Sustainable Learning Through Architecture Elementary School: A Synergy of Metrics

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SUSTAINABLE LEARNING THROUGH ARCHITECTURE

ELEMENTARY SCHOOL: A Synergy of Metrics

by

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A Thesis submitted in Partial Fulfillment of the Requirements for the Degree of
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Preface

The following thesis project was completed in partial fulfillment of a Master of Architecture degree at the Rochester Institute of Technology. The document illustrates a passion of finding solutions for a sustainable future through educating the younger cohorts to lead a sustainable life. It investigates and proposes to change school architecture to become more proactive and practical in teaching students about sustainability. This comes from a mother to her daughter, for the creation of a sustainable future.
Abstract

*Sustainability (noun): “Sustainable development is built environment that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*¹

**When is a good time for our future generations to start learning about sustainability?**

Education is humanity’s best hope and most effective means in the quest to achieve sustainable future. Sustainability has become a priority and needs to be addressed as a school of thought from a very young age to be more effective and achieve better results.² Research shows that sustainability education must begin in early childhood when children tend to learn, absorb, and retain values, attitudes, and form habits/behavioral patterns that will have long lasting impact in later life.³ Hence the goal of this thesis is to design an elementary school that teaches children the idea of sustainability at an early age to support establishing sustainability as a way of life. The school is intended to be a prototype mainly by being an active teaching tool for students through its architecture to help institute a better understanding of the principles of sustainability. The process involves research and providing a design solution for students who would reiterate the above belief for a sustainable future.

Currently sustainability is being more widely accepted and put into practice where educational organizations are embracing the concept of sustainable schools⁴. The design exploration in this thesis is arrived at by investigating old and new educational facilities for methods being used to incorporate sustainability. Current green/sustainable school concepts and new trends, school sustainability policies and agendas, the objective and quantifying metrics, and tools employed to measure sustainability are some topics that would be reviewed upon both in

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literature and case studies. The effectiveness achieved due to these schools along with generic problems being faced in sustainable schools, including the impact on students (personal health) and their performance, are also comprehended within the research domain. Case studies of existing sustainable schools are examined to see how they are achieving their goals and as informants to the design proposal.

To achieve the above stated, a ‘systems approach’ towards sustainability is of primary importance. The systems approach in this context encompasses the ideology of how different metrics/branches of sustainability come together to act as one whole. This method implies integration of metrics such as daylighting, building envelope, HVAC (Heating, Ventilation and Air conditioning), and the use of renewable resources in an interactive and inter-dependent dynamic web where the design of one attribute affects either positively or negatively on another attribute. Therefore, every aspect needs to be taken into consideration to avoid any incapacitation in the building systems. Thus, keeping all the metrics in sight of the design parameters helps guide a sustainable and synergetic output.
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Introduction and Scope of the Project

Why is a sustainable future important?
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Sustainable learning through design
How sustainable are sustainable schools?
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Introduction and Scope of the Project

Why is a sustainable future important?

For a very long time we have been utilizing the earth’s finite resources. In the process we have harmed our own lifestyle and livelihoods.\textsuperscript{1} In the United States alone, buildings account for 72% electricity consumption, 39% energy use, 38% of carbon dioxide emissions, 40% raw materials use, 30% waste output (136 million tons annually), and 14% of potable water consumption.\textsuperscript{2} There are several factors affecting this growth in deterioration such as high population numbers, depleting natural resources, and an increase in harmful human activities.\textsuperscript{3} In such situations smarter technologies and alternative resources are sought. This has led to technological revolutions and globalization both which have further deteriorated the balance by benefiting only one sector of society.

Sustainability aims to look at using renewable resources while giving equal importance to three main domains: society, economy and environment. The idea behind sustainability is to reduce the ill effects of human activities (present and future) in order to continue life effectively. One challenge to achieving this goal is that sustainable efforts are made on an incremental, home by home, and office by office basis.

The Brundtland Report,\textsuperscript{3} released in 1987, states that “the strategy to sustainable development aims to promote harmony among human beings and between humanity and nature.” The pursuit of sustainable development requires:
- “Political system that secures citizen participation in decision making,
- Economic system that is able to generate surpluses and technical knowledge on a self-reliant and sustained basis,
- Social system that provides for solutions for the tensions arising from disharmonious development,
- Production system that respects the obligation to preserve the ecological base for development,
- Technological system that can search continuously for new solutions,
- Administrative system that is flexible and has the capacity for self-correction.”

\textsuperscript{1} Climate Change: Causes, Effects and Solutions by John T. Hardy; Chapter 1 – Earth and the Greenhouse Effect
\textsuperscript{2} Energy consumption report: www.eia.gov/electricity
The most important challenge we face now is to educate the public about the issues and institute an understanding of the importance of saving our planet. To be able to utilize resources and hand them over to the next generations, we need to quickly adapt to a more sustainable way of life, hence the urgency for a sustainable future.

Since the inception of sustainability, the world has been through a lot of changes in its system - politically, economically and socially. Amidst this process of transition, the current state of our environment calls for immediate attention to how we can affect the root cause of the problem, that is changing the mindset of people. While it is difficult for adults to adapt, and change their principles and lifestyle suddenly halfway through their life, one of the most promising ways to bring about change would be to affect the school of thought of younger generations who are yet to figure out their ideals and principles about life.\(^4\) The human collective itself therefore needs to affect its younger generations to make an efficient and effective change for a sustainable future.

**The need for a Sustainable Elementary School**

Our behavior has been the underlying cause of almost all environmental problems such as climate change. Most people are aware about the plight of our environment and many of them express their worries as they intend to treat the natural resources better. Nevertheless, we find our lifestyle to be unsustainable causing negative impacts.

Though we are educated and belonging to the intelligentsia, why has it become so difficult for us to change and act upon our environmental concerns? Research states that one major reason is that though our rational thinking knows the need for change, our behavior is driven by what we have been taught over our foundational years\(^5\). Therefore, it becomes

\(^4\) Sowing the seeds: education for sustainability within the early year’s curriculum by Cynthia Prince; European Early Childhood Education Research Journal, Volume 18, Issue 3, 2010

necessary to change our educational system to orient towards sustainability teachings which would help in making sustainable behavior the social default/norm.

Hence a compelling moral and educational case exists for demonstrating environmental stewardship in schools where children first learn what it is to be in the world, a society with other people. The child’s mind is a clean slate and is ready to grasp onto a lot of new information. To affect the future, we need to train our younger generations to exercise sustainability as a regular lifestyle.

‘Train up a child in the way he should go and when he is old, he will not depart from it.’ – Proverbs 22:6

Children and young adults are informed about the way of life at a very young age and there lies the target age group, which is as early as elementary school stage, which would make a significant change to the sustainable world. Teaching children to understand and appreciate their environment would make them sustainable and responsible adults. In today’s time, initiative is being taken readily and changes are being made to the various facets of the education system such as teaching policy, curriculum, architecture itself and much more. In certain instances, efforts are being made by few parents (known by word of mouth) to teach credible sustainability to children (to the extent/knowledge of their own) but then it is expected to take a full circle by teachings at school and this is where the school’s role in shaping the student’s life and lessons about sustainability become fundamental and crucial.

For students to learn early on, school infrastructure needs to be upgraded to create architectural spaces that are utilized as tools for teaching sustainability concepts in the hope of propelling the prototype to become the change in future. Currently the United States has 98,817 public schools of which there are 4761 public schools in the New York state (Table 1).

6 Whole-school Sustainability framework; Centre for Green Schools, USGBC
The State of New York has 4761 public school building sites. **The average age of these schools is 42 years** and they were not designed to meet future needs and growth demands.\(^8\) These schools are also not the most efficiently designed and lack in several basics such as inefficient HVAC systems and poor lighting levels with excessive artificial lighting, which need to be corrected first. When we look at the facts from Department of Energy (Table 2), the oil and gas resources being used for energy supply and demand is huge. Therefore, there is more urgency in retrofitting the older school buildings for a better future.

Facts:

- Space heating, cooling and lighting account for **nearly 70% of total school energy use**.
- **Plug loads** contribute to the top three electricity energy end users after lighting and cooling.
- Per the National Center for Education Statistics, **per pupil energy expenditure** (K-12) rose by 19% from 2007 to 2008 when national inflation was only 4%.\(^9\) This sharp rise in expenditure reflects upon school designs which has since then continued and has not seen a dip in the per pupil expenditure.

\(^7\) New York State Education Department Information and Reporting Services, The Directory of Public and Non Public Schools and Administrators for The State of New York, Last Updated: June 6, 2013
\(^8\) National Center for Educational Statistics, June 2000
\(^9\) Department of Energy, New York State Education Department Information and Reporting Services
New buildings comprise only 5% of the entire United States school building stock at any given year\textsuperscript{11}. To substantially reduce the impact of building sector, efficiency of existing buildings needs to be improved. As it is often stated, the most sustainable building is the one that has not been built.

\textit{Sustainable Learning through Design;\newline The Learning Environment: A Silent Curriculum}

The National Center for Educational Statistics (2007) reported that nearly 44\% of K-12 schools were displeased with their facilities.\textsuperscript{12} In response, school design has begun to change. Changes included more efficient and sustainable schools. These have been emphasized as high-performance schools benefitting the outdoor environment, by conserving the environment and reducing pollution and landfill. These schools translated into healthier environments for students and staff, reduced energy costs and have become learning laboratories adding to the regular pedagogy.\textsuperscript{13}

Classrooms have always been learning environments providing technological support rather than having them serve as a direct learning tool. The Centre for High Performance Environments (CHPE) along with the support from the American Institute of Architects (AIA)\

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
Fuel Type & Total Annual Consumption & \% Statewide Energy Consumption & Average Retail Rate ($\text{Million/Unit}) & Total Cost Public and Non-Public ($\text{Million}) \\
\hline
& Public & Non-Public & Public & Non-Public & & \\
\hline
Electricity Demand (MV) & 840 & 132 & 2.6\% & 0.4\% & N/A & N/A \\
Electricity Usage (GWh) & 2,426 & 333 & 1.5\% & 0.2\% & $0.158$ & $443.9$ \\
Natural Gas (BBtu) & 6,519 & 1,028 & 0.8\% & 0.3\% & $0.009$ & $68.5$ \\
Fuel Oil (BBtu) & 8,252 & 1,302 & 1.6\% & 1.2\% & $0.021$ & $200.2$ \\
\hline
Total & & & & & & $721.9$ \\
\hline
\end{tabular}
\caption{Total estimated statewide School Annual Energy Consumption and Costs.\textsuperscript{10}}
\end{table}

\textsuperscript{10} U.S. Energy Information Administration, State Energy Data System, 2011
\textsuperscript{11} United States Census Bureau 2012
\textsuperscript{12} National Center For Educational Statistics report; 2007
\textsuperscript{13} Net Zero Energy Building Schools, Wim Zeiler, Gert Boxem; Renewable Energy 49 (2013) pp 282-286
state that they are seeking to transform the design of schools and learning laboratories by influencing learning philosophy through the immense inputs from architecture.\(^{14}\) The goal of sustainable schools is to promote environmental stewardship and an improved awareness of sustainability starting at a very influential young age\(^ {15}\). This being a new take on educational systems, frequent changes are being made since we are learning as we go.

*Learning is the process whereby knowledge is created through the transformation of experience.*\(^ {16}\)

The need for new thinking urges collaboration between architecture and education which prompts interactive physical learning environments which will compel students to be responsible for their own intellectual growth and knowledge of key elements of life. This thesis is an attempt at connecting two complex disciplines of architecture and education for their mutual benefit and for the good of the society in which we live. The primary role is played by the architects and educators who need to understand each other and develop vocabulary integrating educational theories, practicality and developmental requirements of children. Physical environment and ambient quality are active and most important attributes in the learning process which can be achieved by responding to the human experience of school facility users.

\(^{14}\) Guidelines for the design of Sustainable Learning Laboratories that teach through Architecture, Jim Jones Ph.D. Director, CHPLE Virginia Tech

\(^{15}\) Sustainable School Architecture, Lisa Gelfand with Eric Corey Freed

\(^{16}\) David Kolb (1984, p.41)
Although most schools today are starting to teach sustainability concepts and their practicality, it is often done through 2-dimensional medium such as posters, presentations, lectures as shown in (Figure 1). This methodology which is on the rise, once again lacks a primary, interactive teaching method that leads to a gap between practicality and book knowledge.

**How sustainable are Sustainable Schools?**

The decision to create a sustainable school, whether by modernization and renovation of existing structure or by new construction leads to sustainable choices and design which reflects the values and priorities of a school community. To do so, one needs to have knowledge in terms of metrics which would help measure the sustainability and give required direction and dimension to the intent of sustainability. Just as students will graduate with the understanding of sustainability nurtured by their experiences in school, the school itself needs to ‘graduate’ from
the process with knowledge and skills that they carry to their own homes and businesses.\textsuperscript{17} Providing quantifiable attributes to a design assures the quality of sustainability and initiates a very good way of creating and recording for future references and conducting comparative analysis to study building performance.

Another looming issue to sustainability is getting the user to understand and maintain/operate the system designed into the project as intended and in a way making them user-friendly is the current challenge which is further discussed in the literature review of the report. Schools are a unique operating environment that are very volatile and highly active spaces which is a determining factor in relaying the building use depending upon the users. Systems, materials and assemblies need to be designed such that they all interrelate to each other to fit the environment.

Schools that tie sustainability and education into a way of inhabiting the campus support both the running of the facility and the educational activities. As buildings and landscapes that are found in every community, schools constitute a piece of the building sector that is uniquely suited to provide leadership in sustainability.

\textit{Sustainability: Synergy of metrics, a systems approach}

\textit{Synergy: The interaction or cooperation of two or more individual parts to produce a combined effect greater than the sum of their separate effects.}

For a project to be sustainable, all the metrics need to work together for the result to be effective. For the integration to work out, the various relations and networks need to be chalked out in the initial stages of design (Pre-design) which helps in avoiding last minute changes and escalation in design change orders. For example, adequate amounts of daylighting contribute to better health and focus of students enhancing learning while reducing cost for energy as well as demand for artificial lighting which would in turn reduce the resources (energy) needed for it. Synergizing metrics allows for whole building design process where a thorough understanding of metrics and interrelations are mapped out for making better decisions. At earlier design stages

\textsuperscript{17} Linking architecture and education: Sustainable Design for Learning Environments; Anne Taylor
designers opting linear thinking which is illustrated in the (Figure 2) would help considering all the metrics that would affect a singled-out metric.

