

ABSTRACT

Title of Thesis: OVERCROWDING TO OPPORTUNITY:
REINVENTING THE PORTABLE CLASSROOM

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As schools in the United States face issues with overcrowding and chronic underfunding, many turn to portable classrooms as a cheap, quick, and temporary solution. To house its surging student populations, Maryland utilizes nearly 3,000 portables, chiefly in Prince George's and Montgomery Counties. Despite widespread usage, the portable classroom typology is neglected by architects and investors, who instead focus on ground up construction or adaptive reuse as a solution to school overcrowding. The reality is that portable classrooms are critical for

many overpopulated and underfunded schools to operate. Consequently, when schools are unable to afford new buildings or extensive renovations, these “temporary” structures become permanent. Studies conducted by institutions including UCLA, The University of Houston, Western University, and the California Department of Health Services reveal that these portables often do not meet adequate standards to foster a productive learning and teaching environment. Furthermore, the antiquated design of the prototypical portable renders it difficult to transport and a financial liability for its schools.

This thesis asks, “How might portable classrooms be reinvented to be more adaptable, flexible, and reliable learning environments?” Design parameters will be derived from five “research components”. These parameters will guide a design process to formulate an output that is an architecturally refined, sustainable, and healthy solution which cultivates a more educationally supportive environment for our nation’s youth.

OVERCROWDING TO OPPORTUNITY: REINVENTING THE PORTABLE CLASSROOM

by

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Bibliography

List of Abbreviations

AMC	Adaptive Modular Classroom
EPA	United States Environmental Protection Agency
EPRC	Energy Positive Relocatable Classroom
IAC	Maryland Interagency Commission on School Construction
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
HISD	Houston (Texas) Independent School District
LCPPC	Lakeland-College Park Community Center
MCPS	Montgomery County (Maryland) Public Schools
MNCPPC	Maryland National Capitol Parks and Planning Commission
PBES	Paint Branch Elementary School
PBLCP	Paint Branch-Lakeland-College Park
PGCPS	Prince George's County (Maryland) Public Schools
SOC	Sense of Coherence
RC	Research Component
VOC	Volatile Organic Compound

Chapter 1: Introduction

School is a foundational experience for children. It is not just the place where they go to learn and study, it is where they become integrated into society and find their place within the world. The school environment adds immensely to a child's sense of self and the interests, skills, and personal qualities that define their identity.¹ Those currently in school will eventually be able to vote on matters that are of national importance, therefore the significance of education is as much societal as it may be personal. As of 2025, the United States public school system consists of more than 98,000 public preK-12 schools serving 49.4 million students.² Children spend an immense amount of time in school. By the age of 18, this total can amount to 24,000 hours, with up to one in five of all Americans spending part of every day in a school building.³

Yet, the American education system is in crisis. A 2020 Yale University study profiling high schoolers nationwide reports that 75 percent of student feelings towards school were negative.⁴ Having such feelings of disdain for a place where children spend so much of their time is disturbing. In his 2025 article "America is Sliding Towards Illiteracy" published in *The Atlantic*, Idrees Kahloon highlights startling regressions amongst student test scores, including 33 percent of eighth graders reading at a level "below basic". Kahloon reasons that a primary culprit for these declining rates of literacy is "a pervasive refusal to hold children to high standards."⁵ While this assertion is certainly concerning, it begets another question - how can

¹ Leanne G. Rivlin and Carol S. Weinstein, "Educational Issues, School Settings, and Environmental Psychology," *Journal of Environmental Psychology* 4, no. 4 (1984): 347–64, [https://doi.org/10.1016/S0272-4944\(84\)80005-5](https://doi.org/10.1016/S0272-4944(84)80005-5).

² American Society of Civil Engineers, *2025 Infrastructure Report Card: Schools* (Washington, DC, 2025), <https://infrastructurereportcard.org/wp-content/uploads/2025/03/Schools.pdf>.

³ Ed Young et al., "Do K-12 School Facilities Affect Education Outcomes?", January 2003.

⁴ Julia Moeller et al., "High School Students' Feelings: Discoveries from a Large National Survey and an Experience Sampling Study," *Learning and Instruction* 66 (April 2020): 101301, <https://doi.org/10.1016/j.learninstruc.2019.101301>.

⁵ Idrees Kahloon, "America Is Sliding Toward Illiteracy," *The Atlantic*, October 14, 2025, <https://www.theatlantic.com/ideas/archive/2025/10/education-decline-low-expectations/684526/>.

we expect students to adhere to high standards if they are not being provided adequate environments in which to learn?

Literature from institutions such as the US Department of Education (Schneider, 2002; Young, 2003), University of California, Los Angeles (Earthman, 2002), Yale University (Lafortune and Schonholzer, 2018), and Johns Hopkins University (Berman et al., 2018), affirm the condition of school infrastructure is integral to the performance of students and teachers. Yet across the United States, it is common to see a cluster of uninspiring portable classrooms occupying a school's parking lot, outdoor basketball court, or playing field (Fig X.X). As schools in the United States face issues with overcrowding and chronic underfunding, many turn to portable classrooms as a cheap, quick, and temporary solution.



Fig. 1.1: An arrangement of portable classrooms (source: Adobe Stock)

The National Center for Education Statistics, part of the US Department of Education, qualifies a school as underpopulated or overcrowded if the enrollment is 5 percent greater or less than the school's capacity. A comprehensive review of the nation's schools in 1999 revealed that 22 percent of schools nationwide were overcrowded, equating to about 17,400

schools. Fig X.X shows that overcrowding is more prevalent in more urbanized areas and in the South and West regions.⁶

<i>Fig. 1.2 : Overcrowding percentage by school characteristic (Source: NCES, 1999)</i>			
School Characteristic	Percentage of schools overcrowded nationwide (6-25 percent)	Percentage of schools overcrowded nationwide (>25 percent)	Total
All Public Schools	14	8	22
Instructional Level			
Elementary	15	8	23
High School	11	8	19
Locale			
Central City	15	11	26
Urban Fringe	17	8	25
Rural	11	6	17
Region			
Northeast	11	4	15
Midwest	10	5	15
South	18	8	26
West	18	15	33

Overcrowding is a serious issue if left unchecked. It can result in higher rates of absenteeism, burnout, and stress amongst students and teachers. Furthermore, students in smaller classes tend to have superior academic achievement and individualized instruction.⁷

⁶ U.S. Department of Education, *Condition of America's Public School Facilities: 1999*, Government Report NCES 2000-032 (National Center for Education Statistics, 2000), <https://nces.ed.gov/pubs2000/2000032.pdf>.

⁷ Glen Earthman, *School Facility Conditions and Student Academic Achievement*, Technical Report wws-rr008-1002, Williams Watch Series: Investigating the Claims of Williams v. State of California

More students can also increase the rate of wear and tear on school facilities.⁸ The root issue of overcrowding, however, is complex and involves variables of policy, demographics, funding, and macro/micro economic trends. The scope of this thesis is not broad enough or technically capable of solving this root issue. Assuming overcrowding will remain a pressing issue under current conditions, it is clear that portables play a crucial role as a consequence mitigation stopgap.

Given the persistent issue of overcrowding, we must ask, “What can architecture on its own solve?” Despite widespread usage, the portable classroom typology is neglected by architects and investors, who instead focus on ground up construction or adaptive reuse as a solution to school overcrowding. Unfortunately, the American Society of Civil Engineers estimates that there is an \$85 billion funding gap between current facility conditions and reaching a state of good repair.⁹ Thus, the reality is that many overpopulated and underfunded schools will continue to utilize portable classrooms as a critical crutch to operate.

Consequently, when schools are unable to fund new buildings or extensive renovations for years, these “temporary” structures become permanent. Studies conducted by institutions including the University of California, Los Angeles (Shendell et al., 2004), University of Houston (Branham, 2004), Western University (Riveros, 2023; Riveros and Zhou, 2025), and the California Department of Health Services (2004), reveal that these portables often do not meet adequate standards to foster a productive learning and teaching environment. When public school districts rely heavily on the existing typology of portable classrooms, they often fail to deliver quality education to all students, which further negatively shifts support of public education.¹⁰ Furthermore, the antiquated design of the typical portable classroom renders it

(UCLA's Institute for Democracy, Education, and Access, 2002), <https://escholarship.org/uc/item/5sw56439>.

⁸ U.S. Department of Education, *Condition of America's Public School Facilities: 1999*.

⁹ American Society of Civil Engineers, *2025 Infrastructure Report Card: Schools*.

¹⁰ Augusto Riveros, “The Overreliance on Portable Classrooms in Ontario Schools: New Evidence for the Study of Austerity and Disinvestment in Canadian Public Education,” *Canadian Journal of Education / Revue Canadienne de l'éducation* 46, no. 3 (2023): 570–96.

difficult to transport and a financial liability for its schools. With an understanding that the portable classroom will always be utilized, there is a distinct opportunity for architects to reframe how we view the utilization, design, and attitude towards portable classrooms.

This thesis asks, “how can portable classrooms be reimagined to be more supportive, sustainable, and reliable learning environments?” The physical environment can contribute to learning and development in two important ways. First, the actual features of the physical environment can encourage or discourage the processes of learning and development. Second, the processes of designing physical environments can promote the acquisition of skills important to the process of learning and developing.¹¹ Designing spaces to enhance both of these aspects will be crucial to this thesis.

Research methodologies and output will focus on three areas. First is an investigation into the prevalence of portable classrooms, why schools utilize them, and their performance as a learning environment. Second is gaining a comprehension of the ambient and psychological factors critical to optimizing the ideal learning space. Third is exploring innovations in prefabrication and modular construction to provide an option that minimizes environmental impact and site disruption. The response to these findings will be an architecturally refined, sustainable, and healthy solution that cultivates a more educationally enriching environment for our nation’s children.

¹¹ Charles Carney Strange and James H. Banning, *Educating by Design: Creating Campus Learning Environments That Work*, The Jossey-Bass Higher and Adult Education Series (Jossey-Bass, 2001).

Chapter 2: Review of Current Literature

This breath of this chapter is meant to offer context, issues, and possible remedies or opportunities with portable classrooms. How this research flows into the broader project is outlined in Chapter 3: Methodologies, Fig. 3.1. Within this chapter, an introduction offers context to the current typology and usage of portable classrooms. The bulk of this chapter presents research organized into five different “Research Categories” (RC). The intent of each RC is to review information related to issues or potential solutions regarding portable classrooms. Once there is an understanding that the physical classroom environment has substantial effects on those in it, it can be asked, “How can we design a classroom that acts as a catalyst for improved student learning?” To ensure that the end result of this thesis provides an environment conducive to user optimization, design parameters will be created from these research components. The final thesis proposal and architectural response will adhere to these design parameters. Understanding which parameters are important and how they need to be met is the ultimate goal of this chapter.



Fig. 2.1: Typical portable classroom exterior (Source: Modular Genius)



Fig. 2.2: Typical portable classroom exterior and interior (Source: Modular Genius)

Introduction to Portable Classrooms

A portable classroom, also referred to as a “portable”, “trailer”, or “relocatable classroom”, is defined as “a classroom building of one or more stories that is designed and constructed to be relocatable and transportable over public streets”. Although size may vary, they are typically constructed of 12 by 40 foot modular units that are then stitched together to create a full 24 x 40 foot (960 square feet) classroom. Portables are constructed with metal roofs, wall mounted heat pumps with air conditioning, and exterior envelopes of plywood and vinyl.¹² School systems have been utilizing portables since at least the early 1900s (Fig. X.X).¹³

¹² California Air Resources Board and California Department of Health Services, *Environmental Health Conditions in California's Portable Classrooms*, Government Report (2004), http://ww2.arb.ca.gov/sites/default/files/2020-05/pcs_r2l_hi.pdf.

¹³ Riveros, “The Overreliance on Portable Classrooms in Ontario Schools.”

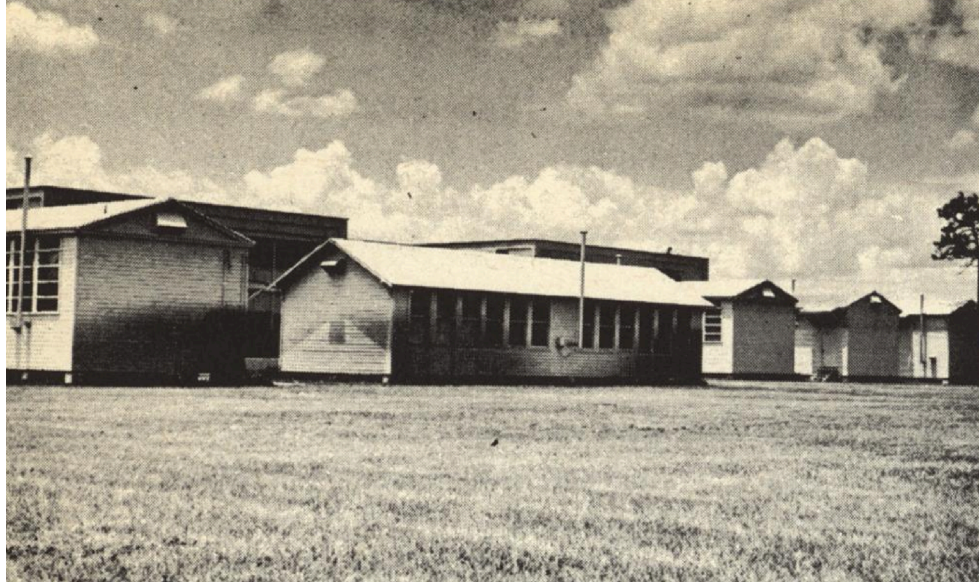


Fig. 2.3: A portable classroom circa 1964 (source: Frank Carioti, Teaching Aids News)

Portable classrooms provide an obvious solution for school districts looking to reach class size restrictions, mitigate overcrowding, and move students during a renovation. These situations also typically occur in the midst of tight budget constraints. In this capacity, portable classrooms serve a critical role. In Maryland, Montgomery County Public Schools (MCPS) identify portables as a direct solution to issues of overcrowding and changing spatial needs in their school in their fiscal year 2025 capital budget, which allocates \$5 million to purchase or lease and install them.¹⁴

Because overcrowding is widespread, the scope of portable classroom usage is similarly broad. As of 2025, there are 200,000 portables used by public school systems throughout the United States according to the Modular Buildings Institute.¹⁵ This does not include portables used by private schools or by third parties, such as general contractors. The usage of portables

¹⁴ Montgomery County Board of Education, *Superintendent's Recommended FY 2025 Capital Budget and the FY 2025-2030 Capital Improvements Program* (Montgomery County Public Schools, 2023).

¹⁵ Modular Buildings Institute, *2025 Annual Report*, Key Financial Data and Metrics for the Relocatable Buildings Industry in North America (Modular Buildings Institute, 2025).

is ubiquitous across the country, as 31 percent of all schools in the country utilize at least one.¹⁶ In 1999, Florida schools averaged nearly 10 portables per school, totaling about 25,000 across the state.¹⁷ In 2001, California public schools utilized up to 85,000 portable classrooms across the state.¹⁸ California's portables house one in three public school students, meaning more than 2 million children learn in a portable.¹⁹ Portables are not isolated to just the United States. In 2020, the Canadian province of Ontario utilized more than 5,200 portables.²⁰ The current portable classroom market is both fractured and competitive, with several distributors offering services in most areas.²¹ In Maryland alone, distributors include Modular Genius, Mobile Modular, Boxx Modular, and Williscott. This raises the question, "If the market is so competitive, why has innovation been lacking?"

¹⁶ NCES, "Nearly One-Third of Public Schools Have One or More Portable Buildings in Use," Government, National Center for Education Statistics, February 14, 2024, <https://ies.ed.gov/learn/press-release/nearly-one-third-public-schools-have-one-or-more-portable-building-s-use>.

¹⁷ Michael Callahan et al., *Evaluation of Energy Efficiency Improvements to Portable Classrooms in Florida*, Technical Report FSEC-CR-1133-99 (Florida Solar Energy Center, 1999), publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-CR-1133-99.pdf.

¹⁸ California Air Resources Board and California Department of Health Services, *Environmental Health Conditions in California's Portable Classrooms*.

¹⁹ D. G. Shendell et al., "Evidence of Inadequate Ventilation in Portable Classrooms: Results of a Pilot Study in Los Angeles County," *Indoor Air* 14, no. 3 (2004): 154–58, <https://doi.org/10.1111/j.1600-0668.2004.00235.x>.

²⁰ Riveros, "The Overreliance on Portable Classrooms in Ontario Schools."

²¹ Nils Gore, "Designing Better Portable Classrooms," *Offsite: Theory and Practice of Architectural Production*, 2012, 121–26.

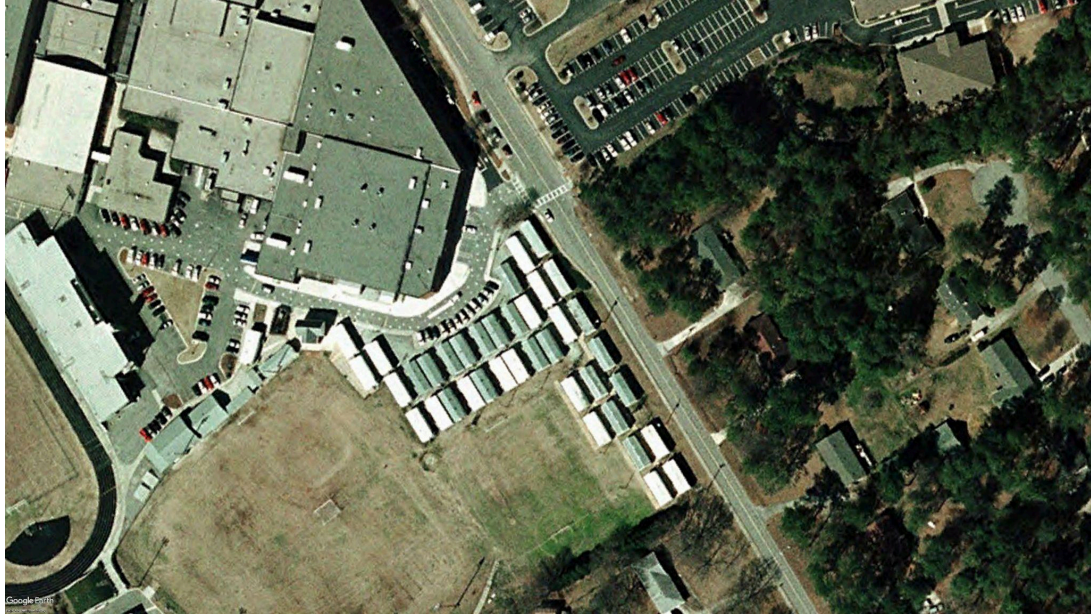


Fig. 2.4: At least 38 portables at South Gwinnett High School, 04/2008 (source: Google Earth)

The number of portables per school can also vary. In most cases, schools do not need more than a handful. There are, of course, exceptions. In one extreme case, South Gwinnett High School (Georgia) peaked at usage of nearly 50 portables (Fig. X.X).²² Another unique example is Louisa County High School in Virginia. In 2011, a 5.8 magnitude earthquake, epicentered in Louisa County, rendered the 71 year old high school a total loss. In 2012, portables were installed to house the entire school population until the new school opened in 2015 (Fig. X.X).²³

²² Tak Cheung Chan, "Do Portable Classrooms Impact Teaching and Learning?," *Journal of Educational Administration* 47, no. 3 (2009): 290–304, <https://doi.org/10.1108/09578230910955746>.

²³ Louisa County Public Schools, "A Timeline of the History of Louisa County High School," Louisa County Public Schools, <https://lchs.lcps.k12.va.us/lchs>.

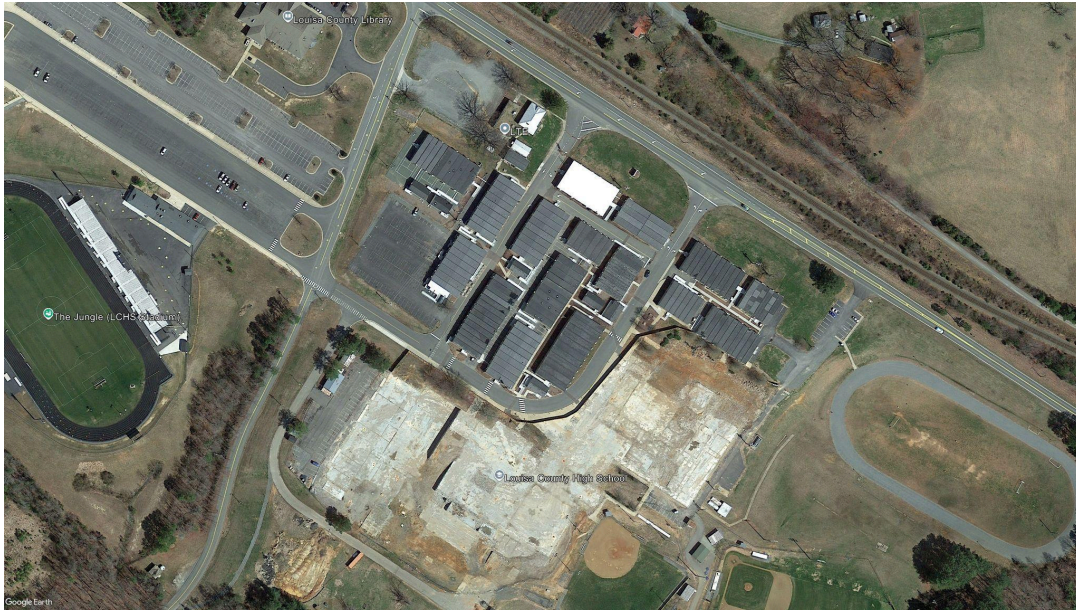


Fig. 2.5: LCHS in portables, demolished school to south, 04/2013 (source: Google Earth)

However, a general trend is that portables are more likely to be found where overcrowding is an issue. But where does that occur? Riveros and Zhou (2025) found that overcrowding may be localized to areas with high numbers of immigrant families and students who speak English as their second language. Their results also show a negative relationship between usage of portables and percentage of students in low income households. While initially surprising, this finding could mean that instead of being supported with portables, these schools serving families of lower incomes are simply being shut down or are not attempting to mitigate overcrowding. This further implies that only wealthier areas can afford to meet class size and facility restrictions through the usage of portables.²⁴ This can be extrapolated into an anticipatory positive feedback loop. Schools in more desirable districts utilize portables as necessary, but because the district is seen as desirable, more move into it, thus exacerbating issues of overcrowding and cementing the important roles that portables play.

²⁴ Augusto Riveros and Chenyang Zhou, "Portable Classrooms: Socioeconomic Context and Implications for Academic Achievement," *Canadian Journal of Educational Administration and Policy*, no. 206 (July 2025): 54–71, <https://doi.org/10.7202/1118734ar>.

The state of Maryland is no exception when it comes to the usage of portable classrooms. In 2025, the state's public schools utilized 2,690 portables.²⁵ Areas closer to metropolitan areas see increased usage of portable classrooms. The counties surrounding Washington, D.C. see particularly high rates of portable classroom usage. Montgomery County Public Schools utilize 474 portables in 2025.²⁶ Neighboring Prince George's County Public Schools (PGCPS) have over 500 portables that house nearly 10 percent of the student population.²⁷ Virginia's Fairfax County Public schools on the western border of Washington, D.C., utilize 785 portable and modular classrooms.²⁸

When "Temporary" becomes "Permanent"

While portable classrooms are seen as an effective stopgap for issues such as overcrowding, they are not intended to be a permanent solution. School districts and administrators anticipate they will be able to secure funding to build new schools, redistrict children to other schools, or enrollment will decline. In most cases, however, once portable classrooms are installed on site, they are there for an extended period of time. The tendency of portable classrooms to become permanent facilities on campus is a trend noted by numerous studies including Callahan et al. (1999), Lewis et al. (1999), Shendell et al. (2004), Chan (2009), Patterson et al. (2009), Gore (2012), Riveros (2023), and Riveros and Zhou (2025). A report by the National Center for Education Statistics found that some portable classrooms have been used for as long as 40 years.²⁹

²⁵ Maryland Interagency Commission on School Construction, Fiscal Year 2026 Capital Improvement Program (The Interagency Commission on School Construction, 2025).

²⁶ Montgomery County Board of Education, Superintendent's Recommended FY 2025 Capital Budget and the FY 2025-2030 Capital Improvements Program.

²⁷ Prince George's County Board of Education, Fiscal Year 2025 Board of Education Approved Annual Operating Budget (Prince George's County Public Schools, 2024).

²⁸ Fairfax County Public Schools, *Fairfax County Public Schools Capital Improvement Plan Adopted 2026-30* (2025).

²⁹ Laurie Lewis et al., *Condition of America's School Facilities: 1999*, NCES 2000-032 (U.S. Department of Education: National Center for Education Statistics, 2001).



Fig 2.6: The same portables at Eleanor Roosevelt High School (MD) from 1993-2025 (source: Google Earth)

Because most districts see portable classrooms as temporary solutions to temporary problems, and thus there is little incentive to invest in a higher quality and more expensive design.³⁰ Reducing the amount of time a portable spends on site is directly correlated to how long it takes for a school district to reduce issues of overcrowding. Preventative and anticipatory measures could be taken by school districts to get ahead of potential issues of overcrowding. Unfortunately, Riveros (2023) finds that districts will only request funding for a new facility once the issues of overcrowding are already present, ultimately extending the amount of time a portable will spend on a campus. The same study showed that 45 percent of schools in Ontario retained the portables on a more permanent timeframe. This was determined by taking the upper amount of time it takes for a school to be built (4 years) and then examining what percentage of portables were kept longer than that (Fig X.X.), up to 10 years.³¹

³⁰ Gore, "Designing Better Portable Classrooms."

³¹ Riveros, "The Overreliance on Portable Classrooms in Ontario Schools."

a. How many schools have 1–4, 5–9, >10 portables?		
Portable Quantity	Frequency	% of Sample
0 Portables	962	34.6
1–4 Portables	1362	48.9
5–9 Portables	392	14.1
> 10 Portables	68	2.4

b. How long do schools maintain portables?		
No. of Years	Frequency	% of Sample
0 Years	962	34.6
1–4 Years	568	20.4
5–7 Years	403	14.5
8–10 Years	851	30.6

Fig. 2.7: Frequencies of portable classrooms duration in Ontario, Canada (Riveros, 2023)

The concept of portable classroom “permanency” is not limited to simply how long a portable classroom sits on a given site. The concept encompasses the fact that portables will always be a necessary tool at the disposal of school districts. Portables will always be in use somewhere. Maryland is no exception, and its schools will be using portables for the foreseeable future.

