Final Report

AIA Upjohn Award

Guidelines for the Design of Sustainable Learning Laboratories that Teach Through Architecture

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Summary
Through this project and the support of the American Institute of Architects, the Center for High Performance Learning Environments (CHPLE), and the School of Education at Virginia Tech, in cooperation with the Southwest Virginia Science Museum, Reader and Swartz Architects and the Shenandoah Valley Discovery Museum, science educators, and the International Institute for Sustainable Labs (I^2SL) are seeking to transform the design of schools and learning laboratories from passive vessels to active participants in learning. The focus of this transformative process is on sustainability and environmental stewardship and the opportunities within architecture to teach these subjects. The results from this work are foundational to an effort to promote the concept of "buildings that teach" and environmental stewardship with the development of a new AIA learning module that describes knowledge-based links between learning, critical thinking, architecture and building technologies. Through a qualitative research paradigm that included case studies, observation and documentation, data reduction and coding, and interpretation, links between building features, museum, laboratories and school displays and exhibits, and learning were identified and mapped to the architectural design process. In addition, a group of middle school students from Southwest Virginia participated in a mock design of an "environmentally responsive" building. Through this qualitative approach dimensions of student learning related to architecture and the environment were identified and translated to architectural decision-making. Through participation on the designs for the Shenandoah Valley Discovery Museum, the Southwest Virginia Science Museum and an Environmental Learning Center for Southwest Virginia, an understanding for the interrelationships between pedagogical issues and building systems was mapped. In addition middle school teachers and museum exhibit designers participated in the development of strategies to explicitly link architecture to learning. By further developing this map through this proposal, lessons-learned were summarized that assist architects in designing environments that directly support learning. A summary of these lessons-learned were presented to a group of architects at the 2009 Labs for the 21st Century conference in September in Indianapolis, Indiana. The material was well-received and the participants provided constructive comment and feedback on extending the materials presented.

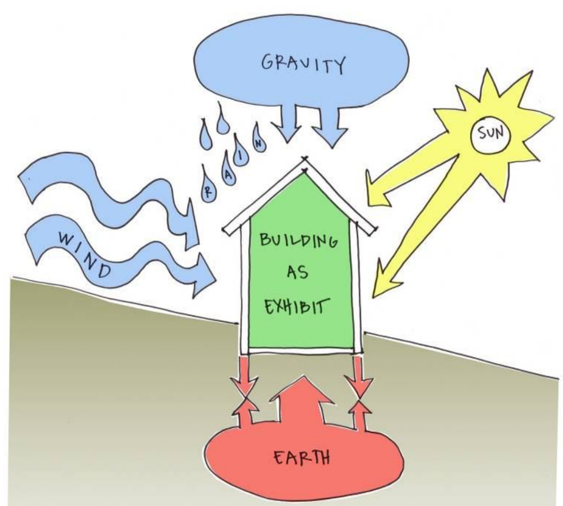

Figure 1. Concept of Building as an exhibit

Summary of Outcomes

There was one goal and two primary objectives for this work. The goal is to promote environmental stewardship and an improved awareness of the role buildings play in our national energy demand. By directly linking architecture and learning through "buildings that teach", buildings are transformed from passive vessels to active participants in learning. The meeting of this goal is long term and will continue to be pursued as the results from this project are disseminated. The first primary objective and outcome from this work was the development of an AIA learning module that specifically addresses emerging design practice that is focused on environmental stewardship while linking the building design and systems explicitly to K through 12 learning. The learning module has been developed and was presented at the 2009 Labs21 conference in Indianapolis Indiana. The module materials were well-received by the attendees and there was consensus that that materials were useful and timely. Through organizations such as AIA and the US EPA's Labs21 program the learning material will continue to be disseminated regionally and nationally. The second objective is to encourage educators to integrate the school's "sustainability" features into lesson plans and laboratory activities for students. This second objective is being promoted through organizations such as the Council for Educational Facility Planners International (CEFPI). The results from this project were submitted to the CEFPI and are being considered for award for its potentially transformative impact.

Project Description

This project builds on recent research activities through the Center for High Performance Learning Environments (CHPLE) that seeks to understand and document the potential for architecture to actively participate in learning. Buildings such as schools and museums are often passive vessels rather than active participants in learning. With the growing concerns for climate change and global warming, and the condition where energy consumption associated with buildings represents over 30 percent of our national energy demand and nearly 50 of green house gas emissions, the role that buildings play in our understanding these issues should be reexamined. Architects in collaboration with educators, school administrators, museum administrators and exhibit designers and building system designers should seek to design buildings that actively participate in learning. Through this project, strategies and issues associate with the concept of "building that teach" were identified, documented, organized and published for the architectural community. The outcomes documented both the procedural design issues as well as specific design strategies that merge architecture with sustainable building systems and learning.

Through a qualitative research paradigm that included case studies, observation and documentation, data reduction and coding, and interpretation, links between building features, museum, laboratories and school displays and exhibits, and learning were identified and mapped to the architectural design process. In addition, a group of middle school students from Southwest Virginia participated in a mock design of an "environmentally responsive" building. Through this qualitative approach dimensions of student learning related to architecture and the environment were identified and translated to architectural decision-making. Through participation on the designs for the Shenandoah Valley Discovery Museum, the Southwest Virginia Science Museum and an Environmental Learning Center for Southwest Virginia, an understanding for the interrelationships between pedagogical issues and building systems was mapped. In addition middle school teachers and museum exhibit designers participated in the development of strategies to explicitly link architecture to learning.

The goals and objectives for this research were met through the following four major tasks.

First, lessons-learned from recent CHPLE research related to buildings that teach was collected, structured and summarized. The CHPLE has been involved in several recent projects that seek to link architecture and learning. The lessons-learned related to 1) design procedures and collaborative relationships, and 2) specific building system decisions that address these linkages were summarized.

Second, the CHPLE been collaborating with Reader and Swartz Architects and museum administrators on the design of the Shenandoah Valley Discovery Museum in Winchester Virginia and the Southwest Virginia Science Museum in Roanoke VA. These projects served as case studies to document and understand the interrelationships between architecture and building systems, and learning. The projects merge building systems such as a green roof, photovoltaic panels, and wind generator with learning exhibits. Through design charrettes and documentation of the decision-making process interrelationships were identified.

