PERKINS+WILL

Research Journal

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SPECIAL ISSUE: INNOVATION INCUBATOR RESEARCH

DESIGN INVESTIGATIONS IN PRACTICE

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Acknowledgements: *We would like to extend* **our APPRECIATION** *to everyone who contributed to the research work and articles published within this journal.*

We would like to extend our **VERY SPECIAL THANKS** *to: Emily Gartland.*

Perkins+Will is an interdisciplinary design practice offering services in the areas of Architecture, Interior Design, Branded Environments, Planning + Strategies and Urban Design.

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JOURNAL OVERVIEW

The Perkins+Will Research Journal documents research relating to architectural and design practice. Architectural design requires immense amounts of information for inspiration, creation and construction of buildings. Considerations for sustainability, innovation and high-performance designs lead the way of our practice where research is an integral part of the process. The themes included in this journal illustrate types of projects and inquiries undertaken at Perkins+Will and capture research questions, methodologies and results of these inquiries.

The Perkins+Will Research Journal is a peer-reviewed research journal dedicated to documenting and presenting practice-related research associated with buildings and their environments. Original research articles, case studies and guidelines have been incorporated into this publication. The unique aspect of this journal is that it conveys practice-oriented research aimed at supporting our teams.

This is the eleventh issue of the Perkins+Will Research Journal. We welcome contributions for future issues.

RESEARCH AT PERKINS+WILL

Research is systematic investigation into existing knowledge in order to discover or revise facts or add to knowledge about a certain topic. In architectural design, we take an existing condition and improve upon it with our design solutions. During the design process we constantly gather and evaluate information from different sources and apply it in novel ways to solve our design problems, thus creating new information and knowledge.

An important part of the research process is documentation and communication. We are sharing combined efforts and findings of Perkins+Will researchers and project teams within this journal.

Perkins+Will engages in the following areas of research:

- Market-sector related research
- Sustainable design
- Strategies for operational efficiency
- Advanced building technology and performance
- Design process benchmarking
- Carbon and energy analysis
- Organizational behavior

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EDITORIAL

Special Issue: Innovation Incubator Research

This special issue of Perkins+Will Research Journal is dedicated to capturing selected results of the Perkins+Will's Innovation Incubator program. Innovation Incubator was initiated in 2010 as a micro-grant program to support the culture of innovation through small, focused, fast-paced investigative projects that are led by Perkins+Will employees. Over the last four years, more than one hundred projects have been funded through the program. This special issue includes articles that capture the process, methodologies and results of seven projects.

"Lighting and the Living Lab: Testing Innovative Lighting Control Systems in the Workplace" presents a study that was conducted to investigate smart lighting control strategies in an office environment. The testing was performed over a period of twelve weeks, with the intent to study the ability of different lighting control strategies to reduce the overall energy consumption. The results were used to determine the benefits and limitations of different control strategies, and their applicability to the tested workplace environment.

"A Case Study in Reflective Daylighting" discusses research that was performed during the design of an atrium for a higher education building, focusing on the methods to increase natural light levels through daylight redirecting strategies. The article reviews physical and digital modeling that was performed during the design to develop reflective building geometry to light the building's interior atrium. The article documents the research methodology, design strategies as well as technical concepts.

"Game Changers: Spaces for Innovative Learning" reviews the connection between the changing paradigms in education and the design of K-12 learning environments. It specifically focuses on the new technologies and introduction of play into learning, and how the built environment should be designed to respond to these new pedagogical directions. Examples of inventive educational facilities are also discussed as well as their physical characteristics and design.

“Is there a ‘There’ There? Online Education & ArchitectureX” discusses the transformations that the online education has brought to higher education, and examines the impacts on the physical spaces. It reviews the risks and opportunities that the online education presents to the traditional campus, and the impacts of educational models that merge online and on-campus learning experiences.

“Between Laboratory and Factory: A British Model for Innovation in Manufacturing and Applied Technologies” discusses the development of a new building type, which merges traditional research and testing functions with manufacturing to promote faster and more effective translation of laboratory discoveries into products and applications. The article discusses history and development of this new concept for academic-industry collaborative research as well as several case studies.