**Figure 2: An integrated approach in comparison to traditional method.**

Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Literature Review

Introduction

Sustainable Learning Environments

Models for Rethinking Classrooms

Justified Sustainability and its Reality

Application of Metrics

Conclusion
Literature Review

Introduction

The thesis was initiated due to the lack of integration of sustainable learning into school architecture and thus the research looks at various forms of sustainable learning environments, in theory and practice. The scholarly research integrates understanding current sustainable school design trends and methods plausible for creating learning spaces that teach through architecture. At present, we see that sustainability is being taught primarily through 2-dimensional medium (paper posters and science fairs) which imparts knowledge in children but does not actually provide a working example. The research is intended to find ways of integrating school architecture as a 3-dimensional learning laboratory that teaches keeping the primary end user (students) in mind.

Sustainable Learning Environments

Architecture and Education intersect when it is time to design, plan and create new learning environments. How can one create active learning environments? What elements in physical learning environments will compel students to be responsible for their own intellectual growth?18

18 Linking architecture and education: Sustainable Design for Learning Environments; Anne Taylor

. The old ‘assembly line’ model no longer supports what we know about how the brain/mind learns (Caine and Caine, 1991, pp. 13-14). This means the architect must provide different configurations for learning environments, more flexibility, adaptability, movable components and future conversion to other uses (Locker & Olsen, 2004).


. Classrooms will become more like studio workplaces (Second National Invitational Conference on Architecture and Education Report, 1992, p-3)

. Special programs and individualization of the curriculum are on the rise and require a variety of specialized spaces and universal access (Preiser, 2001)
The area of providing high performance learning spaces has been explored in depth by several researchers and there are several theories trying to provide different combinational flowcharts. One such approach is the ‘Guidelines for the design of Sustainable Learning Laboratories that teach through Architecture’ by Jim Jones Ph.D. Director, Centre for High Performance Environments (CHPE) Virginia Tech. The author discusses transforming the focus of schools from being passive vessels to active participants in learning and therefore devises three major tasks for the goals and objectives of the research. a) Lessons learned from CHPE research of buildings such as design procedures and collaborative relationships and specific building system decisions that address the linkages illustrated in (Figure 4). b) The CHPE collaborated designs with architects which served as case studies to document and understand relation between architecture and building systems. c) To better understand the target learning group, CHPE conducted mock design of environmental learning center with middle school students. Through observation and documentation of student interactions, a design process was proposed by Dr. Jones which involves participation of several fields as shown in (Figure 4) rather than the ‘Old Design Model’ as illustrated in (Figure 3) showing the linear approach of design; the space and its contents.19

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19 CHPLE website, Virginia Tech: http://www.chpe.arch.vt.edu/
A new framework is suggested in the (Figure 4) for designing buildings that teach, which involves combining a School’s philosophy and goals of sustainability with a Pedagogical system. This model looks at placing teachers at the center of learning as conductors where the orchestrated learning provides opportunities for students to learn from both new material and old knowledge. The above ideal situation is arrived at within the boundaries of the research conducted by Caine and Caine which propels this methodology characterized by themed teaching, reality-based project learning, multisensory learning, teamwork and using physical and perceptual context.  

Since children learn from the entire context they need to have a sense of safety to indulge in free learning, which makes it important to put extra care in designing the environment. The third component identified is ‘active processing’ or the process of learning such as reflection, analysis, contemplation, questions, personal analogies and so on.

The research stresses that for the building that teaches, environmental factors can be important inputs to architecture and form and proposes a framework intended to bring together academia and architecture to form a sustainable future.

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20 Caine and Caine; pp.107-115
In addition to school design reform, an important and integral part is the design of classrooms. Traditional classrooms are all similar shaped box spaces which is teacher oriented and disregards student’s interests. Currently teaching methods are leaning towards student-driven which has led to shift from traditional methods. Modern teaching methods are to foster independent thinking, problem-solving and thought provoking which is transitioning towards rethinking of classroom spaces.

**Models for Rethinking Classrooms:**

A much-needed architectural revolution is needed and therefore six models are drawn up based on research, design and development work. These models are discussed as theories and are intended to be re-produced as arenas for education through the design proposal.

Model 1: The Evolving Remodel
Remodeling, reconfiguring and updating existing classrooms often with student help as a learning experience. Refer (Figure 5) for example.

Model 2: The Diversity Cluster
Providing diverse spaces for a variety of activities, learning zones, usually organized around a centralized group gathering space.

Model 3: The Technology Studio
Motivational and technology-rich spaces and plazas for learning, fully equipped and furnished to support technology use and deployability. Refer (Figure 6) for example.

Model 4: The Cultural Nexus
Architect Steven Bingler refers to schools as nexus of the community, which includes culture and community resources moving into schools, schools serving community and preservation of cultural values through participation and design.

Model 5: The Home Family Learning Center
A family learning environment created through conversion of traditional spaces in home also seen as a model for ambient treatment of smaller school spaces.

Model 6: The Mobile Stage

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21 Linking architecture and education: Sustainable Design for Learning Environments; Anne Taylor
Deconstructing the classroom with flexible environments that may make use of travelling classroom kits, possible privatization of facilities, prefabricated environments and leasing of modern furniture and flexible infrastructure supporting the mobile learning environments.
Figure 5: An integrated approach in comparison to traditional method

Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Figure 6: Breaking down the classroom environment to make intangible boundaries

Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
In the above illustrations, (Figure 5) shows a kindergarten school design which has different levels of study areas pertaining to user requirement and abutting open areas to include open studios and dramatics classes whereas (Figure 6) depicts technology juxtaposed with teaching methods and classroom layout that all converge to make tangible classroom environment.

In the book, *Linking Architecture and Education by Anne Taylor*, the author throws light on possible ways to involve architecture and sustainability in school designs through *Habitability*. Habitability refers to an individual’s well-being in this case being student’s as they spend many hours per day in schools. Good school design should be able to nurture this notion of student well-being which is in turn linked with sustainable design. What is good for the student is also sound ecological practice such as good day-lighting and views which would in turn affect student performance and at the same time reduce lighting energy costs and energy loads for HVAC system. A growing body of research shows a measurable relationship between physical characteristics of school buildings and students performance.\(^{22}\)

![Figure 7: From Vitruvius to Modern school facility: Three qualities of an Effective School](image)

*Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor*

Achieving ecologically responsive designs requires thinking about the whole building and its entire life cycle from initial planning to operation.\(^{23}\) The model (Figure 7) shows transition/extension in the thought process of school architecture from The Vitruvius age where Beauty, Utility and Strong were the themes to an exemplary sustainable and high-performance teaching tool, functional and safe (health and general) which encompasses the goals of holistic approach.

**Justified Sustainability and its Reality**

Sustainability being grand and enormous, it becomes necessary that it is implemented in an effective way. Though recently we have seen an increase in sustainable schools, the quality is questionable. Most buildings though claim to be sustainable in the design stage, the user phase is what defines its success/failure. This parameter of successful sustainability is lacking due to which the framework of sustainability must be evolutionary with a constant feedback loop to take corrective measures along the way. The article ‘Judging the effectiveness of sustainable school; asserts that using sustainable school framework and to be able to say that schools are now addressing sustainability without actually measuring it is somewhat deceptive. However, there is considerable difference between addressing and achieving tangible sustainability.\(^{24}\) To achieve true sustainability, the author strongly urges to take a stand on the type of school that one wants to achieve with a single point agenda/Goal and work towards it. This narrows down the immense spectrum of sustainability and helps in achieving accurate results.

Another critical issue raised by the author is the socio-technical process of Sustainable Design where it is very important to engage end-users. As designers, we need to bring across the technological part of a building to the users and make it more understandable and interactive for the building to be more efficient and effective towards the goal. Users of the building, have much more influence on how sustainable a building can be depending on their knowledge and choices. Due to the issue of end user capability, sustainable buildings tend to underperform.\(^{25}\) Recent research has revealed that many sustainable school buildings perform worse than expected with

\(^{23}\) Olson and Kellum, 2003: National Renewable Energy Laboratory

\(^{24}\) Judging the effectiveness of sustainable schools; SAGE Publications, Vol 3(1) pp 33-39

respect to energy due to the behavior of building occupants\textsuperscript{26} which reiterates the fact that sustainable schools need to be user friendly so that the buildings don’t have the negative impact instead. For instance, there are several things that go wrong in the initial stages of data accumulation (non-responding meters, lag in time and data, malfunctioning of systems and other unknown issues) to have the perfect systems balance.

\textit{The Whole-School Sustainability framework} by Center for Green Schools, United States Green Building Council (USGBC) promotes design and construction of green schools, by greening the operations and maintenance of existing schools, and by incorporating sustainability across curriculum and into communities, to make tremendous impact on student health, learning and their future, school operational costs and the environment. The Center for Green Schools (CGS) along with the Education for Sustainable Development (ESD), work towards the formal sector curriculum in a holistic manner, rather than being taught on a standalone basis. They observe that though there is widespread acceptance of this notion, there is very few active schools that have embraced the idea in their curriculum. The current trend shows partial implementation of just a few aspects of Education for Sustainable Development (ESD) in experiential learning units. Some of these are Australian Sustainable Schools Initiative (AusSSI) which promotes active engagement of stakeholders such as teachers, students, management etc. to start several pilot projects which involves at least 2000 schools to date.\textsuperscript{27}

\textbf{Application of Metrics:}

The most important environmental issues prevalent in school architecture include acoustical quality and noise control, indoor air quality (IAQ), thermal comfort and daylighting.\textsuperscript{28} Vast research about these parameters reiterates the above fact where the older school building stock does not meet the required standards and therefore are not being environmentally responsible.

\textsuperscript{27} LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
\textsuperscript{28} EPA Healthy school buildings
Acoustical Quality and Noise Control: Poor acoustics are mostly the main issue for poor learning as it is a major factor affecting the student’s learning capacity directly. Environmental noise levels during regular school hours should ideally be between four to thirty-eight decibels. Ecologically sound design principles should directly and indirectly address acoustics through better placement of learning spaces away from sources of noise, high quality HVAC designs and proper life cycle maintenance of the acoustical materials. The American National Standards Institute (ANSI) requires learning spaces to meet reverberation standards and acoustical performance including thick walls and roof for external sound absorption, insulation, surface treatments and configuration of spaces to separate noisy areas from quiet ones.

Indoor Air Quality: Indoor Air Quality remains a serious concern for schools as it is tough to maintain balance between the shelter and the enclosed air with relation to bringing in fresh air and keeping the building healthy and breathable. Primary sources of poor IAQ are faulty or poor HVAC systems, contaminants, poor ventilation and inadequate maintenance leading to ‘Sick Building Syndrome’. LEED 2007 awards points for schools with outdoor air delivery monitoring with alarms, automatic measurement and controls and additional ventilation. Low emitting building materials and design that minimizes entry of outdoor pollutants, using green supplies and products, operable windows are helpful in improving air quality.

Thermal Comfort: Thermal comfort is one of the fundamental environmental factors that is to be addressed with the user group in mind. Maintaining appropriate thermal comfort for school would help in increased student performance and good attendance rates. The ASHRAE (American Society for Heating, Refrigeration and Air-conditioning Engineers) recommended levels for humidity are (40-70%) and temperature (68 to 74 degrees Fahrenheit). It also affects IAQ due to potential mold formation. The EPA guide suggests that the key for mold control is moisture control. Energy Star rated HVAC systems ensure appropriate conditions and have adjustable controls. A better performing building increases comfort levels of its occupants.

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29 Effects of Classroom Acoustics on Performance and Well-Being in Elementary School Children: A Field Study by Maria et al; Environment and Behavior September 2010 vol. 42 no. 5 659-692

30 US Green Building Council 2007; Olson and Kellum 2003

31 Sick Building Syndrome: noun: a condition affecting office workers, typically marked by headaches and respiratory problems, attributed to unhealthy or stressful factors in the working environment such as poor ventilation

Daylighting: Using daylighting to improve lighting conditions while conserving energy are the primary aims of sustainable designs. This aspect of sustainability is also helpful in improving student performance by 20 – 40% which is an important criterion for schools. A daylighting system comprises not only of the mechanisms such as skylights and fenestrations but is more efficient when coupled with daylight responsive electric lighting control system. Daylighting cuts down lifetime energy expenses of a building by 30 to 70% through diffuse lights, roof monitors, skylights and clerestories. However, daylighting could also increase energy loads and lead to glare hence requiring lot of care in its design. Light shelves and window treatments used for shading or allowing sunlight to enter combine solar orientation and appropriate sunlight levels helps with the issue of glare and excessive sunlight.

All the above discussed entities are best when designed to be a cohesive and integrated sustainable outcome. These needs to be incorporated from initial design phases as each can affect the other in building design such as using more daylight reduces the energy use from light fixtures and improves ventilation and diffusion of natural light. Since buildings are complex and no environmental factor exists in isolation an integrative approach is of prime importance as there are several other attributes in addition to the ones mentioned above that need to be considered.

There are several tangible and intangible metrics that can verify sustainability in a building. The most important and effective metrics that encompass in a school design are good indoor air quality, lighting, hygiene, thermal comfort, materiality which need to be given priority.

Since sustainability has become the brand ambassador for advertising a company/business, it has pushed developers and designers towards designs favoring one or more metric rather than working on all interrelated metrics. This attitude has led to adverse effects on the occupants and their performance. One such example is the work of a group of authors on sustainable schools in Netherlands where the focus had only been energy saving. The shift from

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concentrating on just one metric to having a holistic approach with more attention to comfort, health and other aspects of sustainability is researched and had better results.\textsuperscript{34} The first Nearly Zero Energy Building (NZEB) is analyzed and is seen that concentration on just one metric has resulted in pushing the other metrics out of design scope. This approach automatically cancels out the user feedback and lacks at providing a balanced school environment.

NZEB pros: Increased thermal comfort due to uniform interior temperatures, reduced cost of ownership due to improved energy efficiency, reduced total net monthly cost of operation, extra cost is minimized for new construction compared to retrofit.

NZEB cons: High initial costs and unexpected geographic inefficiencies such as difficulty to tap into solar energy due to obstructed South in examples discussed in the article.

\textbf{Take away:} Always think of metrics as interconnected network – A systems network. Concentrating on just one metric would result in an unsustainable product even though the Net Energy is Zero (goal).

Some of the existing literature, shows various approaches, theories and methodologies to achieve measurement in sustainability. The theories of Zero Energy Building and AIA Top Ten Metrics discussed below are most widely in use currently and would be incorporated in the design phase of this thesis.

\textbf{Zero Energy Building:} There is no universally accepted definition for Net Zero Energy Building hence each organization has their own definition.\textsuperscript{35}

- American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE): “A building which, on an annual basis, uses no more energy than is provided by the building’s on-site renewable energy sources.”

- National Renewable Energy Laboratory (NREL): “A residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.”

\textsuperscript{34} Net Zero Energy Building Schools, Wim Zeiler, Gert Boxem; Renewable Energy 49 (2013) pp 282-286

\textsuperscript{35} Department of Energy; National Renewable Energy Laboratory: World Wide Web
• Department of Energy (DOE): “A building that produces and exports at least as much emissions-free renewable energy as it imports and uses from emission-producing energy sources annually.”