Third, to better understand the target learning group, CHPLE in cooperation with the School of Education at Virginia Tech conducted a mock design with middle school students. Through group participation these students were tasked with designing a regional environmental learning center. Through observation and documentation of their interactions, as well as documentation of their knowledge-base and knowledge gained, a better understanding of the target learning group was gained. This understanding will be translated to the design process.

Finally, the findings from task one through three were summarized and translated to a new learning module for architects. The material was translated to a continuing education workshop that promotes the concept of buildings that teach. This workshop was presented to a group of architects at the September 2009 Labs for the 21st Century conference in Indianapolis, IN. The workshop was well-received and the participants indicated a consensus of opinion that the material was innovative, timely and presented a challenge to the architectural community.

A summary of the workshop materials accompanies this document as an appendix. This summary will shortly be made available for wide dissemination through the Center for High Performance Learning Environment's website.

Appendix A

Summary of Lessons Learned
"Buildings that Teach"

Transforming Architecture from Passive Vessels to Active Participants in Learning

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Abstract:
The typical school houses learning but does not actively participate in the learning process. This is a missed opportunity for architecture. Researchers at Virginia Tech are seeking to transform the way learning environments are designed by promoting the concept of "buildings that teach". Like biological organisms, buildings respond to dynamic functional, as well as environmental conditions. Indeed philosophers such as Johann Geothe suggest that this response is a critical informant for deriving biological form. When architectural form is derived with these same inputs then opportunities are created for buildings to actively teach through themselves. This is particularly applicable with the current interest in resource conservation. While there are many recently designed schools that attempt to support learning through themselves these efforts typically fall short of their potential with only a sundial near the entry or a dashboard displaying building performance parameters. By fully applying the concept of buildings that teach architecture becomes an active participant in learning and the building serves as an exhibit of environmental responsiveness. However to fully apply the concept of buildings that teach requires 1) the designer understand the philosophical and pedagogical underpinnings of sustainability and environmental responsiveness, 2) work with educators to derive curricula that engages the building and 3) have knowledge of system monitoring equipment for integration into the building. Furthermore the designer should recognize that buildings can participate in learning at more than one level including the explicit integration of building performance data into curricula to implicit learning through an expression of architectural form. Through an immersive-participatory method using a series of case studies including a Regional Environmental Learning Center, the proposed Shenandoah Valley Discovery Museum, and the Science Museum of Southwest Virginia, this transformative process has

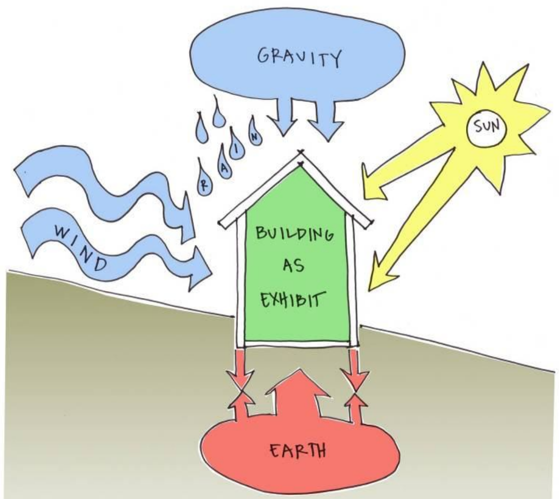


Figure 1. Concept of Building as an exhibit

begun by documenting lessons-learned toward development of continuing education material to promote “buildings that teach”.

1 Introduction

The dominant paradigm that currently informs the design of learning environments such as schools and museums is that buildings are passive vessels for learning that only hold the people who use them and influence only indirectly the activities that take place in them. Classrooms are viewed as spaces to house learning activities as opposed to active participants in the learning process. Beyond providing technology support (media projection, learning boards, etc.), architect’s seldom design to have the building serve as a vehicle for direct learning. Unfortunately this is a missed opportunity for architecture to actively participate in learning. Addressing and impacting this situation is a goal of this work.

The Passive Vessel – A Missed Opportunity

Architecture presents opportunities to actively participant in the learning process, particularly as it relates to resource conservation and sustainability. For example, a recent case study conducted in cooperation with the U.S. Department of Energy- Energy Smart Schools program, documented the links, or lack of, between learning, architecture and sustainability in a middle school in North Carolina. From its inception this building was designed to achieve LEED certification. Among the resource conserving systems were: a) an active thermal solar rooftop collection system, b) a photovoltaic rooftop array, and c) a rainwater harvesting system. The first two systems are visible on the roof as one approaches the building and are examples of the goal for the building to conserve resources. All three systems helped achieve LEED silver certification.


a.

b.

c.

Figure 2. a) Thermal solar water heating system, b) photovoltaic array, and c) rainwater filtering system.

While these systems provide visible and identifiable features that announce the resource conservation occurring in the facility, they fall short of the “buildings that teach” concept. As mentioned the systems include thermal solar hot water for the school cafeteria, a small photovoltaic array that supplements a very small part of the building’s electrical loads and a rainwater harvesting system that reduces the need for purchased water. Unfortunately the water cistern is buried in a courtyard while the filtering system is concealed in a mechanical room, out of site from any of the students – the system has no presence on the campus. Furthermore the none of the systems have provisions to monitor and record performance parameters and there are no explicit connections between the systems and the curriculum. This missed opportunity undervalues the role of architecture and its systems in the learning process.

The typical approach to designing learning environments is to begin by identify the pedagogical, spatial, technological and occupants needs. This includes identifying the pedagogical model(s) that teachers will be working from: 1) direct instructional, 2) direct-social, 3) social, 4) student centered, and 5) radical, or the technological needs of the teachers, 1) media presentation and visualization, 2) writeable surfaces such as blackboard, white board or smart board and access to wireless internet access. This is then combined with the occupant (thermal, visual, acoustic and functional) and spatial needs (proximities, adjacencies, scale, etc.) to design the learning environment. For Buildings that Teach we must look at these domains differently while adding an understanding of sustainability and building monitoring.

