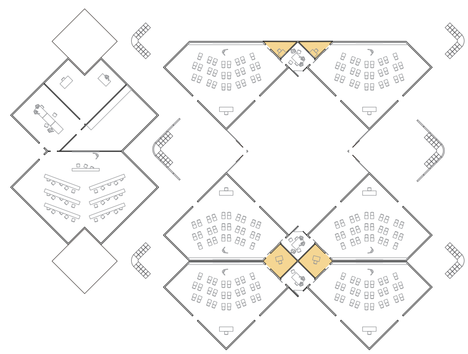
OUTDOOR COURTYARD SPACE



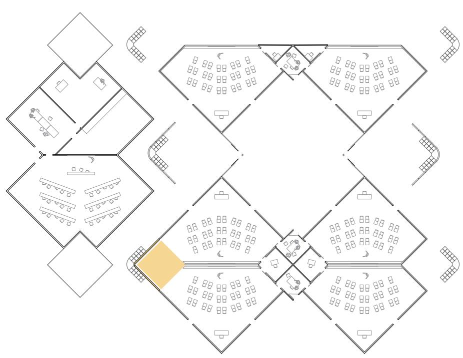
LARGE CLASSROOM LECTURE SPACE



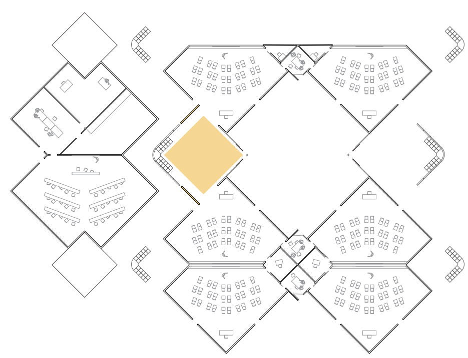
SMALL GROUP BREAK OUT SPACE



INDIVIDUAL BREAK OUT SPACE



SMALL CLASS BREAK OUT SPACE



LARGE CLASS BREAK OUT SPACE

FIGURE 60: Multiple Learning Environments.

7.4 FLEXIBLE CONSTRUCTION

Utilizing modular design and construction techniques, this project empowers the school to grow, modify, or change the school facility as it sees fit and when it has need to. Detachable wall assemblies mean more classrooms may be added as well as allowing for the removal of classrooms should the site area be required for another purpose. Either may be achieved through the nesting of classroom modules around an open-air courtyard space (simply connected by added exterior doors) or disassembly of exterior envelope elements.