National Renewable Energy Laboratory (NREL) has developed a further set of definitions in order to evaluate different gradations of compliance with Net Zero Energy goals.36
• ZEB A: renewable energy sourced within building footprint
• ZEB B: renewable energy sourced on-site
• ZEB C: renewable energy generated on-site from off-site resources
• ZEB D: renewable energy generated off-site

**AIA Top Ten Metrics:** The Committee on The Environment (COTE), AIA determines its Top Ten Measures of Sustainability.37

**Measure 1: Sustainable Design Intent and Innovation**
Sustainable design is an inherent aspect of design excellence. Projects should express sustainable design concepts and intentions, and take advantage of innovative programming opportunities.

**Measure 2: Regional/Community Design and Connectivity**
Sustainable design values the unique cultural and natural character of a given region.

**Measure 3: Land Use and Site Ecology**
Sustainable design protects and benefits ecosystems, watersheds, and wildlife habitat in the presence of human development.

**Measure 4: Bioclimatic Design**
Sustainable design conserves resources and maximizes comfort through design adaptations to site-specific and regional climate conditions. Describe how the building responds to local climate, sun path, prevailing breezes, and seasonal and daily cycles through passive design strategies.

**Measure 5: Light and Air**
Sustainable design creates comfortable interior environments that provide daylight, views, and fresh air.

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36 Zero Energy Schools by Paul C.Hutton; Certified Educational Facility Planner (CEFPI)
37 American Institute of Architects: World Wide Web
Measure 6: Water cycle
   Sustainable design conserves water and protects and improves water quality.

Measure 7: Energy Flows and Energy Future
   Sustainable design conserves energy and resources and reduces the carbon footprint while improving building performance and comfort. Sustainable design anticipates future energy sources and needs.

Measure 8: Materials and Construction
   Sustainable design includes the informed selection of materials and products to reduce product-cycle environmental impacts, improve performance, and optimize occupant health and comfort.

Measure 9: Long Life, Loose Fit
   Sustainable design seeks to enhance and increase ecological, social, and economic values over time.

Measure 10: Collective wisdom and Feedback Loops
   Sustainable design strategies and best practices evolve over time through documented performance and shared knowledge of lessons learned.

   In taking a Systems approach to designing sustainable school, the above measures come in together towards a Net Zero solution.

Conclusion:

A good amount of research is being done to transform schools towards sustainable learning and is the most promising way towards a sustainable future. Research in green architecture and ecologically responsive design reveals some basic benefits specifically for schools. The above-mentioned metrics are possible ways to substantiate sustainability which would be further tailored to be used for school design specific to this thesis. In June 2013, the Center for Green Schools at USGBC brought together stakeholders from academic, corporate, and nonprofit sectors to envision a future where schools support thriving, healthy, and regenerative communities. Participants agreed on a shared vision where all students graduate educated for a sustainable future through the integration of the environment, economy, and equity, with the ability to apply integrated approach to problem solving and decision making by

The National Action Plan for Educating for Sustainability intends to propel efforts to affect policies and practices through collaboration, alignment, and large-scale implementation which is displayed in (Figure 8).
Figure 8: National Action Plan for Educating for Sustainability

Architecture as a school design guide must be aided with curriculum design and end-user design criteria to achieve a holistic approach for designing sustainable school. This thesis therefore assumes the curriculum to slightly shift from the norm to introduce the learning aspect of sustainability into its activities while retaining/adjusting the existing pattern. Since sustainability is vast and the main idea according to which the school will be designed, the architecture of the school is intended to integrate select metrics from the above discussed parameters which would be tailored as per the school site and design conditions. The sustainability goals and design criteria of metrics will be further discussed in the methods and process section.
Precedent Studies

R.E and Euzelle P. Smith Middle High School
Sidwell Friends Middle School
Harley School, the Commons
Edward Gonzales Elementary School
The combination of sustainable school design, an organizational culture, and curriculum aligned with sustainable practices and methodologies sets the stage for a school to utilize their facilities and grounds as a teaching tool. When educational principles are built into the learning environment, the environment transforms itself into a teaching tool. As Anne Taylor observes in the book “Linking Architecture and Education - Sustainable Design for Learning Environments”, “architects must integrate many aspects of design to create a whole and wholesome learning environment by not addressing merely a numerical program, however important size and cost, but also a deeper program responding to the needs of the user, the community, and the Earth”.

The precedent studies are intended to help look at various techniques employed to integrate sustainability into architecture. The case studies are primarily educational facilities for students (Elementary and High schools) to provide an idea of scale and a bigger picture for this thesis.

1. R.E and Euzelle P. Smith Middle High School

Architect: Corley Redfoot Zack
Smith Middle School (Opened 2002)
Chapel Hill, North Carolina
Climate Area: Temperate / humid
Grades: 6-8

Figure 9: Exterior view of R.E and Euzelle P. Smith Middle High School

39 (Taylor & Enggass, 2009)
An open plan (Figure 10) of the building and daylighting conditions are the initial emphasis in this project. In a typical classroom with the light monitors located in the center, meter readings averaged approximately 55 footcandles as compared to the usual artificially lit classrooms. Interior light sensors keep the classrooms at a balance point by automating the overhead fluorescent lighting. Motion sensors turn off the lights when rooms are not occupied. Shading strategies include aluminum shielded light shelves and angled reflectors on the exterior niche of each concave window location.

Design strategies include rainwater reclamation and some active solar panels for electricity. Storm water runoff collected from the roof to an exterior underground tank to be filtered and used for sinks and water closets. Active solar collectors are strategically placed on some of the light monitors. Solar tubes are used for reclamation of hot water for hand washing use in the cafeteria. Photovoltaic collectors activate the night lighting system at the exterior porticos.
Daylighting Strategies:

Most of the daylighting is achieved through clearstories, skylights and is also partially due to the planning and orientation of the building. Most classrooms face East - West orientation and receive the east lighting (Figure 11). This school receives complimentary soft lighting from North lighting and the winter sun angle is moderated with the help of adjustable shades. These design strategies become the most viable catch basins for daylighting for the classroom spaces.

Figure 11: Daylighting strategies implemented at school
**Training and Learning Centre:**

The school employs a lab facility (Figure 12) which helps teachers and students to have real time knowledge of what their building can and cannot do. Training sessions are held to educate the building users and are also provided as electives for students which teach the basics of sustainability using the school as a laboratory.

![Figure 12: Data center equipped with the meter readings and training rooms](image)

**Inference:**

This school exhibits a lot of potential in terms of being a very good example for future generations. It implements both active and passive techniques such as solar panels, water recollection system and natural daylighting with the help of orientation, skylights and clerestories respectively. An interesting part of the design is the inclusion of a training lab that solely exists for educating sustainability to students and teachers whereas the downside being the
lessons provided as electives to students which does not make it compulsory for the curriculum which again brings the notion of teaching sustainability to a tough spot. The school releases annual report on demand-use trends of several categories which is made public to the students. The students though are not involved in the process of calculations for report which again doesn’t involve students directly into the system.

2. Sidwell Friends Middle School

Architect: Kieran Timberlake Associates LLP
Renovated (Opened 2006)
Washington, DC
Grades: K-12

Figure 13: Entryway through the Courtyard
Designed to foster ethics of social and environmental responsibility in each student, the facility demonstrates a responsible relationship between the natural and the built environment.” The project team recognized that the campus also sits atop two watersheds, both of significant ecological value. That insight led to an integrated approach to water management as the centerpiece of a comprehensive appeal to environmental stewardship” (Green Source, 2007).

Materials used in the construction and renovation include cladding made from 100-year-old wine barrels as well as flooring and decking made from salvaged Baltimore Harbor pilings. Other renewable materials used are, linoleum flooring, agrifiber casework, and bamboo doors. All interior finishes were screened for chemical emissions.

A constructed wetland between the new and old wings of the Middle School treats wastewater from the kitchen and bathrooms and serves as a living laboratory where students can learn about biology, ecology, and chemistry (Figure 14). The treated water is then reused in the toilets and cooling towers. Students grow vegetables and herbs for the cafeteria on the green roofs. Excess water flows to the courtyard’s pond and rain garden while filters and swales in the landscape purify rainwater falling on the site. (USGBC.org, 2008).
The project has been recognized by AIA’s Committee on the Environment and Committee on Architecture for Education, but the building is just the beginning. Teachers at all grade levels have access to the project’s landscape and building systems, and many have designed lessons around this opportunity. The school’s green features will continue to teach and inspire, and students will carry their knowledge and appreciation of natural systems for decades to come. (AIA Cote Top Ten, 2007).

Figure 15: Solar chimney designed to let in daylight
Figure 16: Schematic drawing of building Water systems

Inference:

This school design employs several active sustainability techniques pertaining to water systems which are very well interconnected and affect each other such as green roof, wastewater system (grey water) and rain water harvesting that practically balances out the demand-supply of the water system in the building. Material used in the building is 80% reclaimed and reused (as per report) which is explained through posters and clipboards to students to educate them about material choices of the school.

3. Harley School, the Commons

Architect: 9 x 30 Design Architects
Renovated (Completed, January 2014)
Rochester, New York
Grades: K-8
The Commons at Harley school in Rochester, NY is among few educational facilities in the country to offer students multiple dimensions of education based on creating a sustainable future. The school had a recent addition that utilized a recycled frame of a 100-year-old timber barn. This ‘living building’ generates its own energy, warm and cold air, and captures and utilizes water and carbon from a greenhouse.

The Commons has a control center in the building that allows students to set the temperatures, monitor how much energy is produced and track the building’s energy consumption. Students are encouraged to learn sustainability first hand with the help of these systems. ‘The intent was for the student to design and implement systems to enhance operations and sustainability of the facility’ – Ken Motsenbocker, CEO The Harley school.

The school employs sensors/meters for all the active technologies in the school (Figure 18 and Figure 19) and has a greenhouse (Figure 20) setup where different concepts of physics are taught with the help of plants and water.
Figure 18: Building systems sensors – Electricity usage

Figure 19: Temperature and Humidity sensors
The school has a good network system (Figure 21) linking all the tech to a simple database that reports the trends of the school. All the building systems (HVAC, Electric, Solar, Greenhouse) are linked to a server where it informs the users about the energy stored and used.
Inference:

The school has very smart technology such as sensors, metering and software interphase to measure various parameters and look at demand-use patterns. The school being built recently is lacking in making a record for a subsequent academic year. Since the addition is relatively new, it has plans of introducing official auditing reports that would be based on metrics for energy, water and such.

The school being new, has introduced pilot elective courses integrating sustainability learning for students to opt for it. The school itself does not motivate or press the students particularly to take up these electives but the word of mouth technique is used to spread the word about these classes. The students taking these courses are learning to integrate sustainability in their daily activities.

4. Edward Gonzales Elementary School

Albuquerque
Architect: Mazria Inc.
Completed August 2004
Grades: Elementary School

The Edward Gonzales School is designed as a new prototype for the Albuquerque Public Schools with a forward-looking design that acknowledges the impact that buildings have on the environment. The school had a clear vision statement and goals which was stated as, ‘A school that saves energy helps the environment, helps children learn better and saves money for the Albuquerque Public School.’

The floor plan (Figure 22) which demonstrates site features that were used for passive design of this school. The school itself is planned to follow the natural form and rhythm of the site. The major spaces are all placed along the sun path to receive maximum daylight, Therefore, there is rarely any demand for artificial lights during the daytime for these spaces. Classrooms and other gathering spaces are heated by passive solar design principles. The buildings are designed around the school playground which provide both shading and shelter them from
westerly winds. Importance is given to the playground where it is the center of the school and all the classrooms and hallways are designed in a courtyard pattern looking over it. A high level of control is provided to the occupants in terms of heating, cooling, ventilation and lighting systems of the school. (Figure 27) shows the school at present incorporating the site plan as in (Figure 22).

Figure 22: Floor Plan Diagram
Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Figure 23: Classroom configuration showing North Side

Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Figure 24: Classroom configuration showing South Side

Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Figure 25: Main entrance to the School: Window pattern
Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor

Figure 26: Well Lit School Corridors
Source: LINKING ARCHITECTURE AND EDUCATION Sustainable Design of Learning Environments; Anne Taylor
Inference:

The school takes advantage of its location and local weather by harvesting maximum daylighting in an optimum way. The school is designed around daylighting and natural ventilation which is illustrated in (Figure 23 and Figure 24). The roof design and classroom layout are designed to be the main contributors for this. (Figure 25) and (Figure 26), showcase the use of clear windows at different locations to optimize daylight. The school does not translate its architecture into education and thus the students do not gain a practical lesson.

Summary:

The following summarizes design pointers from above case studies that would be helpful in deriving the design solution.

- Sustainability is linked strongly to smart technology that assists us in keeping track of how well we use resources. For a true sustainable building, it has become utmost important to track demand and supply and in doing so technology also helps in putting out these numbers across for the public to realize, to teach and to bring forth a change.

- All the case studies discussed have a very important yet common attribute, that is the importance to local weather and site conditions that could most definitely affect a building’s micro-climate. All the schools take locational advantages such as the solar
chimneys for ventilation, harnessing solar energy, bio retention pond on marshy site areas to retain the rich bio-diversity and design responding to natural lighting.

- All the schools utilize architecture for both active and passive techniques to establish sustainability. In using both, there is lesser dependency upon manufacture which again reduces resources required to do so.

- A systems approach where every building system is interlinked is a pattern being more and more utilized. The integrated mechanism helps to build a stronger and active product that takes advantage of this closely-knit dependency. Likewise, if one part of the system is broken it might affect the others as well. Therefore, it becomes important to keep monitoring these building systems for the operational hazards.

- The last and the most important observation of all these case-studies embodies the entire purpose of this thesis which is, how all these schools do not show a tried attempt at mellowing down architecture to the understanding level of students and utilizing it as a tool to teach about sustainability. Currently all these schools have technology and lots of number crunching which is difficult to interpret, and a student would not be that interested in learning. There needs to be a fresh and evident attempt to teach students in a better understandable process about sustainability through the school’s architecture.
Problem Statement
Problem Statement

This thesis imparts the urgency of educating children at an early age about sustainability and preparing children for the future. It intends to rely on the three attributes of Sustainability – the triple bottom line as discussed below:

Environment

The method employed is to change the way schools are designed and how students are being educated about the real-world impacts. Therefore, the role of Architecture is emphasized and forced to push its envelope in providing a design solution where Schools will be the primary Teachers. This initiative will offset the Environmental impacts by thousand folds as the future generations are taught to make sustainability as their way of life.