Figure 3. Old model for Designing Learning Environments

Recent architectural projects such as the Shenandoah Valley Discovery Museum (SVDM) by Reader and Schcwartz challenge this paradigm by creating an active structure, one that encourages interaction between the systems within the building and those who visit it. Critical in today's learning environments are informal educational opportunities in the sciences, technology, engineering, and mathematics. In this "A Building as an Interactive Exhibit," visitors see and can understand practical applications of design, construction, and operation techniques that respond to the world-wide sense of urgency humans feel about the way we live in our natural and built surroundings. Through projects such as this lessons-learned were translated to develop a new framework from designing Buildings that Teach.

A New Framework

As suggested, Buildings that Teach require a transformation in the way architects design learning environments. This transformation begins with identifying both the underlying philosophy of the institution and the educational goals. The philosophical foundations are grounded in questions of both *what will be taught and how will it be taught*. In the context of the present work, the what is concerned with environmental stewardship and resource conservation. The how is derived from understanding pedagogical models, including: 1) direct instructional, 2) direct-social, 3) social, 4) student centered, and 5) radical, and their appropriateness as a linkage to the building and its systems.

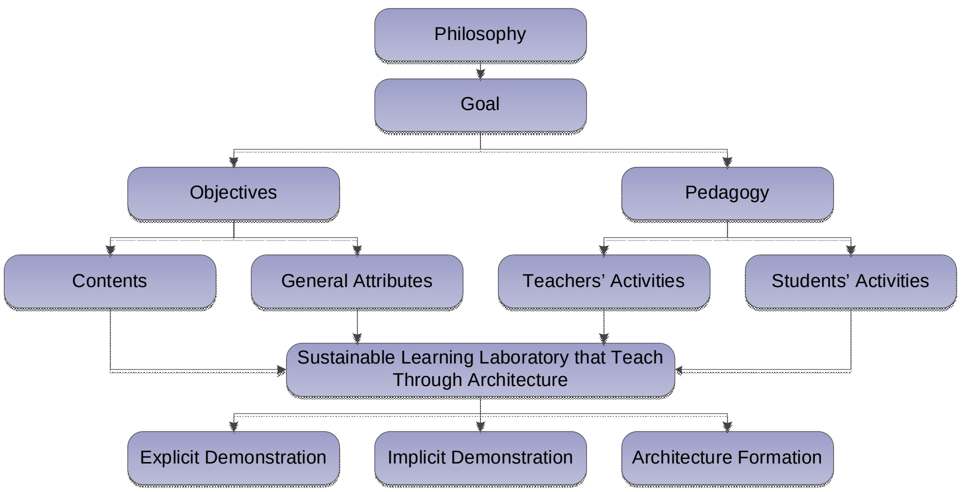


Figure 4. A New Framework for designing Buildings that Teach

For example, in the planning and design of the Shenandoah Valley discovery Museum, the museum administrators in cooperation with the design firm, Reader and Schwartz Architects, developed a philosophical position that explicitly linked the building to the learning experience of visitors to the museum. Developed as a concept of "Building as an Exhibit", the philosophical position is one of designing the building as a series of exhibits that fall into five categories related to environmental stewardship, namely: use, making, keeping, recycling and reuse. The position is further articulated through recognition that the learning experience will be dependent on the level of the visitor. Therefore the learning strategy is developed based on four different learner levels: 1) the wanderer (very young children), 2) focused wanderer (late elementary school), 3) student (middle and high school), and professional. As shown in Figure 5, the building-related exhibits are developed in a layered approach to address these differences for these five topic areas. Through this collaborative process the building actively participates in learning about environmental stewardship.

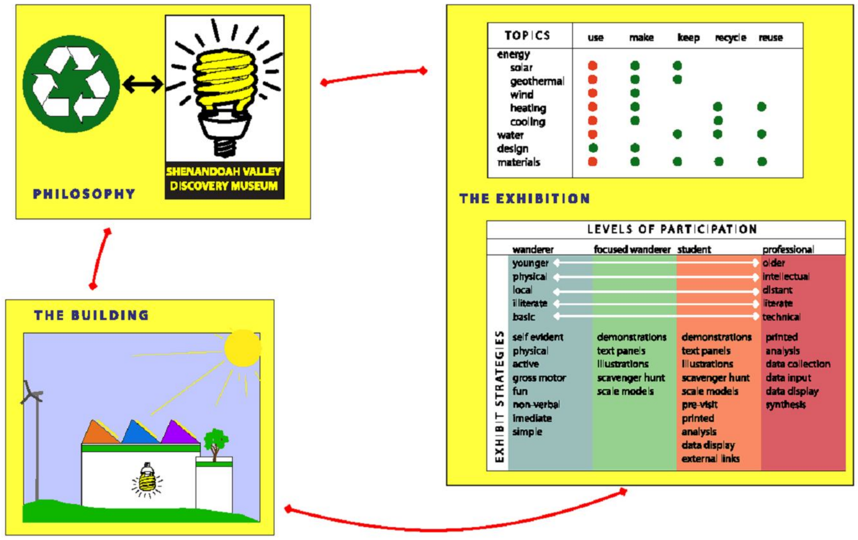


Figure 5. Interrelationships between Buildings, Learning Topics and Levels of Participation as a Philosophical position for the SVDM

The framework shown in Figure 4 suggests that architecture can incorporate sustainability as a strategy to merge the objective and pedagogical domains of content, attributes (of the exhibits in the case of the SVDM), the teacher (learning) activities, and the student (learner) activities. This further suggests the importance of sustainability, as a knowledge-base, in the design process. To understand and apply the framework for Buildings that Teach requires a more in-depth inquiry and understanding of sustainability within the context of a pedagogical strategy, than is typically taken.

Pedagogically Derived Sustainability

The proposed framework for pedagogically derived sustainability has three important domains that architects should understand and seek to express through the building. First must be an understanding of the learning process itself. As a result of interactions with teachers and students observed through this project, the research team proposes a constructivist model as a foundation for Buildings that Teach. The constructivist worldview holds that the *learners build their own knowledge in response to sensory inputs from authentic experiences*, where the sensory inputs and experiences can be derived from the building and its systems. The constructivist paradigm considers the social experiences and cultural backgrounds of both educators and students in constructing knowledge. The philosophical domain of the framework might also consider the following.