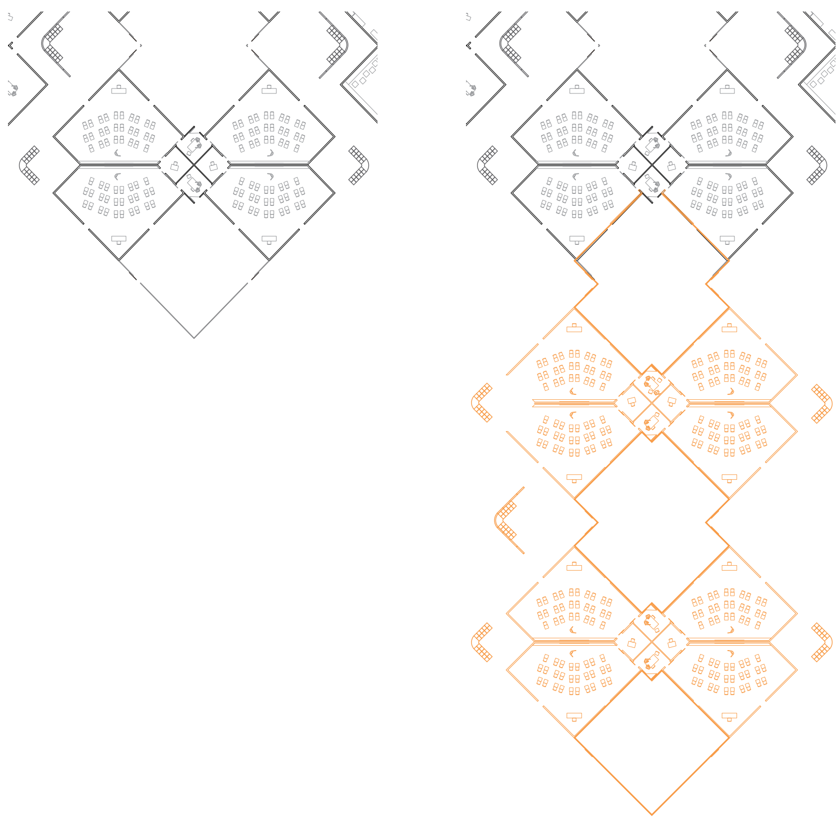


FIGURE 61: Classroom growth.

7.5 CONNECTION TO NATURE

With all classrooms adjoining an enclosed, open-air courtyard, students are constantly awash with fresh air and daylight as well as having the opportunity to leave a predefined classroom's space and exit the building without security risks.