“The Resource Infinity Loop: Designing Resilient Cities” presents literature review on the methods to reclaim wastewater in urban environments through natural process. The article discusses benefits to social and physical health, the built environment and economics of cities. It also presents a case study, and discusses the opportunities for building ecologically resilient cities that the future requires.

“Labor-Delivery-Recovery Room Design that Facilitates Non-pharmacological Reduction of Labor Pain: A Model LDR Room Plan and Recommended Best Practices” discusses architectural design of LDR rooms that use two primary non-pharmacological methods for pain relief during delivery—relaxation through a calm physical environment, and labor in water. The article discusses development of a prototype design, taking into account relaxation, comfort, movement through the physical space, and privacy.

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LIGHTING AND THE LIVING LAB:
Testing Innovative Lighting Control Systems in the Workplace

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ABSTRACT
This research focused on the use of lighting control systems in an office environment by studying the role of smart lighting strategies and their effects on the office. By sequentially testing these strategies for twelve consecutive weeks, this study worked to determine the ability of each approach to reduce the overall energy consumption, while incurring minimal consequences on productivity and comfort. Using two energy management systems installed in the office – Encelium Lighting Control and Pulse Energy Data – three methods were chosen for this study: task tuning, variable load shedding, and daylight harvesting.

The test revealed successes and limitations for each of the strategies. Task tuning suggested an appropriate relationship between reducing lighting loads and maintaining comfortable light levels in the work environment; load shedding revealed the difficulty to shed “secondary” lights with minimal impact in an open office environment; and daylight harvesting challenged the depth at which natural light may be effective as a primary means of illumination.

While this article was developed as a means to analyze and better understand the potential for smart lighting strategies in a work environment, the results derived from this testing were specific to the physical conditions – including solar orientation and lighting design – of the Perkins+Will Washington DC office and may only be used as suggestive reasoning for energy efficient design strategies.

KEYWORDS: lighting, workplace, energy savings, human comfort, efficiency

1.0 INTRODUCTION
The Perkins+Will Washington DC office is continuously searching for ways to improve not only the quality of work produced within the office, but also the quality of its working environment. By testing, analyzing, and implementing workplace design strategies, the LEED for Commercial Interiors certified Platinum space continually works to reduce its energy demand without negatively impacting the productivity and comfort of its employees.

The goal of this study was to evaluate three of the technologies available through Encelium - task tuning, variable load shedding, and daylight harvesting - in order to gather metrics related to energy savings and determine which technology, or combination, could provide the most beneficial energy savings outcome.

In addition to energy metrics, human behavior with respect to productivity and employee comfort was tested and measured in tandem with Encelium technologies to identify relationships. These observations and measurements were analyzed to provide more informed workplace design solutions.

Finally, the findings of each test are presented as a tool for designers to formulate design and lighting strategies as well as provide recommendations towards the implementation of these solutions to clients.

Encelium, the primary tool used throughout this effort, is a lighting control system designed to simultaneously implement energy management strategies and control interior lighting systems. The system is considered to help reduce lighting energy costs within a building from 50 percent to 70 percent through the use of six potential "smart strategies." For the purpose of this research, three of the six possible strategies (as shown in Table 1) were chosen for testing, implementation and analysis:

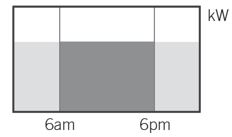
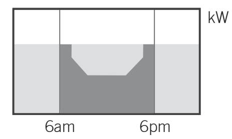
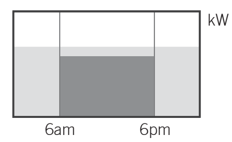
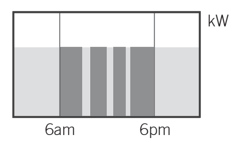
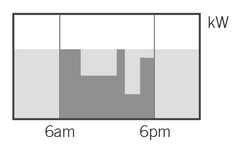
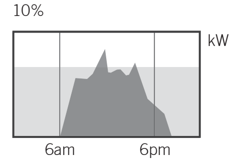
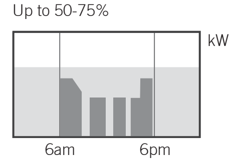
- *Task Tuning:* Setting default (maximum) light levels to suit the particular task or use of a workspace in order to eliminate over lighting[1].
- *Variable Load Shedding:* The automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signals. Load shedding can be done selectively by lowest priority areas first[1].
- *Daylight Harvesting:* Through the use of photo sensors, light levels are automatically adjusted to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary [1].