Economic

The thesis shows United States Public School facilities current situations and facts. The building stock being very old, the operations and maintenance cost a lot as they have older systems that need way more energy to run and are not efficient. Therefore, the need to redesign and retrofit the systems to cut down energy expenses which is the major concern for old schools now-a-days. The thesis targets to upgrade an existing school facility which is at the 42-year-old benchmark (minimum).

Social

The active and interactive nature of design based on sustainability principles are expressed and become an integral part of the architecture itself enhancing the social dialogue around sustainability. By retrofitting and redesigning, the school becomes a way of giving itself back to the society and its community. The thesis anticipates concentrating on its primary (students) and secondary end users who are the future generation to graduate with a full understanding of sustainability and evolve their lives on its principles which would in turn affect the society at large in the future towards its shift for a sustainable future thus encompassing the main intent of this thesis.

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40 Rochester City School District: http://www.rcsdk12.org/rsmp
Methodology

Sustainability [re-design] Goals

Design Methodology and Procedure
Methodology

This thesis asserts that schools can and should teach sustainability to students, *at an early age*, through their architecture and this idea is reflected through the re-design of an elementary school, the primary goal. For these concepts to take form it becomes vital to identify the sustainability goal/intent of this school to prepare a framework to utilize architecture as a tool to teach students first hand experiential sustainability as young as the elementary stage. The re-design goals are prioritized based on the research discussed previously in the literature review section where lighting and ventilation observations prove to have great potential.

*Sustainability [Re-Design] Goals:*

Sustainability, being a vast topic becomes tough to grasp a hold of it and teach it fittingly to the elementary students. It becomes of utmost importance to set specific goal/objective that looks at teaching a few important aspects/indicators involving sustainability. The indicators chosen to be taught should be both essential for life lessons to shape the future responsible adult and at the same time benefit the school in achieving parameters such as good indoor air quality, better acoustics and so on. The most important indicators which would be use in this school design are:

1. Lighting – This being a top issue with the school for the artificial lighting, students would learn the advantages of daylighting and experimenting with it.
2. Thermal Comfort – This parameter is not only to improve the comfort of users but also affects the energy heating and cooling loads. The HVAC redesign forms a major contribution to the thermal comfort also aiding energy efficiency.
3. Energy efficiency – Regulating the use of energy and making it known to the students helps them make conscious decisions going further and at the same time would help reduce the bills.
4. Acoustics – This parameter is of huge importance for student learning and would be dealt in the sustainable way while it could be taken as an opportunity to show the older students about materiality and the story behind its manufacturing which would make them think about life cycle of products.
5. Water – The water demand and supply coupled with rain water harvesting would be taught in this category where it would benefit the school and teach students the importance of water.

6. Recycling – This is the bare minimum level of sustainability currently required and to be mandated but teaching the thought process behind it is equally important for students to give thought before throwing garbage.

**Design methodology and Procedure:**

With the main goal set in place, the principal idea is to design 1) A Sustainable Elementary School that employs 2) design entities to assist in teaching students about sustainability. The sustainable elementary school coupled with those design entities would be the prototype school that teaches practical sustainability basics to students. These design entities are evolved around the above-mentioned sustainability postulates aimed to be taught at school.

To verify the workability of design, two important indicators are chosen - *Lighting* and *Ventilation*. The reason for picking these two is elaborately explained in following sections. For each of these, before and after design scenarios are discussed and success of the design is measured in terms of dependent variables, energy use and student performance.
Pre-Design Analysis

Design Study
Site Selection
Site Analysis
Climate Analysis
Building Program
Existing School Building Analysis
Code Analysis
Pre-Design Analysis

The thesis proposes the re-design of an elementary school whose architecture aids in teaching kids at young age about sustainability. To reinforce the aspect of sustainability and to join intentions with the Rochester City School District (RCSD), instead of designing new structure, an existing school building is redesigned to reflect the intent.

The research carried out leads upon to design stage which needs a thorough ground work to back-up design decisions made for the project. The Pre-Design analysis involves site analysis, climate analysis, building program, existing school building analysis and code analysis.

Design Study:

The design concept leans towards changing traditional school culture which has students being taught by teachers without any interaction in a very monotonous manner (desk and chairs), towards a more innovative methodology of schooling which has students engaged actively with the teachers and the surroundings. This thesis looks at this shift, taking inferences by the literature study and case studies mentioned. A crucial ideology that is proposed is to engage the school architecture itself in a student’s daily teachings. This thought process leads to design decisions that will be further explained in the Re-Design section.

Site selection:

The Sustainable Elementary School is envisioned to be retrofitted in the existing, School No.1, Martin B. Anderson Elementary school which is located at 85 Hillside Ave in Rochester (Figure 28), New York.

The choice of this school matches well with the conditions discussed in the introduction and literature review:

- Redesigning classrooms as sustainable learning environments for teaching future generations about sustainability at an early age (focus on Elementary schools).
- The need for retrofitting old building stock which is the most sustainable solution.
The Rochester City School District (RCSD) has in total of 102 schools (Elementary and high school education). The average age of the school facilities is 65 years old of which over forty percent have some portions of their buildings that are more than 80 years old. The old buildings are not built to ADA standards nor the new building codes, they are not energy efficient, were not built for current teaching and learning practices and do not have the infrastructure for today’s technological needs.

The Rochester City School District has embarked on a proposal, Comprehensive School Facilities Modernization Plan across the entire district to assess current conditions of school facilities and establish the required changes. The initiative is to modernize the facilities and make better use of existing infrastructure to suit educational requirements of today’s generation. **The proposed thesis sees this as an opportunity to take the above-mentioned agenda a step further by proposing a sustainable learning environment design for School No.1, Martin B. Anderson school.**

**Site Analysis:**

**Location:** As illustrated in (Figure 29), the site is abutting the Interstate highway 490 and approximately 2.5 miles from the Rochester Central Business District. The school is very well situated among plush residential neighborhoods predominantly with commercial businesses to its West.

Since the school is an elementary school, though the walk score is 51 and transit score is 38, we can anticipate that all the students would be dropped off by cars and school buses. Though the school site is adjacent to the I-490, it is tucked in and away with local roads and greenery.

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41 Rochester City School District – Comprehensive School Facilities Modernization Plan for Rochester City Schools
Figure 28: New York State Map showing location of Rochester
Site Context:
Project Site: School No.1 Martin B. Anderson
85 Hill side Ave
Rochester, NY

Figure 29: Rochester map showing Project Site location and immediate context
Immediate Context:
Immediate Context:
Shade study:

Figure 32: Shade projected on site for June 21st
Inference:

The school building is isolated and not situated in a dense neighborhood. Hence the building casts its own shadow around the clock. As illustrated in the (Figure 33), the morning shade is along the north-west and south-west side where as the evening shade shifts over to north-east and south-east. This relays that the lack of shade from external structures allows for maximum daylight opportunities within the building. All the classrooms have ample/more amounts of daylighting as they have a long façade of tall windows.

Climate analysis:

Rochester has a humid continental climate zone and has four seasons including cold and snowy winters. Climate is analyzed through average weather data to arrive at possible design decisions pertaining daylighting and ventilation.
Inference:

We observe from the (Figure 35) above that the site has predominant winds in the Southwest and West directions with high frequencies. This could be advantageous since the structure is oriented opposite to the wind direction which would enable to capture wind for
natural ventilation. Natural ventilation would be a design solution to reduce the HVAC energy loads during summer and to circulate fresh air during the winters as the buildings are sealed up tight to prevent leakages.

**Sunlight:**

![Figure 36: Number of hours during which sun is visible and degrees of daylight](source)

*Source: weatherspark.com/Greater Rochester International Airport weather station*

**Cloud cover:**

![Figure 37: Median cloud cover](source)

*Source – weatherspark.com/Greater Rochester International Airport weather station*
Inference:

The average hours of daylight are 8 hours but has a minimum of 69% cloud cover throughout the year. This shows that there is less potential for solar power when compared to sunny regions and a constant supply of daylight during the morning hours for daylight activities.

Precipitation:

![Figure 38: Types of precipitation and annual average percentages](source)

Humidity:

![Figure 39: Average Relative Humidity](source)
Inference:

Since Rochester swings between extreme weather conditions (summer and severe winters), thermal comfort is of prime importance as it could hinder regular school days. There are two things that need to be considered in the design, the building envelope and the building site. For the building envelope, old buildings tend to have thermal leaks over time and therefore it is important to tightly seal off the building envelope to reduce the thermal load. As for the building site, it is important to address water and show run off end control on site. Rainwater harvesting could solve the issue of water runoff to storm drains and designing for ground water percolation would help replenish it.
Figure 40: Site plan graphic depicting wind direction and sun path
Building Program:

The solution is redesign of School No. 1 Martin B. Anderson which is 89 years old with a built-up area of 43345 square feet and one story structure with ceiling height of 18 feet. As discussed in the earlier sections, the rejuvenation of old school building stock can be considered a huge step towards sustainable site. The Rochester City School District (RCSD) vision of upgrading the school infrastructure to befit the teachings of present age is altered into a huge stride of going a step further and making it a sustainable building as well aid in teaching sustainability to students.

The site is in the Rochester downtown in a residential neighborhood. Research and assessment of several case studies have been completed for design development. The school is a Pre-K to 6th grade currently accommodating 322 students. It has 2 classrooms per grade and one kindergarten classroom adding up to 13 classrooms in total. The total 322 students are distributed in each grade as shown in the tabular below Table 3:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- K</td>
<td>18</td>
</tr>
<tr>
<td>Grade 1</td>
<td>50</td>
</tr>
<tr>
<td>Grade 2</td>
<td>50</td>
</tr>
<tr>
<td>Grade 3</td>
<td>50</td>
</tr>
<tr>
<td>Grade 4</td>
<td>50</td>
</tr>
<tr>
<td>Grade 5</td>
<td>52</td>
</tr>
<tr>
<td>Grade 6</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 3: Number of students in each grade
In addition to the 13 classrooms there are auxiliary programs/spaces supporting the school which are listed below in Table 4:

<table>
<thead>
<tr>
<th>ROOM NAME</th>
<th>AREA (sqft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classrooms (13)</td>
<td>21011</td>
</tr>
<tr>
<td>Administration and Office</td>
<td>989</td>
</tr>
<tr>
<td>Teacher lounge</td>
<td>200</td>
</tr>
<tr>
<td>Nurse room</td>
<td>369</td>
</tr>
<tr>
<td>Copy Room</td>
<td>330</td>
</tr>
<tr>
<td>Toilets (2 Boys &amp; 2 Girls)</td>
<td>2328</td>
</tr>
<tr>
<td>Library</td>
<td>1336</td>
</tr>
<tr>
<td>Computer Lab</td>
<td>734</td>
</tr>
<tr>
<td>Gym</td>
<td>4627</td>
</tr>
<tr>
<td>Mechanical Room</td>
<td>2272</td>
</tr>
<tr>
<td>Janitor Room</td>
<td>394</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>3351</td>
</tr>
<tr>
<td>Kitchen</td>
<td>496</td>
</tr>
<tr>
<td>Music/Art Room</td>
<td>1635</td>
</tr>
<tr>
<td>Storage</td>
<td>3269</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>43345</strong></td>
</tr>
</tbody>
</table>

Table 4: Spatial Planning Chart of the existing spaces (sqft)

The design and layout of the existing spatial planning is illustrated in the (Figure 41) below. The redesign of the school is intended to maintain the above-mentioned functions and adding few primarily required spaces for sustainability teachings/activities. Though the spatial planning of classrooms is changed, the square footage is maintained to be the same as required for the educational facilities.
Figure 41: Original Floor Plan Layout
Below, in *Table 5* is the newly proposed/configured spatial planning list.

<table>
<thead>
<tr>
<th>ROOM NO.</th>
<th>NAME</th>
<th>AREA (sqft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lobby</td>
<td>805</td>
</tr>
<tr>
<td>2</td>
<td>Admin Office</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>Principal Office</td>
<td>350</td>
</tr>
<tr>
<td>4</td>
<td>Copy room</td>
<td>102</td>
</tr>
<tr>
<td>5</td>
<td>Nurse Room</td>
<td>340</td>
</tr>
<tr>
<td>6</td>
<td>Toilet</td>
<td>360</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>GRADES 2,3,4</td>
<td>8860</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>GRADES 5,6</td>
<td>5970</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Toilet</td>
<td>360</td>
</tr>
<tr>
<td>17</td>
<td>Gym</td>
<td>3185</td>
</tr>
<tr>
<td>18</td>
<td>Gym Storage</td>
<td>410</td>
</tr>
<tr>
<td>19</td>
<td>Library</td>
<td>2310</td>
</tr>
<tr>
<td>20</td>
<td>Teacher's Lounge</td>
<td>605</td>
</tr>
<tr>
<td>21</td>
<td>Janitor Room</td>
<td>190</td>
</tr>
<tr>
<td>22</td>
<td>Computer Lab</td>
<td>582</td>
</tr>
<tr>
<td>23</td>
<td>Mechanical Room</td>
<td>685</td>
</tr>
<tr>
<td>24</td>
<td>Smart Tech Hub</td>
<td>2395</td>
</tr>
<tr>
<td>25</td>
<td>Toilet</td>
<td>530</td>
</tr>
<tr>
<td>26</td>
<td>Toilet</td>
<td>530</td>
</tr>
<tr>
<td>27</td>
<td>CLASS 1</td>
<td>1500</td>
</tr>
<tr>
<td>28</td>
<td>Storage</td>
<td>210</td>
</tr>
<tr>
<td>29</td>
<td>Music/Art Room</td>
<td>815</td>
</tr>
<tr>
<td>30</td>
<td>PRE K</td>
<td>1865</td>
</tr>
<tr>
<td>31</td>
<td>Kitchen</td>
<td>480</td>
</tr>
<tr>
<td>32</td>
<td>Storage</td>
<td>148</td>
</tr>
<tr>
<td>33</td>
<td>Food Lab</td>
<td>88</td>
</tr>
<tr>
<td>34</td>
<td>Cafeteria</td>
<td>3020</td>
</tr>
<tr>
<td>35</td>
<td>Park area</td>
<td>3030</td>
</tr>
<tr>
<td>36</td>
<td>Biogas Cistern</td>
<td>145</td>
</tr>
<tr>
<td>37</td>
<td>Greenhouse</td>
<td>1320</td>
</tr>
<tr>
<td>38</td>
<td>Circulation</td>
<td>3270</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td><strong>43345</strong></td>
</tr>
</tbody>
</table>

*Table 5: Proposed area configuration*
Existing School Building Analysis:

The existing structure of School No. 1 Martin B. Anderson is photo documented with observations and design problems identified which are to aid for the design phase. User interactions, both students and teacher experiences are also incorporated in this process.