- Knowledge is relevant to leaner's experience
- Learning involves both memorizing and cognitive restructuring
- Learners are active participants in the process
- Teaching by understanding students
- Systematic view of knowledge and discipline
- Learning and teaching have to be planned systematically
- The educational system is an open system

Two examples might demonstrate some of these propositions. First is a proposed design for a kindergarten. The design borrows directly from the philosophical basis for the Kindergarten as a classroom in the garden. The school is designed such that each classroom extends to an outdoor garden where the boundary between inside and out is intentionally blurred. The cognitive restructuring occurs in a number of ways including establishing a child-level datum in the lobby through a change of materials. Below the child's height the concrete walls are covered with wood. The wood presents a surface to mount and display the work of the children while providing a tactile experience of differences in materials. In the classrooms the primary structural elements, beam and column, are given presence. Daylight is allowed to spill around the beam providing a temporal marking of time throughout the day. In these and other ways the architecture actively participates in a cognitive restructuring related to environmental awareness.

As a demonstration of a systematically planned learning experience where the architecture participates, consider the design of a regional environmental learning center as an extension of a middle school in southwest Virginia. Table 1 shows a matrix of building related learning experiences that are derived cooperatively between the architect

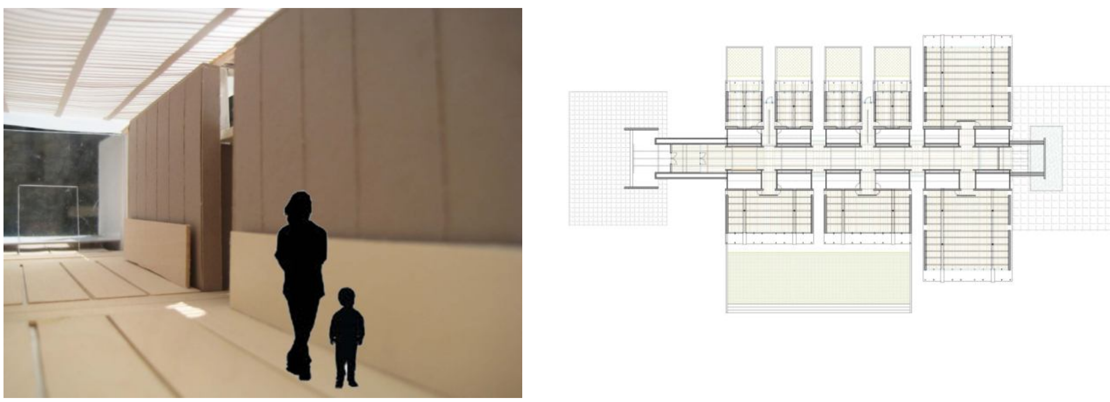


Figure 6. Elevation (left) of lobby and plan view of a proposed kindergarten.

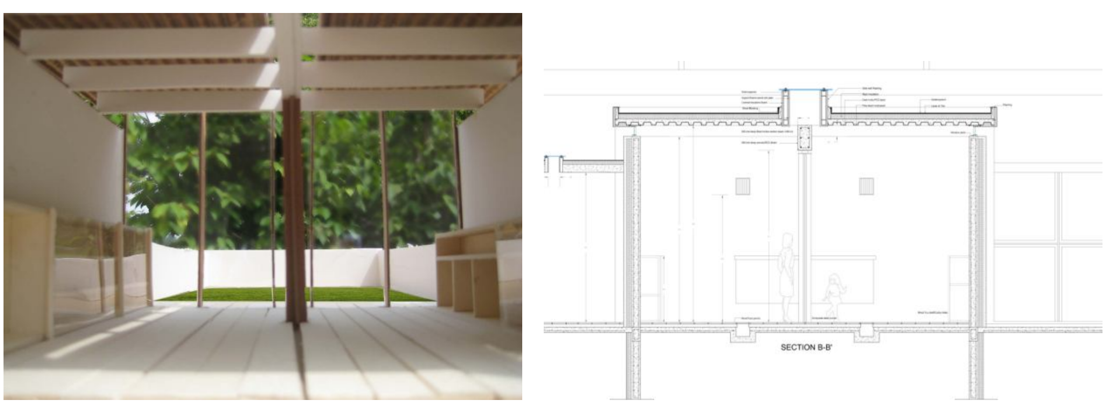


Figure 7. Model of classroom (left) and section.

and the teachers using this facility. The matrix links the architecture with questions related to Environmental Science questions and learning methodology. In both spaces opportunities are left for an open educational system where teachers can encourage students to interact with the architecture in various ways.

Table1. Educational Matrix for a Regional Environmental Learning Center

Architecture Question	**Architecture Issues**	**Architecture Methodology**	**Environmental Science Question**	**ES Fundamental Issues**	**ES Methodology**
Why do we consume energy?					
How do buildings consume energy?	Thermal comfort Operations Hot water Embodied energy	Personal inventory	What is energy and how is it consumed?	Mechanistic – cyclic (Laplace, Newton) Thermodynamic (Carnot (Reflexions), Joule	Difference between combustion and work
Maintaining Thermal Comfort					
How does a building regulate thermal comfort?	Sun spaces, conditioned air and MRT	Experiencing thermal spaces	What is the physiology of human comfort?	Metabolism, convection and radiation	Measuring TC effects – students as a measure
Regulating thermal imbalance					
What are the heat losses and gains in buildings? When does a building balance?	Heat sources Enclosure energy flow	Monitor heat of light Monitor heat flow through ELS walls	How is the sun a heat source? What are the thermal properties of materials?	Solar radiation and intensity Thermal conduction	Monitor solar radiation Compare heat flow through materials
Understanding building materials					
What are the differences between typical enclosure assemblies?	R-values Thermal mass	Monitor and compare alternatives	What are the thermal properties of materials?	Thermal capacitance and specific heat	Experimentally compare alternatives
Naturally maintained balance					
How do buildings maintain thermal balance?	Passive solar, Shading Natural ventilation	Lessons learned from the ELS	What are environmental sources of free heating or cooling?	Solar inclination, properties of glass (green house effect)	Experimentally monitor sun space
Mechanically maintained balance					
How do buildings maintain balance?	Water, air and heat pumps	Monitor building systems	What is efficiency?	Energy input vs use	Experimental comparison
Hot water demand					
Why do we need hot water? What is a typical HW system? What does a solar HW system include?	Water heating and pumping	Monitor ELS system	What is life cycle cots?	Cost vs savings True cost	Calculation
Embodied Energy					
What is the energy of construction? Modularity	Material manufacture	ELS materials	What energy goes into building materials?	Cost vs life expectancy	Comparison of alternatives
Meeting the building function					
Why do buildings consume electricity? Understanding utility rates and demand charges? Why does daylighting make sense?	Demand vs collection Cost vs savings Energy Star ratings Heat of light Light control Atrium and borrowed light	Monitor ELS Monitor lighting	What are the typical conversion efficiencies? What is a PV panel? How much heat of light?	AC and DC electricity Light and heat	Experiment and calculations Heat of lilght