In addition to Encelium, energy use within the office is monitored and recorded by Pulse, an energy management software. Pulse aims to assist facility managers in properly understanding and managing energy demand and usage within a building or space through recording and comparing real time data. The software is capable of numerically breaking down total energy consumption in order to recognize which loads are acting as the primary contributors. Additionally, Pulse compares this collected data to previously recorded metrics to help establish a pattern in which energy demand can be easily identified.

In the Perkins+Will Washington DC office, lighting is one of the lowest contributing factors to overall energy consumption; however lighting in this office typically uses approximately 200 kW of energy per day (or around 7kW/h), which is about 6 percent of total energy consumption for the office. Using previous metrics recorded by Pulse as a foundation, the team was able to set a baseline for these strategies to be measured against.

The percent energy-use due to lighting is relative to the light fixtures installed in the office; and is capable of significant variance when altered to respond to daylighting conditions. This workplace environment is designed as an open office with minimal interior partitions and a combination of daylight and shared electrical lighting (Figure 1). With floor-to-ceiling glass on its eastern exposure as well as punched openings on the north and south facades and a central atrium, the open office absorbs a high level of natural light throughout the day reducing the amount of electrical lighting needed. Dimmable linear fluorescent fixtures are the primary light source center-mounted over each row of work stations, while supporting ceiling-mounted fixtures line the corridors and adjustable LED task lighting is available at each individual desk.

Table 1: Encelium – a lighting control system used for this research – uses six strategies for lighting control and energy management[1].

Strategy	Savings
Smart Time Scheduling In areas of a building where occupancy sensor control is not appropriate, time scheduled switching or dimming of lights can be employed for zones as small as a room or individual light fixture.	10-40% 
Daylight Harvesting Through the use of photo sensors, light levels are automatically adjusted to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary.	5-15% 
Task Tuning Setting default (maximum) light levels to suit the particular task or use of a workspace in order to eliminate over lighting.	5-20% 
Occupancy Control Through the use of occupancy sensors, lights are automatically turned on or off or dimmed based on occupancy detection.	25-50% 
Personal Control Through the Personal Control Software, individuals can control (dim) the light levels in their workspace to suit their personal preferences from their desktop PC.	5-15% 
Variable Load Shedding The automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signal. Load shedding can be done selectively by lowest priority areas first.	10% 
Combined Energy Savings Potential cumulative savings from above strategies.	Up to 50-75% 

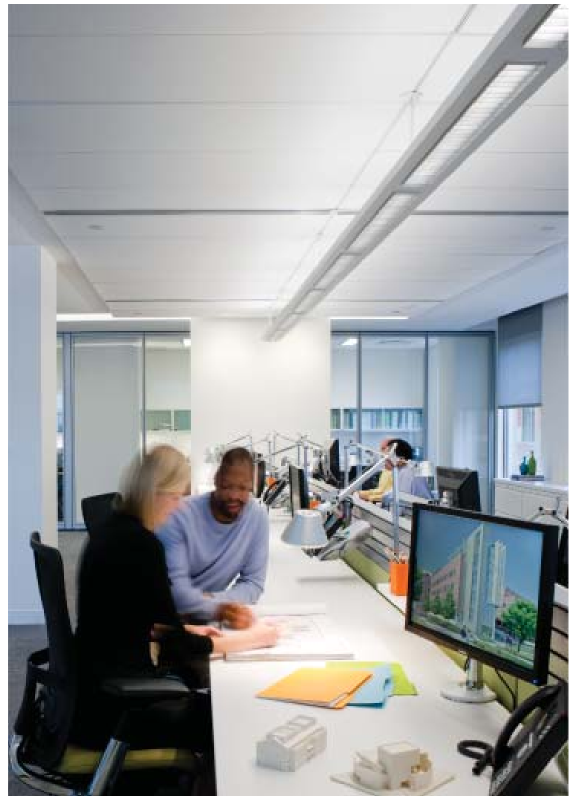


Figure 1: The open studio of the Washington DC office of Perkins+Will uses a combination of fluorescent, LED, and natural daylighting strategies.