Entrance and Façade:

![Figure 42: School No.1 existing facility](image1)

**Observation:** The entrance is characterized by a striking façade of Greek Doric columns with brick facing and tall windows (Figure 42) whereas the driveway area (Figure 43) is rather
banal, consisting of a concrete path. In addition, the site abutting I-490 also lacks in subtle transition, lacking an appropriate ambience of an elementary school.

*Design note:* From the drop off to the entrance, there needs to be a designed changeover with a fun-filled and educational (eye-catchy sustainable) as an experience for both parents and students.

**Corridors:**

![Figure 44: Corridor space and walls](image)

*Observation:* The corridors are wide and always use artificial lighting. Corridor walls are dull colored covered with notice/activity boards (Figure 44) which make it an uninteresting feature.

*Design Idea:* Since corridors are necessary for noise reduction and to keep the students from being distracted, they need to be designed in a way to celebrate them. Another primary design requirement is to reduce the use of artificial lighting as it contributes to a lot of energy use. The corridor ends are neglected to be culminated in plain sight. The ends also need to be uplifted as they connect to the exteriors and are a strong visual feature for users.
Skylights:
Girl’s Toilet
Boy’s Toilet

Figure 45: Toilets with skylights

Observation: Skylights in Boys and Girl's restrooms suggests last minute addition of toilets and skylights not used to their intended potential.

Design Idea: Relocate toilets to make use of skylights for teaching purposes. These spaces could involve teaching about the daylighting and conduct experiments with switching between daylight and artificial to see how much energy is used compared to other classrooms without the skylights.
**Classrooms: Layout**

*Observation:* Classic layout with storage on the perimeter and seating in the center facing the teacher and whiteboard. Classrooms are huge and cluttered. Teacher rooms/work areas are integrated with classrooms using collapsible partitions, extreme right in the (Figure 47).

![Classroom Interior](image)

**Figure 46: Classroom Interior**
The typical classroom layout is shown in (Figure 48) where each classroom varies from 800 – 900 sqft.
Design Idea: To design better learning spaces to assist teaching sustainability which is the main idea and improve the existing conditions.

Classrooms: Lighting

Observation: The exterior wall of the classroom is a band of tall windows from roof to sill level which lets in ample amounts of daylight. This is a concern by both teachers and students since there is no way to regulate the excessive daylight along with heat and glare issues. Hence the windows are covered permanently in most of the classrooms (Figure 50).

Figure 49: Classroom Interior
This aspect in a way is used in a positive way where the blinds become extra board space where student work is displayed on.

*Design Idea*: The windows are under-used and so they need to be brought back. The problem with excessive daylight and glare must be solved with the help of mechanical control system to let in desired amount of daylight only. In doing so it would help in reducing the dependency upon artificial lighting. The artificial lighting used can be adjusted from dim to brighter spaces of the classroom as required with the help of sensors. This change in lighting would help improve student performance and at the same time help in reducing energy consumption of the school.
**Classrooms:** An interesting feature!

**Observation:** Transom doors and walls feature can be found in the school making it possible for light to travel through into the interior spaces.

**Figure 51: Classrooms – Transom walls**

**Figure 52: Classrooms – Transom doors**
**Design Idea:** Since achieving daylight into the interior parts of the school such as corridors can be challenging, the transom idea could be taken as a design inspiration to open up the exterior envelope and interior walls at the top for continuous daylight.

**HVAC system:**

**Observation:** All the old-school building stock in USA has inefficient and old HVAC systems that were not designed to meet the future needs and growth. The school currently has the following facility for HVAC system as shown in (Figure 53).

**Design idea:** The proposed Comprehensive School Facilities Modernization Plan by Rochester City School District majorly looks at switching the old HVAC systems as they are of priority to the modernization. Since HVAC affects indoor environment quality, the new HVAC system is proposed to benefit the school environment for better performance as well as making it sustainable and energy efficient.

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Accessibility and ADA standards:

![Accessibility and ADA standards](image)

**Observation:** The school is not well equipped with ADA standard toilets and the main entry/exits for the school are not all wheelchair accessible.

**Design idea:** Redesign to make the building ADA compliant with required attention to corridor widths doorways and landings.

**Original Floor Plan Layout:**

**Observation:** The original layout follows the traditional pattern of corridors and school classrooms that are segregated according to grades. There is not much interaction between different age groups as well as all the classrooms look alike resembling factory assemblies.

**Design Idea:** The spaces are to be shuffled and made more interactive with each classroom being distinctive and student friendly. The corridors are to be maintained if not elevated in design and celebrated where they become transitory sharing spaces. This also helps to avoid isolate corridors and in a way become truly a part of education. Thought the spatial
planning of classrooms is very functional, changes will be made to add in secondary programs to create space shifts.
Summary:

The new re-design will address above discussed observations of existing structure, School No. 1 while accommodating these main design goals outlined below:

- **Thermal Comfort and Energy Efficiency**: All old-school buildings have very old HVAC systems being inefficient and using up lot of energy. The design challenge would be to reduce dependence on energy demand through natural ventilation. Natural ventilation could get tricky in cold weathers and therefore a mixed ventilation system that works for both summer and winter are proposed in the design of HVAC.

- **Lighting and Energy Efficiency**: The most challenging problem in this school is excessive daylighting and glare issues due to which there is high dependency on artificial lighting. Lighting can be improved in this school to increase daylight and use alternative methods for artificial lighting that are more efficient and user controlled. The existing skylight features are misused and need to be re-designed to fit them appropriately so as to use them for educational purposes.

- **Acoustics**: *Classrooms* and *corridors* need to be coherently designed to achieve required acoustical quality. The design intervention for corridors is to retain and celebrate them since they help in noise cancellation and at the same time maintain discipline. The corridors at present are monotonous and dull with artificial lighting and filled with notice/activity boards. The corridors are to be made active spaces where there can be occasional activity spill over. On the other hand, the present classroom layout is very traditional and functional, it has great potential in favoring sustainable and modern teaching methods. Since the layout of classrooms is along the periphery of the building, there is scope for daylighting and outdoor activities for students.

- **Water**: The entrance to the school building is very grand with Greek Doric columns feature and brick facing whereas the drop off is very uninteresting with a soccer field grassland and concrete pathway which lead to water run-off. A design opportunity is to re-work the existing site into sustainable site features through proper treatment of pavement areas to allow for ground water percolation. Introducing an entrance design element such as rain garden to make initial experience interesting for both parents and students as well as imparting knowledge about natural water use, in a fun way.
• **Accessibility:** Making the entire building, Americans with Disabilities Act (ADA) compliant as it does not adhere to the present building code requirements.

**Code Analysis**

**Zoning Code Analysis:**
The site lies in the R-1 (Low density Residential) zone as per the Monroe county zoning code. The zoning code in detail is in the Appendix section.

**Existing Building Code Analysis:**
The building being an existing structure had to be analyzed for the Existing Building code. The breakdown code analysis is shown in the Appendix section.

**Building Code Analysis:**
The building being an existing structure had to be analyzed through New Building Code since the new additions need to adhere to the new code guidelines. The breakdown code analysis is shown in the Appendix section.
The [Re]Design

Designing for Sustainability

Proposed Schematic Site Plan Design

Design Development

Proposed Schematic Floor Plan – Spatial Layout

Proposed Floor Plan – Spatial Layout with Flexible Walls

Proposed Floor Plan – Space Diagram

First Floor Egress Plan

Elevations

Teaching Sustainability Through Architecture
The [Re]Design

The design solution can be identified as a two-fold entity as discussed in the methodology section, one being the re-design of School No.1 into a sustainable school and thereby being used as a learning laboratory and the second being the architecture (design entities) designed for elementary students that would teach them about sustainability concepts. This ideology is both linear, as these notions are happening side by side daily within the same set of sustainable postulates/framework and at the same time non-linear since the way they are sketched out and executed in terms of design and architecture are in contrast. These two design paths are co-existent, and their dependency is high since the sustainable school will only work with better participation and increase in knowledge of sustainability concepts and vice-versa. These two design units will be demonstrated in this section with the help of sketches and illustrations.

Designing for Sustainability – a learning laboratory

The spatial configuration of the school would be redesigned and enhanced to make it an apt teaching tool for sustainability while being a sustainable building itself. This is done through a holistic approach which ties in both site and the structure. The individual aspects such as lighting, building envelope, HVAC system, natural ventilation are treated/improved to achieve the big picture.

Site design

Rain Garden and Permeable pavers at the drop-off zone:

The drop-off zone is a very dull and in stark contrast to the entrance of the school. The design intent here is to improve the drop-off zone with an interesting sustainable and eye catchy feature.

The climate analysis shows quite some amount of snow and rain which leads to designing a rain garden with native plants as shown in (Figure 56). Whereas the existing concrete pathway is replaced with permeable pavers. Permeable pavers allow for water percolation replenishing the ground water and reducing run off to the storm drains. These pavers as shown in (Figure 57) incorporate gravel and spaces between the pavers to allow for water percolation through ground.
Rainwater harvesting: For rainwater harvesting, size of cistern and the catchment area needs to be calculated. Basic approach includes collection of rainwater in gutters which drain to the collection vessel through down-pipes. The calculated capacity is a 12000-gallon cistern which is installed in the school.

Figure 56: Rain Garden at the drop-off zone

Figure 57: Permeable Pavers for pathways

Source: by Marta Ratajszczak, Writer on Jun 22, 2014 in Environment Posts, Landscape architecture Posts
Parking Lot:

Parking lots contribute to 30-40% of pavement in America.\(^4\) This has led to Heat Island effect where the asphalt and concrete absorbs sun’s heat, retaining it and contributing to higher temperatures than their surrounding areas. This has become a rising urban problem which has affected to increase in the energy sources as well to improve the conditioned spaces due to rising temperatures. The school No. 1 has parking lot which is approximately 43,000 sqft that is almost the size of the school building with 65 parking spaces and remaining being the asphalt access roadways. This scenario of black asphalt road equivalent to the built-up area is a huge area and it becomes important to provide solution for this as it affects the immediate microclimate of the site.

Solar shaded parking lot:

The system consists of canopy of solar PV which is installed at a higher ground thus shading the cars and the roadways reducing the heat island effects and at the same time producing alternate energy. As illustrated in the (Figure 58), we see that the entire parking spots are shaded whereas the roads are shaded with the shadows of the structure.

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\(^4\) Environmental Protection Agency – Urban Heat Island Basics
Building Redesign

Building envelope:

Building envelope is the only barrier between the outside environment and the indoors, it plays a significant role in maintaining comfortable indoors. The envelope needs to be reinforced to achieve an energy efficient building. The three most important steps to do so are:

*Roof coatings:* Applying **reflective roof coating** reduces solar radiation which reduces heating the roof and total heat transfer keeping the interior temperatures down. Energy Star labeled coatings reflect at least 65% of solar radiation. The U.S Department of Energy states that dark roofs reach temperatures of 150 deg. F or higher whereas roofs with reflective coatings reach up to 50 deg. F which would affect the interiors drastically.

*Windows:* This school’s building envelope has a vast expanse of fenestrations which makes it vulnerable for energy losses. The windows being wooden frame, need to be

*Insulation:* Adding extra insulation with effective R-value to prevent thermal leaks and reduce energy loss which is necessary to keep the interiors conditioned.

Natural Ventilation:

Rochester’s climate is humid with a relative humidity ranging from 60% - 80%. Such climate requires natural ventilation to keep the indoor environment ambient. The most effective passive technique would be to introduce vent stack/wind scoop which are modern versions of the traditional technique of capturing prevailing winds and redirecting them to the interior of the building for cooling and ventilation. Wind scoops function in a multitude of ways depending on how they are constructed.

- Facing the opening towards prevailing winds, allows for evaporative cooling due to the movement of air but the air itself is not necessarily cooled.
- Facing the opening away from the prevailing winds: When this is done in conjunction with an underground channel, warm air is drawn into the channel and cooled as it flows into the building and out the tower. The pressure differential between the various sections of this system ensures air flow.
- In windless environment or waterless house: The tower acts as a solar chimney creating a pressure gradient that allows the warmer, less dense air to rise up and out of the tower.
Examples of modern wind catchers meant to take advantage of this effect are seen in (Figure 59) where they are placed as additional elements on roofs which do not disrupt the existing structure.

Figure 59: Modern wind catchers

For this project, the building envelope can be used to let in natural wind which could help refresh the air circulation of the interiors. As seen in the Climate analysis, the primary wind direction is Southwest. Therefore, perforations need to be designed to catch the wind in that direction.

The concept emulates the wind catchers’ principle where fresh air is pulled in and circulated within and used air is pumped out through the exhaust vents. This happens naturally due to the temperature difference phenomenon. In adopting this idea for the school’s design, as shown in (Figure 60), the perforations are incorporated in the building envelope itself to give it an integrated look thus serving an aesthetic purpose as well. The cross section of a part of the building (Figure 61) shows the wind flow diagram reiterating the concept.
Lighting:

Daylighting: Rochester has good amounts of daylight and thus needs to be used to its fullest potential. As observed in the existing building conditions, the school currently faces the problem of excessive sunlight due to which all the windows are covered with blinds throughout the year cutting off entire daylighting. This has resulted in complete dependency on artificial
lighting. Since these issues are inter-related, making the windows useful and efficient is the foremost design task which in turn would reduce the artificial lighting load on energy demand.

The first design initiative would be to shade the windows which could be manually responsive as per the users of the building. Since the shades would be receiving maximum sunlight, incorporating solar power in them would help harness alternate clean source of energy.

![Figure 62: PV Blinds for windows](image)

One of the major source of solar power would be the shades covering the huge expanse of windows which also helps in reducing/controlling the amount of light entering the interior space. The solar shades as exhibited in (Figure 62), have PV strips on the face of blinds and therefore they tend to receive good amounts of sun. These adjustable PV shades help to regulate the amount of lighting reaching the space as well as double up as energy source. These shades are silicon fabric and can operate as simple pull-down shades and this flexibility helps harness solar energy without disrupting the functionality of the windows.

Artificial Lighting: The combined lighting strategy involves use of artificial lighting when natural lighting becomes inadequate for regular activities in school to increase the illumination levels in a space. One important application of artificial lighting is the motion/lighting controlled illumination where the farthest and darkest corner of the space receives more artificial lighting when compared to the space closest to the windows receiving daylight as shown in (Figure 63) where this combined lighting strategy is illustrated.
Acoustics:

In most education settings, speaking and listening are primary modes of communication where upto 60% of classroom activities involve speech between teachers and students or amongst students itself\(^{45}\). In most cases, poor listening conditions could lead to long term problem. In addition, noise levels are reported to be the highest in the classrooms of the youngest children.\(^{46}\)

Traditional teaching, where the teacher stands at the front of the class and talks to a row of neatly arranged desks and pupils has started shifting towards modern methods where the emerging trend is encouragement of learner participation which means active learning, interaction, and social engagement. Hence it is increasingly important to introduce new learning space design. This shift in educational system brings its own challenges especially in acoustics.