Water use					
What is potable, grey and black water?	Typical plumbing system Alternative system	Rainwater collection from the roof – monitor and calculation	What are typical water pollutants?	Filtration and UV dosing	Water monitoring and analysis

To take this a step further for the Buildings that Teach concept would be to extend Table 1 to include consideration of learning content associated with Standards of Learning testing. While the merits of SOLs are debatable the current reality is that teachers must often teach to the SOLs. This creates another opportunity for architecture to become an active participant in the learning process. For example, in both the Shenandoah Valley Discovery Museum and the Regional Environmental Learning Center the educators and architects worked collaboratively to link SOL content to the building features and systems. Through this elicit link between formal and informal learning using fifth and sixth grades as targets SOL learning categories such as Computer/technology, Earth Science, Biology, Chemistry and Physics were all identified as opportunities to link to the building. Examining the learning standards within these categories suggested that at least 15 of the SOL objectives could be met through careful design of informal exhibits in the participating facilities. For example, the Earth Science category, section ES.7 indicates that:
The student will investigate and understand the differences between renewable and nonrenewable resources. Key concepts include

- *Fossil fuels, minerals, rocks, water and vegetation*
- *Advantages and disadvantages of various energy sources*
- *Resources found in Virginia*
- *Use of resources and their effects on standards of living, and*
- *Environmental costs and benefits.*

The Physics category standard PH.8 indicates that:
The students will investigate and understand that energy can be transferred and transformed to provide usable work. Key concepts include

- *Transformation of energy among forms, including mechanical, thermal, electrical, gravitational, chemical, and nuclear, and*
- *Efficiency of systems.*

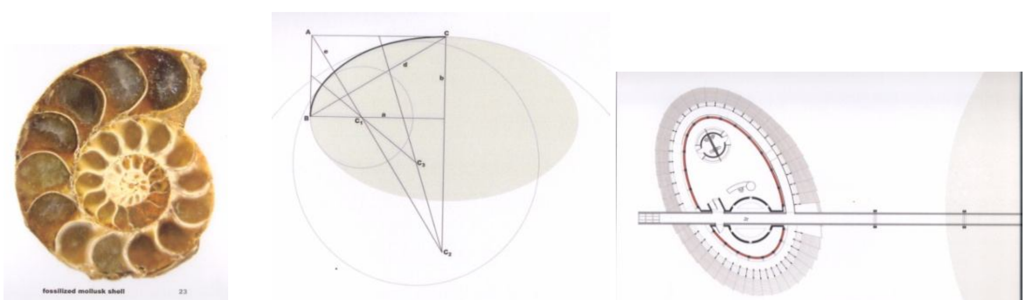
In both buildings features and systems were designed to explicitly serve teachers for SOL content.

For Buildings that Teach the building must be designed to link to the curricula and must be philosophically grounded. For this work the philosophical grounding has two domains, one being derived from the pedagogical philosophy of the teachers and the second domain for sustainability itself. The foundations for a pedagogically derived understanding of sustainability may begin with environmentalist and author David Orr. Orr suggests that environmental education should be grounded in the following.

- All education is environmental education (for better or worse)

- Environmental issues are complex and cannot be understood through a single discipline or department.
- For inhabitants, education occurs, in part, as a dialogue with a place and has the characteristics of a good conversation.
- It follows that the way education occurs is as important as its content.
- Experience in the natural world is both an essential part of understanding the environment, and conducive to good thinking.
- Education relevant to the challenge of building a sustainable society will enhance the learner's competence with natural systems.
- Education should be relevant to the transition to sustainable society demands an uncompromising commitment to life and its preservation.
- Education for sustainability should help students and teachers understand the world of nature and develop competence in considering natural systems
- Education for sustainability will connect disciplines as well as disparate parts of the personality: intellect, hands, and heart.
- A multidisciplinary approach and the aim of personal wholeness and transcendence are both essential in ecological design education.
- Education for sustainability must include an awareness of the tragic in human affairs: the limit of growth.

As suggested by Orr architecture should support a dialogue with a place. For example consider the design of a environmental learning station for a national forest in Southwest Virginia. As shown in Figures 8 through 12 the design concept is derived from natural system and proportions such as the Fibonacci series that can be found in nature. The underlying geometry of the building's plan is a direct translation of the Fibonacci series to the proportioning of the ellipse. The progression of the changing ellipses, in section, create a condition where the building seems to grow from the topography of its site. The construction is of a series of layers, each having an environmentally responsive role, similar to the skin of an organism. The building itself demonstrates underlying principles from nature – the building is organic.



Figures 8, 9 and 10. Nautilus shell from Fibonacci series, application of Fibonacci to ellipse development and resulting plan. (Alan Todd 2008)

Figures 11 and 12. Images of the Environmental Center showing the building merging with the site and extending from the topograph**y.**

Architecture such as this is grounded in environmental science and can teach at multiple levels.

As a direct translation of issues of sustainability and environmental design to architecture the educational principle put forward by Orr could be combined with building rating systems such as LEED. The rating categories put forth in LEED map fairly well to the environmental education principles suggested by ORR. The LEED categories that best map are: 1) Sustainable sites, 2) Water Efficiency, 3) Energy and Atmosphere, and 4) Materials and Resources. However, when designing Buildings that Teach, LEED objectives must be viewed differently. Rather than the design strategies and building system selections being made to achieve a desired certification level, these design decisions should be viewed in support of learning objectives. For example, for the design of the Regional Environmental Learning Center (RELC) presented in Table 1, a LEED objective was to reduce off-site water consumption. For this a rainwater harvesting strategy was employed. However, unlike the system shown in Figure 2c that is hidden in the mechanical room, the system used in the RELC is visible and celebrates the act of water collection.