Testing was completed over a twelve week period during the summer; each strategy was tested for two consecutive weeks during Phase 1, and another two consecutive weeks during Phase 2. The primary goal of the first phase was to gather data based on lighting and energy levels within the office. Task tuning, load shedding, and daylight harvesting were hypothesized to have different levels of impact on office productivity depending on occupant awareness. Therefore, the second phase included a series of messaging techniques in which office employees were made aware of the testing. In essence, Phase 2 was more specifically geared not only toward gathering numerical and spatial data, but also toward observing human behavior in the Living Lab.

Using a combination of recorded data, evaluation and occupant surveys, the team evaluated each strategy and developed a series of recommendations for future implementation. These recommendations, which evaluate potential applications or a combination of strategies, are outlined at the end of this article.

In order to accurately record data and communicate with office employees a number of tools were used throughout this twelve week testing period, such as a digital light meter and electronic surveys. These tools, while helpful in making design decisions regarding different forms of energy use, ultimately served to generate a larger tool derived from these studies. The findings presented in this report were intended as a reference that can assist and influence design and lighting strategies in future projects as well as provide encouragement toward energy efficient, comfortable lighting solutions to clients.

2.0 TESTING AND PROCEDURES

2.1 Task Tuning

2.1.1 Hypothesis

The team observed that employees rarely used task lighting in the open office environment due to the relatively high ambient light levels. We hypothesized that using task tuning to gradually lower ambient lighting levels in the studio and observing when occupants turned on task lighting for supplemental light would allow us to establish a target range for reducing ambient light levels.

Identifying the range of reduction will allow us to realize maximum reduction in our lighting power consumption with no impact on occupants.

2.1.2 Environment

The open office has an addressable system installed by Encelium that employs several strategies for lighting control. For this test, the team highlighted the task tuning strategy in order to test our hypothesis. Task tuning is defined as "the technology that sets a default, or maximum, light level to suit the particular task or use of a workspace in order to eliminate over lighting"[1]. The most common ways lighting energy is wasted are inefficient lighting systems, too much light for the visual task involved, lack of automatic occupancy controls, and surface finishes that absorb too much light[2]. The over-lighting of spaces is what task tuning aims to correct in order to maximize energy savings while still providing adequate light for the task being performed[1].

The workplace that was studied in this research has benching style workstations with a 42" high center spine. The workstations run east-to-west, perpendicular to an all glass eastern façade. The northern and southern façades have punched windows from 25" to 100" above the finished floor. The studio is anchored by support spaces on the western side of the floor plan. There is direct access to exterior views from 100 percent of the studio.

Linear fluorescent pendant-mounted, direct-indirect fixtures centered over the workstation spines serve as the primary light source for the studio. Supplemental lighting is supplied through linear LED pendants over collaborative areas and wall washers along the partitions at the western end of each workstation run. Additional downlights are located along the primary circulation on the eastern end of the studio. Every workstation has a fully adjustable LED task light connected to an occupancy sensor.

Medium-toned carpet anchors the otherwise white space, which was intentionally designed to maximize light reflectance and increase ambient light levels. This combination of lighting and finishes results in an average range of 20 to 300 footcandles (fc) on the work surfaces, depending on proximity to the exterior and time of day. Various organizations, such as the Illuminating Engineers Society of North America, have set the minimum level of footcandles appropriate for a work surface in an open office environment at 30, with the maximum recommended level at 50 fc[2,3,4]. The lower end of the range is ideal for computer work. Paper intensive tasks are typically easier to preform when footcandle levels are at the higher end of the range.