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\(^{45}\) Accredited Standards Committee, S12, Noise, 2002
\(^{46}\) Investigating the effect of intrusive noise levels on speech perception in an open-plan Kindergarten classroom, Kiri T. Mealings, Katherine Demuth Jorg M. Buchholtz, and Harvey Dillon, Macquarie University, National Acoustics Laboratories
Modern teaching, such as working in small groups, normally involves lively communication. This leads to circumstances where although the number of students remains the same, the noise level in the classroom rises further and further. Hence open plan classrooms were introduced where the acoustics have taken the worst hit and has affected students’ performance. Several case studies have been conducted to compare enclosed and open plan classrooms. These results show the importance of further research into the noise levels of open plan classrooms to determine if they are suitable learning spaces for young students.\(^{47}\) Hence a true effort is made in designing acoustic preferable closed teaching spaces that foster modern teaching methods which also aid sustainability teachings.

**Recycle/Upcycling:**

Recycling is often NOT required in schools in the USA and therefore the responsibility falls onto the school concerned. Recycling helps to reduce landfill waste produced by schools, increase awareness in waste creation, educate students about responsible consumption and encourage students a life-long habit of recycling.\(^{48}\) The re-design of school no. 1 proposes a Recycle Plan which assists the following:

1. Assemble a Team: Planning for school recycling program must include the custodial staff, students, teachers, parents, school administrators and a representative of a local community recycling program to ensure the success and sustainability of the program.
2. Analyze the Trash: The students with the teacher’s help can assess the school’s waste stream to identify the type, quantity, and/or origin of the potential recyclable materials. This information can assist to form school recycling goals and procurement of recycling containers and/or other needed materials.

Example - How much waste does the school produce?\(^{49}\)

a. Weigh a typical classroom’s trash at the end of each day for one week.

b. Average the weight of the trash over the five days.

\(^{47}\) An investigation into the acoustics of an open-plan compared to enclosed Kindergarten classroom, Kiri Trengove MEALINGS, Jorg M. BUCHHOLZ, Katherine DEMUTH; Harvey DILLON, Macquarie University, Australia, National Acoustics Laboratories, Australia


c. Multiply the answer to #(b) by 20 to obtain an estimate of trash produced per month for a classroom.

d. Multiply the answer for #(c) by the number of classrooms to get an estimate of trash disposed by all classrooms per month.

e. Do steps #a-c for the cafeteria, library, teacher work room, office and other school areas and add the results to the total amount of trash from classrooms to obtain a monthly total. Working closely with the custodial staff to estimate would help the team of students.

Examples:

a. 10 lbs. + 7 lbs. + 5 lbs. + 12 lbs. + 6 lbs. = 40 lbs./one classroom/week

b. 40 lbs. ÷ 5 days = 8 lbs. of waste produced per classroom per day

c. 8 lbs. x 20 school days = 160 lbs. of waste produced per classroom per month

d. 160 lbs. x 20 classrooms = 3,200 lbs. of waste produced by all classrooms per month

e. 3,200 lbs. classroom waste + 1,800 lbs. waste from other areas = 5,000 lbs. by the school per month

3. Identifying methods to remove the recyclable materials from school:

To dispose the regular/dry recyclable trash from school hauler to be identified. With regards to food waste, the recycle program for this school intends to include the design of a biogas container for the food waste from cafeteria. The design is to consider the average amount of food waste for a week to arrive at the container sizing and pipe sizes. The requirements for the design of biogas plant are illustrated in the (Figure 64).
Building Systems:

The building systems in this design refers to building automation such as sub-metering, energy and water systems which follow the efficiency first approach and then employing technology to aid in achieving results. Here we look at the automated systems pertaining to Energy, Water, lighting controls and HVAC individually and how they are related to each other affecting each other’s performance.

Sub-metering:

Energy and Water: Since sustainable application is mainly about managing resource use, it becomes important to measure as it is known, ‘What can’t be measured, can’t be managed.’ A major step towards this is shift towards the smart grid where technology is utilized to meter utilities which helps in the following:\(^5\):

- Reduce energy and water use
- Reduce energy and water costs
- Improve overall building operations.
- Verification of utility bills

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• Measurement and verification of energy project performance.
• Benchmarking building energy use

The use of metered data is critical to the building’s metering program and can be used towards the mentioned reasons. **Plan – Do – Check – Act** strategy helps to manage energy and water systems.

![Automated sub-meter dashboard](image)

**Figure 65: Automated sub-meter dashboard**

*Source: Automated metering systems, Agilewaves by Peter Sharer*

**Energy:**

Since the energy use is directly linked to the HVAC equipment, a whole building approach is necessary where renewable energy resource can be tapped into which in turn reduces the non-renewable resourced energy demand.

To make the systems work more efficiently, HVAC is redesigned and building envelope is re-worked to remove thermal leaks. These steps help to remedy any loopholes in the building which would lead to excessive energy consumption. The other components of the building which are related with energy parameter are also worked upon. Artificial lighting is one such criteria which could be reduced with regulated and satisfactory levels of daylighting. Natural ventilation is also designed as per orientation and existing building to assist with the HVAC loads. Alternate energy resource is produced which are to assist with balancing out the demand-supply numbers of the school.
An average USA elementary school consumes 5.6 kWh/sqft per year where the average operating hours are 10 hours per day\textsuperscript{51}. Using this as a broad benchmark, it helps to arrive at average amount of energy consumption at School No. 1:

\[
\text{School No. 1 area} = 43345.40 \text{ sqft} \\
\text{Energy consumed} = 5.6 \times 43345.40 \\
= \textbf{242,734.24 kWh/year}
\]

**Alternate Energy Source:**

Parking lot:

Area – 43,000 sqft (0.99 acres)

Solar carport annual energy generation – 238,000 kWh

Window Blinds:

Total solar power (kWh) = 3926 kWh

**Total Alternate Energy Source: 241926 kWh**

We can see that the alternate energy source produces 241,926 kWh in total whereas the school demand per year is 242,734.24 kWh. The difference of 808.24 kWh can be bridged with the help of sustainable practices at school and reducing dependency on energy and increasing dependency on natural resources.

The energy consumption of the School No. 1 is to be taken as the baseline to compare with alternative energy source. As shown in the (Figure 66), the average energy consumption can also be used as a benchmark to get started with. Comparisons can be made to arrive at clean energy alternative and reducing the energy footprint of School No. 1.

\textsuperscript{51} Department of Energy – Elementary Schools; Energy consumption for the year 2011-2012
Water:

In addition to metering water usage, it is also important to use water efficiently. Water efficiency helps protect aquifers and supply of renewable fresh water. There are three main goals of water efficiency namely: reduce potable water use for outdoor needs, reduce municipal water use and reduce the need for treatment of waste water.

Outdoor water use strategies: For this criterion, landscape plays a major role where plant selection determines amount of water used. Plant selection is also important as native plants tend to survive when water restrictions are implemented while the conventional plants may not. Another of the water reduction practices is utilizing drip irrigation as it minimizes use of water and fertilizer as it lets water drip slowly to the roots through a network of valves and pipes. Furthermore, municipal water use for landscaping can be reduced by choosing alternate water sources such as rainwater and graywater which are non-potable and considered to be best alternatives. Rainwater harvesting refers to collecting rainwater in storage tanks or cisterns. For rain water harvesting, it is important to know the amount of rainfall that the region receives and the catchment area, based upon which the cistern/collecting vessel size is determined. This also
limits the amount of rainwater flowing into drains helping rainwater management issues. **Permeable pavers** used for walkways helps for rejuvenating ground water and reducing runoff that in turn reduces the storm water drain.

*Indoor water use strategies:* Indoor water usage in toilets can be reduced by either utilizing the High Efficient Toilets (HET) or dual flush toilets. The HET utilizes 1.28 gallons per flush (gpf) which is very less compared to regular toilets. To further mitigate the water use and to put the water to good reuse, graywater (relatively clean waste water from sinks and other kitchen applications) system is designed in the school which is used for watering the plants and flushing the toilets.

The discussed design features are illustrated and mapped in the proposed schematic site plan.
LEGEND

1. DROP-OFF ZONE
2. RAINGARDEN WITH NATIVE PLANTS
3. PLAY AREA
4. BIOGAS CISTERN FOR FOOD WASTE
5. SHADED SOLAR PARKING AREA
6. EXPERIMENTAL GREENHOUSE
**Design Development:**

The design approach is met through the process outlined in the methodology section where the building re-design and design elements are incorporated to teach sustainability overlap. This then leads to becoming an example for teaching sustainability and at the same time being a sustainable building itself.

For design entities to exist there are “must have variables” that need to be accounted for:

_ The first variable consists of, bringing change to a traditional classroom layout following a traditional method of teaching constricting a student’s imaginative perception. Changing the teaching modes, area configurations and making spaces flexible with dual use program, would help in nurturing student’s subconscious. This flexibility aims at teaching two very important ideologies of sustainability, the interrelations between different parameters and the user impact on resource usage. The former is more of a logical mapping which tries to instill various possible connections which could be taught as a lab lesson where all the parameters are metered and their values could provide the rationale of metrics for students. The latter needs to impart a thinking instinct in students at an early age in a subtle manner making them more thoughtful regarding the choices they make for using resources.

_ Second is the importance of design being fun, exciting and most importantly to be thought provoking. Students are of elementary school age, therefore, to make the design student friendly and thought provoking, *flexibility* is used as the main means to achieve the contemplation towards sustainability and its pertaining concepts. In using flexible spaces, the students could be personally involved in increasing and decreasing spaces which in turn affects depending factors such as HVAC, energy use, lighting, thermal comfort, and so on. Thus, the students are motivated to think before each of their actions which would be a huge step towards achieving sustainability. The proposed design provides a combination of both enclosed and shared teaching spaces fostering group, individual and one-on-one teaching methods. This also allows for better acoustics since open plan classrooms are criticized for being too noisy and affecting student performance. The fixed spaces and shared spaces are interchangeable with the help of *flexible pocket walls*. The design idea of flexible walls is discussed elaborately in the following postulate explaining the design details with illustrations.
Third, classroom designs and layout should become dynamic and flexible spaces to accommodate diverse learning needs. Space should be large enough and furniture and other classroom objects should be easily reconfigurable to allow multiple learning activities to occur simultaneously. Flexible learning spaces allow for interactions and collaborative work, fundamental to the development of several 21st century skills. Some such skills include: leadership, communication, teamwork, and interpersonal skills. In the context of School No.1, flexible spaces are also used to teach basic concepts of sustainability to students. The changing spaces are intended to provoke thought processes for students as to how flexible spaces will have the domino effect on other aspects such as energy use, lighting, thermal comfort – cooling/heating, and water use among other features.

A sufficiently flexible classroom would facilitate the following learning formats:

. Evolving – changing spatial configurations
. Diversity cluster – varied types of group works
. Tech studio – easy availability of computers and technological information
. Cultural nexus – a student gathering space/hub
. Individual study and reflection
. One-on-one instruction

Flexible classrooms are student centered and driven by the students’ interests. These environments allow for small group discussions and work projects, individual workstations, and distance learning, as well as traditional classroom settings. Focusing on elementary student’s education experts assert that space and furniture are more influential on learning than many would suspect. The article suggests elementary school students need large classrooms to accommodate the diversity of learning activities that (should) occur in the elementary grades. It also claims classroom furniture should be easily reconfigurable to accommodate these activities as well as a wide range of student sizes and movements.

As discussed earlier, the major concept in designing classroom space is flexibility to introduce interchangeable and shared learning spaces both teachers and students can use as per the requirement. For School No.1, this is achieved by introducing retracting pocket walls that can

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extend up or down into the soffit per the need for expanse or decrease in the teaching area. This idea is possible due to the existing ceiling height of 18 feet making it feasible to introduce pocket walls. The design and workability are illustrated in (Figure 67).

Figure 67: Flexible Pocket Walls
The shared classroom space can be turned into an acoustically sound classroom for classes and one-on-one teaching that requires quiet space as shown in (Figure 68). The pocket
wall comes with its own exit door keeping in mind the egress requirements during emergency evacuations; Refer to (Figure 69).

A conscious effort is made in designing classroom areas in a more modern and student friendly atmosphere, as well as retaining some percent of the old tradition of closed classroom plan with corridors. When referred to the old layout, we see that all the classrooms are similar and equal sized with minimum to no interaction among various grades. The new design solution tries to club at least two grades together literally, and in terms of proximity. Furthermore, the redesign provides different area configurations so there are more one-to-one interactions between the teachers and students.

Fourth, classroom furniture plays a major role in motivating students to be engaged in studying and performing well. Since the modern teaching techniques prioritize student involvement, it is unfitting to utilize the same old traditional fixed class furniture. The students require space for imagination and cage-free environment to move around and be active. The teaching spaces need to be flexible and the furniture as well needs to be flexible. The flexible seating furniture would help in achieving different types of teaching and learning opportunities for both teachers and students respectively. Such seating would also ensure student needs as they can be moved and placed as per child’s comfort. Thus the teaching spaces are personalized leading to fun learning and exploration of ideas. This shift in classroom furniture is necessary to educate the future cohorts towards a better future with a different mindset.
Figure 70: Flexible School Furniture

Source: Saluda Trail Middle school, Rock hill, South Carolina; https://www.steelcase.com/insights/case-studies/saluda-trail-middle-school/

Figure 71: Flexible School Furniture

Source: Poland primary school no. 267, Zoliborz, Poland; https://www.steelcase.com/insights/case-studies/poland-primary-school
In addition to the main goal of redesigning classrooms and spatial configurations to teach sustainability, there are other design problems that need to be addressed in specific to School No.1. These are to improve daylighting, to better ventilation (both stuffy and uncomfortable); to redesign HVAC, to redesign the school entrance, and to improve acoustics and alternative energy sources. In parallel to setting out goals and framework for both the sustainable elementary school and its design entities, the schematic redesign was also being worked out. This helped to tie up the thoughts and lead to the design stage. Discussed below are the thought process and various tools utilized such as bubble diagram and adjacency diagrams employed to arrive at design solution.

Thought Mapping:

The ideas generated during the design process are mapped out as it becomes challenging to keep track of ideas and the link between different rationales. In (Figure 73), the overarching idea of school teaching sustainability is central and the remainder of it is the inspiration drawn from the big idea.
The re-design is started with bubble diagramming and adjacency diagrams. The (Figure 74) shows the new spatial planning where, circulation and secondary spaces are left as is along the central axis of the structure since those are placed right and classroom spaces are around the central core. Since flexibility is the main concept for classrooms here, it was necessary to show different possible outcomes for teaching spaces.