A main reason for sustained usage of portables is the issue of overcrowding. Many school regions within PGCPs and MCPs face severe overcrowding. For example, in 2025 Langley Park-McCormick Elementary School operates at 156 percent capacity, Charles Carroll Middle School at 150 percent and High Point High School at 144 percent. All of these schools currently utilize portables. These schools all operate in the same “geographic cluster” within PGCPs, indicating that redistricting would not alleviate overcrowding. The high school in the “cluster” with the lowest occupancy is Northwestern High School, which still sits above capacity at 100.26 percent.³²

³² Prince George’s County Board of Education, *FY 26 Capital Budget and FY 2026–2031 Capital Improvements Program* (Prince George’s County Public Schools, 2024).

Another reason portables will continue to be used is a result of aging facilities throughout the country. If a school district does not have the luxury of a dedicated swing school space, portables will likely be used to house students during school renovations. In the United States, schools are in dire need of renovation. In their report 2025 Infrastructure Report Card: Schools, The American Society of Civil Engineers rated American school facilities as a “D+”. The average age of a school is 49 years, with common defects including unreliable electricity, clean drinking water, and functioning mechanical units.³³ Thus, while a portable may not be permanent on a particular site, their availability in a school district’s toolkit ensures that their presence will always be somewhere.

The Maryland Interagency Commission on School Construction (IAC) publishes an annual report that assesses the quality of school facilities statewide, using Facility Condition Index (FCI) as the key metric. FCI is a percentage of the facility’s condition depleted with respect to the expected useful lifespan, and is useful to describe the age and quality of a facility. A higher percentage score indicates that the building has utilized more of its useful lifespan, indicating that the facilities are likely to be in worse condition. The 2025 report shows that statewide, four out of five school facilities sit above 45 percent, classifying them as “needs repair” or “functions unreliable”. Between MCPS and PGCPs, 200 schools score beyond the 45 percent threshold on their FCI score.

MCPS is in a particularly dire situation. Given the current age of their schools, MCPS should be renovating, renewing, or replacing 6-7 elementary schools every year for the next 20 years, at a cost of \$221-345 million every year. Along the same lines MCPS should be renovating, renewing, or replacing 2+ secondary schools every year for the next 20 years, at a cost \$135-210 million every year. In total, this amounts to at least 160 new schools in the next

³³ American Society of Civil Engineers, *2025 Infrastructure Report Card: Schools*.

two decades . In the entire 6 year capital improvement plan, there are only 5 schools total (2 elementary, 3 high school) in the pipeline.³⁴

Costs

While this thesis will not produce an advanced cost estimate for the development of a new portable, it is important to understand the costs associated with the existing typology of portable classrooms in order to understand their value proposition. A commonly cited reason for the usage of portable classrooms is the relatively cheap costs in comparison to large scale renovation or ground up construction of new school facilities. Most states do not allocate state capital outlay funds for the purchase of temporary facilities, so local school districts end up assuming the cost of providing portables. They do this by using school district reserve funds and the special purpose local options sales tax.³⁵

FY 2027 – \$4.5M		
School Name	Scope of Project	Expected Budget
Montgomery Blair HS	Relocatables Removal (5)	\$80,000
Albert Einstein HS	Relocatables removal (4)	\$100,000
Burtonsville ES	Relocatables removal (6)	\$100,000
Clarksburg ES	Relocatables removal (5)	\$80,000
Greencastle ES	Relocatables removal (6)	\$100,000
Oakland Terrace ES	Relocatables removal (5)	\$80,000
Northwest HS	Relocatables removal (5)	\$80,000
J. H. Blake HS	Relocatables placement (2)	\$1,000,000
Waters Landing ES	Relocatables placement (2)	\$1,400,000
Transportation Depots	Refurbishment and replacement (2)	\$1,480,000

Fig. 2.8: MCPS (source: MCPS data, Exhibits for FY27-32 CIP)

³⁴ Oct 14, 2025 Facilities and Boundaries Preliminary Presentation and Work Session, directed by Montgomery County Board of Education, 2025, Video, <https://mcpsmd.new.swagit.com/videos/357947>.

³⁵ Judith Patterson et al., “Portable Classrooms: Immediate Solutions to a ‘Growing’ Problem,” *School Business Affairs*, June 2009, 23–25.

Fig X.X exhibits data that is used to supplement the MCPS Capital Improvements Plan. The numbers reveal that while the average cost to remove a relocatable is only \$17,000, the cost to install a portable is of another magnitude, averaging \$647,000. Overall, the average cost to move a portable classroom is \$107,000.

Furthermore, portables require more maintenance than permanent classrooms.³⁶ Paired with high maintenance expenses, this makes portables far more costly in the long run than a permanent building.³⁷ Because of their “temporary” and “portable” nature, these structures are often not built with the best materials or intended for prolonged usage. Thus, the short term, immediate fix to overcrowding schools can lead to costly chronic issues. As time goes on, the portable structures deteriorate at an exponential rate. A 2011 study in California found that maintenance costs for portables amounted to over \$17,000 over a 10-year duration to nearly \$70,000 over a 25-year duration.³⁸ Even though the portables may not be on a single site for this amount of time, the service life of a portable can often reach this 25 year tenure. This equates to an average annual maintenance cost of \$2,800. Escalating these costs from 2011 to 2025, sees the annual maintenance costs jump to \$4,130.

The argument to be made with these statistics is not that portables are more expensive than traditional construction to house student populations. Rather, an argument can be made that the value proposition of portable classrooms is not justifiable. If portables do not provide a financial benefit, then a major rationale for their widespread usage is illegitimate. The following research components analyze what constitutes an “ideal” classroom environment, how portables often fail to meet these standards, and investigate possible solutions for what a better portable classroom could be.

³⁶ Patterson et al., “Portable Classrooms: Immediate Solutions to a ‘Growing’ Problem.”

³⁷ “The Rise of the ‘Portable’ Classroom,” *Teaching Aids News* 4, no. 10 (1964): 10–12.

³⁸ Joe Dixon and Steve Wilkerson, *Aging Portable Classrooms: Santa Ana’s Replacement Plan to Save Dollars*, HMC Architects, November 9, 2011, <https://hmcarchitects.com/news/aging-portable-classrooms-santa-anas-replacement-plan-to-save-dollars/>.

Research Component 1: School facilities and user performance

The purpose of this research component is to examine how the physical properties of a school environment impact user performance, if at all. Variables of the ambient environment include the indoor air quality, temperature, humidity, lighting, and acoustics. This research bolsters the importance of placing children in an environment that helps to optimize their learning experience.

Investigations into the quality of school facilities, such as Earthman (2002), Branham (2004), Barrett et al. (2015), Lafortune and Schonholzer (2018) bolster the argument that the condition of school infrastructure has crucial consequences for the performance of students and teachers alike. It is particularly important that children learn in a healthy environment. Their smaller size, combined with still developing respiratory and neurological systems makes them physiologically vulnerable to chemical exposures.³⁹ Therefore, the quality of primary, elementary, and middle schools must be given particular attention. After conducting a broad literature review, a study from the Lawrence Berkeley National Laboratory posits that the generally hypothesized links in causal chains from building characteristics flow from building characteristics through indoor exposures and physical conditions in schools to student attendance and performance (Fig. X.X).⁴⁰

³⁹ J. D. Berman et al., “School Environmental Conditions and Links to Academic Performance and Absenteeism in Urban, Mid-Atlantic Public Schools,” *International Journal of Hygiene and Environmental Health* 221, no. 5 (2018): 800–808, <https://doi.org/10.1016/j.ijheh.2018.04.015>.

⁴⁰ GA Heath and MJ Mendell, *Do Indoor Environments In Schools Influence Student Performance? A Review of the Literature*, LBNL-49567 (Lawrence Berkeley National Laboratory, 2002), <https://eta-publications.lbl.gov/sites/default/files/lbnl-49567.pdf>.

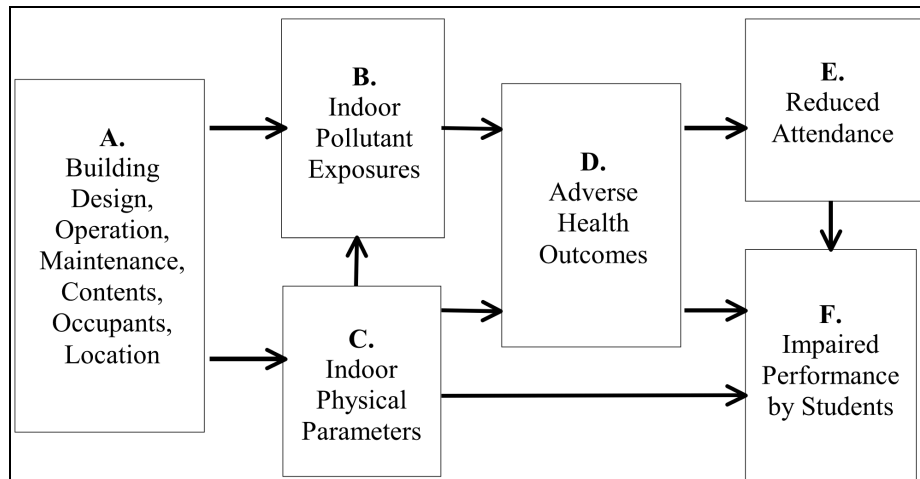


Fig. 2.9: Links in hypothesized causal chains (source: Heath and Mendell, 2002)

A major repercussion resultant from ailing facilities is increased attendance and drop out rates.⁴¹ The most important factor of all for a student is showing up to school in the first place. How can we expect students to perform at a high level in school buildings that are substandard? What is the standard?

Conversely, as school facility conditions improve, so too do student achievement scores.⁴² Well-equipped classrooms have significant positive effects on the academic achievements scores of students.⁴³ After analyzing data on the Los Angeles Unified School District, Lafortune and Schonholzer (2018) determined that school facility investments lead to gradual improvements in student academic performance, but also large and immediate improvements in student attendance and effort. The scope of the study is significant, as it encompassed nearly 750,000 students (every year of the study) over a ten year period from 2003-13.⁴⁴

⁴¹ David Branham, "The Wise Man Builds His House Upon the Rock: The Effects of Inadequate School Building Infrastructure on Student Attendance," *Social Science Quarterly* 85, no. 5 (2004): 1112–28, <https://doi.org/10.1111/j.0038-4941.2004.00266.x>.

⁴² Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

⁴³ Hamidreza Azemati et al., "Effective Environmental Factors on Designing Productive Learning Environments," *Armanshahr Architecture & Urban Development*, 2018.

⁴⁴ Julien Lafortune and David Schonholzer, *Do School Facilities Matter? Measuring the Effects of Capital Expenditures on Student and Neighborhood Outcomes*, December 31, 2018.

Indoor Air Quality

According to the United States Environmental Protection Agency (EPA), indoor air quality (IAQ) refers to characteristics of the air in buildings and structures that can impact the health, comfort, performance and productivity of the people inside. It is a crucial component of any indoor space, as poor IAQ is an environmental risk factor that can worsen health outcomes, decrease productivity and increase building maintenance expenses and other building-related costs.⁴⁵ The importance of IAQ is magnified for spaces with children because they breathe a greater volume of air in proportion to their body weight than adults.⁴⁶ Furthermore, schools have much less floor space per person than most office buildings, meaning more people are in a smaller space.⁴⁷

Ventilation is key to maintaining optimal levels of indoor air quality. If not maintained properly, carbon dioxide levels can build. This is shown to decrease student performance and concentration and increase student complaints of health problems.⁴⁸ Barrett et al. (2015) find that students perform better in classrooms with better mechanical ventilation and operable windows.⁴⁹ Improved ventilation can bring about less asthma, better school attendance, and improved academic performance.⁵⁰

Poor indoor air quality is also associated with increased student absenteeism.⁵¹ A study by Berman, et al. (2018) at Johns Hopkins University analyzed how school environmental

⁴⁵ US EPA, "Factsheet: What Is Indoor Air Quality?," Overviews and Factsheets, June 30, 2025, <https://www.epa.gov/indoor-air-quality-iaq/factsheet-what-indoor-air-quality>.

⁴⁶ Heath and Mendell, Do Indoor Environments In Schools Influence Student Performance? A Review of the Literature.

⁴⁷ Mark Schneider, *Do School Facilities Affect Academic Outcomes?* (National Clearinghouse for Educational Facilities, US Department of Education, 2002).

⁴⁸ Schneider, *Do School Facilities Affect Academic Outcomes?*

⁴⁹ Peter Barrett et al., "The Impact of Classroom Design on Pupils' Learning: Final Results of a Holistic, Multi-Level Analysis," *Building and Environment* 89 (July 2015): 118–33, <https://doi.org/10.1016/j.buildenv.2015.02.013>.

⁵⁰ Schneider, *Do School Facilities Affect Academic Outcomes?*

⁵¹ Schneider, *Do School Facilities Affect Academic Outcomes?*

conditions impact academic performance and achievement in the state of Maryland. The study population included Baltimore City public school children in third through eighth grade. Results show that higher attendance rates and better school facilities increased academic performance. Most importantly, the study shows that the “presence of poor ventilation, mouse or cockroach allergens, and deficient classrooms were all found to reduce attendance and impede educational performance, especially amongst younger students.”⁵²

Thermal Properties

Students perform mental tasks best in rooms kept at moderate humidity levels (40-70 percent) and moderate temperatures in the range of 60 to 74 degrees Fahrenheit.⁵³ Earthman (2002) argues that this range is even tighter, between 68-74 degrees Fahrenheit, with significant reductions in student comprehension above these temperatures. Increases in temperature beyond these comfortable thresholds decreases worker efficiency and increases the risk of work related accidents.⁵⁴ Furthermore, students were found to perform better in rooms where temperatures are easy to control.⁵⁵

Acoustics

Good acoustics are a necessity for good academic performance. Being able to clearly hear and understand what is being spoken is a prerequisite for effective learning.⁵⁶ Less noise is associated with higher student achievement, while higher rates of intrusive and excessive noise

⁵² Berman et al., “School Environmental Conditions and Links to Academic Performance and Absenteeism in Urban, Mid-Atlantic Public Schools.”

⁵³ Schneider, *Do School Facilities Affect Academic Outcomes?*

⁵⁴ Earthman, *School Facility Conditions and Student Academic Achievement.*

⁵⁵ Barrett et al., “The Impact of Classroom Design on Pupils’ Learning.”

⁵⁶ Earthman, *School Facility Conditions and Student Academic Achievement.*

increased student dissatisfaction and increased stress. Noise can significantly impair an instructor's ability to teach, which in turn, affects learning.⁵⁷

Lighting

Lighting is fundamental for visual comprehension in the classroom. Classroom lighting derives from two sources: natural daylight and artificial illumination. Better lighting has positive effects on achievement, attendance rates, and the health of the user of the room.⁵⁸

Beyond health impacts, research shows natural light significantly affects academic performance. Manke (1996), Heschong et al. (2000), Young et al. (2003), and Barrett et al. (2015) have shown that natural light has significant positive effects on students and teachers. Natural light provides the best lighting conditions in a classroom,⁵⁹ and better daylighting fosters higher student achievement.⁶⁰

An influential study regarding daylighting and student performance was conducted by Heschong et al. (2000). They examine how daylighting, from windows and skylights, affected the test scores of students in elementary schools. Portables formed a significant portion of classrooms studied in the most detailed school district in the San Juan Capistrano, California school district. Fig. XX shows the results of the study.

⁵⁷ Schneider, *Do School Facilities Affect Academic Outcomes?*

⁵⁸ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

⁵⁹ Schneider, *Do School Facilities Affect Academic Outcomes?*

⁶⁰ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

Capistrano	Analysis Results				Percentage Effect	
NEA	Difference in Average		Statistical Certainty		Difference as a a % of	
Core Level tests	Test Improvement				District Average	
Range: -29 to +79	(normalized RIT points)				Improvement	
Change, Fall to Spring	Reading	Math	Reading	Math	Reading	Math
Combined Daylight Model						
Daylight, Min. to Max.	2.8	2.3	99.9%	99.9%	26%	20%
Operable Windows	0.8	-	99.8%	n/s	7%	-
Separate Skylight and Window Model						
Windows, Min. to max.	2.4	1.7	99.9%	99.9%	23%	15%
Skylight A	2.0	2.3	99.7%	99.9%	19%	20%
Skylight B	-2.2	-	94.9%	n/s	-21%	-
Operable Windows	0.9	0.8	99.6%	99.9%	8%	7%

Fig. 2.10: Findings for San Juan Capistrano school district (source: Heschong et al, 2000)

The study shows strong positive effects of natural light on student performance. All other things held equal, students in classrooms with larger amounts of natural light learned reading at a 26 percent faster rate and math at a 20 percent faster rate. Two other school districts in Seattle, Washington and Fort Collins, Colorado, which have differing climates than San Juan Capistrano, were also studied. The pattern of improvements in student performance in classrooms with more natural light is observed in these locations as well (Fig. XX).⁶¹

⁶¹ Lisa Heschong et al., *Daylighting and Productivity: Elementary School Studies*, January 2000.

Seattle		Analysis Results		Percentage Effect	
ITBS		Difference in		Difference as a % of	
Iowa Test of basic Skills		Average Test Scores	Statistical	District Average	
NCE Scale 1-99		(NCE percentage points)	Certainty	Score	
Spring Scores		Reading Math	Reading Math	Reading Math	
Combined Daylight Model					
Daylight, Min. to Max.		7.5 5.6	99.9% 99.9%	13% 9%	
Separate Skylight and Window Model					
Windows, Min. to max.		7.7 8.7	99.9% 99.9%	13% 15%	
Skylights, Min. to Max.		3.9 3.4	99.9% 99.8%	7% 6%	

Fort Collins		Analysis Results		Percentage Effect	
NEA		Difference in		Difference as a % of	
Core Level tests		Average Test Scores	Statistical	District Average	
Normalized Scale 1-99		(normalized RIT points)	Certainty	Score	
Spring Scores		Reading Math	Reading Math	Reading Math	
Combined Daylight Model					
Daylight, Min. to Max.		3.8 3.4	99.9% 99.9%	7% 7%	
Separate Skylight and Window Model					
Windows, Min. to max.		10.2 7.0	99.9% 99.9%	18% 14%	
Skylight Monitor		- 1.6	n/s 99.7%	- 3%	

Fig. 2.11: Findings for Seattle and Fort Collins school districts (source: Heschong et al, 2000)

A follow up study was conducted by Heschong and Wright (2002) amid concerns of the methodology of the previous study. This new study concluded that the daylight variable of the original analysis was not an inadvertent effect of teacher assignment bias. This means that there was no evidence that “better” teachers were assigned to rooms with more natural light, thus eliminating the possibility that such teachers were the confounding reason for the improved student performance. This 2002 study also could not find any evidence that daylight has a different cumulative effect on student performance by grade.⁶²

From the initial study and the follow up, it can be determined that higher levels of natural light improves student performance. There are, of course, situations where daylight is not ample or may even be discouraged in the classroom. In these situations, artificial lighting must be utilized. Classrooms that have fluorescent lighting without ultra violet components have higher

⁶² Lisa Heschong and Roger L. Wright, *Daylighting and Human Performance: Latest Findings*, June 2002.

absence rates. Thus full spectrum lighting with ultra-violet content is an important variable when considering lighting.⁶³

It is important to understand that while all of these ambient environmental variables play considerable roles in how we consider the design of our school facilities, what is even more important is the ability to control them. The ability to adjust the temperature and lighting as necessary are key to ensuring teachers and students can work in the most suitable environment possible.

Research Component 2: Portable Classroom Deficiencies

With an understanding that the quality of the physical environment in which students learn impacts their performance, it is pertinent to ask, “Do portable classrooms meet these standards?” In many cases, the answer is no.

Spatial and environmental issues of portable classrooms have been documented since at least the 1960s. A segment from the publication *Teaching Aides News* reads, “In most cases... school districts found that the relocatable structures provided inadequate space for modern instructional programs and that less than a fraction of one per cent of the total reflect any real infusion of creative design or advanced educational planning.”⁶⁴ Inside the portables, commonly cited issues include health complaints such as eye irritation, allergies, asthma, headaches, fatigue, and complaints of exposure to materials emitting volatile organic compounds (VOCs).⁶⁵

If not maintained well or used for extended periods of time, the quality of portables can deteriorate significantly. Portables are a subset of the 2025 IAC report’s data. The FCI score for portables used by MCPS on average is 55 percent, indicating, “visible need of repairs,

⁶³ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

⁶⁴ “The Rise of the ‘Portable’ Classroom.”

⁶⁵ California Air Resources Board and California Department of Health Services, *Environmental Health Conditions in California’s Portable Classrooms*.

uncomfortable portions, and occasionally unreliable systems”. The average for portables used by PGCPs is even worse at nearly 70 percent. Anything above 60 percent warrants “significant repairs, uncomfortable environments and unreliable building functions.”⁶⁶ These scores indicate portables being utilized either at one site or multiple for longer than intended, whilst also receiving inadequate maintenance.

There are also ambient environmental deficiencies in portables. Shendell et al. (2004) found that portable classrooms in California measured low ventilation rates as compared to ASHRAE Standard 62 and compared to typical classrooms. These low air exchange rates were due to various factors, mostly concerning the irregular operations and maintenance of mechanical equipment. This also contributed to the portables often failing to provide a comfortable temperature. Concerningly, these low ventilation rates were associated with increased prevalence of adverse health effects.⁶⁷ The Environmental Protection Agency and ASHRAE Standard 61 recommend a maximum carbon dioxide concentration of 1,000ppm for a classroom.⁶⁸ In their study Callahan et al. (1999) find that the rates of carbon dioxide inside portable classrooms spike above this threshold from 11:00am to 5:00pm. These levels peaked above 1500ppm for over three hours, from 12:00pm-3:00pm (Fig X.X), showing unacceptable levels of exposure.⁶⁹

⁶⁶ Interagency Commission on School Construction, *Statewide Facilities Assessment Fiscal Year 2025 Annual Report*, Government Report (State of Maryland, 2025).

⁶⁷ Shendell et al., “Evidence of Inadequate Ventilation in Portable Classrooms.”

⁶⁸ OAR US EPA, “Reference Guide for Indoor Air Quality in Schools,” Overviews and Factsheets, October 2, 2014, <https://www.epa.gov/iaq-schools/reference-guide-indoor-air-quality-schools>.

⁶⁹ Callahan et al., *Evaluation of Energy Efficiency Improvements to Portable Classrooms in Florida*.

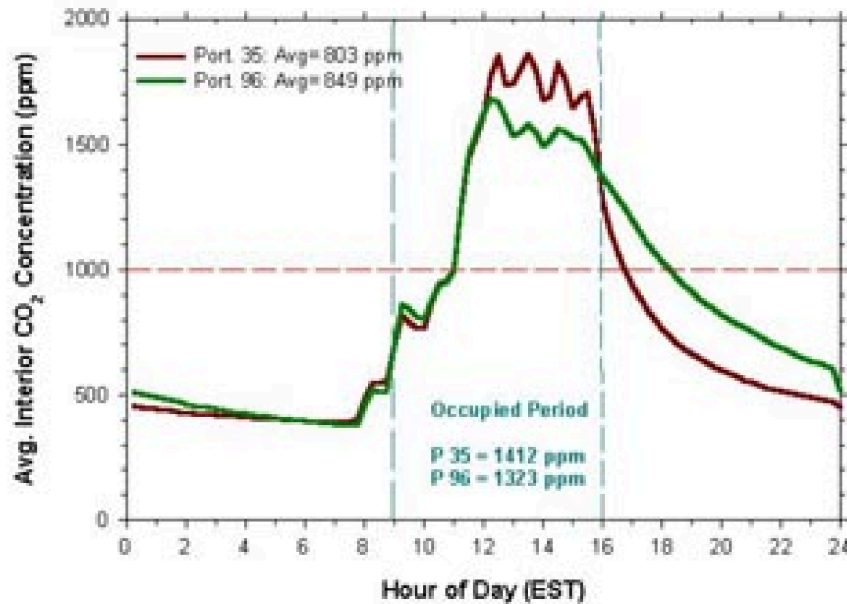


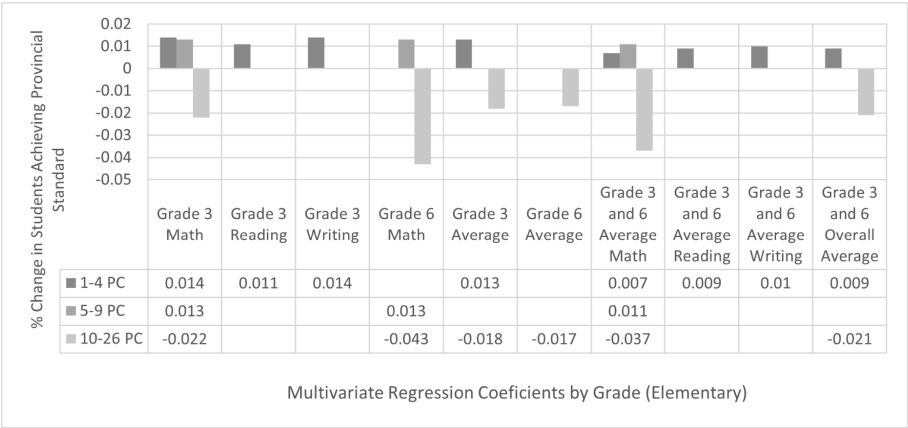
Fig 2.12: Average weekday carbon dioxide concentration levels in the study's portables over a nine month baseline period (source: Callahan et al., 1999).

Another study examining portable classrooms in California was conducted jointly by the California Air Resources Board (part of the state Environmental Protection Agency) and the California Department of Health Services. The results show that compared to typical classrooms, portables have higher levels of VOCs, interior mold, noise intrusion, and lower levels of lighting. There are several key takeaways. First, 60 percent of teachers in portables indicated that they turn off the ventilation systems at times due to excess noise (compared to 23 percent in traditional classrooms). Doing so compromises the indoor air quality that users inhale. Portable classrooms also had more issues with their HVAC systems than traditional, including higher rates of dirty air filters, blocked outdoor air dampers, poor condensate drainage, all of which can lead to microbial contamination.⁷⁰ The principal lesson learned from this study is that the HVAC system plays a critical role in maintaining a suitable classroom environment. It must

⁷⁰ California Air Resources Board and California Department of Health Services, *Environmental Health Conditions in California's Portable Classrooms*.

be able to be easily and intuitively controlled, provide consistent air of the right quality and temperature, and be quiet enough as to not disturb teaching sessions.

The inferior quality of these spaces affects user achievement in portables. Perhaps the most important question that can be asked is whether students in portables perform better, the same, or worse than peers in regular classrooms. Based on the number of portable classrooms present at a school, Riveros and Zhou (2025) determine that moderate usage of portable classrooms does not negatively affect achievement. However, intensive overreliance on portables to house the school population does have significant negative effects (Fig. X.X).⁷¹



Note. PC = portable classrooms.