2.1.3 Methods

Phase 1 of testing was conducted over a two week period from June 11- 22. The office lighting is typically set at 80 percent capacity during normal daily operation. Using this as a baseline the team lowered light levels in the office an additional five percent each day, starting with 20 percent reduction (or 80 percent capacity) on Day 1 and ending with a 60 percent reduction (or 40 percent capacity) on Day 10. The lights were dimmed at the beginning of each day before occupants arrived to make dimming more inconspicuous and less distracting. Thirty-eight workstations out of approximately 100 were selected as testing points throughout the studio (Figure 2). Light level readings, measured in footcandles, were taken at these workstations three times daily at 9:00 AM, 12:00 PM and 4:00 PM over the course of the testing period. In addition to light levels, the team recorded the weather at each reading time. The total number of task lights observed to be on in the studio was also recorded at each reading time to determine if occupants used them to supplement the lowered ambient light levels. Additionally, the office manager was enlisted to track the number of occupant complaints regarding light levels.

Occupants were not informed about the specifics of the test, although the team made no effort to conceal the fact that they were recording light levels. If occupants made inquiries, team members replied that it was part of a lighting level study without providing specifics. No restrictions were placed on occupant control of the manually operated solar shades at the perimeter windows and weather throughout the testing period remained a variable.

Phase 2 followed the same pattern as Phase 1 over two weeks starting on July 23rd and ending on August 2nd. Lighting levels were again gradually lowered by five percent each day, starting with 40 percent reduction on Day 11 and ending with an 80 percent reduction on Day 19. Before Phase 2 testing commenced, an e-mail notification was sent out to all office occupants informing them about the nature of the test. Additionally, the notification stated that a survey would be conducted at the end of the testing period to gather feedback. Data

Figure 2: Zoning diagram for lighting level data collection.

was gathered in Phase 2 in a manner consistent with Phase 1 with the exception that the team also tracked occupant vacancy in the office to determine if there was a correlation between the number of people in the office and the number of task lights turned on.

An electronic survey was conducted on Day 20, including all employees who occupy the open office area in order to gather feedback related to their comfort and ability to perform their job functions throughout Phase 2.

2.1.4 Variables

There were a number of variables throughout both phases that impacted the collected data. These included:

- Weather conditions and resulting daylight levels,
- Occupant interaction with manual perimeter solar shades,
- Type of work being performed ("heads down" paper driven tasks vs. computer driven tasks impacted tolerance to lowered light levels).

2.1.5 Tools

Tools used in various phases of the study included:

- Digital light meter,
- Encelium – lighting control system,
- Pulse Energy – data collection & reporting system,
- Electronic occupant survey,
- Digital messaging (Email),
- Complaints log.

2.1.6 Results

The team evaluated the lighting levels by zone and by time of day in order to establish relationships between the average light levels in the studio with the lighting power reduction. It was noted that the morning readings were consistently higher than the afternoon readings, which is a result of the building's orientation and all-glass eastern façade. Generally, the energy reduction trend was to decline over the testing period at both 9:00 AM and 4:00 PM, even though the weather and window shade locations were variable.