Figure 73: Thought Map
A bubble diagram is worked upon to arrive at the final design. The original floor plan layout is very functional and is retained though the spatial configuration is changed. The proposed design concept tries to strike a balance between the traditional classroom, corridor arrangements and modern teaching spaces that can incorporate sustainability into curriculum. The classroom spaces are not entirely segregated since exchange of knowledge is encouraged in the re-design. Therefore, 1st grade and pre-K are separate classrooms, 2nd 3rd and 4th grades are combined as one huge classroom provided with a variety of learning spaces and 5th and 6th grades are combined as a classroom.

The circulation is very simple and kept as the original with core activities (classrooms) in the periphery and the secondary activities are clustered in the center as they are easily accessible and do not require many hours of lighting.

Proposed schematic floor plan:

The rain garden courtyard at the entrance is designed to create a subtle transition to the school entrance that becomes an interesting, fun and learning experience for students. Selective plants are labeled and displayed to increase awareness for students about native plants requiring
less water. External water/rain management is designed such that it is clearly visible and interactive for students to learn about water savings.

Since open plan classrooms are being criticized for acoustic issues traditional classroom spaces are fitted with more flexible learning spaces that have architectural design elements allowing for teaching sustainability. The learning spaces are mainly categorized as illustrated in the (Figure 75) that allow for interactions and collaborative work, fundamental to the development of several 21st century skills such as leadership, communication, teamwork and interpersonal skills.

![Figure 75: Modern Classroom Configurations](image)

The teaching spaces are conceived to be of two kinds, fixed and shared learning spaces. The fixed spaces have flexible furniture to provide for modern teaching techniques, and shared learning spaces are flexible through walls such that corridors shift character and become teaching spaces. In doing so, the thought process is to teach students how different spatial configurations upon changing affects the resource usage. Exercises in classroom are designed to consider those changes and consider the sustainability side of the resource usage. The design details are discussed in depth in the following section along with illustrations of floor plans.

Figure 76: Proposed Schematic Design
Figure 77: Proposed Schematic Plan
First Floor Spatial Layout with Flexible walls

LEGEND
- GREEN: SHARED SPACES
- RED: RETRACTABLE POCKET WALLS
First Floor Space Diagram

CREATING
APPLYING
DELIVERING
COMMUNICATING
DECISION MAKING
First Floor Egress Plan

EXIT TRAVEL DISTANCE

PRIMARY CIRCULATION

EXIT/ENTRY

CARPET AREA
Teaching Sustainability through Architecture

The most significant goal of this thesis is to design a school that would teach sustainability first hand to the students to create a sustainable society in the future. Although most sustainable schools are teaching laboratories themselves, only a mere percentage of them attain the true outcomes in teaching the actual concepts and techniques. Furthermore, most of these school’s target middle and high schools while passing over the elementary school stage which is believed to be a tough phase to make students understand sustainability concepts.

The thesis design proposal looks precisely at bridging this gap in thought process by providing exciting, fun, and thought provoking spatial experiences for the students that can help imbibe sustainability early in the student’s lives. Proposed design solutions and entities are evolved within a framework (sustainable) that has been detailed in the above section. Most of the design entities are designed to be visual, tactile, sensual, and auditory. These means of communication become a hands-on experience for the students meant to be reflected everywhere in the school, so all students can have group discussions and learning activities planned around it.

Thermal Comfort

This parameter is more of a sensual satisfaction with the immediate surroundings thus making it a subjective evaluation. Most of the time the controls of the room temperature are set to a temperature convenient for the majority of users. Teaching about this category to kids would have to be more about feeling it on their own when temperatures drop or rise. The visual effects on classroom walls would be a fun experience for students, when coated with thermo-chromic paint. This paint changes to red in color when in contact with a warm or hot surface. The walls with windows and walls without windows show significant temperature difference. Hence, painting each of these walls with a swatch of this paint would show the students visual differences as in (Figure 78). Furthermore, the temperature could be moderated with a supervising teacher to conduct an exciting activity to observe the user perception and senses of changing indoor air temperature.

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54 Education for Sustainable Development (ESD) Sourcebook; UNESCO 2012.
HVAC system: Giving an understanding of HVAC principles to students is tough but important. Therefore, an interesting visual design intervention is the HVAC ductwork made from fabric which comes to life when the HVAC is turned on. The ‘sustainability hub’ space of the school is intended to be fitted with the fabric HVAC so that the dynamic system catches onto the students’ attention. Also, this space being a transitory/group activity space, the HVAC can be temporarily turned off to see the response on thermal comfort and then run again to see the air flowing through the ducts.
Recycle

Biogas cistern is proposed for the School No. 1, recycle program where the waste food is converted to alternate energy source. In order to teach students about food waste, a Food Lab is proposed in the design where the students are personally disintegrating the trash receptacles and are segregating the recyclables and bio waste. This exercise helps them to learn how to distinguish waste types, and also provides a visual outlook on how much food is wasted.

![Image of Food Lab Layout](image)

**Figure 80: Example of Food Lab Layout**

Energy

Energy demand and supply is best understood in terms of numbers especially for younger students. The entire building is metered and sub-metered which gives accurate details about energy use. Each of the classrooms are fitted with the latest smart screen displaying the amount of energy used by them. The numeric values are to be simplified and presented in the form of a net number (For example- 2kW per day).

With this there could be two educational activities formed. First, the Energy Race where students of each grade would compete with creating the lowest baseline. For this purpose, the energy forum area is provided with a smart screen wall, which projects information onto it for presenting forums. While doing so they could do experimental activities under teacher supervision with respect to electrical systems such as shutting down the lights when not using the space, or shutting down the HVAC for a short duration in a designated space during late spring...
season and relying on natural ventilation for some time and so on. These activities would then reflect upon how the students could reduce the energy use.

![Figure 81: Energy Race Forum Scenario Equipped with Smart Screen Wall for Presentations](image)

**Acoustics**

Acoustics for schools require best sound proof quality building materials. In order for students to know what goes in a wall, there would be specifically located walls, left partially unfinished that are structurally sound and guarded with heavy-duty glass. These walls are intended to show the students what a wall looks like and how many materials go into making a wall. An additional feature would be the short stories by Mr. Wall where there is an electronic voice describing the life cycle of these materials through kid friendly videos.
Lighting

The school has two skylights which are interesting features, but located in restrooms due to poor spatial planning. The skylight area is redesigned for classroom space. The (Figure 83) illustrates how these spaces can be used to do lighting experiments by turning off artificial lighting and using daylight for the few classes. This results in students understanding how natural lighting is beneficial both for society and the environment.
Reduce and Reuse Water

An average school in the United States utilize 22,284 gallons of water per day\textsuperscript{55} which accounts up to approximately 267,500 gallons per year. Water use is to be regulated on site both inside the building and outside. For exterior water use regulation, rain garden is installed with

\textsuperscript{55} Watercredit/water.org
native plants and a drip irrigation system for watering. The irrigation and other non-potable water uses are also supplemented by rainwater harvesting. The rain garden is easily approachable, and activities are planned around it involving students. Rainwater storage tank has a transparent gauge making it a visible tool to look at storage and usage patterns while giving a perspective baseline.

Figure 84: Water Network Feature for the Garden at Entrance
The inside of the building employs high efficient toilets and faucet fixtures which have a minimum of 1.28 gallons per flush and 1.5 gallons per minute of use respectively. Besides the fixtures, the attitude of students towards water use needs to be changed as well where they realize and take note of the amount of water being used. A fun way to illustrate this to students is by installing a clear and transparent plumbing infrastructure in toilets and tagging a number notification screen that would depict the number of gallons used. In doing so the girls’ and boys’ restrooms could compete for a lesser water use agenda.

![Figure 85: Transparent Plumbing Infrastructure Used in Restrooms](image1)

![Figure 86: Transparent Plumbing Infrastructure Used in Restrooms](image2)
Figure 87: Spatial Diagram Locating the Discussed Design Ideas
Not to Scale
Design Evaluation

Lighting Metric

Ventilation Metric
Design Evaluation: Synergy of Metrics

The prototype ideology of designing a school that teaches sustainability through its architecture is an effort to experiment and push the design envelope. The above section details the design strategies that will be employed in the re-design. These parameters come together to create a synergy by implementing several sustainable indicators/metrics to make a successful sustainable building. In this context, the importance of synergy of various components that are employed in this design cannot be more stressed. Here the synergy of these indicators/metrics is mapped and represented in the illustration below along with design scenarios which are translations from research to help in understanding the established synergy of metrics.

<table>
<thead>
<tr>
<th>DESIGN INTERVENTION</th>
<th>METRIC/INDICATOR</th>
<th>Energy</th>
<th>Acoustics</th>
<th>Water efficiency</th>
<th>Recycle &amp; Reuse</th>
<th>Lighting</th>
<th>Thermal Comfort</th>
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*Table 6: Mapping Synergies Between Indicators and Design Interventions*
The above mapping indicates how each category is interrelated and can affect each other. We see that all the design interventions discussed previously have a huge influence on energy, water, and recycling categories. Of these metrics, two of the most critical metrics are lighting and ventilation since the school currently is not doing good at all with respect to these categories. As seen in the Existing Building Analysis, both lighting and ventilation need to be given importance as these metrics affect the user group – students’ health, comfort, and mainly performance. Both metrics are broken down and a clear before and after scenario is provided as to how their improvement would affect the school and its users.

**Lighting**

Lighting has always been an important factor in the design and operation of schools. Healthy spaces need responsible and efficient daylighting thus reducing the need to depend upon artificial lighting. As we have observed in the *Existing Building Analysis*, Martin B. Anderson School No.1, depends entirely on artificial lighting as it faces the problem of excessive daylighting as shown in (Figures 88 and 89). Due to the classrooms being along the periphery of the building, each classroom has a band of tall windows allowing excessive lighting and heat along with severe glare issues. As a result of this, the windows are shut down by blinds throughout the year and the facility highly depends upon artificial lighting.

![Figure 88: Classroom Interior: Blinds being used partially to let in daylight during non-class hours.](image-url)
Analysis

To understand the current scenario, daylight analysis is done which involves choosing a metric to measure the required lighting levels in this school and run simulations by applying design inputs to gather at before and after scenario. For this purpose, the design measure used is the daylight factor. Daylight factor is the ratio of light levels inside a structure compared to the light levels outside the structure. An interior space with average daylight factor of 5% or more is well lit and does not require electric lighting and interior spaces with less than 2% daylight factor require frequent electric lighting. Recommended daylight factor in schools, mainly classrooms are between 2% to 5% and will require electric lighting between the months of October and March. Initially a simulation is run to see what the daylight factor entering the space is before any design interventions.

56 WIKIPEDIA Daylight factor: https://en.wikipedia.org/wiki/Daylight_factor
As observed in (Figure 90) above, it indicates that currently the daylight factor is between 6% and 8%. This is excessive lighting and is highly uncomfortable for users.

**Design Solutions**

The lighting situation currently in this school is poor as they entirely depend on artificial lighting because of excessive natural daylight due to which some windows are permanently shut down with blinds. The redesign proposes manually operable PV blinds that will help in opening the windows for natural lighting thus reducing the dependency upon artificial lighting. The energy harnessed is stored in the batteries lined up against the lintel of the wall which is both visible and out of reach of children. This Solar Wall feature would help in teaching the students about PV cells and how the energy is redirected for school use. The school structure is
individually situated, and as a result there is no shade factor other than its own shade to account for which allows for daylight in all the classrooms. Furthermore, light shelf design element is introduced to the window unit as illustrated in the exterior wall cross-section (Figure 93). The light shelves are designed for dispersing incident light farther in to the required space without much glare inconvenience, and at the same time acts as shading reducing the excessive daylight into the classrooms.

**Corridor**

Design inspiration is taken from existing transom walls and doors as shown in the (Figures 91 and 92) to reduce artificial lighting in corridor spaces, these transom elements let in light throughout the spaces making the corridors daylit as well.
Figure 92: Classrooms Transom Doors

**PV Blinds**

Area of one window: $3' \times 9' = 27\,\text{sqft}$

Total number of windows: 162 windows

Total window area: 4374 sqft

Energy generated per window: 150–196 watts per hour implying $150\times6\,\text{hrs (avg)}$\(^{57}\)

Total PV Blinds Wattage generation per day: 3936 kWh approximately

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\(^{57}\) Plug and Save Energy Products; David Curran
Figure 93: PV Blinds and The Storage Battery Installation In a Typical Classroom; The Solar Wall
Fig 94: The Designed Scenario of Day Lighting in School No. 1

Software: Velux Daylight Visualizer

The after scenario is shown in the (Figure 94) above where the day light factor is mitigated to required levels of 5%. The range of daylight factor is 2.88% to 4.75%. This range is convenient for users to carry out activities.

**Combined Lighting Strategy**

By reducing the daylighting to required levels, the spaces could depend less on the artificial lighting. The artificial lighting also needs to be motion sensor and work on the principle of increasing lighting intensity only to the farthest space of a room receiving lesser daylight. This is depicted in the (Figure 95) below.
Efficiency of the New Lighting Design

In employing these strategies, the lighting of the classroom space improves by 60% on an average which is shown in the graphic (Figure 96) below by plotting the figures from the current scenario against the improved and designed scenario.
Student Performance

Better lighting conditions also contribute to improving student performance. Change enhancement can be plotted by comparing average student performance of a grade after re-design against the performance during the original scenario giving an average performance percentage. By modeling the existing and redesigned scenarios we can see that the student performance improves by 15-20%. This is illustrated in the graph below.

![Graph showing improved student performance in day lit classrooms](image)

*Figure 97: Improved Student Performance in Day Lit Classrooms*

*Source: Velux Daylight Visualizer Software*

Ventilation

Indoor air quality ensures healthier and better learning environments for students. It is for this purpose ventilation plays a very important role. Indoor air can be two to five times more polluted than the outdoor air, and thus risking an increased rate of students being susceptible to indoor pollutants. On the other hand, increased outdoor air can result in high heating and air conditioning costs. Therefore, a balanced design solution is needed to handle the scenario.
Ventilation is a critical attribute to any climatic region as it replaces old, stale indoor air with fresh outdoor air flushing out potential pollutants caused by combustion or off-gassing of materials. Ventilation helps to improve the indoor environment quality by refreshing air within while controlling the humidity factor. Moist air, when not exhausted, leads to potential damages due to rot and mold. Ventilation is of three types:
Natural Ventilation
Mechanical Ventilation
Mixed system Ventilation

Natural ventilation involves natural forces, namely wind and buoyancy parameters for airflow within a space. For mechanical ventilation, the same is achieved with the help of motors to direct the air in desired location. The three main goals of ventilation are to improve indoor air quality, reduce energy consumption, and maximizing thermal comfort for users of the space.