Fig. 2.13: Elementary achievement and number of portable classrooms (source: Riveros and Zhou, 2025)

Branham (2004) examined the Houston (Texas) Independent School District (HISD) to see how temporary structures, including portables, affected student performance. The comprehensive study included data of 190,000 students and 226 schools. The results of the study show that the use of temporary buildings, such as portable classrooms, lowers attendance rates in the schools. Specifically, the model shows that if a school of 1,000 students uses

⁷¹ Riveros and Zhou, “Portable Classrooms.”

portables as just 5 percent of its total building space, it can expect one more student absent per day than a school that does not use temporary facilities. Even more alarming, the study finds that in a secondary school that houses 5 percent of its 1,000 students in portables, it can expect 9-10 more dropouts per year than a school without temporary facilities (Fig. XX).⁷²

Tobit Analysis Determinants of Drop-Out Percentage at Secondary-School Level

	1	2
Constant	- 13.18** (4.89)	- 9.45** (3.54)
Percentage temp buildings	0.183** (0.059)	0.209** (0.056)
Structural repair	1.15* (0.609)	1.21* (0.598)
Square feet per custodian (× 1,000)	0.406** (0.128)	0.410** (0.124)
Square feet per student	0.004 (0.012)	
Percentage black students	- 0.010 (0.024)	
Percentage Hispanic students	- 0.019 (0.052)	
Percentage limited English	0.036 (0.042)	
Student to teacher ratio	0.192 (0.149)	
Average teacher experience	- 0.183 (0.118)	- 0.277 (0.115)
Enrollment (× 100)	0.195** (0.062)	0.272** (0.056)
Mobility	0.040* (0.023)	0.048* (0.022)
Poverty	0.002 (0.026)	
Teacher likeness	0.022 (0.044)	
Middle school	- 1.44 (1.03)	- 1.14 (0.774)
Chi-square	57.65	48.17
SEE	1.42	1.58
N	54	54

**Significant at the 0.01 level, one-tailed test; *significant at the 0.05 level, one-tailed test.
NOTE: Standard errors are in parentheses. Ten dependent variable predictions were censored at less than zero in each model.

Fig. 2.14: Determinants of dropout percentage at secondary school level (source: Branham, 2004)

These results suggest that if the most important variable is ensuring that students are even at school, then portable classrooms are a detriment to school systems' pursuit of this goal. A common rebuttal to the information cited in Branham's work is the question, "Do schools put worse teachers or students in the portable classrooms?" If there is a bias for "worse" performing students or teachers to be placed in portable classrooms, the blame for these discrepancies is shifted to the quality of instruction or student engagement. The existing literature does not indicate any evidence in support of this claim. Chan (2009) found that many principals actually assign their best teachers to the portable classrooms.⁷³ Similarly, in order to counteract the

⁷² Branham, "The Wise Man Builds His House Upon the Rock."

⁷³ Chan, "Do Portable Classrooms Impact Teaching and Learning?"

negative perceptions of portables, MCPS principals will often put their best teachers in portables.⁷⁴ Heschong and Wright (2002) find no teacher assignment bias in their investigation of student performance in classrooms.⁷⁵

In the case of Branham's (2004) study of HISD, student selection bias is also highly unlikely. First, the diverse nature within the district at the time of the study makes it very difficult for any one group to exercise partiality over another, and no ethnicity had a majority on the school board. The Texas Education Agency also employs an accountability method which evaluates equality within schools that reflects on the entire school district, making creating a bias against any group within a school unlikely. Lastly, any bias within the study should be controlled for with independent variables, and should not be affected by the variable such as temporary facilities.⁷⁶

Usage of portables also affects user morale. Teachers cite many student misbehaviours happen while travelling between portable classrooms and school buildings. If such cases involve bullying, harassment, or activity that engenders negative feelings towards others, it will impact a student's attitude towards school. As a result, students in regular classrooms demonstrate more positive attitudes towards their schools than those in portables.⁷⁷

The aesthetic quality of portable classrooms and the resulting public opinion must be addressed. Portable classrooms are generally not well received by the public. They are an immediate indicator that a school is dealing with issues of overcrowding, which further insinuates a lack of adequate resources for each individual child. Some perceive them as eyesores that devalue their properties.⁷⁸ Perhaps most importantly, parents view portable

⁷⁴ Andrea Swiatocha, "Interview with Andrea Swiatocha, Deputy Chief, Office of Facilities Management, Montgomery County Public Schools," November 14, 2025, Phone.

⁷⁵ Heschong and Wright, *Daylighting and Human Performance: Latest Findings*.

⁷⁶ Branham, "The Wise Man Builds His House Upon the Rock."

⁷⁷ Chan, "Do Portable Classrooms Impact Teaching and Learning?"

⁷⁸ Chan, "Do Portable Classrooms Impact Teaching and Learning?"

classrooms as inferior to the main school building, and thus assume that the instruction in them will be inferior as well.⁷⁹

However, not all research findings regarding portable classrooms have been negative. A study done by Tak Cheung Chan at Kennesaw State University in 2009 found, “No significant impact of portable classrooms on teacher perception, teacher morale, teacher job satisfaction, student achievement, and behaviour.”⁸⁰ Certainly, not all portables are equal, and some may be perfectly suitable learning environments. However, the study notes that many teachers believe their ability to instruct effectively can outweigh the physical characteristics of the learning environment itself. While the teacher themselves might be the most important factor in effective learning for students, the physical environment also has undeniable effects on student’s learning, achievement, and growth into members of our society.⁸¹ Furthermore, the study did not differentiate between the age of the portable classrooms surveyed, and it is understood that portables tend to deteriorate rapidly.⁸²

Therefore, even while some facilities may be deemed as satisfactory to their users, this thesis endeavors to expand upon how we may further optimize the learning environment to provide a higher standard for our children. As Gore (2012) argues, “It is not unfair to say that even the best of most of these units is sub-optimal, in the sense that they have not been designed for maximum educational effectiveness: they have, instead, been optimized for transportability, for minimum cost, and for rapid deployment.”⁸³

Even though portables may relieve issues of overcrowding in a classroom, they do not solve overpopulation issues for a school. The increased traffic still puts significant strain on school common areas, such as restrooms, libraries, cafeterias, gyms, and the staff that serve

⁷⁹ Patterson et al., “Portable Classrooms: Immediate Solutions to a ‘Growing’ Problem.”

⁸⁰ Chan, “Do Portable Classrooms Impact Teaching and Learning?”

⁸¹ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

⁸² Chan, “Do Portable Classrooms Impact Teaching and Learning?”

⁸³ Gore, “Designing Better Portable Classrooms.”

those areas. So while experiences in the classroom may be typical, the ability to effectively conduct other activities vital to the educational experience is inhibited.

Research Component 3: Classroom ambient environment (hard parameters)

Azemati et al. (2018) identify four environmental factors that affect space productivity, shown in Fig. X.X. These four factors of environmental comfort, visual factors, layout of the environment, and psychological factors offer a framework of parameters.⁸⁴ These factors have been sorted into more objective “hard parameters” and more subjective “soft parameters” for this chapter. RC 3 will focus on hard parameters; the factors of environmental comfort and layout of the environment. Visual factors and psychological factors, the soft parameters, will be addressed in RC 4.

Effective Environmental Factors	Factors Affecting Space Productivity
The Use of Natural Light, The Fitting of a Suitable Window, Temperature Control, Air Quality and Acoustic	Environmental Comfort
Color, Scale, Visual Appearance, Materials, Visual Connection between Spaces and Nature	Visual Factors
Circulation, Accessibility, Flexibility, User Involvement in Space Design, Connection between inside and outside Space, Furniture, Open Space and Plan Layout	Layout of Environment
Secure Space, Environment Readability, Private Space, Social Environment	Psychological Factors

Fig. 2.15: Environmental factors affecting space productivity (source: Azemati et al., 2018)

What qualifies as “good” classroom design changes with the age of the school demographics. In elementary schools it is important that children feel ownership of the classroom. Fostering these feelings of responsibility promotes greater participation and involvement in the learning process. Because younger students spend higher proportionate

⁸⁴ Azemati et al., “Effective Environmental Factors on Designing Productive Learning Environments.”

amounts of time in a single classroom, the design of the classroom in particular is important for these students' school experience.⁸⁵

However, as students age, so do the importance of various factors in their surrounding environment. College students sharply perceive differences between standard and updated classrooms. Students are more satisfied and enjoy classes to a higher degree in these updated classrooms. When compared to standard classrooms, teachers were rated higher in the newer ones. More comfortable chairs, tiered seating, and lighting are particularly impactful variables.⁸⁶

Environmental Comfort

Environmental comfort encompasses the use of natural light, usage of suitable windows, temperature control, air quality, and acoustics.⁸⁷ As discussed in RC 1, a room's physical qualities play a critical role in creating an environment in which students and teachers can succeed.

The US EPA recommends a three step approach to establish high quality IAQ. First is source control to eliminate or reduce sources of indoor pollution. Next is improved ventilation to bring in fresh air to dilute indoor pollutants and exhaust them to the outdoors. Last is filtration and air cleaning to help remove pollutants from the air.⁸⁸ The Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) call for between fifteen to twenty cubic feet of air per minute per person.⁸⁹

⁸⁵ Barrett et al., "The Impact of Classroom Design on Pupils' Learning."

⁸⁶ Mary C. Hill and Kathryn K. Epps, *The Impact of Physical Classroom Environment on Student Satisfaction and Student Evaluation of Teaching in the University Environment*, 14, no. 4 (2010).

⁸⁷ Azemati et al., "Effective Environmental Factors on Designing Productive Learning Environments."

⁸⁸ US EPA, "Factsheet."

⁸⁹ Schneider, Do School Facilities Affect Academic Outcomes?

Temperature and humidity are important to control. The ideal temperature should be within 68 - 74 degrees Fahrenheit. Relative humidity should be kept at 50 percent. Significant losses in performance are noticed above these ranges.⁹⁰

Effective noise reduction must be ensured to combat stress and improve efficiency (SOC #13).⁹¹ The American National Standards Institute (ANSI) and Acoustical Society of America (ASA) recommend portable classroom noise maximum levels be 35 decibels, with maximum reverberation of 0.5 seconds.⁹²

The presence of natural light in the classroom is non-negotiable. In their 2024 study, Leif and Loftness find that 100 percent of participants feel that sunlight would, “certainly have a positive impact on students and teachers.”⁹³ This is reaffirmed by the results of the Heschong et al. (2000) study detailed in RC 1. However, light needs to be incorporated strategically into the classroom so that glare does not become a distracting factor. Within the study, this issue is shown by tracking and examining two types of skylight (Fig. X.X). Skylight Type A diffuses light equally throughout the classroom. Skylight Type B acts more like a window on the roof, allowing a full beam of light to enter the classroom. While Type A skylights greatly improve reading and math scores, Type B skylights have significant decreases in test scores, likely due to glare issues (Fig X.X).

⁹⁰ Earthman, *School Facility Conditions and Student Academic Achievement*.

⁹¹ Parul Minhas and Prakash Nair, *The Design of Learning Environments To Promote Student Health & Well-Being* (Association for Learning Environments, 2022).

⁹² American National Standards Institute (ANSI) and Acoustical Society of America (ASA), *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 2*, ANSI/ASA S12.60-2010 (R2020), Melville, New York, 2010.

⁹³ Kari Leif and Vivian Loftness, “A Toolkit of Biophilic Interventions for Existing Schools to Enhance Student and Faculty Health and Performance,” *Architecture* 4, no. 2 (2024): 445–56, <https://doi.org/10.3390/architecture4020024>.

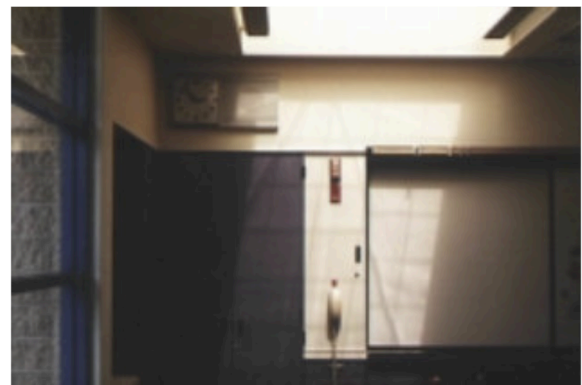


Fig. 2.16: Skylight Type A (left) and Type B (right) (source: Heschong et al, 2000)

Capistrano	Analysis Results				Percentage Effect	
NEA	Difference in Average		Statistical Certainty		Difference as a a % of	
Core Level tests	Test Improvement				District Average	
Range: -29 to +79	(normalized RIT points)				Improvement	
Change, Fall to Spring	Reading	Math	Reading	Math	Reading	Math
Combined Daylight Model						
Daylight, Min. to Max.	2.8	2.3	99.9%	99.9%	26%	20%
Operable Windows	0.8	-	99.8%	n/s	7%	-
Separate Skylight and Window Model						
Windows, Min. to max.	2.4	1.7	99.9%	99.9%	23%	15%
Skylight A	2.0	2.3	99.7%	99.9%	19%	20%
Skylight B	-2.2	-	94.9%	n/s	-21%	-
Operable Windows	0.9	0.8	99.6%	99.9%	8%	7%

Fig. 2.17: Skylight effects on performance in San Juan Capistrano school district (source: Heschong et al, 2000)

Therefore, windows should be plentiful enough to allow an abundance of natural light into the classroom. Shading devices, both blackout and with some percentage of openness, should be a standard option allowing building users to limit light intrusion when necessary. Skylights that diffuse light into the deeper recess of the room are also necessary, and help maintain consistent lighting levels throughout the space. These skylights should also be able to be dimmed as necessary.

Artificial lighting sources are also a necessity for any interior environment. Literature suggests that full spectrum lighting with ultra violet content has significant positive effects on attendance and scholastic performance.⁹⁴ A study conducted at the Ohio State University in 1984 found that under full spectrum lights, general performance of students increased by 12 percent and that full spectrum lights greatly improved visual performance. Manke (1996) goes on to assert that full spectrum light should, “definitely be installed in classrooms, libraries, gymnasiums, and administrative offices.”⁹⁵ However, it is not just the quality of the light that matters. Having sufficient quantities of lighting correlates strongly with students' learning progress.⁹⁶

Layout of Environment

The layout of the environment involves circulation, accessibility, flexibility, user involvement of space design, connection between inside and outside space, furniture, and plan layout.⁹⁷ When considering the contemporary classroom, designing to encourage student interaction and engagement should be paramount. Students who engage themselves as active learners, regardless of setting, show greater gains from the learning experiences encountered.⁹⁸ This is supported by many publications, amongst them Strange and Banning (2001), Brooks (2011), Muthyala and Wei (2013), Rands and Gansemer-Topf (2017), and Baum (2018). Classrooms should ideally house 20 or fewer students, as this improves the scores of students in primary school from the 50th percentile to above the 60th percentile.⁹⁹ However, lack of space or available teachers often pushes the number of students per classroom well in excess of 20.

⁹⁴ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

⁹⁵ Frank H. Mahnke, *Color, Environment, and Human Response: An Interdisciplinary Understanding of Color and Its Use as a Beneficial Element in the Design of the Architectural Environment* (Van Nostrand Reinhold, 1996).

⁹⁶ Barrett et al., “The Impact of Classroom Design on Pupils' Learning.”

⁹⁷ Azemati et al., “Effective Environmental Factors on Designing Productive Learning Environments.”

⁹⁸ Strange and Banning, *Educating by Design*.

⁹⁹ Earthman, *School Facility Conditions and Student Academic Achievement*.

Learning spaces must be designed for maximum flexibility. This allows natural evolutionary changes in pedagogy, as it is also much easier to replace furniture and equipment than it is to add or remove walls.¹⁰⁰ Facilitating multiple modalities of learning through flexible spaces also promotes design for salutogenic health (SOC #10),¹⁰¹ which is further outlined in RC 4. In terms of space efficiency, empty rooms contribute nothing to the school or student learning. The true cost of space is how effectively and efficiently the space provides access to learning resources.¹⁰² Flexibility also inherently promotes a more sociopetal environment, in which human interaction is encouraged.¹⁰³ Conversely, traditional lecture style seating often leads to a more sociofugal environment, in which interaction is discouraged and rigid. Classrooms should allow personalization to encourage ownership/territoriality and facilitate multiple modalities of learning by designing flexible spaces. This helps to increase a student's sense of coherence (SOC #17).¹⁰⁴ Higgins et al. (2005) find that people think that the display of students' work makes the school more welcoming, and increases the feelings of ownership and involvement, and thus leading to improved motivation.¹⁰⁵ Similarly, Barrett et al. (2015) emphasize that consideration must be given to fostering the students' sense of ownership in a classroom. This is particularly relevant for younger children, where permanent displays of student artwork or achievements and unique architectural design elements in a room significantly correlate with learning progress.¹⁰⁶

It is important, however, that a room's flexibility not become disorganized and haphazard. Children who are placed in more thoughtfully arranged rooms have been shown to

¹⁰⁰ Stephen R. Acker and Michael D. Miller, "Campus Learning Spaces: Investing in How Students Learn," *Educause Center for Applied Research, ECAR Research Bulletin*, vol. 2005, no. 8 (2005).

¹⁰¹ Minhas and Nair, *The Design of Learning Environments*.

¹⁰² Acker and Miller, "Campus Learning Spaces: Investing in How Students Learn."

¹⁰³ Strange and Banning, *Educating by Design*.

¹⁰⁴ Minhas and Nair, *The Design of Learning Environments*.

¹⁰⁵ Steve Higgins et al., *The Impact of School Environments: A Literature Review* (Centre for Learning and Teaching, University of Newcastle, 2005).

¹⁰⁶ Barrett et al., "The Impact of Classroom Design on Pupils' Learning."

produce more complex approaches to activities and have greater rates of conversation amongst themselves.¹⁰⁷

A popular approach to teaching in the 21st century is the deployment of the active learning classroom (ALC). Characteristics of active learning classrooms encourage students to become participants in the learning process, rather than relying strictly on memorization. Some strategies to increase student participation are asking them to be more involved, to share thoughts and values, and engage in analysis and synthesis rather than memorization. To achieve this, instructors can encourage small group discussion, peer questioning, cooperative learning, case studies, and other strategies.¹⁰⁸ Students find ALC classrooms more satisfying to work in than normal classrooms designed for lectures.¹⁰⁹

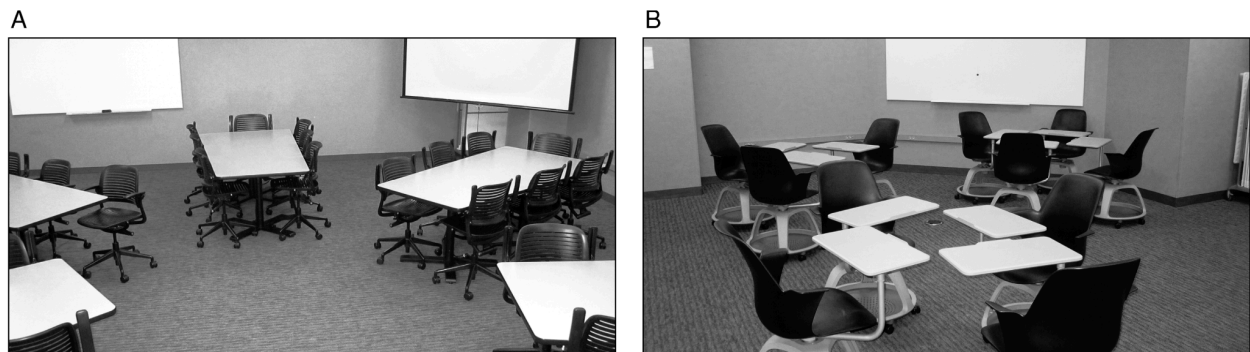


Fig. 2.18: A “spoke” ALC (A) and a “node” ALC (B) (source: Muthyala and Wei, 2013)

The layout of the ALC is what sets it apart from a typical classroom. Between various forms of active learning classrooms, such as the node model and spoke model (Fig. X.X), there

¹⁰⁷ Rivlin and Weinstein, “Educational Issues, School Settings, and Environmental Psychology.”

¹⁰⁸ Melissa L. Rands and Ann M. Gansemer-Topf, “The Room Itself Is Active: How Classroom Design Impacts Student Engagement,” *Journal of Learning Spaces* 6 (November 2017): 26–33.

¹⁰⁹ Edward J. Baum, “Learning Space Design and Classroom Behavior,” *International Journal of Learning, Teaching and Educational Research* 17, no. 9 (2018): 34–54, <https://doi.org/10.26803/ijlter.17.9.3>.

is no significant difference in student performance or outcomes.¹¹⁰ However, they do promote different types of group activity. The node best supports small group projects, while the spoke is better for case studies and large group activities. Students can perceive more social pressure to work in the group environment in the node classroom.¹¹¹

Brooks (2011), Rands and Gansemer-Topf (2017), and Baum (2018) note that the ALC is a powerful catalyst for improving student-teacher relationships. Students feel that ALC design “erases the line” between them and the teacher. ALC encourages more interaction and fosters more personal connections between students and instructors.¹¹² Students believe that their professors teach better, there is more student participation, and they get to know their classmates better.¹¹³ Increasing student-instructor interaction ultimately results in students feeling more valued.¹¹⁴

Mobility of tables and chairs plays a large role in enabling conversation. By using open spaces and portable furniture, large improvements in student experiences are achieved through small initial investments. ALC also increases student engagement and offers multiple mediums to absorb information.¹¹⁵ When deployed at the University of Minnesota, both students and faculty saw the ALCs as useful for changing the manner in which they learned and taught, and noted a difference in the student-faculty relationships.¹¹⁶ Most revealing is that when placed in a normal classroom versus an ALC, students in the latter exceed both expectations of their own grades (as predicted by ACT scores) and outperformed their peers in traditional classrooms.¹¹⁷

¹¹⁰ Rajeev S. Muthyala and Wei Wei, “Does Space Matter? Impact of Classroom Space on Student Learning in an Organic-First Curriculum,” *Journal of Chemical Education* 90, no. 1 (2013): 45–50, <https://doi.org/10.1021/ed3002122>.

¹¹¹ Baum, “Learning Space Design and Classroom Behavior.”

¹¹² Muthyala and Wei, “Does Space Matter?”

¹¹³ Baum, “Learning Space Design and Classroom Behavior.”

¹¹⁴ Rands and Gansemer-Topf, “The Room Itself Is Active: How Classroom Design Impacts Student Engagement.”

¹¹⁵ Rands and Gansemer-Topf, “The Room Itself Is Active: How Classroom Design Impacts Student Engagement.”

¹¹⁶ D. Christopher Brooks, “Space Matters: The Impact of Formal Learning Environments on Student Learning,” *British Journal of Educational Technology* 42, no. 5 (2011): 719–26, <https://doi.org/10.1111/j.1467-8535.2010.01098.x>.

¹¹⁷ Brooks, “Space Matters.”

Finally, school facilities should also have the capacity to serve the community when school is not in session. A number of studies have shown that the school extending its function into the local community is considered desirable. Not only does this increase efficiency of school usage, using school facilities for community programs increases parental involvement and improves perceptions of the school.¹¹⁸ Some districts, including MCPS, already have such programs. The Community usage of public facilities (CUPF) program, “provides community organizations and public agencies with access to public schools and government facilities for community services, programs, and events... after business hours, and at affordable rates.”¹¹⁹ The ALC naturally lends itself to this dual usage.

There is also considerable data concerning the optimal dimensions for a classroom. Due to the prefabricated nature of portables (outlined in RC 5), there are likely to be restrictions on the dimensions of what is possible based on the maximum sizes of what can be placed on the flatbed of a truck. However, we can still use such data to examine generally which direction to design for (bigger or smaller).

Portable classrooms are utilized to relieve overcrowding. A key component to mitigating feelings of overcrowding in the classroom is ceiling height. Higher ceilings in classrooms produce decreased perceptions by both teachers and children of crowding, with the height of the classroom ceiling correlating significantly with teacher satisfaction in the room.¹²⁰ In the United States, the standard ceiling height is just 8 feet.¹²¹ Although 9 foot high ceilings are becoming more common, should we be advocating for taller, more open spaces?

Vartanian et al. (2014) found that people have an aesthetic preference for rooms with higher ceilings and more openings (doors, windows, views). They also concluded that lower

¹¹⁸ Higgins et al., *The Impact of School Environments: A Literature Review*.

¹¹⁹ Montgomery County, Maryland, “Community Use of Public Facilities,” Government, Montgomery County, Maryland, <https://www.montgomerycountymd.gov/cupf/>.

¹²⁰ Higgins et al., *The Impact of School Environments: A Literature Review*.

¹²¹ Oshin Vartanian et al., “Architectural Design and the Brain: Effects of Ceiling Height and Perceived Enclosure on Beauty Judgments and Approach-Avoidance Decisions,” *Journal of Environmental Psychology* 41 (March 2015): 10–18, <https://doi.org/10.1016/j.jenvp.2014.11.006>.

ceilings and enclosed spaces elicit greater avoidance decisions, meaning that people did not enter or quickly exited these spaces.¹²² This indicates that in order for a classroom to be more approachable and desirable, it should be more spatial in the vertical dimension and offer greater perceived “openness”, likely through increased amounts of glazing. There is also evidence to support that improved sight lines and open layouts help with perceived sense of security amongst students.¹²³

A study conducted by Zhang et al. (2024) was published in Nature further reveals that the height of the ceiling does indeed influence how people operate in a classroom. Participants in the study were more likely to show positive emotional responses in bigger classrooms with bigger ceilings. This significant positive correlation between the subjective evaluation of pleasure and relaxation in the spaces with higher ceilings and the scores of tasks tests indicates that when students are more comfortable, they are more efficient and productive learners. Further analysis shows that classrooms with high ceilings may lead to more socially interactive behavior. Changes in the horizontal size of the classroom had smaller effects on participants' performance on tasks than the change in height. Most importantly, students who performed best in big classrooms with high ceilings had significantly higher GPAs than other students.¹²⁴

From these studies, we can determine that ceiling height is a critical variable in user comfort. Giving ample vertical space so that users do not feel oppressed can be a catalyst for production and effective learning. There is still a balance to strike. Ceilings should not be too high, however, as this can negate effects of better lighting and increase acoustic problems due to reverberation.¹²⁵ A sense of scale that is appropriate to the age of the users and learners

¹²² Vartanian et al., “Architectural Design and the Brain.”

¹²³ Perkins&Will, *Design for School Safety: An Overview of Crime Prevention through Environmental Design*, 12.01, Perkins&Will Research Journal (2021).

¹²⁴ Yalin Zhang et al., “The Effect of Classroom Size and Ceiling Height on College Students' Learning Performance Using Virtual Reality Technology,” *Scientific Reports* 14, no. 1 (2024): 15341, <https://doi.org/10.1038/s41598-024-65754-2>.