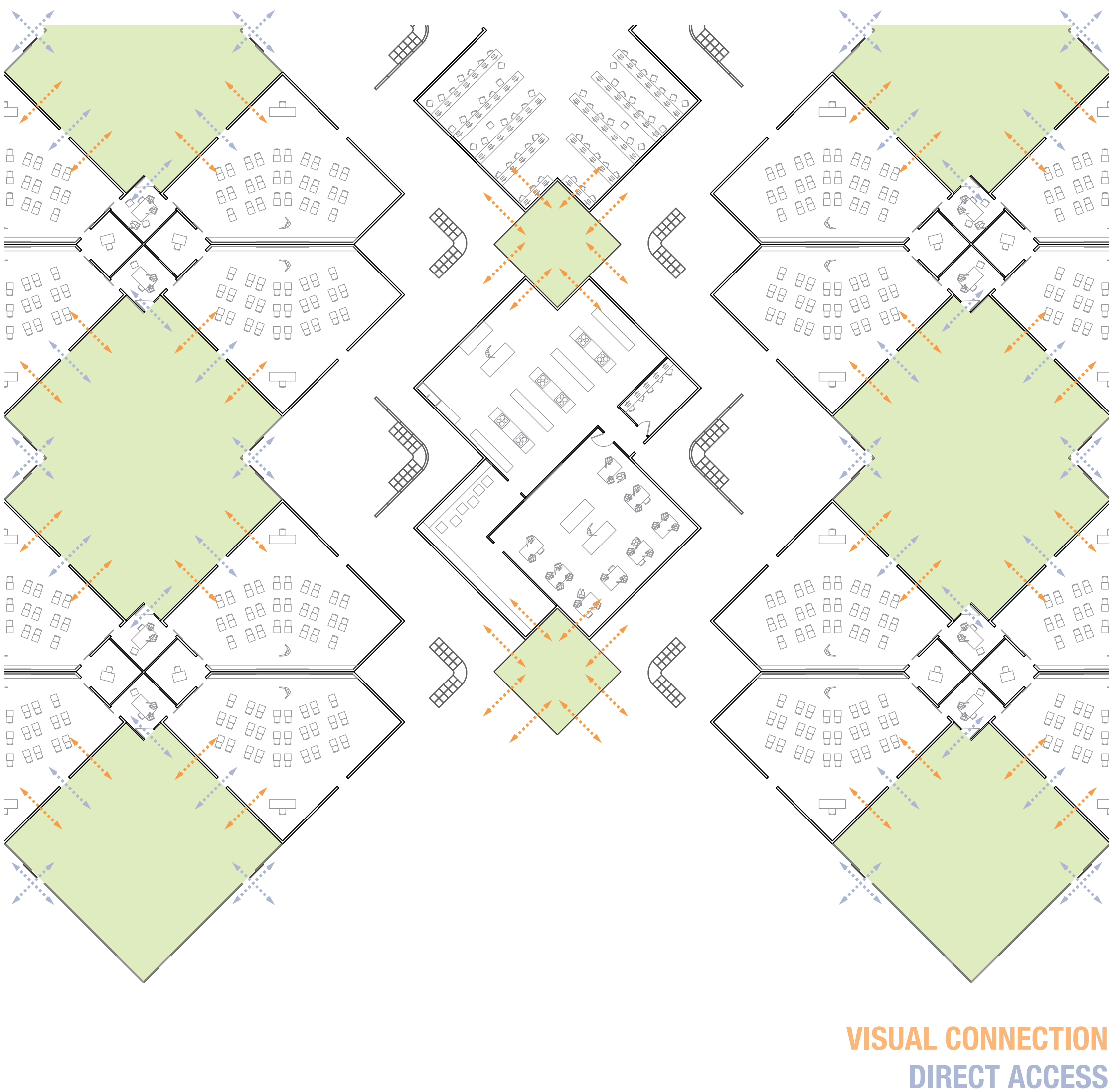


FIGURE 62: Visual and Direct Connections to Nature (Outdoor Courtyards).

7.6 GREEN ROOFS

Because the design proposed is a single story structure in order to maximize light and air into the building as well as address accessibility issues, the roof-tops of the building are engineered as habitable green roofs. The resulting park connects the surrounding community to the school by allowing neighbors open access to the vast green space without the security risks associated with an open campus. The ample vegetative stock will also serve to cleanse the air of the site's micro climate and insulate the building, significantly reducing energy consumption.

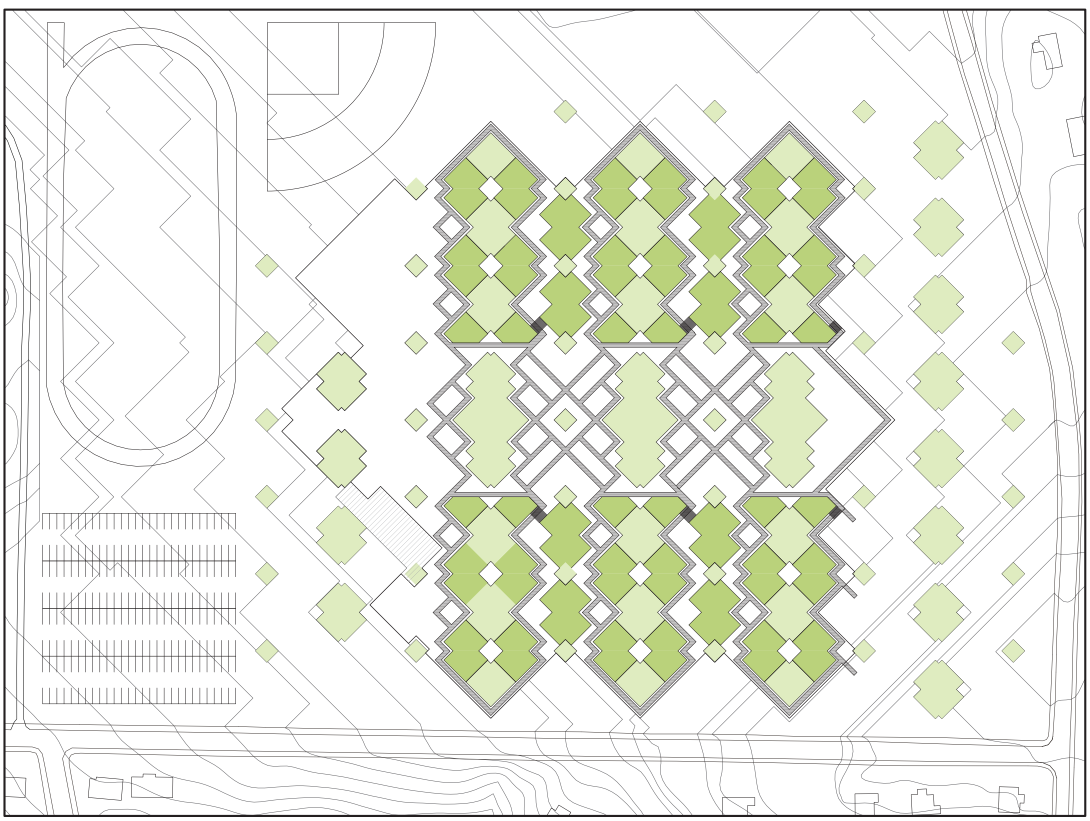


FIGURE 63: Roof Plan displaying green roof park.