Ventilation design is majorly affected by the regional climate and varies with respect to the local winds and wind temperatures. The School No. 1 is in Rochester, NY which has a very cold climate with snow for almost four to five months of a year and good sunny days of seven to eight months. The climate of Rochester, NY is explained in detail under the climate analysis section. Ventilation becomes important in cold climates where buildings are often built tighter and allow for less natural air-leaks. At the same time, ventilation for winter climates is a challenge as the temperatures in winter keep going down and, there is a desire to retain as much heat as possible. Ventilation systems tend to cycle in cold and fresh air and let out warm air resulting in spiked up electricity bills due to increased heating loads and a colder indoor environment which could lead to discomfort of the users. School buildings especially need good ventilation as it affects the student's health and their attendance hours. Ventilation must bring in clean outdoor air, mix it with indoor air, filter the air, distribute the mixed air, and exhaust part of the indoor air.

School No. 1, at present employs a very old mechanical ventilation system as shown in (Figure 98). The old ventilation system, is also leading to an increased energy loads. In addition to this, since the windows are fixed and non-operable and there is no other openings mechanism in the school to let in direct fresh air. The indoor environment
feels stuffy and claustrophobic. This is seen in the (Figure 99), where the simulation results of the school’s ventilation is the current scenario.

![Figure 98: Existing HVAC System](image)

In the simulation conducted we can see that the predominant wind direction is southwest and west. The wind goes around the building due to lack of cross ventilation. The building being entirely sealed up does not allow for any natural ventilation.
Ventilation System Design

The proposed redesign looks at implementing a hybrid/mixed ventilation system employing both natural and mechanical ventilation methods since the climatic conditions go both ways due to extreme hot summer days and very cold winter days. A hybrid ventilation system is needed, to balance the energy dependence and achieve better indoor environment. The natural ventilation system is to be used during the summer season and a mechanical system for the winter season.
Natural Ventilation

Simulations are done to understand the before redesign situations to provide design solutions. The Flow Design software by Revit is used to simulate the building ventilation energy and the results are discussed in the following section.

Mechanical Ventilation

The US Environmental Protection Agency (EPA) identifies Energy Recovery Ventilation system (ERV) to potentially address both technical and financial issues pertaining to ventilation in schools. The required ventilation rate recommended by American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE 62-2001)) for classroom is 15 cubic feet per minute (cfm) per person of outdoor air. A study conducted by the EPA of an average old school building stock is around five cubic feet per minute (cfm) which is very much below the recommended levels, and thus affecting the educational quality of students.¹

An energy recovery ventilation system (ERV) demonstrates effective means of reducing energy and HVAC loads. ERV works on air-to-air heat exchange principle that transfers both latent and sensible heat. A map of the United States is generated using the Energy Recovery Ventilation (ERV) Financial Assessment software tool. The ERV can acquire recommended ventilation rate by ASHRAE 62-2001 of 15 cubic feet per minute.
Energy efficiency:

Zone 1: Total recovery or sensible only recovery ERV systems recommended
- Total recovery payback typically 0 to 2 years
- Sensible only recovery payback typically 2 to 7 years

Figure 100: The School Advanced Ventilation Engineering Software _ US EPA
**Student Performance**

Indoor air quality helps ensure healthier and improved student performance. The ventilation equipment chosen for School No.1, Martin B. Anderson allows for reducing indoor pollutants by refreshing the indoor stale air and providing the recommended levels of outdoor air. As seen from the below graph (Figure 101). Student absenteeism is reduced by 1.3% and the pass percentage for standardized tests is increased by 2.3% whereas math and reading capabilities are improved by 1.5% and 0.7% respectively.

![Graph showing improved student performance](source: Autodesk Flow Design Software)
Design Summary
Design Summary

Design goals for School No.1, Martin B. Anderson were met through extensive research, sustainable agendas, and innovative design ideas. The project goals are summarized below along with proposed architectural solutions.

1. To design not just a sustainable school, but also a school that teaches basic sustainability concepts to elementary students through its architecture.
   The design proposed is a two-part process that achieves sustainability through both passive and active sustainable design efforts. The sustainable school building incorporates fun, thought provoking architectural elements designed for elementary students to impart basic sustainability knowledge.

2. Design keeping in mind the sustainability goals which also are important parameters in achieving healthy educational spaces improving student performance and school’s efficiency
   Six main goals, namely thermal comfort, lighting, energy, water, recycling, and acoustics are postulated and adhered to in re-designing the school space. The design embodies these six concepts such that they can also be easily taught to the students.

3. To make sure the sustainability postulates follow a systems approach with synergy of metrics as a strong underlying base.
   To illustrate metrics and dependency of metrics on one another, two major issues of this school are dealt with elaborately. Day-lighting can offset the energy use of school and improve student performance while reducing artificial lighting use. This is shown with the help of simulations and before-after design scenarios where we can see the improvement achieved. Similarly, ventilation is also an issue in the school as it lacks any openings and has a very old and inefficient HVAC system. For ventilation a hybrid solution is tasked for due to extreme summer and winter seasons in Rochester. A HVAC design is proposed which is effective in reducing energy use and providing better indoor environment.

4. To provide students a variety of spatial configurations such that it allows for learning in different dimensions and pushing the envelope for students themselves.
The design centers around the main idea of flexibility where it becomes an important tool to achieve a variety of teaching spaces and breaks the rigidity while retaining the traditional classroom-corridor relation.

5. *Redesigning the school entrance to provide a better transition and assist in informing students about water conservation and its best practices.*

The school entrance is dull and uninteresting in contrast to its grand building entrance. The front entry has a highly unsustainable soccer field grassland. The entrance is redesigned to house a raingarden with native plants, water network, and access to students such that they can learn about micro-ecosystems.

6. *Designing for alternative energy source to reduce the energy use from grid.*

Alternative energy resources are designed a) in the parking lot where, a solar carport is proposed to cover the parking area else resulting in increased heat island effect for school affecting micro-climate, and b) the windows are covered with solar photovoltaic blinds which also help generating energy and at the same shade the classroom from excessive daylight.

Continuing Research

As any given research paper, there is always scope for improvement, opportunities, and expanding research horizons. For this thesis, research can be continued to explore new design ideas to inspire students about sustainability and teach them to change their lifestyle to a more sustainable style. Furthermore, taking a step forward, this idea needs to be incorporated across all stages of schooling including middle school and high school with design ideas suitable to cater their age groups. Various methods of systems integration and metrics could be explored to improve efficiencies and look for concrete metrics that can be applied to judge the betterment. This would in turn affect the efficiency of schools in the USA making a great achievement towards the sustainable future of our descendants.
Conclusion
**Conclusion**

The School No.1 Martin B. Anderson elementary school is redesigned to provide an environmentally sustainable school synthesizing architecture and education. It is to bring change in the style of education at an early stage of elementary schooling encouraging students to change and transition to a lifestyle that would protect them. The architecture of the school interacts with its students on a one-on-one basis to teach them about sustainable choices in a fun, thought provoking manner. The children become the beacon of hope for a bright sustainable future.

The school produces 241,926 kWh of alternative, clean energy annually to offset the grid demand. In addition to this the students who become the citizens of tomorrow are brought out to the world much more educated about sustainability than today’s people. The lifestyle thus adopted would help in achieving sustainable future. School No.1 is to become a responsive architecture promoting efficiency and innovative solutions for teaching sustainability that is age appropriate for students.

Being a conceptual project, plausible design ideas are provided with respect to School No.1 that can be further modified, adopted, or become inspiration for design in other schools. Since all the redesign goals are common problem areas for schools, the ideas presented here can be further explored and applied wherever teaching sustainability is a priority.
Zoning Code and Analysis

Zoning Analysis for Rochester, New York

<table>
<thead>
<tr>
<th>Zoning District - R1</th>
<th>Allowable Use</th>
<th>Existing Use</th>
<th>Proposed Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Density Residential District</td>
<td>School No. 1 Elementary School</td>
<td>Special Permit Use</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>REQUIRED</th>
<th>EXISTING</th>
<th>PROPOSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking</td>
<td>No Parking required</td>
<td>69</td>
<td>61 + 4 handicapped parking</td>
</tr>
<tr>
<td>Maximum Building Footprint</td>
<td>35%</td>
<td>9.15%</td>
<td>9.15%</td>
</tr>
<tr>
<td>Maximum Lot Coverage</td>
<td>50%</td>
<td>22.10%</td>
<td>22.10%</td>
</tr>
<tr>
<td>Minimum Front Setback (ft)</td>
<td>20ft</td>
<td>120'</td>
<td>120'</td>
</tr>
<tr>
<td>Minimum Rear Setback (ft)</td>
<td>20ft</td>
<td>300'</td>
<td>300'</td>
</tr>
<tr>
<td>Minimum Side Setback (ft)</td>
<td>10 FT minimum with combined width of both side yards of 25 FT</td>
<td>135'</td>
<td>135'</td>
</tr>
<tr>
<td>Height Restriction</td>
<td>35ft</td>
<td>20'</td>
<td>20'</td>
</tr>
</tbody>
</table>

# Existing Building Code and Analysis

## Existing Building Code of New York State 2010

**Project**  
School No. 1 Martin B. Anderson School

### Existing Building: General

| Height | 20' |
| Storeys | 1 storey |
| Area | 43345.40 sqft |
| Use | Elementary school |

### Prescriptive Compliance Method

| Fire escape | (EBC) 303; 303.1.2 | Existing fire escapes shall be accepted as a component in means of egress in existing buildings only. |
| Accessibility for existing buildings | (EBC) 308; 308.2 | Anything constructed or altered to be accessible shall be maintained accessible during occupancy. |
| &nbsp; | &nbsp; | 308.3 Alterations shall not reduce or have the effect of reducing accessibility of building. |
| &nbsp; | &nbsp; | 308.4 Existing buildings that have a change of group or occupancy shall have following accessible features |
| &nbsp; | &nbsp; | 1. At least one accessible building entrance. |
| &nbsp; | &nbsp; | 2. At least one accessible route from an accessible building entrance to primary function areas. |
| &nbsp; | &nbsp; | 3. Signage complying with Section 1110 of the Building Code of New York State. |
| &nbsp; | &nbsp; | 4. Accessible parking, where parking is being provided. |
| &nbsp; | &nbsp; | The above items shall conform to the requirements to maximum extent that is technically feasible. |
| &nbsp; | &nbsp; | 308.6 Alterations must comply with Building Code of NYS for new buildings. |
| &nbsp; | &nbsp; | 308.7 Alteration affecting primary function shall be accessible including toilet facilities/drinking fountains. |

### Classification of Work

| Alteration | (EBC 404; 405; 406) | Reconfiguration of space, addition or elimination of any door or window, reconfiguration or extension of any system or installation of any additional equipment shall comply with NBC |

### Repairs

| EBC Chapter 5 |  |
| EBC 502.1 | Materials: Hazardous/banned materials are not permitted. |
| EBC 503.1 | Fire and life safety: Maintain existing level of fire protection. |
| EBC 504.1 | Egress: Maintain existing level of fire protection. |
| EBC 505.1 | Accessibility: Repairs must maintain the existing level of protection. |
Building Code and Analysis

**Building Code of New York State**

<table>
<thead>
<tr>
<th>Use and Occupancy</th>
<th>Existing Occupancy</th>
<th>Proposed Occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC 302</td>
<td>Educational Group E</td>
<td>Educational Group E</td>
</tr>
</tbody>
</table>

| Type of Construction | Existing: Type B |

<table>
<thead>
<tr>
<th>Height and Area</th>
<th>BC 503</th>
<th>Required/Allowable</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td>Height</td>
<td>Area</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>UL</td>
<td>43345.40 sf</td>
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</table>

**Sprinkler system BC 903**

<table>
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<th>903.2</th>
<th>Required/Allowable</th>
<th>Proposed</th>
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<tbody>
<tr>
<td></td>
<td>Group E 903.2.3</td>
<td>Automatic sprinkler system for areas greater than 20,000 sf</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Automatic sprinkler system installed.</td>
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</table>

**Fire Resistive Construction BC 601**

<table>
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<th>Type B Construction</th>
<th>Required/Allowable</th>
<th>Proposed</th>
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<tbody>
<tr>
<td></td>
<td>Exterior Walls</td>
<td>2 hr</td>
</tr>
<tr>
<td></td>
<td>Interior Walls</td>
<td>2 hr</td>
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<tr>
<td></td>
<td></td>
<td>2 hr fire proofed walls are installed</td>
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</table>

**Interior Finishes and Fire Rating BC 801**

<table>
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<tr>
<th>Table 803.5</th>
<th>Required/Allowable</th>
<th>Proposed</th>
</tr>
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<tbody>
<tr>
<td>Sprinklered</td>
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<td></td>
</tr>
<tr>
<td>Group E</td>
<td>Exit/Passages</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Corridors</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Rooms</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Exit/Passages</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Corridors</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Rooms</td>
<td>B</td>
</tr>
</tbody>
</table>

**Occupancy Load BC 1004**

<table>
<thead>
<tr>
<th>Use Group</th>
<th>Area per Occupant Sq.ft.</th>
<th>Area Sqft per Classroom</th>
<th>Occupant load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classrooms</td>
<td>20</td>
<td>500 sf</td>
<td>25/classroom</td>
</tr>
<tr>
<td>Kindergarten</td>
<td>30</td>
<td>660 sf</td>
<td>22/classroom</td>
</tr>
</tbody>
</table>

From the above Occupant Load, Egress is calculated:

**Egress BC 1005**

<table>
<thead>
<tr>
<th>Maximum Travel Distance</th>
<th>Egress Width (inches)</th>
<th>Maximum number of Exits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1016.1</td>
<td>Table 1015.1</td>
<td>Table 1005.1</td>
</tr>
<tr>
<td>Use Group</td>
<td>Allowed</td>
<td>Proposed</td>
</tr>
<tr>
<td>Educational Group E</td>
<td>200 ft</td>
<td>200 ft</td>
</tr>
</tbody>
</table>
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HVAC - Heating, Ventilation and Air conditioning
CHPE - Centre for High Performance Environments
AIA - American Institute of Architects
USGBC - United States Green Building Council
CGS - Center for Green Schools
ESD - Education for Sustainable Development
AusSSI - Australian Sustainable Schools Initiative
IAQ - Indoor Air Quality
ANSI - American National Standards Institute
ASHRAE - American Society for Heating, Refrigeration and Air-conditioning Engineers
NZEB - Nearly Zero Energy Building
NREL - National Renewable Energy Laboratory
DOE - Department of Energy
NREL - National Renewable Energy Laboratory
COTE - Committee on The Environment
RCSD - Rochester City School District
ADA - Americans with Disabilities Act
HET - High Efficient Toilets
GPF - Gallons Per Flush
EPA - Environmental Protection Agency
ERV - Energy Recovery Ventilation system
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The End.