¹²⁵ Higgins et al., *The Impact of School Environments: A Literature Review*.

must be considered, as it helps foster autonomy and self esteem (SOC #3).¹²⁶ Even though vertical space seems to be a more sensitive variable than the room's length and width, maintaining enough square footage per person in the classroom is still important. When spaces are too small they create a higher density and sense of crowding, which can lead to conflicts, tensions, and bullying.¹²⁷

Research Component 4: Classroom psychological comfort (soft parameters)

While RC 3 analyzes the physical, tangible parameters of a classroom, RC 4 focuses on the subjective, "soft parameters" of classroom design. These parameters are based on the criteria outlined by Azemati et al., (2018). The two main categories of this research component are visual factors and psychological factors (Fig X.X). Visual factors include color, scale, visual appearance, materials, and visual connection between spaces and nature. Psychological factors include secure spaces, environmental readability, private space, and social environments.

What is the responsibility of a school? Rivlin and Weinstein (1984) say that, "It is to educate - that is to foster cognitive development, to transmit information about subjects of the curriculum, and to communicate the joy and excitement of learning." The physical characteristics of the school setting can influence both the behavior of its users and the educational program. Children are more productive in happy environments.¹²⁸ Claus and Girrback state that, "The effective school establishes a well disciplined, secure, and wholesome learning environment, and maintains clean and orderly school buildings."¹²⁹ In a similar vein, when it comes to poorly maintained schools, Branham (2004) asserts that, "disrepair will create an atmosphere of

¹²⁶ Minhas and Nair, *The Design of Learning Environments*.

¹²⁷ Mahnaz Izadi and Roger Hart, "The Influence of the Physical Environment on Social Behavior, School Climate, and Bullying in Schools," *Children's Geographies* 22, no. 1 (2024): 66–81, <https://doi.org/10.1080/14733285.2023.2232751>.

¹²⁸ Rivlin and Weinstein, "Educational Issues, School Settings, and Environmental Psychology."

¹²⁹ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

instability that tends to strangle social order and the educational process. Students in such an environment perceive they are not special, that school is not important... giving education a low priority in their lives.” To effectively learn and grow, children need the positive influence of a responsible adult and an environment conducive to stability.¹³⁰

A white paper published by the Harvard Graduate School of Education establishes a linkage between spaces that are physically safe and habitable, have optimal stimulation, and foster learner connection and academic achievement. The paper asserts that designing with affordances for learning must consider learning as both a process and an outcome. Spaces can be designed to encourage the process through which students learn, which includes the practices of noticing, wondering, and helping. In sum, the authors argue that designing with qualities of contrasting, flowing, and closeness create affordances for how learners learn, and ultimately aim to change or support interactions amongst people.¹³¹

The essence of these ideas are formally expressed in another whitepaper by Minhas and Nair (2022), in which they highlight the importance of influencing a child’s sense of coherence (SOC) through the design of learning environments. SOC is a concept within salutogenesis, which promotes building design that seeks to enhance health and well being. Salutogenesis is derived from the studies of Aaron Antonovsky’s Health, stress, and coping (1979), in which he defines sense of coherence as, “a global orientation that expresses the extent to which one has a pervasive, enduring though dynamic feeling of confidence that one’s internal and external environments are predictable and that there is a high probability that things will work out as well as can reasonably be expected.”¹³²

¹³⁰ Branham, “The Wise Man Builds His House Upon the Rock.”

¹³¹ Paula Garza Gonzalez et al., *Making the Space for Learning*, White Paper (Harvard Graduate School of Education: Project Zero, 2022), <https://pz.harvard.edu/sites/default/files/Making%20the%20Space%20for%20Learning.pdf>.

¹³² Aaron Antonovsky, *Health, Stress, and Coping*, 1. ed., 6. print, The Jossey-Bass Social and Behavioral Science Series (Jossey-Bass Publ, 1979).

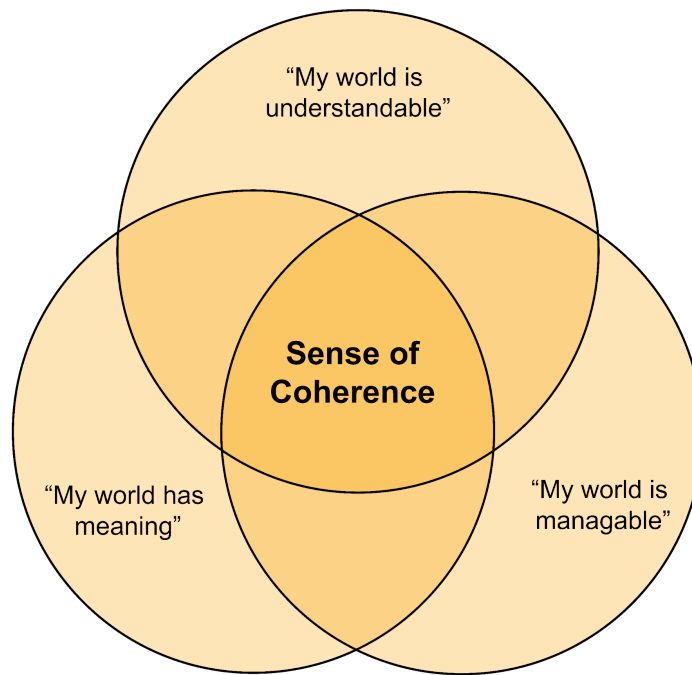


Fig. 2.19: Components of SOC (source: Minhas & Nair, 2022, adapted by author)

There are strong correlations between SOC and mental health and quality of life, since it offers people a sense of worldly understanding, management, and meaning.¹³³ Enhancing SOC is vital for classroom design success. Minhas and Nair (2022) offer 27 design guidelines for salutogenic health (Fig X.X). Several of the guidelines will be incorporated into the development of design parameters for this thesis, including SOC #1, #3, #5, #6, #10, #17, #22, and #23.

¹³³ Minhas and Nair, *The Design of Learning Environments*.

1. Use effective wayfinding strategies to improve legibility and build assurance.
2. Ensure safe community involvement and access control for enhancing competence.
3. Consider appropriate scale & developmental needs to foster autonomy and self-esteem.
4. Apply ergonomic considerations to improve posture and increase efficiency.
5. Use colors carefully to avoid visual fatigue and enhance psychological comfort.
6. Provide outdoor spaces to augment collateral learning and social connections.
7. Manage density & crowding to improve self-worth and ensure social distance.
8. Apply universal design principles to improve accessibility and build self-esteem.
9. Ensure ample natural light for enhancing overall health and efficiency.
10. Facilitate multiple modalities of learning by designing flexible spaces.
11. Provide common spaces for peer/ teacher interaction to enhance a sense of community/belonging.
12. Provide a variety of spaces that enhance engagement and initiate a state of flow.
13. Ensure effective noise reduction to combat stress and improve efficiency.
14. Maximize natural ventilation and thermal comfort to improve efficiency and overall health.
15. Create a welcoming entry and signature elements to help children comprehend the environment better and feel connected.
16. Ensure safety and security through natural surveillance and other design interventions.
17. Allow personalization of spaces to encourage ownership/territoriality
18. Use sensory aesthetics and active design elements for optimum stimulation (physical & psychological).
19. Provide spaces for self-reflection (privacy) and small group activities to enhance autonomy, competence, and relatedness.
20. Maximize authenticity and psychological comfort through the use of appropriate materials.
21. Create homelike environments with familiar elements to enhance the feeling of security and psychological freedom.
22. Promote agentic learning and environmental stewardship through visible green/sustainable architecture features.
23. Apply biophilic design principles to counter nature deficit and for effective attention restoration.
24. Provide spaces for pets in school in order to inculcate responsibility and empathy.
25. Allow student participation in planning and design of new facilities as well as maintenance/renovation projects.
26. Provide stimulating playgrounds to build risk competence and to experience a sense of adventure.
27. Enhance overall sense of coherence (SOC) by splitting bigger schools into small learning communities.

Fig. 2.20: 27 design guidelines for salutogenic learning environments (source: Minhas and Nair, 2022)

A similar thesis for educational design is proposed by Strange and Banning (2001), who argue that educational environments are most powerful when they offer three fundamental conditions: a sense of security and inclusion, mechanisms for involvement, and an experience of community. Designing at the human-scale allows students to become familiar with and feel

competent in their environments, and further engenders a feeling of confidence. In language akin to Minhas and Nair, Strange and Banning say, "Motivation and emotional connection to the learning process increase when children can influence and participate in the social decision making process, enabling a sense of purpose."¹³⁴ Children need to feel both that they belong at the school, and the school belongs to them.¹³⁵ Both publications emphasise design that provides holistic support to the student experience.

Thus the guidelines for salutogenic learning environments can be applied towards the goals proposed by Strange and Banning. The design of educational spaces has to ensure an inclusive, safe, and secure environment for all students, but also involve students in effective learning experiences that require taking on meaningful roles and responsibilities, and challenges.¹³⁶ Finally, ensuring proper maintenance of any education facilities is just as important as the initial design. Doing so can lead to a more positive image of the environment, increasing community pride and a sense of belonging amongst students.¹³⁷

Color/Materiality

"Color for the sake of color accomplishes little that is constructive," writes Frank Mahnke (1996), President of the International Association of Color Consultants/Designers and director of the American Information Center for Color and Environment. When it comes to the learning environment, he, like many others, asserts that the school needs to provide children with a feeling of security, which develops when they are surrounded by understanding and nurturance. This feeling can be enhanced or diminished through effective usage of color.¹³⁸ Environments that engage the senses through material qualities of color, texture, and pattern are particularly

¹³⁴ Strange and Banning, *Educating by Design*.

¹³⁵ Minhas and Nair, *The Design of Learning Environments*.

¹³⁶ Strange and Banning, *Educating by Design*.

¹³⁷ Izadi and Hart, "The Influence of the Physical Environment on Social Behavior, School Climate, and Bullying in Schools."

¹³⁸ Mahnke, *Color, Environment, and Human Response*.

important to motivate a child's desire for a sense of coherence (SOC #5).¹³⁹ Furthermore, other studies show an unequivocal correlation between color and increased productivity.¹⁴⁰ Thus, strategic usage of color is an important tool for designers and educators to consider.

Color is one of the primary variables influencing the level of stimulation a student may experience. Both under and over-stimulation make for less than ideal work environments. For example, for work productivity and accuracy, keeping walls all white is understimulating and detrimental. Studies have shown a 25 percent decrease in human efficiency in off-white business environments, while the US Navy found introducing color reduced the rate of drop accidents by 28 percent. In areas with monotone color, people become more introverted and have increased feelings of anxiety and stress from understimulation. This also results in feelings of restlessness.¹⁴¹

The impact and preferences of color change as we age, so it is impossible to prescribe general conditions for color usage in the classroom. However, the end goals for designers should remain the same. Color should be used carefully to avoid visual fatigue and enhance psychological comfort.¹⁴²

For younger children, maintaining focused attention in a classroom environment can be particularly challenging, as over stimulating visual features can tax their fragile ability to focus on task goals and ignore distractions.¹⁴³ Mahnke recommends a warm, bright color scheme for children in kindergarten through elementary school. These may include light salmon, soft, warm yellow, pale yellow orange, coral, and peach. Colors that are of the opposite temperature should be used as accents.¹⁴⁴

¹³⁹ Minhas and Nair, *The Design of Learning Environments*.

¹⁴⁰ Young et al., Do K-12 School Facilities Affect Education Outcomes?

¹⁴¹ Kathie Engelbrecht, "The Impact of Color on Learning," paper presented at NeoCON, June 18, 2003, <https://www.yumpu.com/en/document/read/11608042/the-impact-of-color-on-learning>.

¹⁴² Minhas and Nair, *The Design of Learning Environments*.

¹⁴³ Barrett et al., "The Impact of Classroom Design on Pupils' Learning."

¹⁴⁴ Mahnke, *Color, Environment, and Human Response*.



Fig. 2.21: Color should be used to avoid visual fatigue (source: Minhas and Nair, 2022)

For older students, subtle and cooler hues enhance the ability to concentrate. These colors can include beige, pale or light green, and blue green. To enhance quietness and concentration in certain areas such as libraries, pale or light green may be used.¹⁴⁵ Relaxing shades of blue significantly reduce systolic diastolic blood pressure, which may be more important at levels of education where students may feel more stressed, such as in high school or college.¹⁴⁶ In classrooms where students typically face a single direction, the front wall should be a different color from the side and back walls to break up the monotony of the space and allow students' eyes to relax when they look up. The front wall could be medium tones of green or blue. Engelbrecht (2003) agrees with these criteria, adding that end walls should be a neutral hue, with the remaining walls being a neutral color such as beige, oyster white, or sandstone.¹⁴⁷

Color can be formative in the creation of place identity and wayfinding. Wayfinding is particularly important for younger children, who begin to match, recognize, and associate

¹⁴⁵ Mahnke, *Color, Environment, and Human Response*.

¹⁴⁶ Young et al., *Do K-12 School Facilities Affect Education Outcomes?*

¹⁴⁷ Engelbrecht, "The Impact of Color on Learning."

color.¹⁴⁸ Beyond physical “landmarks” (furniture, walls, etc.) within a classroom, colorful signs and pictures can be useful tools for adolescents to enhance their spatial cognition.¹⁴⁹ Designers could incorporate contrasting textures of materials to create multisensory experiences and create varying levels of visibility to influence how learners connect and feel connected.¹⁵⁰

The design of a portable classroom should be unique and interesting not just to simply add aesthetic value to a school's campus. It has been shown that distinct architectural characteristics of the classrooms in which students work strengthens student's sense of ownership and their participation in their work.¹⁵¹

Biophilia

There is increasing literature that suggests the ability to relate to nature whilst inside the classroom has beneficial effects on cognitive performance. This trend of creating indoor spaces that simulate natural features and foster connections to nature is known as biophilic design. Biophilia is mankind's innate connection to nature.¹⁵² Minhas and Nair (2022) assert, “Classrooms should apply biophilic design principles to counter nature deficit and for effective attention restoration (SOC #22).”¹⁵³

The primary theory that may explain the beneficial effect of natural views on cognitive performance is the Attention Restoration Theory (ART). ART holds that the ability to maintain mental focus can become fatigued or depleted through sustained use. However, this capacity can be restored through the relaxed attention promoted by natural environments.¹⁵⁴ Similar to

¹⁴⁸ Engelbrecht, “The Impact of Color on Learning.”

¹⁴⁹ Rivlin and Weinstein, “Educational Issues, School Settings, and Environmental Psychology.”

¹⁵⁰ Garza Gonzalez et al., *Making the Space for Learning*.

¹⁵¹ Barrett et al., “The Impact of Classroom Design on Pupils' Learning.”

¹⁵² Kaigang Li et al., “Impact of Biophilic Design on College Student Perception of Mental Health and Environmental Benefits: A Dose-Response Study,” *Building and Environment* 267 (January 2025): 112318, <https://doi.org/10.1016/j.buildenv.2024.112318>.

¹⁵³ Minhas and Nair, *The Design of Learning Environments*.

¹⁵⁴ Jesus G. Cruz-Garza et al., “EEG-Based Investigation of the Impact of Room Size and Window Placement on Cognitive Performance,” *Journal of Building Engineering* 53 (August 2022): 104540, <https://doi.org/10.1016/j.job.2022.104540>.

proper use of color in the classroom, natural views can also be leveraged as a calming and destimulating measure that quiets the prefrontal cortex and rejuvenates students and teachers' cognitive fortitude.¹⁵⁵



Fig. 2.22: Green wall at Washington University in St. Louis (source: Sam Fox School)

Browning and Determan (2024) studied the implementation of biophilic design principles at Green Street Academy in Baltimore, Maryland. This study is unique because no living plants were not utilized. The design strategies focused on low cost, easily implementable interventions such as biophilic design patterns on the carpets, walls, and shades. The window shades reduced glare but could be opened for views outside to nature when the room did not receive direct sunlight. The results showed that students in the biophilic classroom attained better testing scores than the students in prior years in a regular classroom (Fig. X.X).¹⁵⁶ This study shows that improvements in performance through biophilic design can be achieved with low cost methods that do not introduce living species directly into the classroom.

¹⁵⁵ William Browning and Jim Determan, "Outcomes of Biophilic Design for Schools," *Architecture* 4, no. 3 (2024): 479–92, <https://doi.org/10.3390/architecture4030026>.

¹⁵⁶ Browning and Determan, "Outcomes of Biophilic Design for Schools."

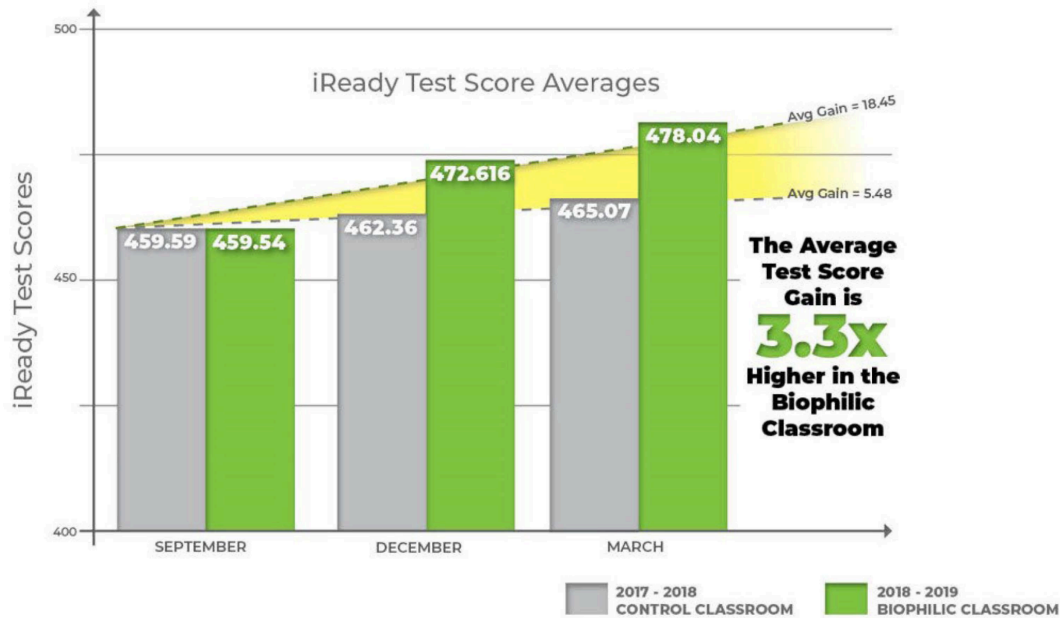


Fig. 2.23: Green Street Academy study results of biophilic design impacts on student test score averages (Browning and Determan, 2024)

Similarly, Leif and Loftness (2024) investigate 42 biophilic design and retrofit strategies for K-12 schools. Their study highlights the level which teachers and students value windows to provide views outside and natural lighting inside. Other straightforward and cost effective strategies to incorporate elements of biophilia include utilizing wooden furniture, having direct access to the outdoors, and plenty of natural ventilation.¹⁵⁷

However, what if we expand beyond simple views out to natural vegetation, and bring plants into the classroom? Li et al. (2025) found that plant placement in a classroom increased students' perceived indoor environmental quality, air freshness, and productivity. Adding up to 50 plants into a classroom was effective, but returns diminished after this point. While the study did not find that the plants in the room influenced students cognitive performances or perceived

¹⁵⁷ Leif and Loftness, "A Toolkit of Biophilic Interventions for Existing Schools to Enhance Student and Faculty Health and Performance."

stress, it does show that plants enhance students' perceptions of their environment and productivity. Furthermore, these improved perceptions of the classroom's indoor environmental quality regressed once the plants were removed from the classroom.¹⁵⁸ The implications of this study show that even if biophilic measures do not actively improve student's performance in the classroom, they are tools that can be utilized to make the classroom more comfortable, attractive, and potentially improve attendance and attention.



Fig. 2.24: Outdoor classroom space (source: Minhas and Nair, 2022)

There are also findings that suggest well designed and maintained outdoor spaces contribute to student academic performance.¹⁵⁹ Another principle for enhancing sense of coherence is to provide outdoor spaces to augment collateral learning and social connections (SOC #6).¹⁶⁰ Therefore, incorporating biophilic design principles and maximizing exposure to

¹⁵⁸ Li et al., "Impact of Biophilic Design on College Student Perception of Mental Health and Environmental Benefits."

¹⁵⁹ Higgins et al., *The Impact of School Environments: A Literature Review*.

¹⁶⁰ Minhas and Nair, *The Design of Learning Environments*.

nature in the design of education spaces should become universal, and will be utilized as a design element in this thesis.

Research Component 5: Prefabrication and Modular Construction

Constructing portable classrooms through methods of prefabrication offers numerous advantages. Even today, the existing typology of portables are already prefabricated (Fig. X.X). This is because prefabrication leads to higher quality products, reduced overall construction costs, reduced construction waste, and shorter construction timelines.¹⁶¹ Prefabricated construction takes about $\frac{2}{3}$ the amount of time as regular construction methods. However, if sitework and prefabricated construction is done concurrently, prefabricated construction can be completed in as little as $\frac{1}{2}$ the time of conventional construction.¹⁶² Furthermore, when prefabrication and modular construction are used, the number of reportable accidents are reduced by 80 percent, indicating it is a much safer method of construction.¹⁶³ Due to cost savings and higher build quality, usage of higher grade finishing materials and furnishings provide equivalent or even better indoor air quality than that of existing school buildings constructed traditionally.¹⁶⁴

¹⁶¹ Fred Boafo et al., "Performance of Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways," *Sustainability* 8, no. 6 (2016): 558, <https://doi.org/10.3390/su8060558>.

¹⁶² V. Tavares et al., "Prefabricated versus Conventional Construction: Comparing Life-Cycle Impacts of Alternative Structural Materials," *Journal of Building Engineering* 41 (September 2021): 102705, <https://doi.org/10.1016/j.jobe.2021.102705>.

¹⁶³ Giovanni Tumminia et al., "Life Cycle Energy Performances and Environmental Impacts of a Prefabricated Building Module," *Renewable and Sustainable Energy Reviews* 92 (September 2018): 272–83, <https://doi.org/10.1016/j.rser.2018.04.059>.

¹⁶⁴ Truong Dang Hoang Nhat Nguyen et al., "An Innovative Approach to Temporary Educational Facilities: A Case Study of Relocatable Modular School in South Korea," *Journal of Building Engineering* 76 (October 2023): 107097, <https://doi.org/10.1016/j.jobe.2023.107097>.



Fig. 2.25: A portable classroom module being built in a factory (source: Boxx Modular)

Prefabricated architecture involves an offsite manufacturing process that takes place at a specialized facility in which various materials and building systems are joined to form a component or part of a larger final assembly on site, or a unitized building system to be installed on-site.¹⁶⁵ According to Mark and Peter Anderson, principals at Anderson Anderson Architects in California, the greatest advantage to prefabrication is predictability. This is vital for architects, builders, and owners, who can make more accurate predictions for project scope, schedule, and cost.¹⁶⁶

There are no special codes for modular buildings, and the industry is primarily regulated at the state, provincial, and local levels. Along with the 200,000 portable classrooms in the United States, another 300,000 relocatable buildings make up an industry total 500,000 relocatable buildings worth \$8 billion. In 2024, revenue from modular buildings related to the

¹⁶⁵ Boafu et al., "Performance of Modular Prefabricated Architecture."

¹⁶⁶ Ryan E. Smith, *Prefab Architecture: A Guide to Modular Design and Construction* (John Wiley & Sons, 2011).

education market totalled \$1.6 billion.¹⁶⁷ Despite the advantages, this market share is a very small fraction of the overall \$2.1 trillion construction industry.¹⁶⁸

In their 2002 book *PRE FAB*, Arieff and Burkhart highlight an issue that has stymied the widespread adoption of prefabrication. They say, “The house may be produced in the factory, but the land it is built on and the people who live in it aren't. The mistake of most producers of mass-produced housing is that they often fail to consider or acknowledge the unique factors operating when human beings and environment are involved.”¹⁶⁹ Although this point focuses on prefabricated housing, it is certainly relevant to portable classrooms, which are often plopped on site without consideration of the design of the interior or exterior environment. This thesis will provide an examination of a more desirable relocatable classroom solution that is site agnostic. The product should be flexible to be used in any number of locations for multiple types of uses. However, the ways in which a kit of parts can be arranged on site to enhance place making will be an important facet of this project's success.

There are two main methods of prefabricated construction, panelized and unitized. Panelized prefabrication construction could increase efficiency in transportation to the site. However, panelized design requires more on site construction time, which increases a critical variable of risk and cost.¹⁷⁰

Sustainability

A goal of this thesis is to ensure that the structure itself serves as a learning and teaching tool to the users in it. This aligns with SOC #22, which holds that, “classrooms should promote agentic learning and environmental stewardship through visible green and

¹⁶⁷ Modular Buildings Institute, *2025 Annual Report*.

¹⁶⁸ U.S. Census Bureau, “Total Construction Spending: Total Construction in the United States,” Federal Reserve Bank of St. Louis, November 17, 2025, <https://fred.stlouisfed.org/series/TTLCONS>.

¹⁶⁹ Alison Arieff and Bryan Burkhart, eds., *PRE FAB*, 1. ed., 2. print (Gibbs Smith, 2002).

¹⁷⁰ Gore, “Designing Better Portable Classrooms.”

sustainable architecture features.”¹⁷¹ To do this, the final design must be highly sustainable.

Studies show that there is significant room for improvement in the design of portable classrooms with regards to their environmental impact. Portables are not intended to be used for very long periods of time. When they are, they incur higher energy costs for years at a time.¹⁷²

Prefabrication yields many advantages to portable classroom typology beyond flexibility, but perhaps most important are the sustainable benefits. Portables are not currently built for energy efficiency. Callahan et al. (1999) estimate that the total energy costs from portables amounts to \$20 million (~\$38 million in 2025), accounting for nearly 10 percent of the annual energy costs for Florida public schools. The study affirms that thoughtful, affordable alterations to portable classrooms can improve energy performance and consequently have positive IAQ and economic side effects. Their strategies include replacing T8 lighting systems with electronic ballasts, installing a high efficiency heat pump with enthalpy recovery ventilation, installing more site appropriate roofing materials, and occupancy sensors for lighting and air conditioning. Consequently, total annual energy consumption was reduced by 41 percent, with a lighting energy use reduction of 53 percent and space conditioning by 39 percent. These alterations saved \$370 annually (~\$730 in 2025) per portable in energy operation costs.¹⁷³ Another very easy, low up front cost way to improve energy performance is to install a programmable thermostat. The North Carolina Solar Center at North Carolina State University recommends that every portable should have a programmable thermostat, as they provide dramatic energy savings with no effect on user comfort.¹⁷⁴

Ensuring high sustainability standards is an advantage of using prefabrication. Tavares et al. (2021) affirm that, “prefabricated buildings have lower environmental impacts and cost the same (or even less) than conventional buildings while having similar performance, using less

¹⁷¹ Minhas and Nair, *The Design of Learning Environments*.