7.7 FUTURE GROWTH AND USE

As a flexible construction system, the resultant building may morph and change form drastically over its future life enabling many more unforeseen uses and programs. The building could easily serve a much larger high school student population, include elementary and middle school students, or serve as a community learning center with robust facilities supporting an even larger variety of learning environments.

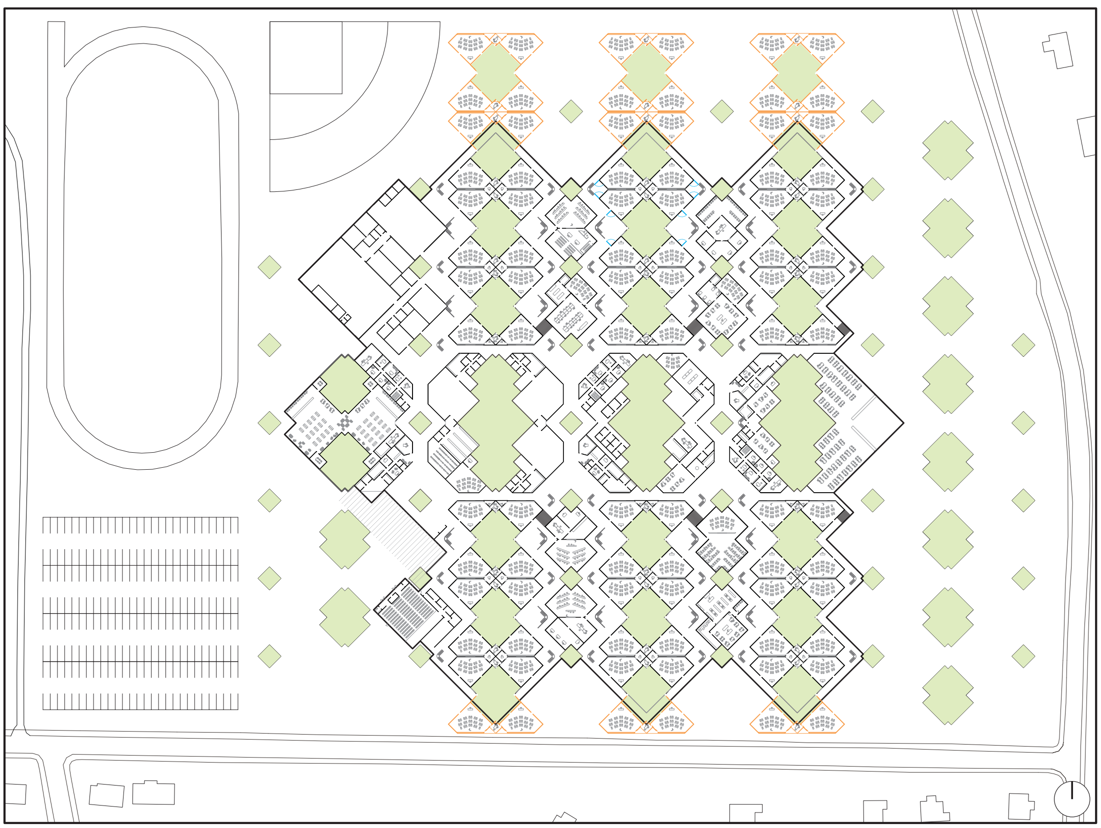


FIGURE 64: Site Master Plan showing possible classroom growth.

CHAPTER 8: CONCLUSION

8.1 SUMMARY AND FINDINGS

Through a focused inquiry into construction systems and fabrication technology, this thesis proposes a variable construction system allowing the mass-customization and reconfiguration of the building structure and envelope through the utilization of a modular wall and facade assembly system. Modular customization exists at three key scales - at the small scale of individual wall panels, at the medium scale of classroom walls able to modulate and reconfigure learning spaces, and at the building scale through the ability to disassemble exterior walls and add, to grow or modify the building as a whole. Such a rich level of customization and assembly is only possible through evolved paradigms of construction technology which are uniquely suited to address the needs of the contemporary American high school of tomorrow.

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