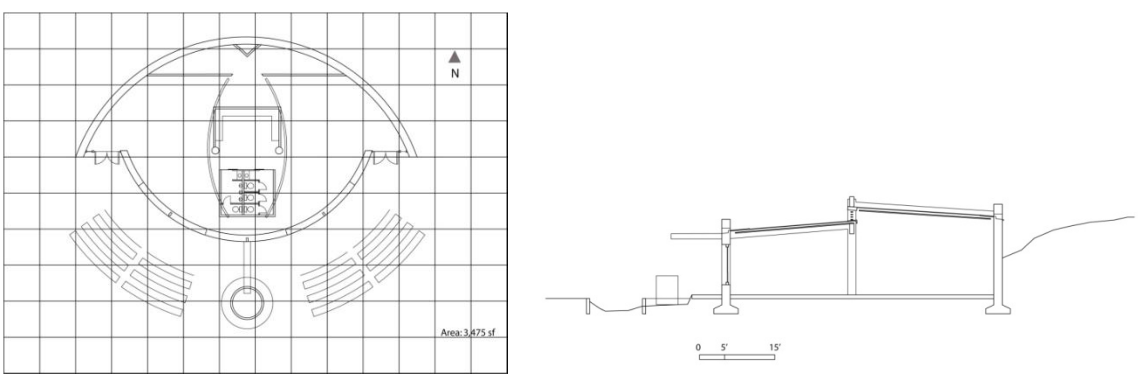


Figure 13. Plan and Section of a Regional Environmental Learning Center with visible Rainwater Harvesting System.

A second example of going beyond LEED to achieve a Building That Teaches is the previously introduced Shenandoah Valley Discovery Museum. Designed as a “Building as an Exhibit”, this project is intended to achieve LEED Platinum certification. For this the building incorporates several design features and systems that conserve resources, see Figure 14. But beyond this, the research team (paper authors), SVDM administrators and architects explicitly approached the integration of building and learning. The building actively participates in a “scavenger hunt”, where visitors are prompted to inquire into the environmental features in greater detail. Through hand-held personal displays and a layered digital inquiry approach, visitors directly interact with the building and its’ systems. The layered approach allows the inquiry to address various levels of learners as presented in Figure 5. The result is a LEED platinum building that actively teaches about environmental stewardship.

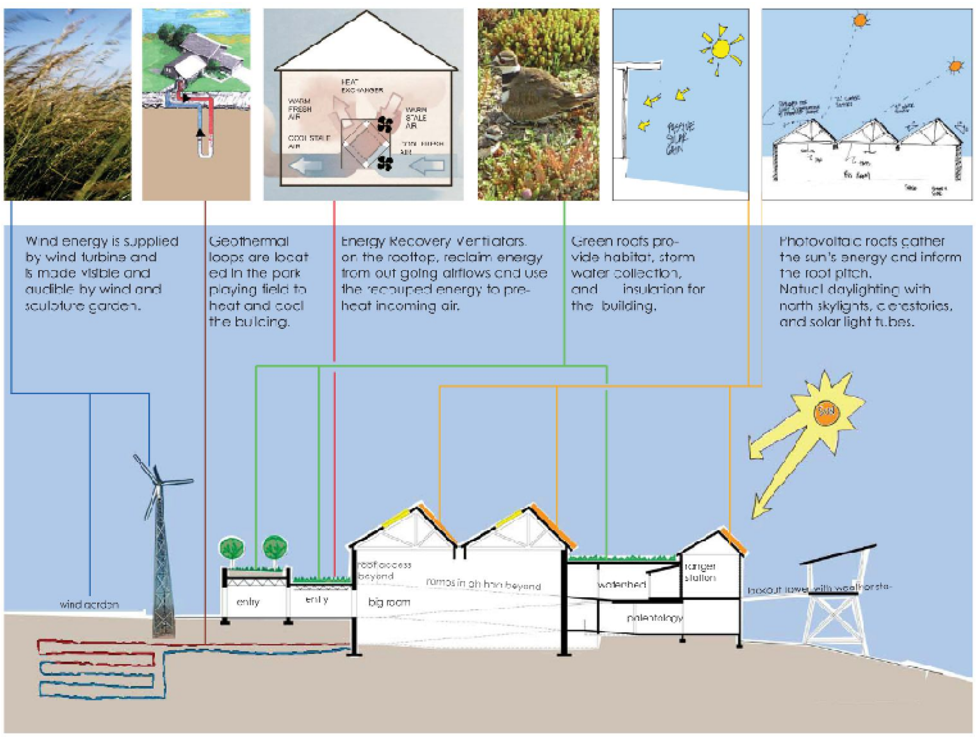


Figure 14. SVSM Design Features and Systems for LEED Platinum Certification.

Three Domains of Architectural Integration

Figure 4 suggests that there are three domains for architectural expression of Buildings that Teach, these include: explicit demonstration, implicit demonstration and architectural formation.

The building, and its’ systems, as an explicit demonstration, relates to one of the most common approaches to architecture as a learning vehicle. Examples of explicit demonstrations have been previously presented, as in Figure 2. Although a common approach, it could be argued that this is the lowest level of the building as an active participant in learning. As previously discussed, the systems shown in Figure 2 (a and b), while being visible upon arrival to the building, are not integrated into the pedagogical structure of the learning. The rainwater harvesting system shown in Figure 13 is arguably a better solution than in figure 2c, as the act of collecting water is celebrated and has presence as one looks out from the classroom on a rainy day.

The implicit demonstration goes beyond just presenting the environmental system to one of making a cognitive connection with the learner. As previously introduced, the kindergarten project shown in Figures 6 and 7 uses daylight to provide a cognitive map of daily and seasonal sun and light cycles to very young learners. And, the scavenger hunt for the Shenandoah Valley Discovery Museum directly links the building and its' systems to the learning experience as visitors are led through the building.