¹⁷² North Carolina Solar Center, *Purchasing a High Performance Portable Classroom* (North Carolina State University, 2005).

¹⁷³ Callahan et al., *Evaluation of Energy Efficiency Improvements to Portable Classrooms in Florida*.

¹⁷⁴ North Carolina Solar Center, *Purchasing a High Performance Portable Classroom*.

materials, and producing less waste.” This is because prefabricated construction improves material use efficiency, waste reduction, shortens construction times, increases product quality, and improves building performance.¹⁷⁵

Prefabrication helps the pursuit of a “Cradle to Cradle” life cycle of the construction materials used in portable classrooms. Compared to conventional construction methods, modular construction for schools produces four times less carbon.¹⁷⁶ Similarly, a 50 year life cycle analysis comparing modular and conventional housing, it was found that the conventional home produced 2.5 times more construction waste, while the modular construction led to a 5 percent reduction in total energy consumption and global warming potential. Because prefabricated construction can significantly reduce the amount of time it takes to erect a building, the impact of greenhouse gas emissions can be reduced from workers travelling to and from the site over an extended period.¹⁷⁷

For prefabrication, the early life stages of a building are critical to consider when analyzing environmental impact. Tumminia et al. (2018) find that the operational phase of a traditionally constructed building contributes 80 to 85 percent of the total life cycle impacts of the building. However, for prefabrication, this shifts heavily towards the materials production phase, accounting for 70 to 90 percent. Therefore, much more emphasis must be given to choosing construction materials and installation options with lower environmental impacts during this phase.¹⁷⁸

At the end of a prefabricated building's life, waste recycling is higher because of the types of materials used and because the dry assembly systems enable the complete separation of materials.¹⁷⁹ A survey of modular construction facilities found that practically all building

¹⁷⁵ Tavares et al., “Prefabricated versus Conventional Construction.”

¹⁷⁶ Nguyen et al., “An Innovative Approach to Temporary Educational Facilities.”

¹⁷⁷ Bofo et al., “Performance of Modular Prefabricated Architecture.”

¹⁷⁸ Tumminia et al., “Life Cycle Energy Performances and Environmental Impacts of a Prefabricated Building Module.”

¹⁷⁹ Tavares et al., “Prefabricated versus Conventional Construction.”

materials were reused, with the exception of some gypsum and copper wire.¹⁸⁰ Nguyen et al. (2023) find that relocatable modular schools can be disassembled and achieve recycling rates of up to 99 percent.¹⁸¹

The foundation accounts for approximately 10-15 percent of the total embodied emissions of a modular building. Most modular buildings utilize a strip foundation.¹⁸² However, these foundations are more disruptive to the site and costly in material and labor. Hamza, et al. (2023) studied four types of foundations for modular units of 5m x 10m (16.4ft x 32.8ft) to examine their environmental impact (Fix. X.X).

¹⁸⁰ Boafo et al., “Performance of Modular Prefabricated Architecture.”

¹⁸¹ Nguyen et al., “An Innovative Approach to Temporary Educational Facilities.”

¹⁸² Omar Hamza et al., “Emissions-Based Options Appraisal for Modular Building Foundations: A Case Study,” *Proceedings of the Institution of Civil Engineers - Engineering Sustainability* 177, no. 3 (2024): 162–73, <https://doi.org/10.1680/jensu.22.10017>.

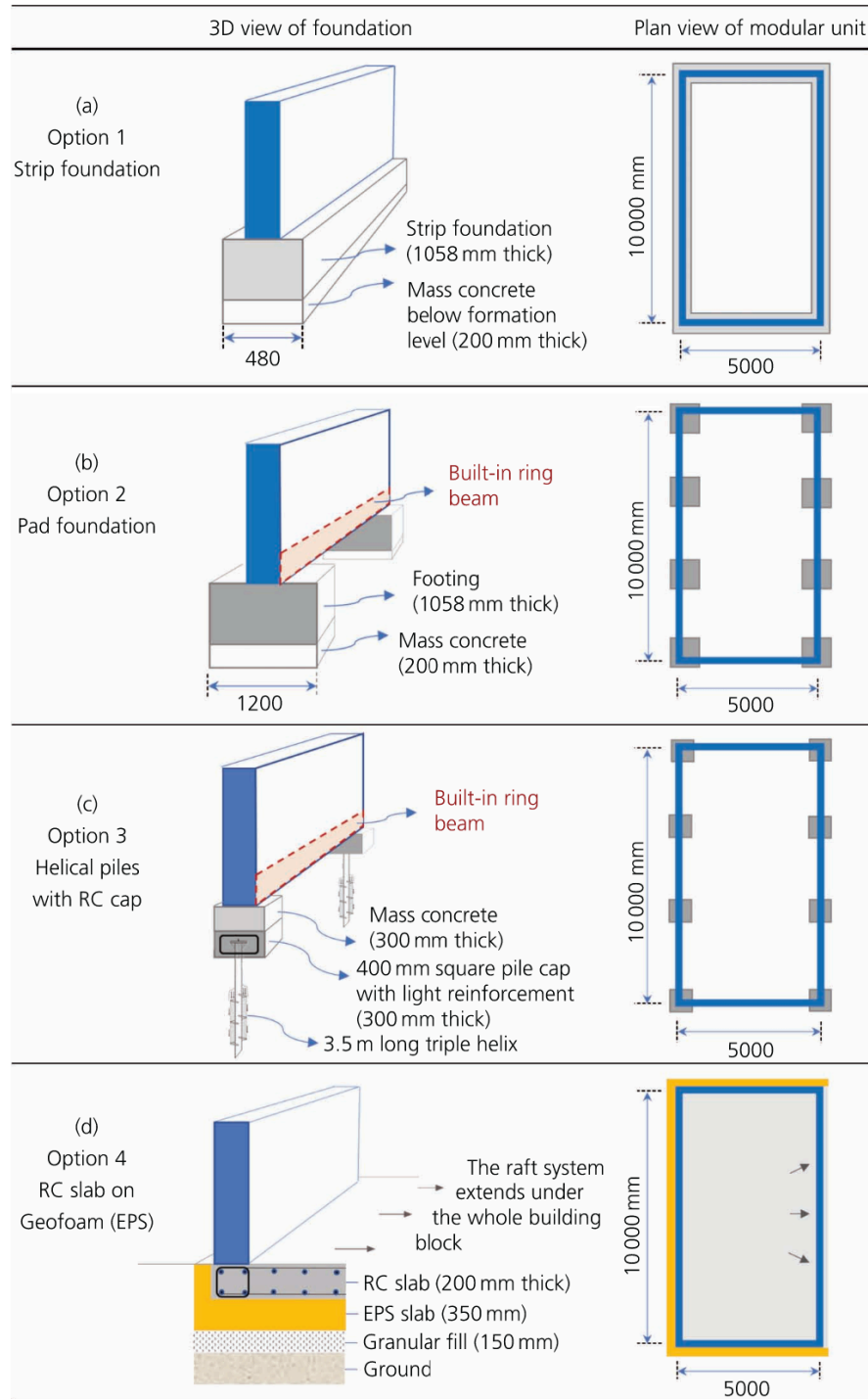


Fig. 2.26: Illustrations of four design options of foundations (source: Hamza et al., 2023)

They conclude that the most significant environmental impact is caused by the usage of a standard strip foundation. Alternatively, a helical pile is the least disruptive. Fig. X.X shows the

results of estimated embodied emissions of the options of the foundations: (a) using Portland Cement only; (b) with 75 percent cement replacement using ground granulated blast furnace slag these results. There are also potential cost savings when using helical piles, because they take significantly less time, machinery, and manpower to install as compared to the typical foundations.¹⁸³

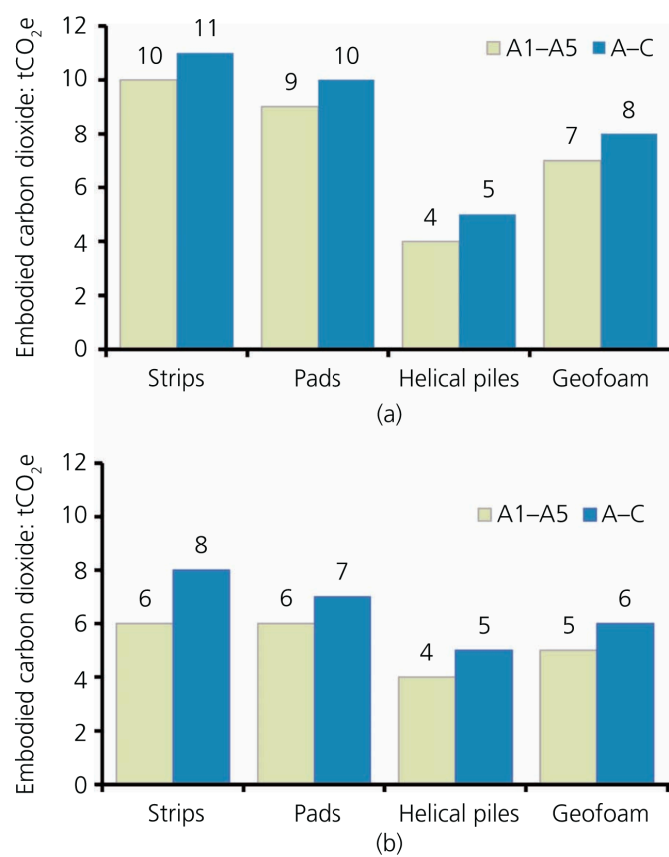


Fig. 2.27: Estimated embodied emissions of the foundation options (source: Hamza et al., 2023)

To further examine the effectiveness of each foundation type, Fig. X.X shows a ranks the four design options against 2030 targets set by the Royal British Institute of Architects, London Energy Transformation Initiative, and the Structural Carbon Rating Scheme. The two charts

¹⁸³ Hamza et al., “Emissions-Based Options Appraisal for Modular Building Foundations.”

show the foundations with Portland Cement (a) and with 75 percent Portland Cement replacement (b). Helical piles score the best.¹⁸⁴



Fig. 2.28: Ranking and comparing the four design options (source: Hamza et al., 2023)

Although it is beyond the scope of this thesis, prefabrication allows the ideas applied to portable classrooms to be easily scaled horizontally. The kit of parts ideas for the design of this thesis could be adapted for workforce housing, portable labs, training centers, disaster relief shelters, mobile medical clinics, and many other applications.

Conclusion (Design Parameters)

This chapter is meant to highlight both problems and solutions associated with portable classrooms. Portables fail to fulfill their purpose in nearly every manner. With significant areas

¹⁸⁴ Hamza et al., “Emissions-Based Options Appraisal for Modular Building Foundations.”

for improvement and a sound foundation of knowledge, it is possible to establish a set of parameters that the final design of this thesis must conform to. In the pursuit of creating the most optimal environment for the user, the final design of this thesis will strive to optimize six parameters. Three are hard parameters, and three are soft parameters. Hard parameters are those qualities that will be standardized in the AMC. Soft parameters are qualities that are more subjective to user preferences and will be variable based on the situation.

Hard Parameters

HP 1: Ambient environmental factors

This is achieved by providing the right air quality, temperature, humidity (SOC #14), lighting (SOC #9), and acoustic levels (SOC #13) for users, and is the most fundamental of the parameters. Because preferences and situations change, each of these factors should be easily controllable by the users.

HP 2: Quality and assembly

Portable classrooms are ephemeral in theory, but permanent in reality. Designing with an intent to create the highest quality product, instead of a product “good enough for a short period of time” ensures that the AMC can serve a decades long lifespan without becoming a liability for the user. Enhancing efficiency of assembly and disassembly ensures that in the case an AMC is only on site for a short period of time, it can be moved quickly and with minimal disturbance to the site. Prefabrication will be the primary construction method used to ensure quality control, minimize construction on site, and allow for flexibility.

HP 3: Sustainability

Following the ethos of minimizing its impact on the site, the AMC will be net zero and give heavy consideration to the embodied carbon in the design. Striving for net zero reduces energy costs. Aiming for a 100 percent cradle to cradle design ensures that at

the end of its lifecycle, the AMC can be repurposed with no waste and greatly reduces embodied carbon. Turning the space students are learning in into a machine for sustainability in itself provides an agentic method of learning and promotes environmental stewardship (SOC #22).

Soft Parameters

SP 1: Psychological comfort

Using the right colors and in the correct manner helps to avoid visual fatigue (SOC #5) and improves wayfinding strategies to build assurance (SOC #1). In a similar vein, incorporating methods of biophilic design allows for greater connection to nature and visual relief from the rest of the room.

SP 2: User ownership

Allowing for customization, flexibility, and display of work enhances a users' attachment to a space (SOC #17), therefore fostering greater participation. Students especially need to feel that the space is their own.

SP 3: Enhance placemaking

The current typology of portable classrooms fundamentally fails at creating spaces that are attractive to users. In order for the AMC to be successful, both the spaces inside and outside of the classroom must be considered equally. Therefore, the outdoor environment and entry thresholds will be included (SOC #6), as well as a way in which users can customize the spaces to make them feel on their own.

Following these parameters will ensure that the final design of this thesis achieves the goal of being a more architecturally refined, sustainable, and healthy solution which cultivates a more educationally supportive environment for our nation's youth.

Chapter 3: Methodologies

The research methodology of this thesis is structured as shown in Fig. 3.1. Adhering to this structure provides clear progression from establishing a problem to creating parameters for a solution and finally to applying a final design on a selected site.

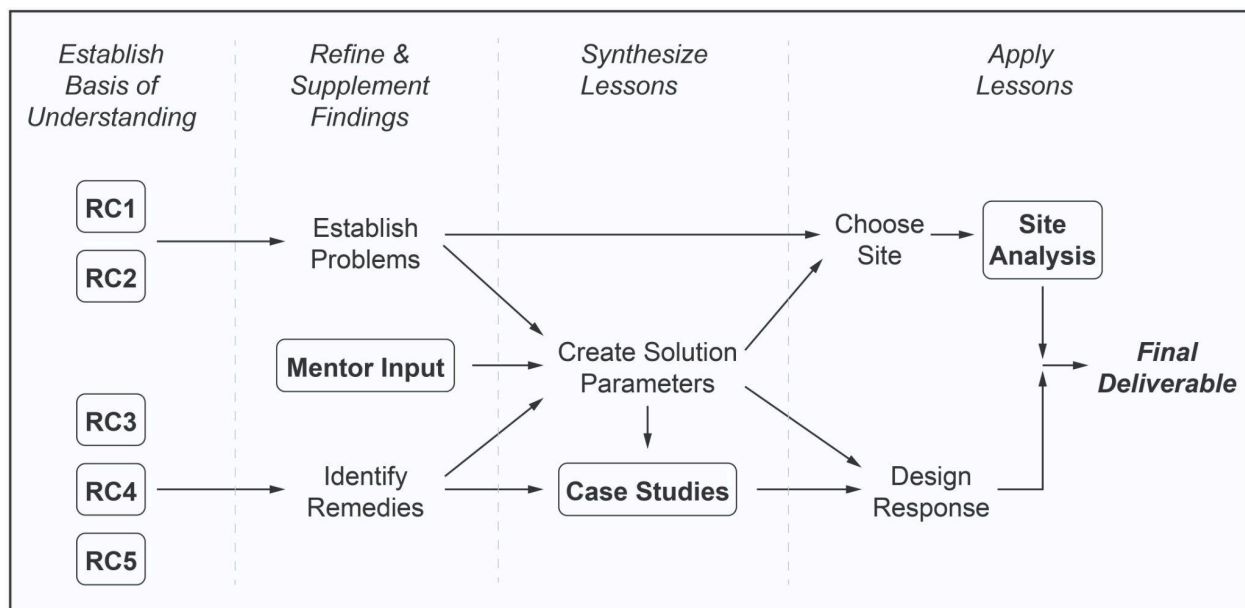


Fig. 3.1: Progression of methodological research, analysis, and implementation (Source: author)

Research Components

This thesis will analyze the impact that the built environment has on students, evaluate why portable classrooms often provide sub-optimal learning conditions, and finally propose an alternative that is more architecturally refined, sustainable, and healthy. To do so, this thesis has five main Research Components (RC):

RC1: School facilities and user performance

RC2: Portable classroom deficiencies

RC3: Classroom ambient environment (hard parameters)

RC4: Classroom psychological comfort (soft parameters)

RC5: Prefabrication and modular construction

This research methodology will begin with a literature review. RC1 and RC2 will encompass the quantitative aspects of classroom design and largely focus on existing literature that outline this thesis' "problem statement". RC3 and RC4 will establish parameters around which the final solution will be designed. Considering how environmental psychology plays a role in educational space is particularly important because the users have specific needs and are in a defined power relation.¹⁸⁵ RC 5 will be the means by which RC 3 and RC 4 are accomplished.

Research

The foundation of this thesis is built upon peer-reviewed research published by academic journals and information published by federal, state, and local governments. Articles published by academic and third party institutions also constitute a bulwark of the evidence. Finally, books discussing matters related to theory, strategy, and history are also used as a resource, particularly for RC 3 and RC 4.

Interdisciplinary Expertise

Tackling this thesis requires the consultation of experts that are outside the direct field of architecture. It is vital to gain an understanding from all perspectives, so that any solution is sensitive to every stakeholder's values. Beyond the chair and advisors on the committee of this thesis, several mentors and other experts in their field are consulted to provide their insight into the usage of portable classrooms and the role they play in the education system. Key mentors for this thesis are:

¹⁸⁵ Ray Lucas, *Research Methods for Architecture* (Laurence King Publishing, 2016).

John Costas, Chief Operations Officer, Modular Genius

Andrea Swiatocha, Deputy Chief, Office of Facilities Management, Montgomery County
(Maryland) Public Schools

Mr. Costas serves as a voice from the distribution perspective. Comprehending the portable classroom industry is a first step in understanding why potential issues with portable classrooms arise. Ms. Swiatocha provides valuable experience from the perspective of the end user. On the record interviews are conducted separately with Mr. Costas and Ms. Swiatocha on a monthly basis. Their firsthand experience supplements the initial research, and is extremely useful for understanding the dynamics of the local suppliers and public education systems.

Precedents

The study of architecture precedents is the oldest form of architectural research.¹⁸⁶ Understanding that precedents and architectural history are not a neutral set of facts, a variety of precedents of different eras, geographies, scales, and programs are analyzed. From the research components emerge several key questions that need to be asked of each precedent:

How does the precedent empower the user within the space?

How does the precedent provide a space whose program is flexible?

How does the precedent deal with “void” spaces between the main program areas, particularly if these are exterior spaces?

What innovative tectonic systems does the precedent use to be more dynamic, sustainable, and utilitarian?

Each precedent provides insight into how a particular issue was resolved, and is a lesson that can be folded into the overall solution. To understand these insights, drawings, sketches, maps, and diagrams will be made. Visual exploration is a legitimate method of research in the field of

¹⁸⁶ Lucas, Research Methods for Architecture.

architecture, which is incomplete when kept solely in the realm of text.¹⁸⁷ Therefore, methods of drawing are an important aspect of this thesis. Relevant findings will be included in this thesis.

Site Analysis

One of the most important factors of the thesis is that the final design can be utilized anywhere. So in many ways, the design will and should be site agnostic. Nonetheless, this thesis must be situated somewhere in order to display the successful qualities of the project in relation to a context. Therefore, the site selected must meet the following criteria.

1. The site will be located in Prince George's or Montgomery County, as this ensures easy logistics for site visits. Furthermore, both PGC and MC are part of the Maryland National Capital Parks and Planning Commission (MNCPPC). MNCPPC runs "park schools", which are joint community centers and schools that share facilities. Having both the established school and community programs allows flexible deployment of the portable classrooms. The new portables could be used for class during the day and community events on evenings/weekends. Both counties have established systems through which the public may rent out spaces in schools, including classrooms.
2. The school should already have portables on site, as this demonstrates ongoing issues with overcrowding.
3. The site should have ready access to trails. While all schools will not have trail access, for the purpose of this thesis considering such access filters out many sites. Considering trail access and localized pedestrian movement can also greatly inform the site analysis. Placing the classrooms along a trail also allows for broader access if it is utilized as part of the community center and offers a better opportunity for public display.
4. The school and community center facilities should be old or aging. At face value, an aging school is indicative of facilities in worse condition. Age could also be an indicator

¹⁸⁷ Lucas, *Research Methods for Architecture*.

of potential future construction/renovation, in which case the school users may need to be housed somewhere during construction, possibly in portables. While there are cases of newer (<10 years) schools requiring portables, it is more sensible that the target site for this thesis be an older facility that has been “waiting for its turn”.

Similar to the precedent studies, analysis of the site will occur primarily through visual mediums such as sketches and diagrams. Photographs, videos, and audio recordings can also be utilized to accurately capture the conditions of the site. Such methods will be used to determine the best location on the site to place the portable classrooms, and in what arrangement. It must be emphasized that although the final design can be placed anywhere, everywhere it is placed there is opportunity for placemaking. Thus, the site analysis will have a significant role in ensuring that the final design implementation on the chosen site is successful.

Conclusion

To establish a clear direction for this thesis, five research components are used to act as a narrative guide. The research collected in pursuit of these components forms a robust basis from which the remainder of the thesis will build upon. Methodologies will include traditional methods of research such as reviewing current literature and interviews with inter-disciplinary experts. Architecture specific methodologies include diagramming and mapping precedent studies and performing a thorough site analysis.

Chapter 4: Precedent Studies

The challenges faced by this project are not new. Investigating how other architects and designers have approached solutions to the problems outlined in this thesis offers useful insight. As Ray Lucas says in his book *Research Methods for Architecture*, “The study of architecture precedents is the oldest form of architectural research.”¹⁸⁸

The following precedents are listed in chronological order of completion date.

Zip-Up House (1969)

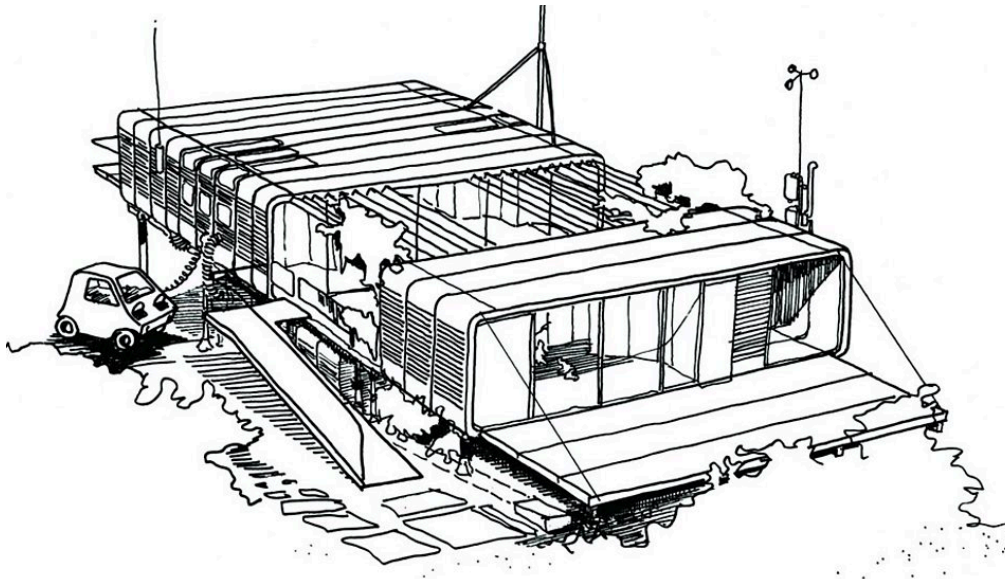


Fig. 4.1: Zip-Up House Illustration (source: BBC.com)

The Zip-Up house is an unbuilt concept project designed by Richard Rodgers for the chemical company Dupont. Taking inspiration from the Eames House (1949) in California, this proposal was designed to be assembled from mass produced parts, including panels from refrigerated trucks and windows from buses. The goal was to have rapid installation at minimal cost, while also allowing for modules to be added or removed simply.¹⁸⁹ The interior was absent

¹⁸⁸ Lucas, *Research Methods for Architecture*.

¹⁸⁹ RSHP, “Zip-Up House,” RSHP, rshp.com/projects/residential/zip-up-house/.

of structure, which allowed partitions to be arranged as needed within the space, offering maximum flexibility. Rodgers imagined that the owners of such a house would go to their local supply stores to customize the space in whatever way they saw fit.¹⁹⁰ This further increased the sense of ownership, attachment, and pride that the users would feel for the building. Anchoring the building to the ground are adjustable steel piloti, able to accommodate sloping sites.¹⁹¹

Another fascinating aspect of this project is that Rodgers gave considerable attention to the creation of exterior spaces. As seen in Fig. X.X, void spaces can be created between or at the ends of enclosed modules. These spaces can be utilized to create meaningful entry thresholds and outdoor gathering spaces. Providing ample space between each module allows for considerable amounts of natural light to enter.

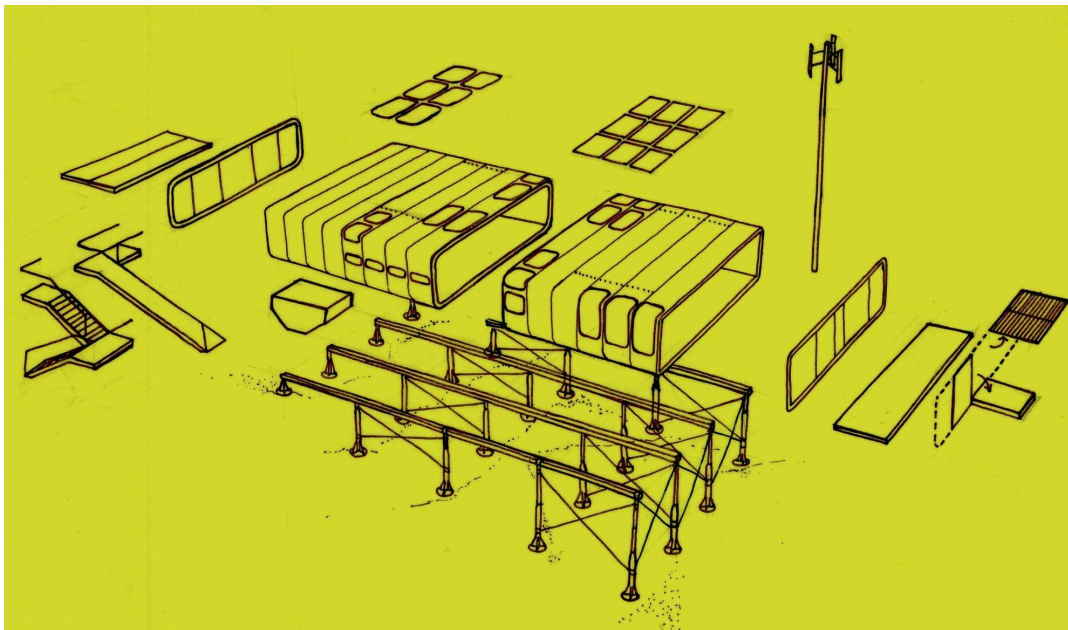


Fig. 4.2: Exploded axonometric of house components (source: RSHP)

¹⁹⁰ Arieff and Burkhart, *PRE FAB*.

¹⁹¹ Colin Davies, *The Prefabricated Home*, Reprinted (Reaktion Books, 2005).

The Zip-Up House employs a number of strategies that can be considered for this thesis, including modularity of building, modularity of scale, and how the structure interacts with the ground. How the systems and the program are incorporated into the building and the tectonics of how each piece connects needs to be investigated further.

Fuji Kindergarten (2007)



Fig. 4.3: Aerial view of Fuji Kindergarten (source: TED Ideas)

At the time of its construction, the Fuji Kindergarten, designed by Tezuka Architects, was the largest kindergarten in all of Japan. What is immediately noticeable about the building is the roof, which is often covered in children (Fig. X.X). The design adheres to the Montessori methodology, which holds that satisfaction, contentment and joy are encouraged when children are able fully to participate in daily activities, individually and collectively, in a place where they can understand, engage with and control their own environment. As a hands-on approach to learning which dismisses traditional tests and measurements of achievement, it encourages

children to develop skills by doing activities that use the five senses and that promote movement.¹⁹²

Fundamentally, school should be an enjoyable experience, and there is no better way to encourage fun than by making the school itself the playground. All of the horizontal planes in this building can be occupied and played on. The classrooms open up directly to the central courtyard and trees sprout through the floor and out the roof. The building is at once whimsical yet highly efficient.

There are several key lessons we can learn from this project. First, it shows that the building itself can become a playground for young children. The circular form encourages meeting in the center and cross pollination of students, but this arrangement is also very secure. Usage of sliding partitions allow porosity in between space, and the easy creation and dismantling of space (Fig. X.X). Perhaps most importantly, it is evident that the design of the school prioritizes children as the client, and emphasizes their connection to nature.



¹⁹² Rob Gregory, "Learning Curve: Running Circles around Other Schools, Fuji Kindergarten Is Leading the Way," sec. 32, *The Architectural Review*, August 2007, Gale Academic OneFile.

Fig. 4.4: Operable partitions and trees (source: Katsuhisa Kida, Tezuka Architects)

Energy Positive Relocatable Classroom (2014)



Fig. 4.5: Front entry of energy positive relocatable classroom (source: Archdaily)

This unique portable classroom was a collaboration between Anderson Anderson Architecture and Blazer Industries for the Hawaii Department of Education. It was prefabricated as three modules in Oregon that were then shipped to site in Ewa Beach, Hawaii. The classroom generates energy through wind and daylight and collects rainwater.¹⁹³ The solar panels on the roof produce 13,727 kWh/year, which is 180 to 400 percent of the building's usage.¹⁹⁴

Structural and mechanical systems are exposed and systems performance criteria are monitored and broadcast, all in the vein of making the building a learning tool. The framing is

¹⁹³ Smith, *Prefab Architecture*.

¹⁹⁴ "Outstanding Energy Performance in a Modular Building," Holcim Foundation for Sustainable Construction, May 27, 2014, <https://www.holcimfoundation.org/about/news/project-updates/outstanding-energy-performance-in-a-modular-building>.

steel, with rigid foam sandwich panel flooring. This minimizes material usage and maximizes thermal performance. All glazing is operable to induce natural ventilation. Interior surfaces are low VOC emitting products.¹⁹⁵



Fig. 4.6: Interior of energy positive relocatable classroom (source: Archdaily)

This precedent is important because it shows that there is an interest in improving upon what a portable classroom can be. The project redefines what a portable classroom can look like and embodies an ethos of learning into the classroom environment. It still relies on methods of prefabrication and modularity seen in other portable classrooms, which demonstrates. The project is highly sustainable (at least in the chosen environment) and intelligently utilizes materials for energy efficiency and insulation. The only real issue is that only one of these prototypes was built. This not only shows that there must be some significant holdup from mass

¹⁹⁵ Smith, *Prefab Architecture*.

adoption, such as cost, but it also limits understanding of how well this design would perform in other locations.

Kwel Ka Baung Migrant Learning Center (2014)

a.gor.a Architects, Jan Glasmeier

Portable Classroom



Fig. 4.7: Typical portable classrooms (source: Modular Genius)

This precedent analysis would be incomplete without examining the existing typology of portable classrooms. The qualitative aspects of portable classrooms are further discussed in Chapters 1 and 2. The design and outwards aesthetics of portables has changed little over the years (Fig. X.X). Because they are shipped by truck to each site, portable classrooms are designed in prefabricated sections to enable easier transportation. Portables are designed to last 25 to 30 years, but this is highly dependent on consistent maintenance.¹⁹⁶

¹⁹⁶ John Costas, “Interview with John Costas, COO, Modular Genius,” November 11, 2025, Online.

Chapter 5: Zones and Program

In order to distinguish this project from the existing array of portable classroom options, this thesis will refer to the final design as an “adaptive modular classroom (AMC)”. Doing so differentiates new from old and attempts to distance this project from any stigma that is associated with the words portable classroom, portables, trailers, etc. Further usage of the terminology “portable classroom(s)” will strictly relate to existing works that predate the investigations of this thesis.

Program Zones

The primary purpose of this project is to create a space that provides the most effective, sustainable, and reliable learning environment for students and teachers. The unique nature of the program is that it focuses heavily on creating this singular space. However, in the pursuit of “placemaking”, it is imperative that the components of the program provide a holistic experience for the users. Therefore, the program will consist of two zones: interior and exterior. The interior space will provide space in which the program can function, while the exterior spaces will supplement the interior spatial needs and ensure that negative space created by the AMC modules can be utilized as more than just circulation space.

A visualization of the function of the program zones is shown in Fig. X.X. Building on the “kit of parts” analogy, each part of the program should be easily added or subtracted from a larger whole, similar to Legos. When put together, the program zones will be *supportive* to ensure students, teachers, and every other user have access to the resources they need to grow; *secure*, so users and their loved ones know they are in a physically and emotionally safe environment; *flexible*, so that any space can serve multiple populations, services, and activities; and playful, to show that users they are valued and to inspire interest in their working environment.

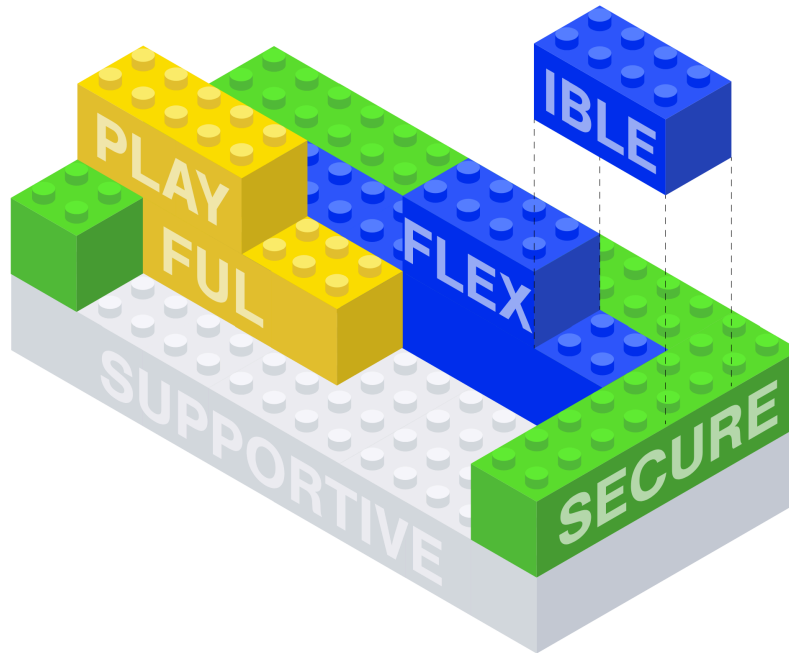


Fig. 5.1: Program zone diagram, drawn by author

Recognizing that the AMC can act as a supplement to the main school building, the major programmatic space needs to be flexible. Prefabrication and modularity will allow the construction of the AMC to vary while being made from the same “kit of parts”. Off-site fabrication ensures quality consistency and reduces operations on-site. The classroom will be constructed from standard “modules”. The number of modules will vary depending on the required program square footage. The interiors can then be furnished as programmatically necessary. It is important to consider that this “flex space” should be able to be programmed to accommodate a wide variety of activities hosted by the school or community. This means that the kit of parts needs to be variable enough to be deployed as a standard lecture classroom, science lab, library space, or physical fitness area during school hours. At nights and on weekends, the possibility of utilizing the space for community events should also be considered.

Precedent Analysis

The previous chapter discusses several architecture precedents that offer relevant insight into aspects of the design for the AMC. However, two are particularly relevant to the programming of the AMC. The first is the existing portable classroom. Understanding the programming dimensions for these existing portable classrooms will allow us to draw definitive comparisons once the design of the AMC has been finalized. These dimensions provide a good baseline for the programming size of the AMC. Below, two floor plans are analyzed from reputable distributors of portable classrooms, Modular Genius and Ramtech. The second precedent is the Energy Positive Relocatable Classroom (EPRC) by Anderson Anderson Architects.

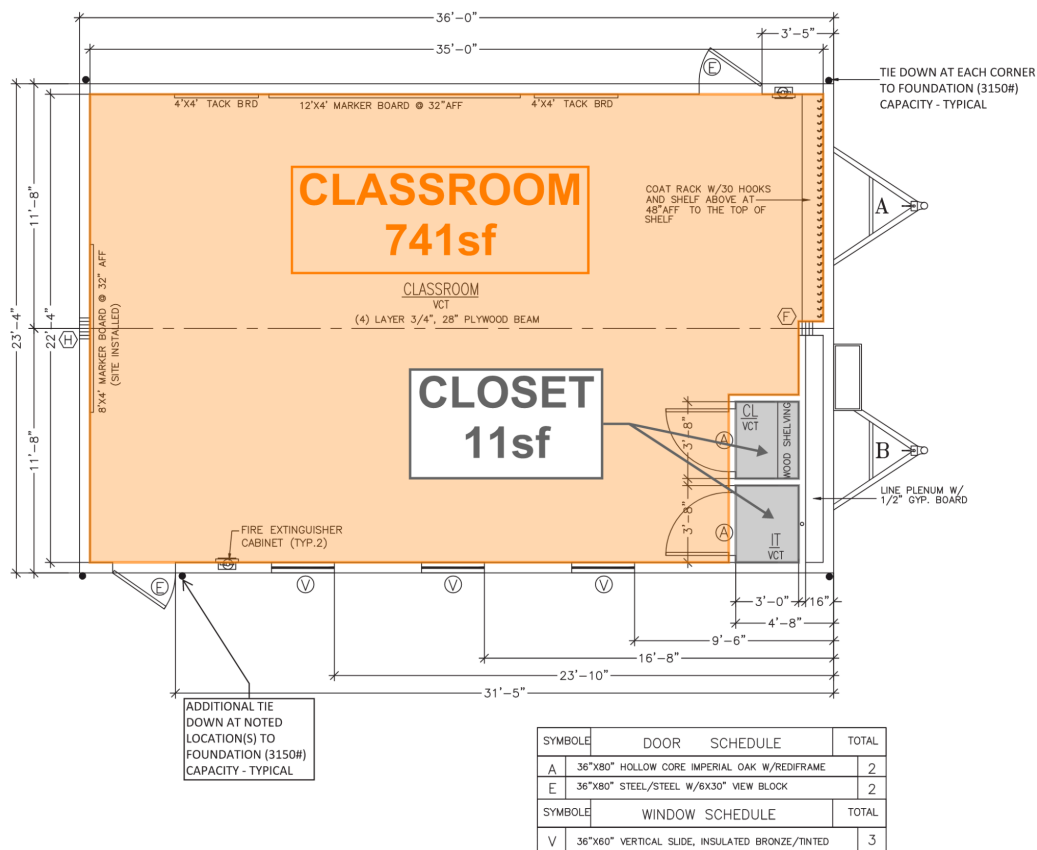


Fig. 5.2: Modular Genius classroom plan (source: Modular Genius, adapted by author)

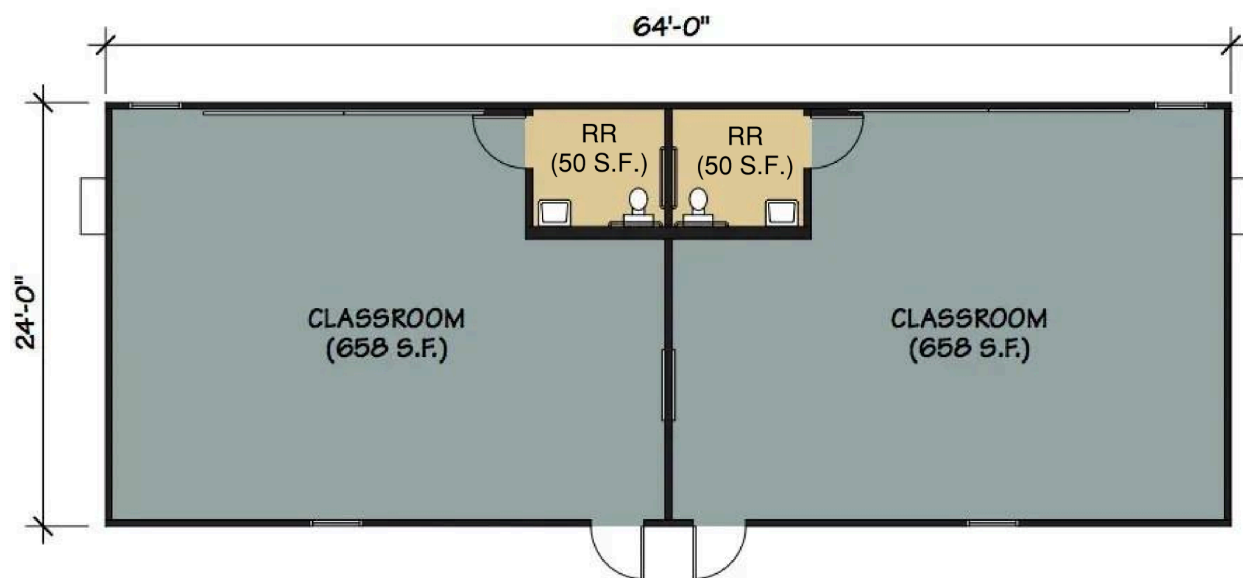


Fig. 5.3: Ramtech classroom with restrooms plan (source: Ramtech)

These plans both show a classroom with various support spaces. The Modular Genius classroom includes storage space, while the Ramtech option includes restrooms. Both plans show classrooms roughly 24 feet in length. The Modular Genius plan is slightly longer per classroom at 36 feet, while the Ramtech option is only 32 feet. Per MCPS, the classroom capacity is 23 students and a single teacher, for a total of 24 occupants.¹⁹⁷ This yields 31 square feet per student in the Modular Genius options versus 27 square feet in the Ramtech. Both are above the required International Building Code (Table 1004.5) floor allowances of 20 net square feet per occupant in classroom spaces.

To ensure that the design of the AMC is comparable to the best qualities of portable classrooms, the target square footage per occupant will match the 31 square feet of the Modular Genius plan. The same strategy will be used to determine the appropriate amount of restroom (50 sf) and storage (22 sf) space needed. A final, critical note is that each portable is designed

¹⁹⁷ Montgomery County Board of Education, Superintendent's Recommended FY 2025 Capital Budget and the FY 2025-2030 Capital Improvements Program.

with only a single means of egress. This could have significant implications for the design of the AMC.

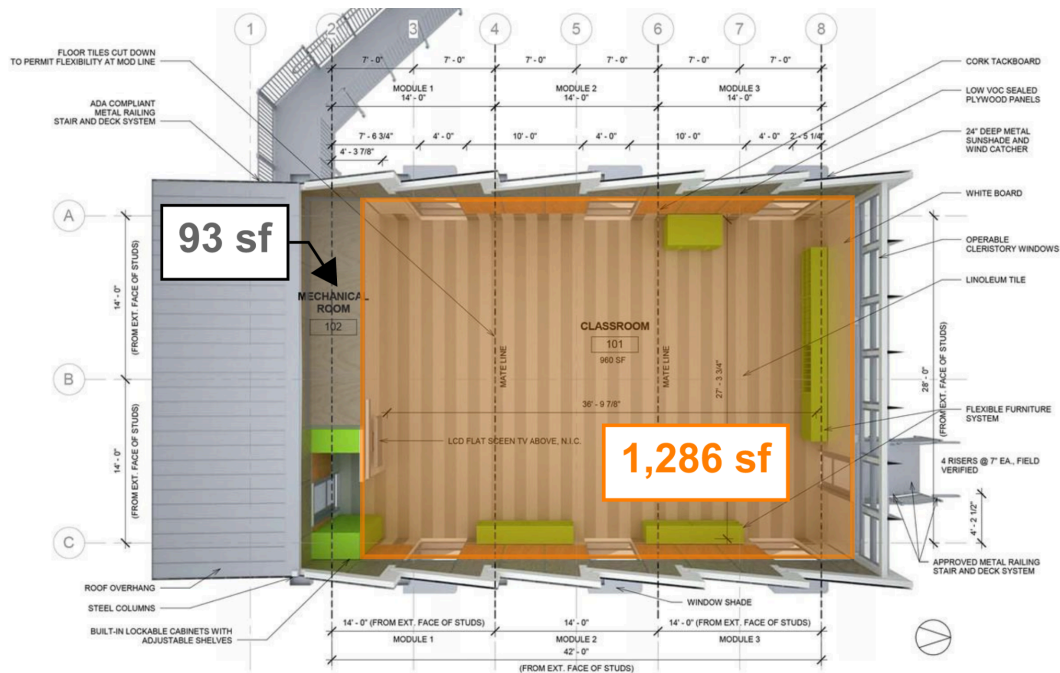


Fig. 5.4: EPRC floor plan (source: Archdaily, adopted by Author)

The EPRC is nearly twice the size of the Modular Genius and Ramtech options, and equates to 54 sf per occupant. This is because it utilizes three 14 foot wide modules, as opposed to two 12 foot modules typically utilized. While this excess amount of space may be beneficial by lowering the occupant density of each classroom, it is overly excessive and likely incurs significantly higher costs due to increased material usage and a 50 percent (minimum) increase in installation labor.

The spatial allocation to the mechanical room is useful to analyze. The dedicated mechanical room houses HVAC equipment as well as technology that monitors the energy efficiency of the building. Because a mechanical room is typically sized based on the scope of the area that it serves, using a percentage of floor area allocated will be more useful than the 93 square feet shown in Fig. X.X. This is also useful since the AMC is meant to be expandable in

size. A minimum size of a mechanical room could be calculated based off of the floor area or number of continuous modules utilized. In the EPRC, the mechanical room square footage is 7 percent of the classroom square footage.

Program

From the precedents, we can determine that the program revolves heavily around this main space. Secondary spaces support the comfortable occupancy of the primary space. At a minimum, this will include mechanical and storage space. Optional spaces could include restrooms. Because schools may utilize dozens of portable classrooms at a single time, it is reasonable to assume that multiple AMCs will be deployed on sites simultaneously as well.

The exterior of the building necessitates space to accommodate egress circulation. A standard exterior platform will provide a landing, and be attached to the ground via stairs and ramps. Another module type can provide an exterior gathering space, which can be expanded with the addition of more similar modules. These can be placed at the ends or in between classroom modules to create connections to surrounding landscapes. The lessons taken from the precedent studies and determined program zones results in the following table detailing specific pragmatic elements.

<i>Fig. 5.5: Table of Programmatic Elements of the AMC</i>			
Zone	Space Type	Description	Dimensions
Interior	Main Space (programmed as necessary, spaces shown are options)	Standard classroom for 23 students & 1 Teacher	32 sf per occupant 768 sf minimum
		Science Lab	TBD
		Library/Study Space	TBD
		Physical Fitness Room	TBD
		Community Room	TBD

Fig. 5.5: Table of Programmatic Elements of the AMC

	Support Space (required)	Mechanical	Area = 7 percent of main space square footage
		Storage	22 sf minimum
	Optional	Single User Restroom	50 sf minimum
Exterior	Circulation (required)	Entry Platform	TBD
		Stairs	TBD
		Ramp	TBD
	Optional	Gathering Platform	Width: standard module Length: TBD

Chapter 6: Site Selection and Analysis

This thesis is designed to be applicable universally. However, to examine how the system will work, a site was selected. The site will be located in Montgomery County, Maryland.

Montgomery County follows a similar trend of aging facilities throughout the country and state. The Maryland Interagency Commission on School Construction (IAC) publishes an annual report that assesses the quality of school facilities statewide, using Facility Condition Index (FCI) as the key metric. The 2025 report shows that statewide, four out of five school facilities sit above 45 percent, classifying them as “needs repair” or “functions unreliable”. Between MCPS and PGCPs, 200 schools score beyond the 45 percent threshold.

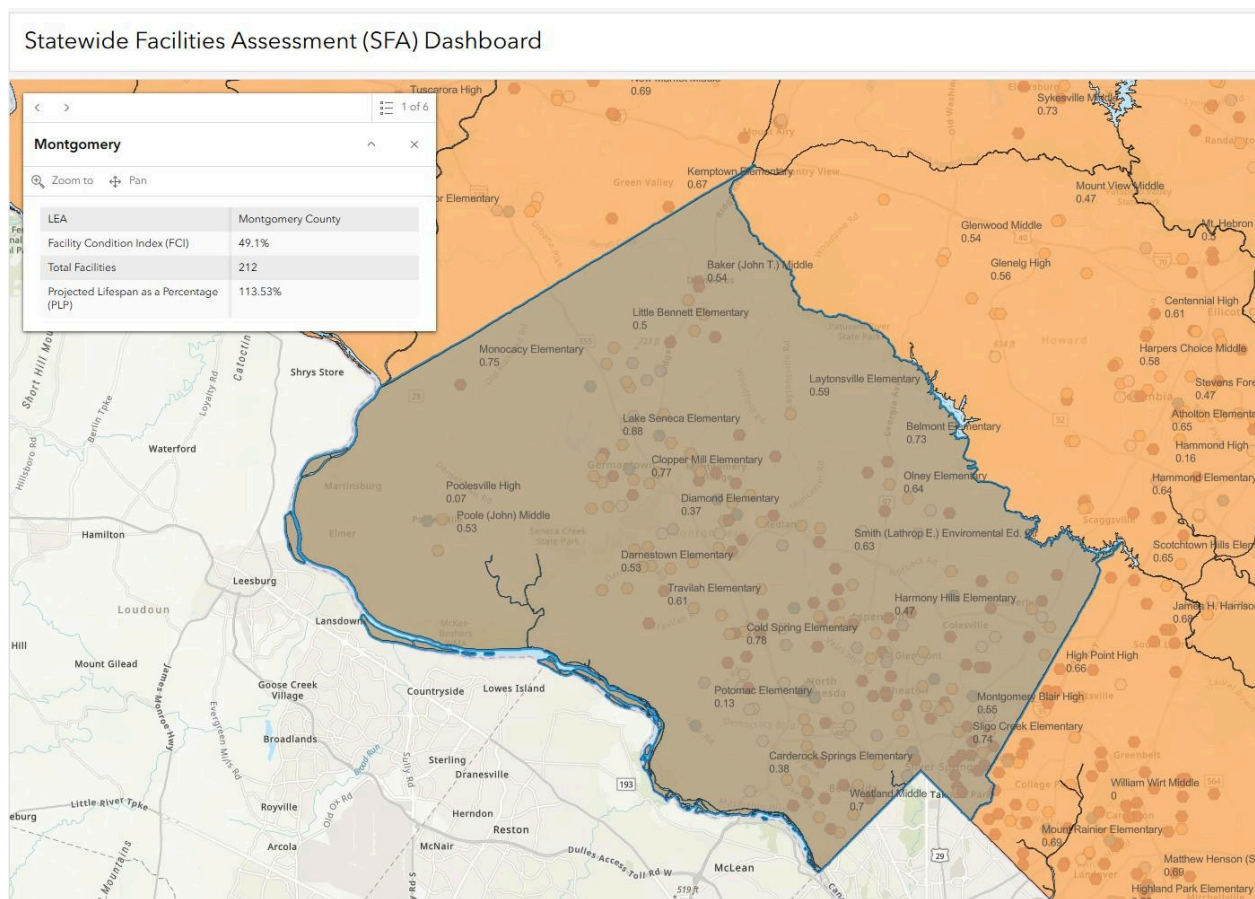


Fig. 6.1: MCPS School FCI Report (source: MD IAC)

MCPS is in a particularly dire situation. The FCI Score of 49.1% indicates that many many school facilities are in need of repair. Given the current age of their schools, MCPS should be renovating, renewing, or replacing 6-7 elementary schools every year for the next 20 years,

at a cost of \$221-345 million every year. Along the same lines MCPS should be renovating, renewing, or replacing 2+ secondary schools every year for the next 20 years, at a cost \$135-210 million every year. In total, this amounts to at least 160 new schools in the next two decades. In the entire 6 year capital improvement plan, there are only 5 schools total (2 elementary, 3 high school) in the pipeline.¹⁹⁸ Given the mounting number of schools equipped with deteriorating facilities, and the lack of new schools coming online, renovations will be commonplace amongst MCPS' inventory of schools. During such renovations, students must go somewhere. This will almost certainly be portables. Therefore, portables will continue to remain an active tool in the kit utilized by MCPS. This reality will occur even in spite of any regression in the county's population growth. MCPS utilizes 474 portables in 2025.¹⁹⁹

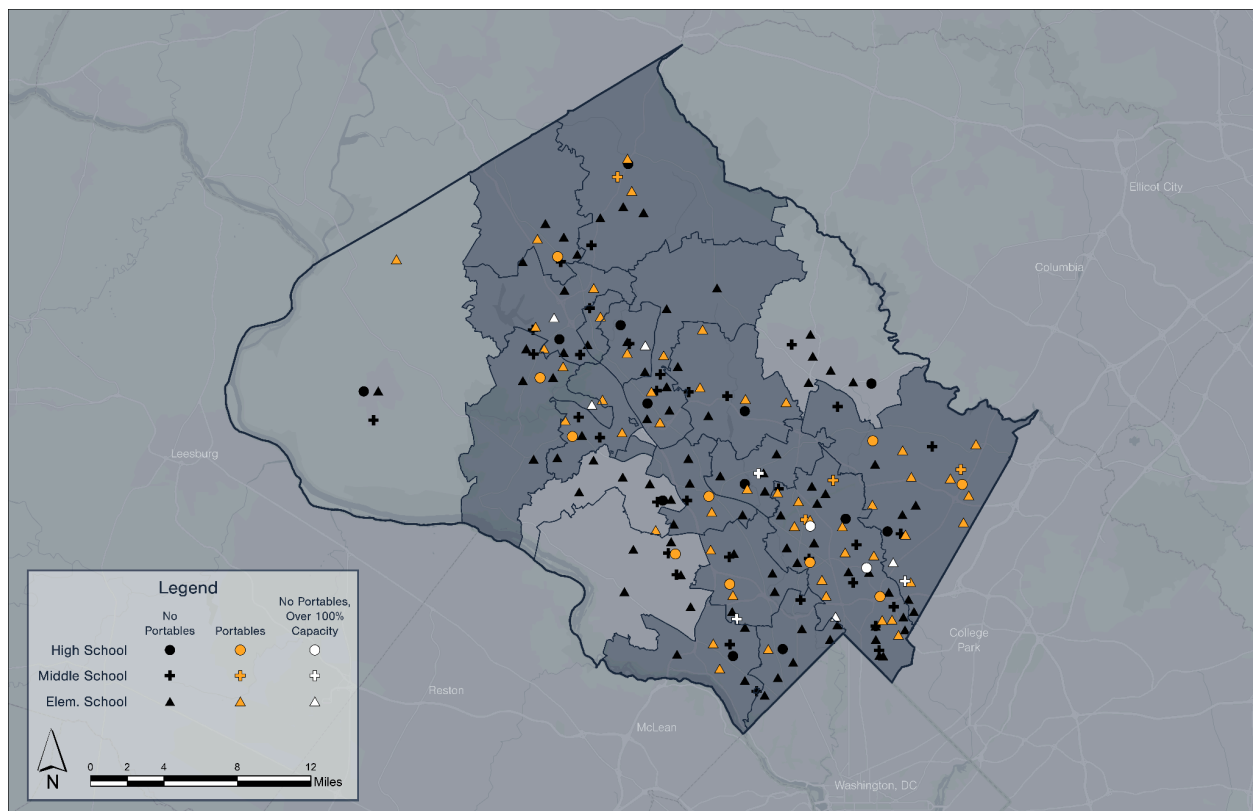


Fig. 6.2: Portable usage at elementary, middle, and high schools in MCPS (created by author)

Overlaying the schools that have portables on site or are overcrowded reveals that generally, usage is higher closer to Washington, DC, and more urban areas, as well as in

¹⁹⁸ Oct 14, 2025 Facilities and Boundaries Preliminary Presentation and Work Session.