The third domain, that of architectural formation, should be of greatest interest to architects. Form is a foundation for the discipline of architecture. There are many formative influences that the architect might choose to elevate in importance during the design process. For the Building That Teaches, environmental factors such as climate, site, sun, light, wind and precipitation can be important inputs to architectural form. The environmental learning station shown in Figures 8 thru 12 is a formal response to the underlying geometry and proportioning found in natural systems such as nautilus shells. The formal design of an elementary school shown in Figure 15 is derived from an expression of strategies to integrate natural ventilation. The wing-like element above the hallway demonstrates a basic principle of aerodynamics, namely the Bernoulli principle, as a strategy to induce air movement through the building. The environmental strategy is expressed rather than concealed. Similar formative opportunities exist for the other environmental factors.

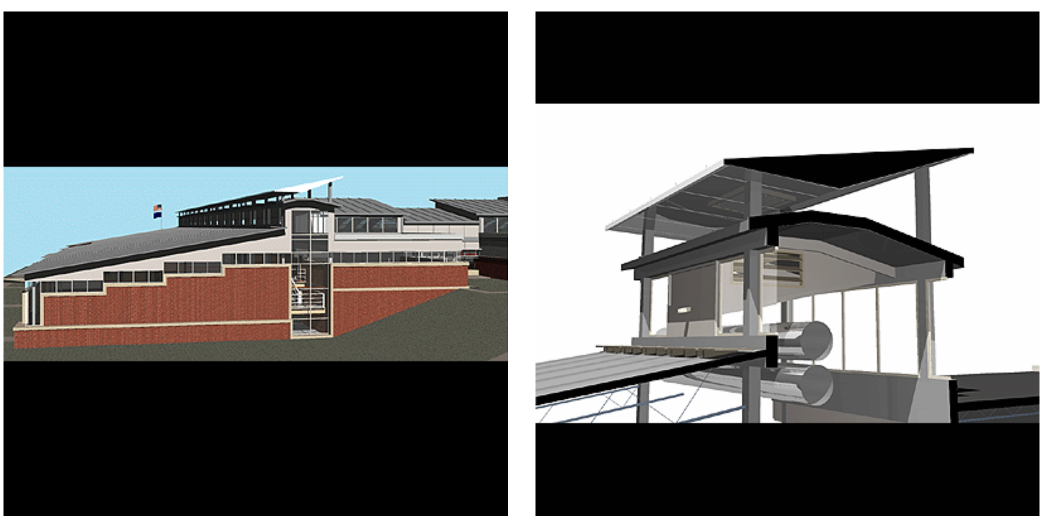


Figure 15. An Elementary School Designed with Formal expression of Natural Ventilation. (James Henderson 2001)

An Additional System: Data Collection and Monitoring

The previous discussion suggests that the building as an implicit demonstration or as a formal response to environmental factors best support the concept of Buildings that Teach. For this, the design process must be modified to include the integration of an additional building system, namely the data collection and monitoring system. While today many buildings include monitoring and automated control of heating, ventilating and air conditioning, and lighting systems, for the Building that Teaches the role of the monitoring and control system must be modified and expanded. In this case the data must be more accessible, and monitoring made more visible either in general to the building population (lobby display) or directly to the classroom. In projects such as the SVDM and the Regional Environmental Learning Center, the design and integration of the data collection and monitoring became a formal phase of the project.

For the SVDM, the scavenger hunt concept linked the building system directly to the learner experience. For this the research team, the SVDM administrators, the architects and data collection and monitoring vendors met and discussed strategies to achieve the desired goals. From these interactions the strategy was mapped as shown in Figure 16 and 17. Because of the complexity of the strategy to interactively link the building systems to personal display devices, several team interactions and discussions were necessary. This project also included several discussions with system vendors as no one system had all of the desired capabilities.

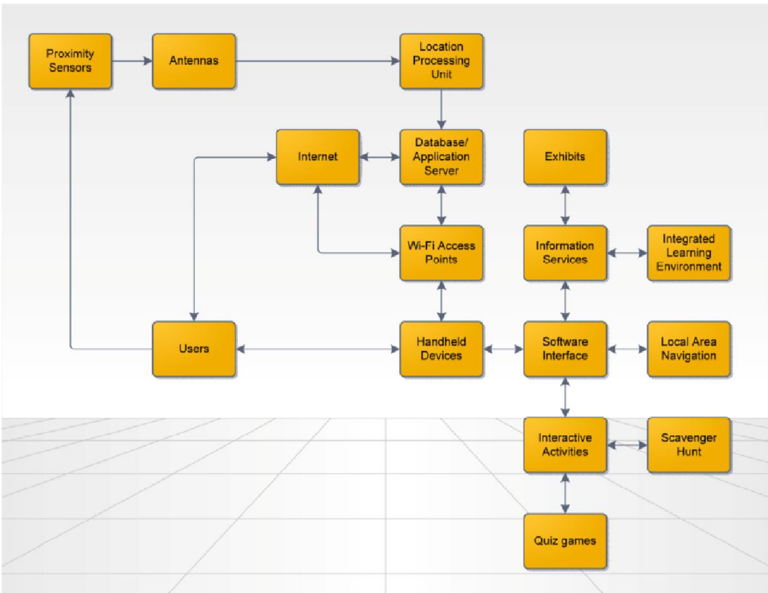


Figure 16. System Map for SVDM Data Collection and Monitoring System

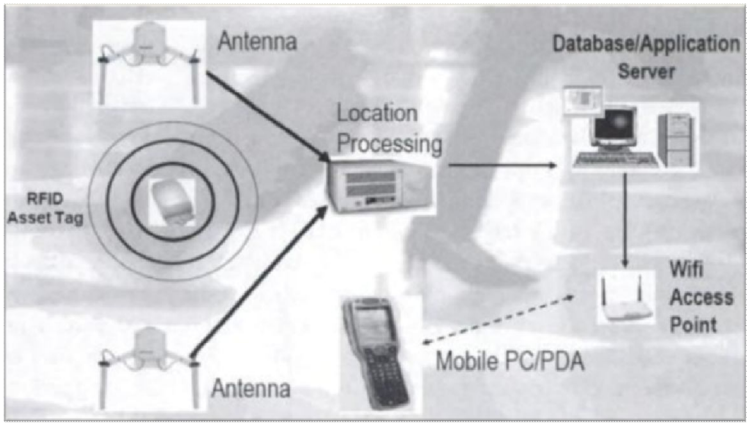


Figure 17. Schematic System Component Strategy for SVDM Scavenger Hunt

Similarly for the Regional Environmental Learning Center project, the research team, teachers and architect collaboratively developed a specific set of system requirements to meet the learning objectives shown in Table 1. These requirements were described and formatted as shown in Table 2. The data collection system description included the building system identifier, the desired measurement points and the corresponding units and output signal. This table could then be used as part of the building specifications and construction documentation for the bidding process.