¹⁹⁹ Montgomery County Board of Education, *Superintendent's Recommended FY 2025 Capital Budget and the FY 2025-2030 Capital Improvements Program*.

clusters around I-270 (connects Frederick, MD to Washington, DC) and Rockville Pike (355, runs parallel to I-270).

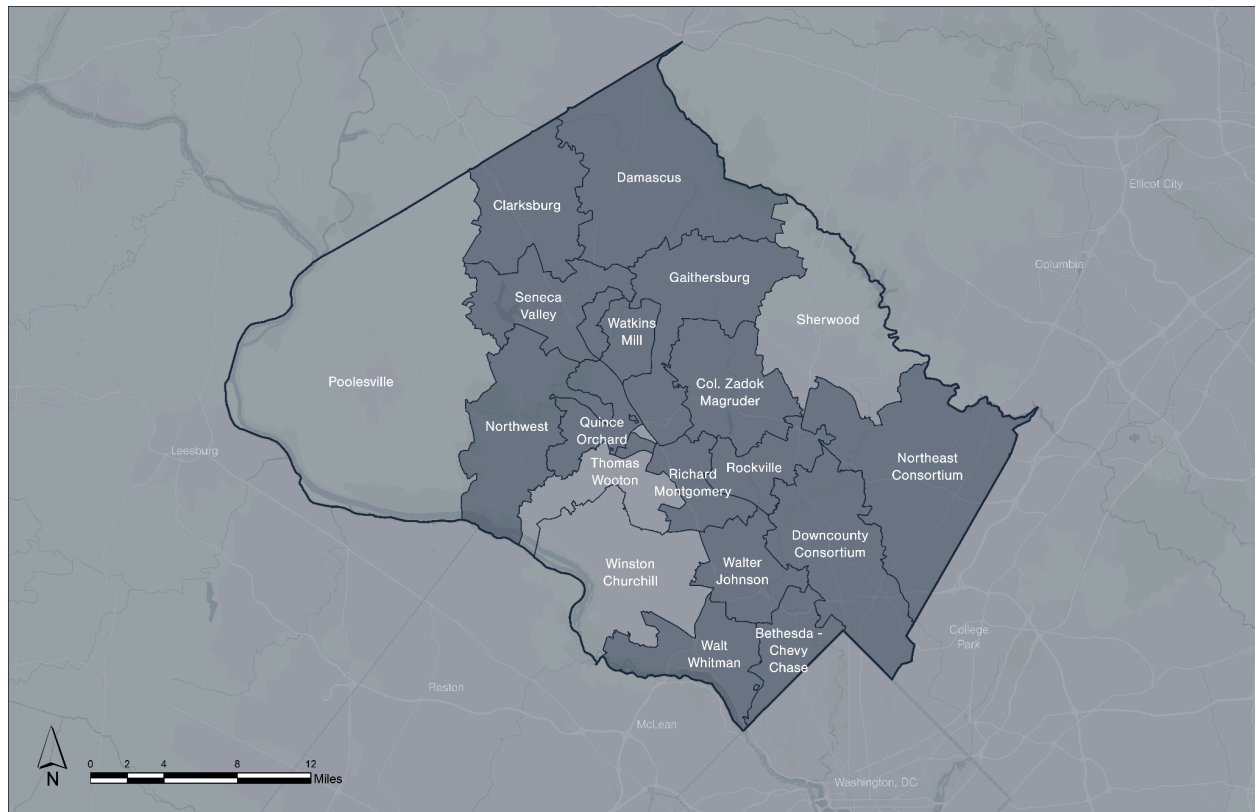


Fig. 6.3: MCPS Clusters with schools with portables and/or are overcrowded (created by author)

The specific school that this thesis will be tested on is Montgomery Blair High School, located in Silver Spring, which is part of the Downcounty Consortium. Built in 1998, Blair High School (BHS) is the largest in the state, with about 3,200 students. This is in part due to two magnet programs in Art and Science, which attract students from across Montgomery County. The large student population puts it at 111% its capacity, while the FCI score for the school is 55%, indicating needs of repair.

Because it is currently over capacity, BHS utilizes 19 portable classrooms. Interestingly, these portables are grouped into two distinct “campuses” to the east and west of the main

building, as seen in Fig. X.X. Removing and replacing these portables with the AMCs allows for two test arrangements on a single site.



Fig. 6.4: Site imagery of BHS

Chapter 7: Conceptual Kit of Parts

General Sizing

Based on reverse engineering of appropriate sizing for a portable classroom (Chapter 5), the target total square footage for the adaptive modular classroom (AMC) is 990 square feet.

This is to maintain comparable sizing to competing portable classrooms.

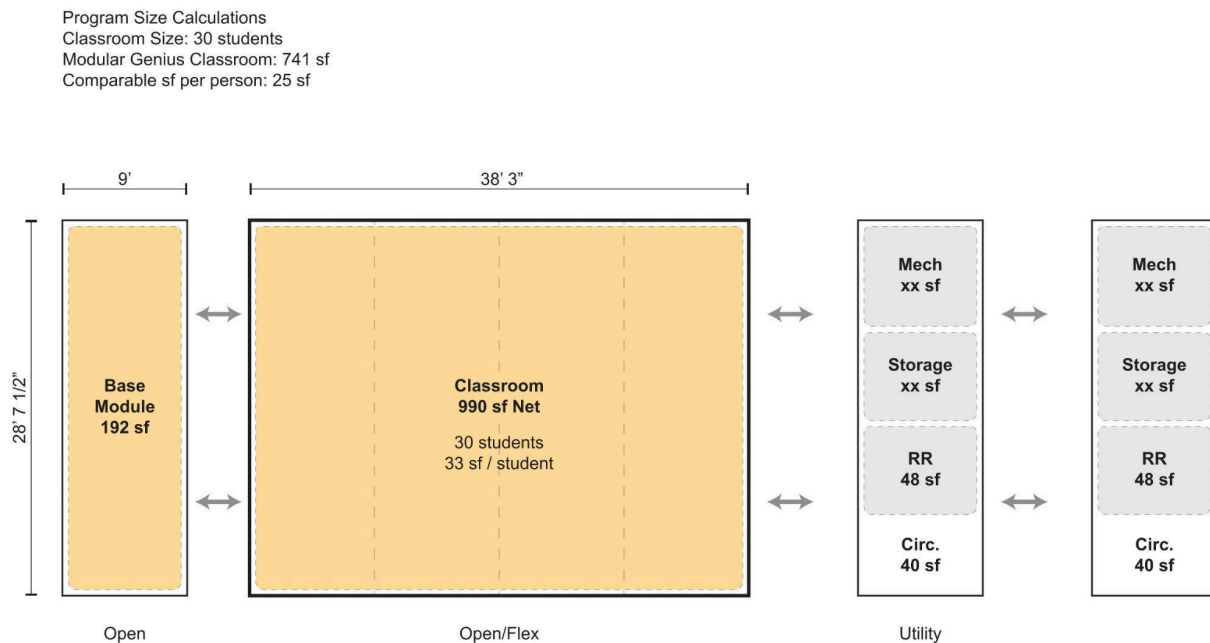


Fig. 7.1: Sizing and programming of modules (drawn by author)

The standard module size will be 28' - 7 1/2" in width by 9' in length. This creates a 1:3 proportioned module when accounting for the thickness of the panels. The sizing of these modules allows for two flat panels to fit on a single 53 foot long flatbed truck (Fig. X.X). The base module is open and optimized for flexibility of space usage. 4 modules create a single, standard classroom. A utility module, potentially containing a restroom, storage, and mechanical spaces can be easily appended to the other modules.

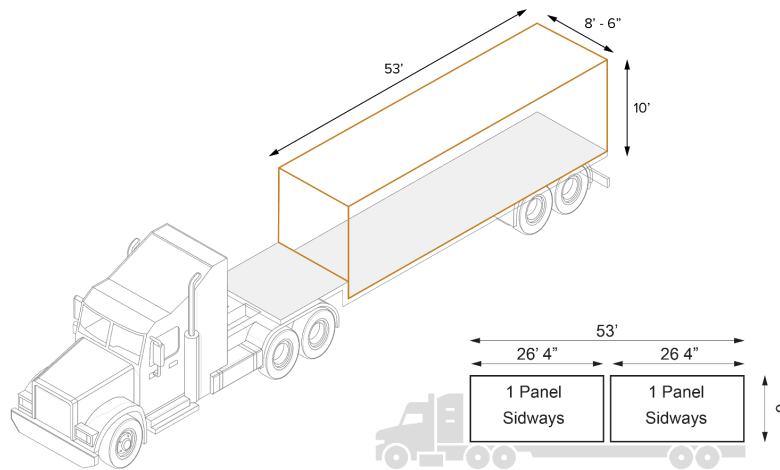


Fig. 7.2: Transportation sizing diagram (drawn by author)

The Kit of Parts

The AMC kit of parts is made up of three types of panels: floor, roof, wall, as well as accessories. Wall panels are designed to be the most diverse, and thus provide the most flexibility. There are also custom structural insulated panels (SIPs). The kit was designed to have minimal thermal bridges through the usage of overlapping panels and SIPs. Furthermore, the kit aims to utilize low embodied carbon materials or carbon sequestering materials when possible. This is primarily down through the usage of cross laminated timber (CLT) as the main structural material of the panels, and rigid wood fiber insulation as the main insulation material.

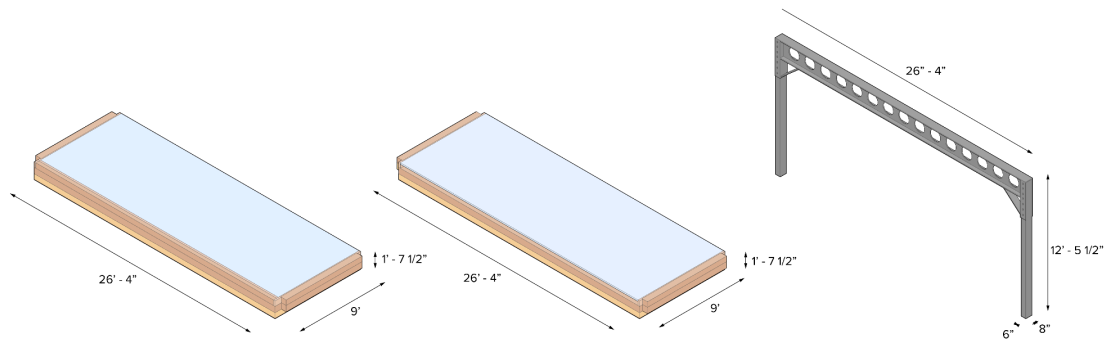


Fig. 7.3: Floor panels and steel structure (drawn by author)

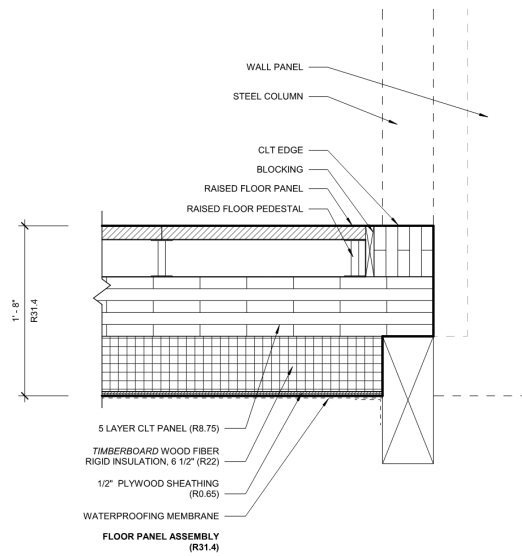


Fig. 7.4: Floor Panel section detail (drawn by author)

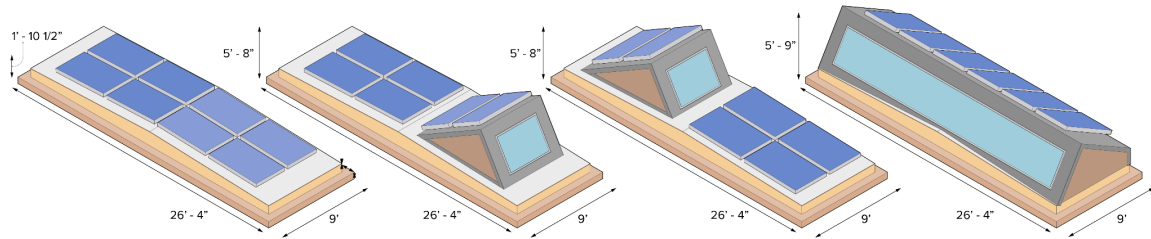


Fig. 7.5: Roof Panels (drawn by author)

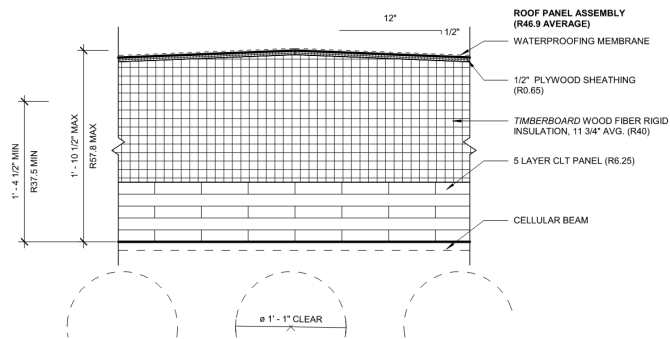


Fig. 7.6: Roof Panel section detail (drawn by author)

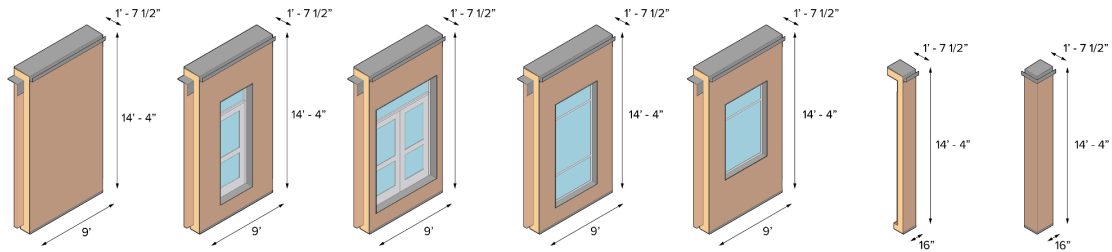


Fig. 7.7: Wall Panels (drawn by author)

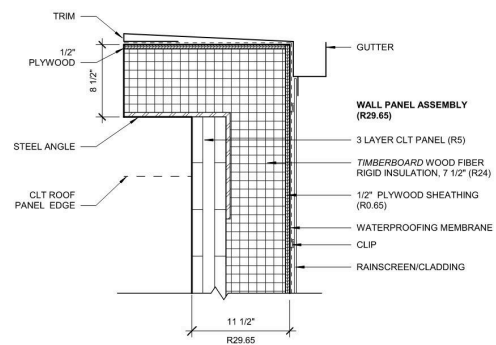


Fig. 7.8: Wall Panel section detail (drawn by author)

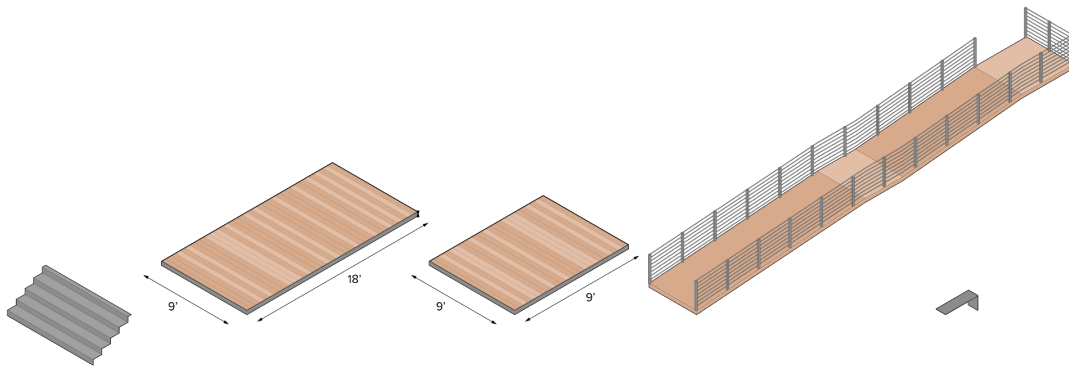


Fig. 7.9: Accessories (drawn by author)

Installation Process

The installation process for the AMCs is designed to be quick, require minimal on site fabrication, and be flexible and adaptable to change.

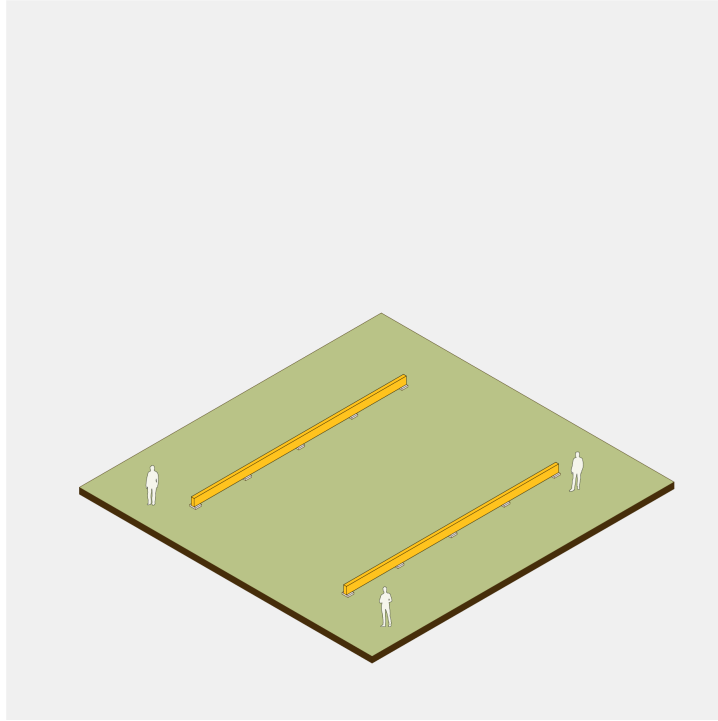


Fig. 7.10.1: Step 1: Support beams are installed (drawn by author)

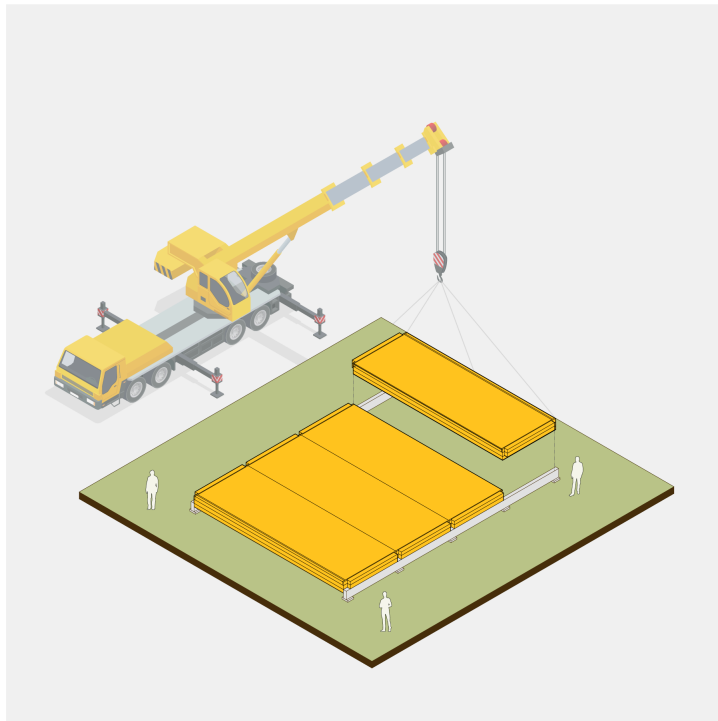


Fig. 7.10.2.: Step 2: Floor panels installed (drawn by author)

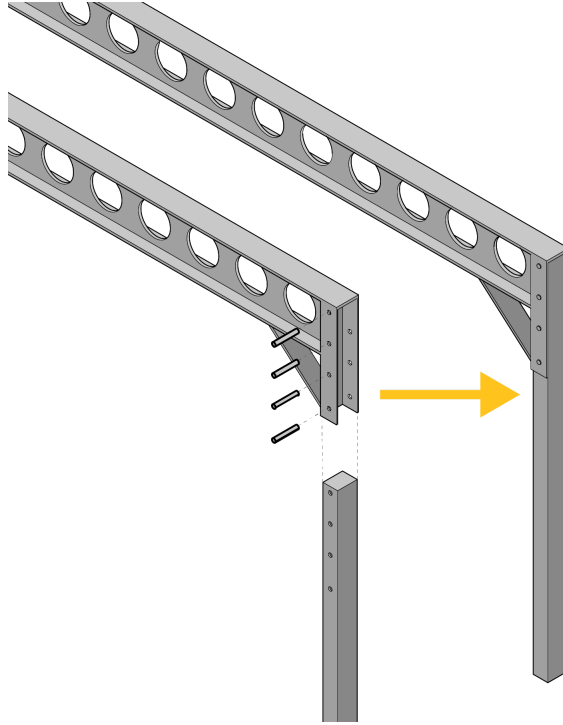


Fig. 7.10.3A.: Step 3A: Steel column and beam assembled (drawn by author)

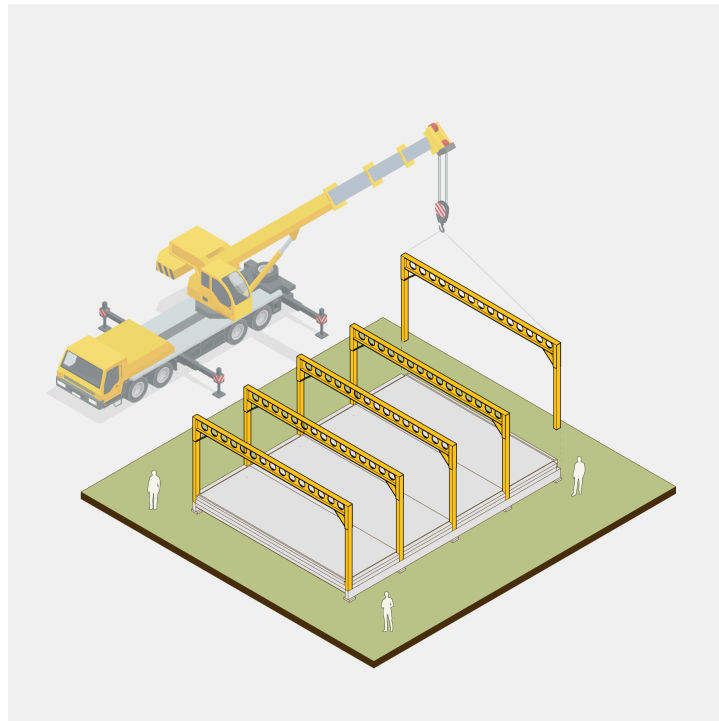


Fig. 7.10.3: Step 3: Steel installed (drawn by author)

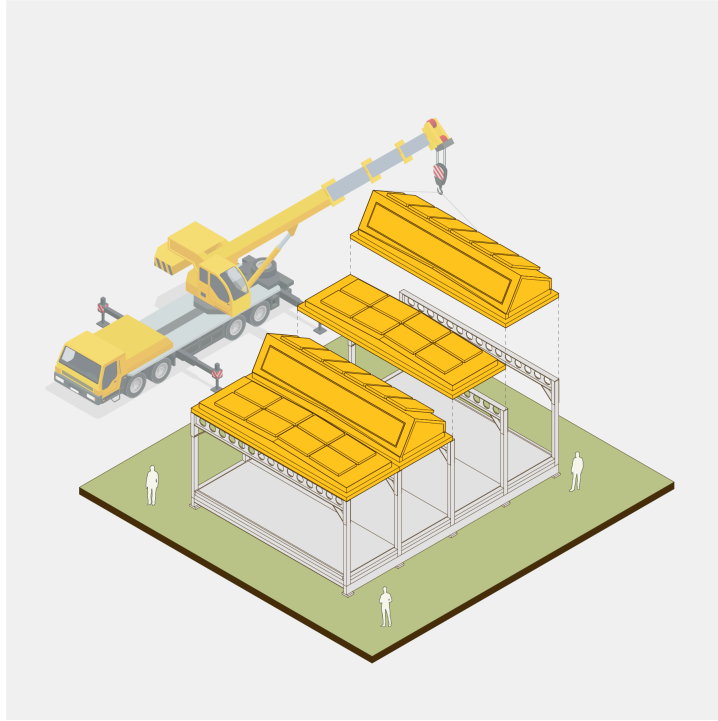


Fig. 7.10.4: Step 4: Roof panels installed (drawn by author)

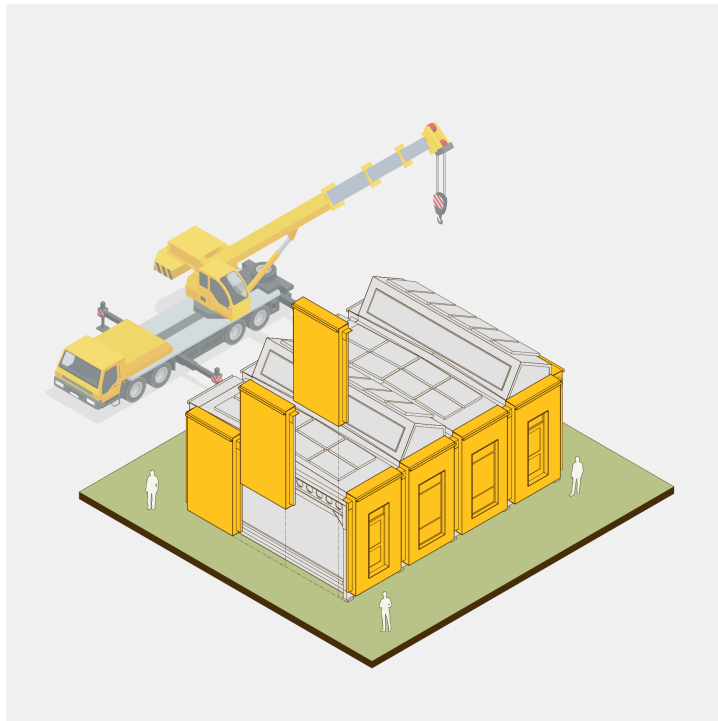


Fig. 7.10.5: Step 5: Wall panels installed (drawn by author)

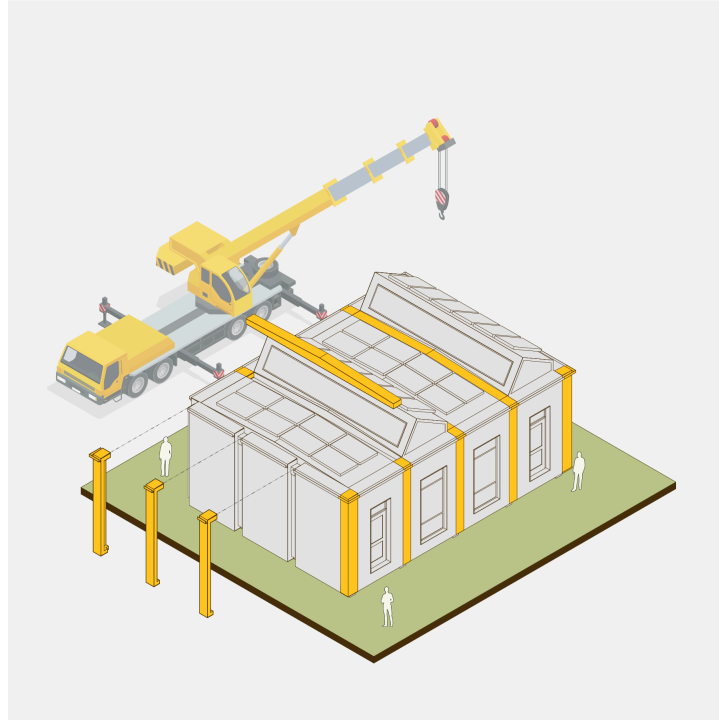


Fig. 7.10.6.: Step 6: SIPs and Waterproofing (drawn by author)

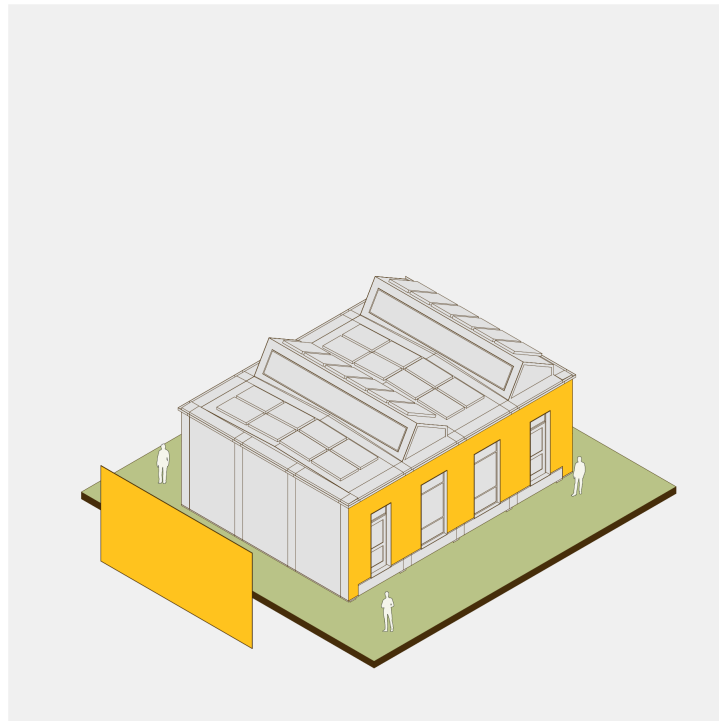


Fig. 7.10.7: Step 7: Rainscreen and cladding (drawn by author)

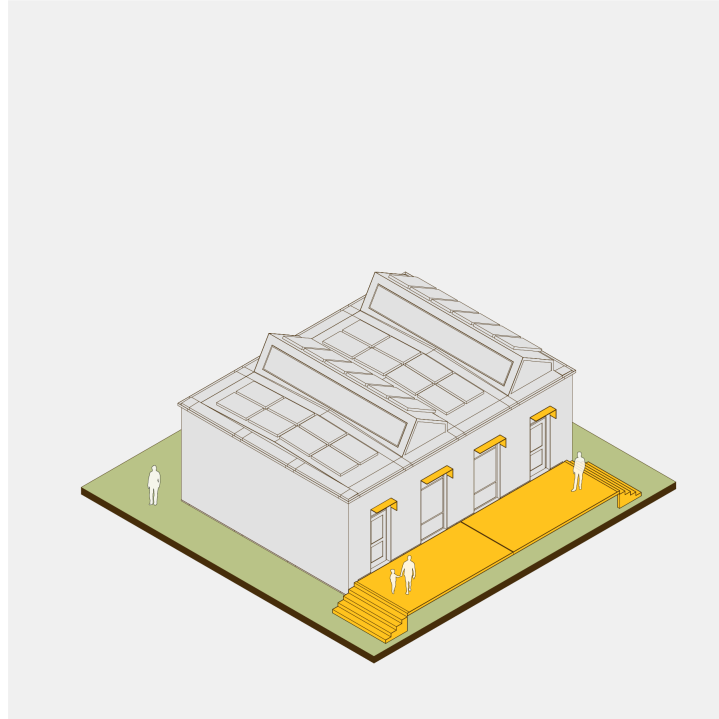


Fig. 7.10.8: Step 8: Accessories installed (drawn by author)

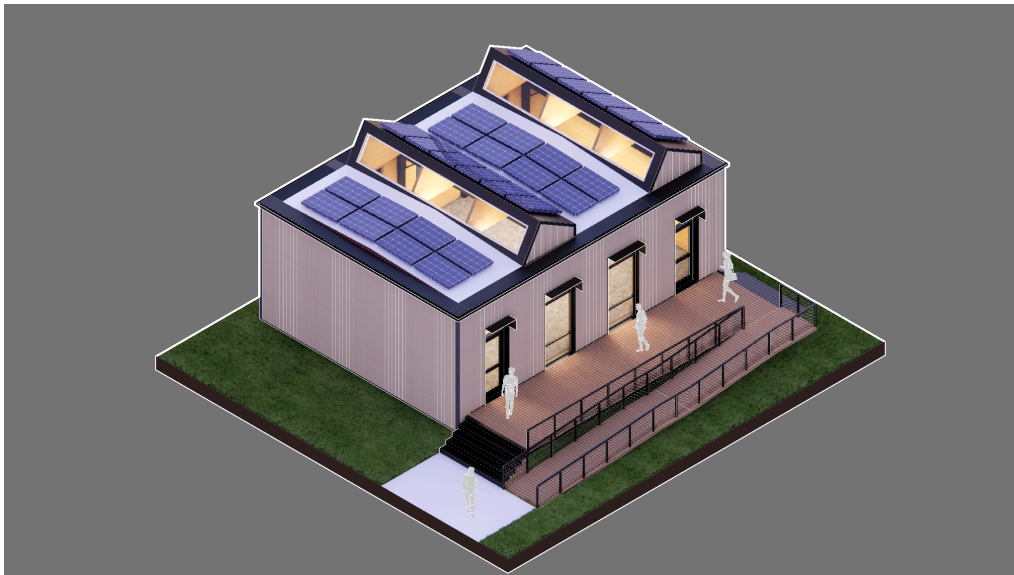
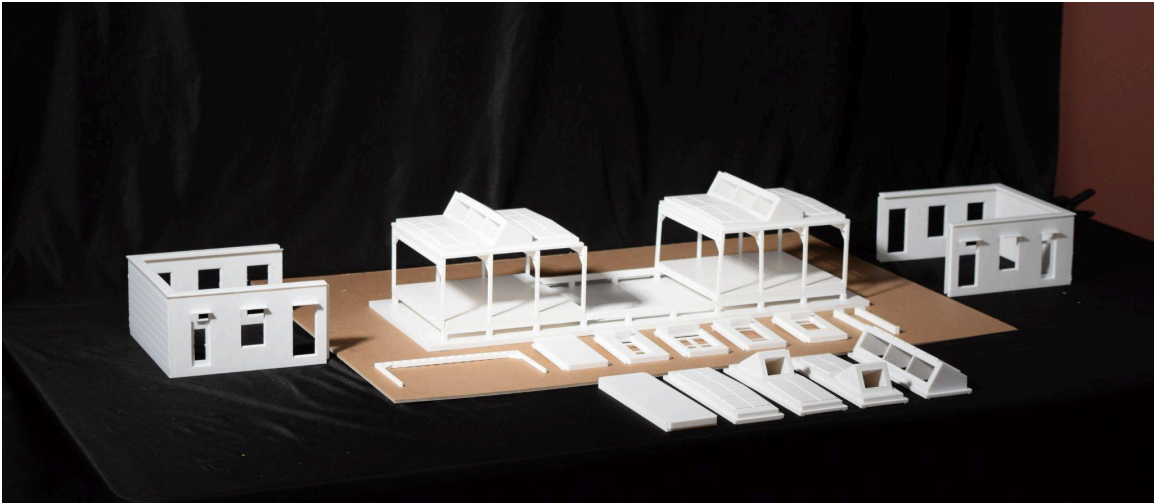
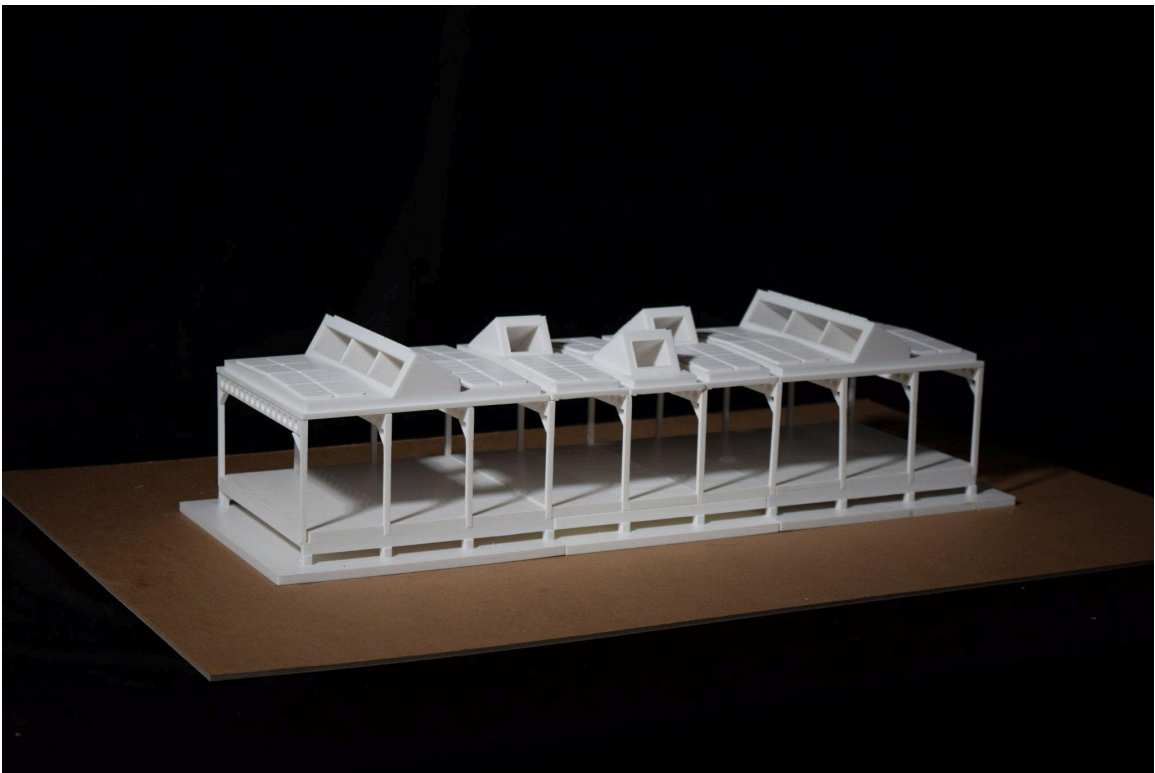
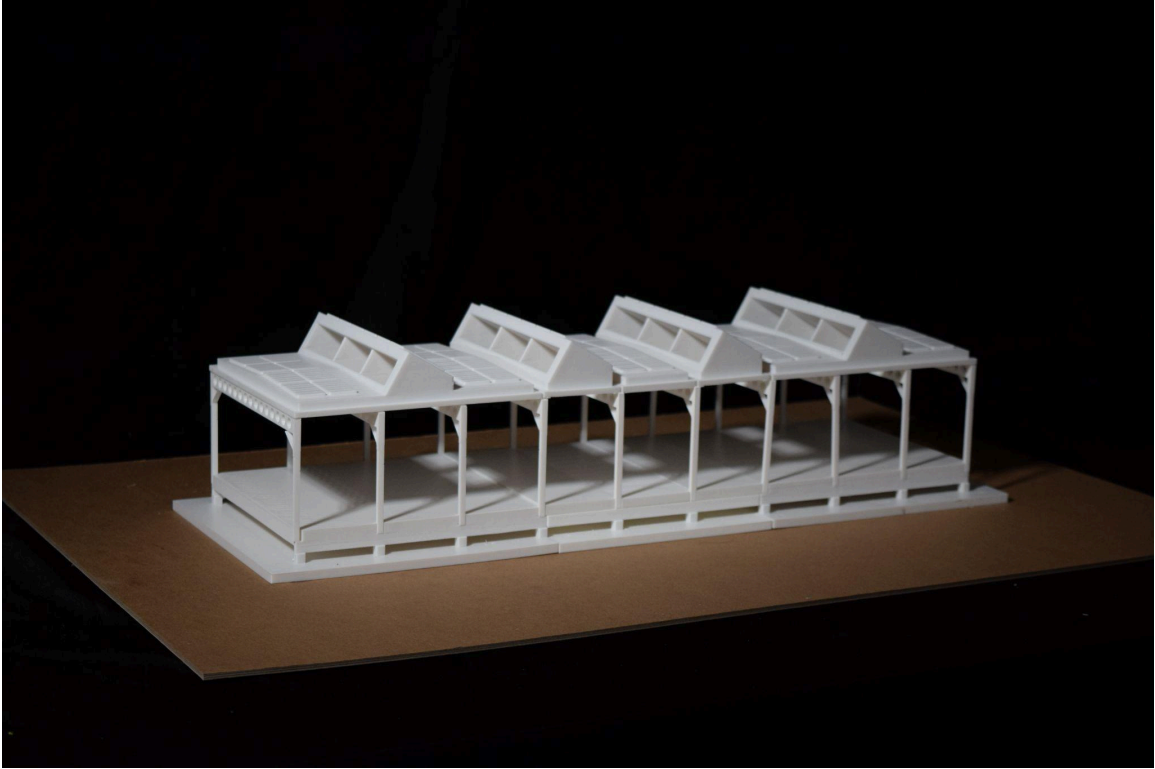


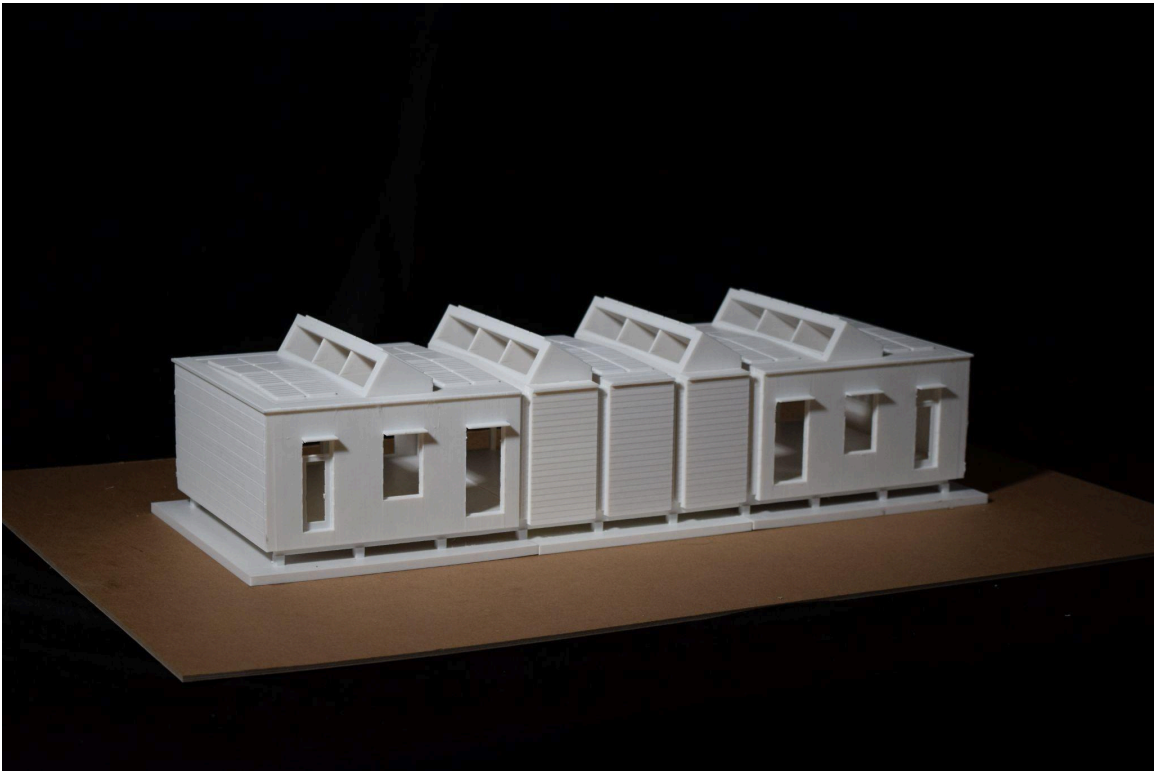
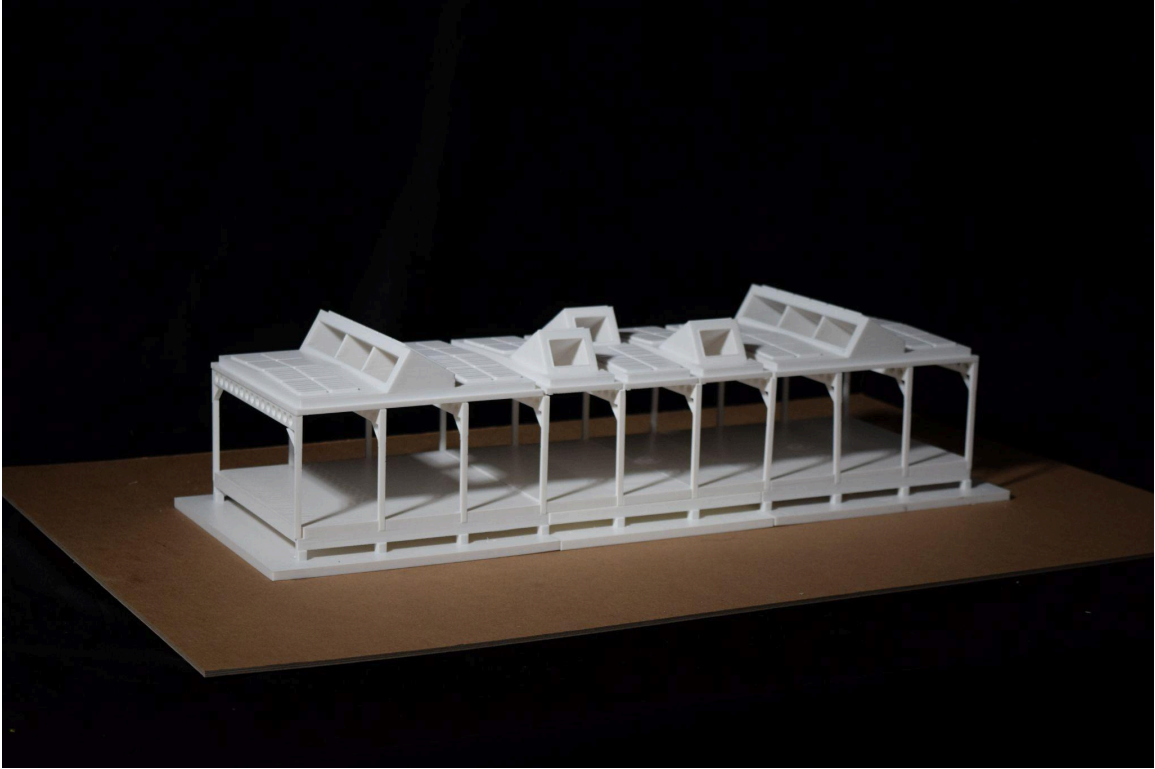
Fig. 7.11: A single unit AMC (drawn by author)

Model

To get an understanding of how these pieces interacted in real life, a $\frac{1}{4}" = 1' - 0"$ physical model was made.







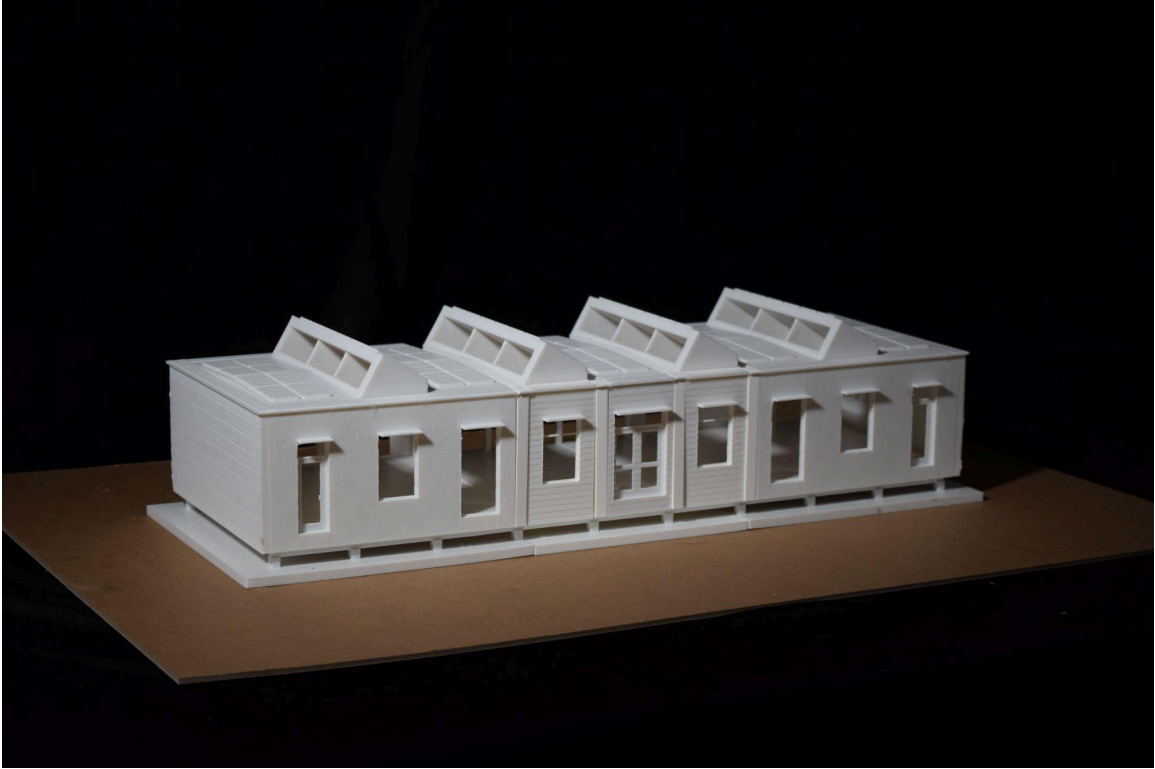


Fig. 7.12: Model Photos (photos by author)

Chapter 8: Design Explorations

This project proposes a replacement of all of the existing portable classrooms at BHS with AMCs. The new AMCs will provide extended programs beyond typical classroom facilities, and will be open to users throughout the community.



Fig. 8.1: Existing BHS Site Plan (source: Google Earth)



Fig. 8.2: New Site Plan (source: Google Earth with author edits)

The AMCs have been arranged into two new “villages” where the portable classrooms once were.



Fig. 8.3: East Village Plan (drawn by author)



Fig. 8.4: East Village Axon (drawn by author)



Fig. 8.5: East Village Sections (drawn by author)



Fig. 8.6: West Village Plan (drawn by author)



Fig. 8.7: West Village Axon (drawn by author)



Fig. 8.8: West Village Sections (drawn by author)



Fig. 8.9: East Village Outside Perspective (drawn by author)



Fig. 8.10: West Village Outside Perspective (drawn by author)



Fig. 8.11: Active learning classroom perspective (drawn by author)



Fig. 8.12: Lab / makerspace perspective (drawn by author)



Fig. 8.13: Gym perspective (drawn by author)

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