Table 2. Data Collection System Specifications for a Regional Environmental Learning Center.

System	Measurement Point	Units	Signal
Photovoltaic	Circuit voltage	Volts	MV/volt
	Circuit current	amps	MV/amp
	Total solar radiation	Watts/sq.ft.	MV/watt/sq.ft
	Diffuse solar radiation	Watts/sq.ft.	MV/watt/sq.ft
Thermal Solar roof	Inlet Temp	Deg. F	MV/deg.F
	Outlet Temp	Deg. F	MV/deg.F
	Air flow rate	CFM	V/CFM
	Incident radiation	Watts/sq.ft	MV/watt/sq.ft
Solar HW	Inlet Temp	Deg. F	MV/deg.F
	Outlet Temp	Deg. F	MV/deg.F
	Fluid flow	GPM	V/GPM
	Incident radiation	Watts/sq.ft	MV/watt/sq.ft
Lighting	Light level	footcandles	MV/fc
	Power	amps	MV/amp
	Ambient light	footcandles	MV/fc
HVAC	Discharge air temp	Deg. F	MV/deg.F

	Room air temp	Deg. F	MV/deg.F
	Return air temp	Deg. F	MV/deg.F
	OA temp	Deg. F	MV/deg.F
	Mixed air temp	Deg. F	MV/deg.F
	OA flow	CFM	V/CFM
	Total flow	CFM	V/CFM
	Compressor power input	amps	MV/amp
	Condenser inlet temp	Deg. F	MV/deg.F
	Condenser outlet temp	Deg. F	MV/deg.F
Enclosure - wall	Exterior surface temp	Deg. F	MV/deg.F
	Section temp	Deg. F	MV/deg.F
	Section temp	Deg. F	MV/deg.F
	Interior surface temp	Deg. F	MV/deg.F
Enclosure roof	Exterior surface temp	Deg. F	MV/deg.F
	Section temp	Deg. F	MV/deg.F

Vendors such as LogiXML and Lucid Design are now offering complete systems such as Building Dashboards, that combine data collection, monitoring and display in one package. Other data collection and monitoring systems vendors such as National Instruments have products that are adaptable to Buildings that Teach applications. In any case, this needs to be a task in the design for Buildings that Teach. In addition to cost, the ease of operation (need for teacher training) and maintenance of these systems should be a consideration during this phase.

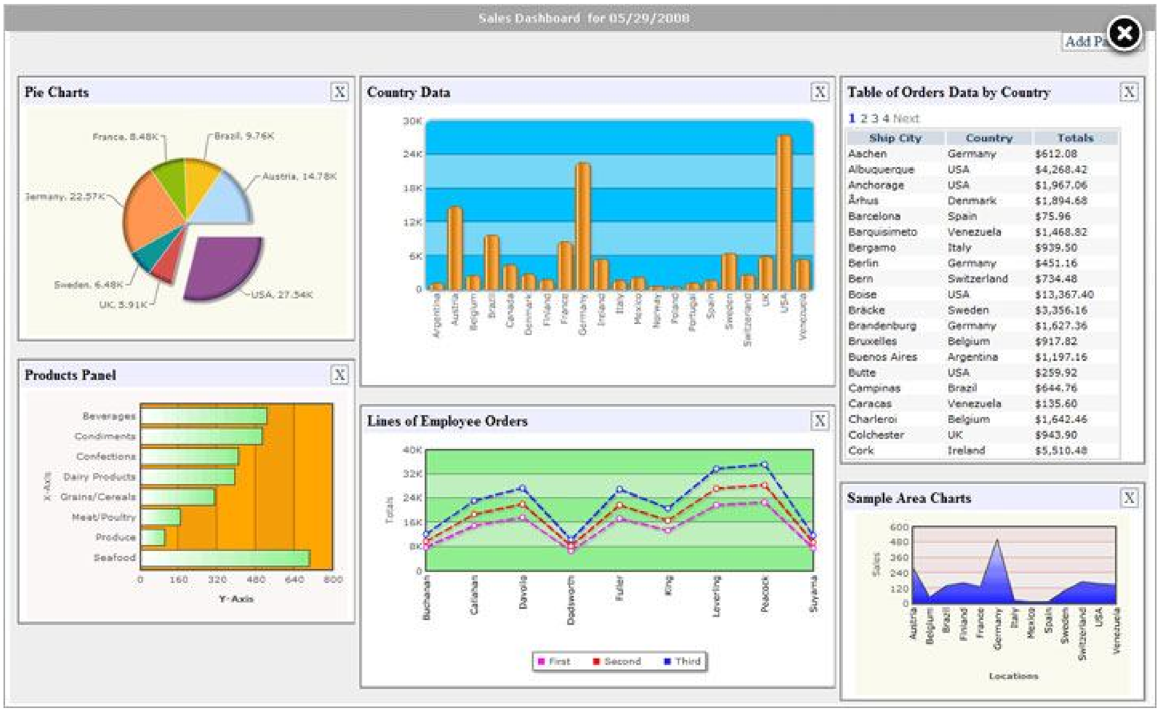


Figure 18. Example of a Building Dashboard Display.

Conclusions

This paper presents a proposition for an initial framework that seeks to transform the design of learning environments from passive vessels to active participants in learning. The framework is intended to challenge architects and designers of schools, museums, environmental learning centers, etc. to rethink the role of architecture in what and how we learn. The framework is an initial proposition, one that is expected to evolve and adapt to the challenges of learning in the 21st century.