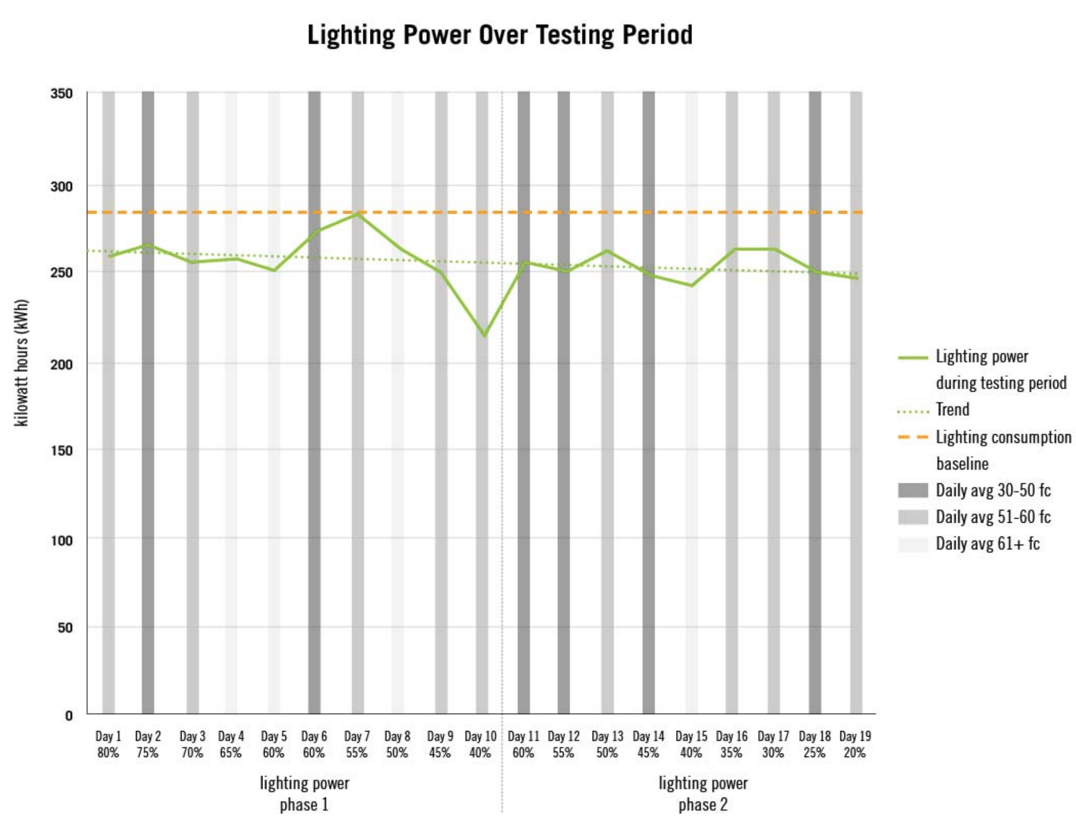


Figure 3: Lighting power over testing period graph for task tuning.

Over the course of the 19-day testing period, the percentage of lighting power reduction was varied from 20 percent to 80 percent, with the percentage varying between Phase 1 and Phase 2. The studio was able to realize a 10 percent energy reduction over the course of the testing period despite the variable percentages. Setting a consistent percentage of lighting power reduction enables the office to experience an even greater energy savings.

The graph shown in Figure 3 represents the actual energy savings as measured through Pulse Energy software for the lighting fixtures in the open office area. In the open office, the linear pendant-mounted fixtures centered over the workstation spines are Peerless Bruno series with one 32 watt 3500K T8 fluorescent lamp per fixture. The days are coded with the average light levels in the studio in order to compare the days where the office average fell within the recommended range of 30-50 fc.

Results from the electronic survey at the end of Phase 2 allowed us to gather feedback related to occupant comfort. Generally, staff felt no change to their productivity, however, most respondents felt the lighting levels were too low at some point during the testing period, but continued to work without taking corrective action. This confirms that a threshold was reached when the lighting levels were too low and the occupants could no longer work without disruption to their comfort. The email sent prior to the Phase 2 testing did not influence most people's actions, however, a few respondents noted that they would not have turned on their task light had the email not been sent.

Typically, most people do not use their task light, but if it is used it is usually because the general lighting levels are too low. A few people noted, that they use their task light when doing "heads down", paper-related work. Employees were also given the option to report complaints to the office manager and only two were logged throughout the testing period (both on Day 1).

Ergonomics is an important facet of employee comfort in the workplace and task tuning has the ability to impact an occupant through their posture and eye strain. In lower-lighting scenarios employees may adjust their posture to avoid glare or reflections and cause stress on their backs, necks, or hands[2]. Lighting that may be too bright or too dim also can cause eye strain[5]. An ideal lighting power reduction would minimize negative impacts to employee health while also maximizing energy savings.

Zones D and E currently uses daylight harvesting technology, so we would not recommend task tuning for these zones in order to maximize the benefits of this technology. Zones A and H do not take advantage of the all-glass eastern façade and had consistently lower footcandle ranges so task tuning to lower the lighting power is not recommended in these locations. Zones B, C, F, and G were evaluated based on average footcandles at 9:00 AM, noon, and 4:00 PM for each testing day in order to establish the recommended lighting power reduction that balances energy savings and human comfort.

Because of the building's orientation and all-glass eastern façade, the morning light readings were consistently well above the range of 30-50 footcandles and were not included in the general analysis of these four zones. Zone C had the most consistent lighting levels and was used as the model to establish the recommendation

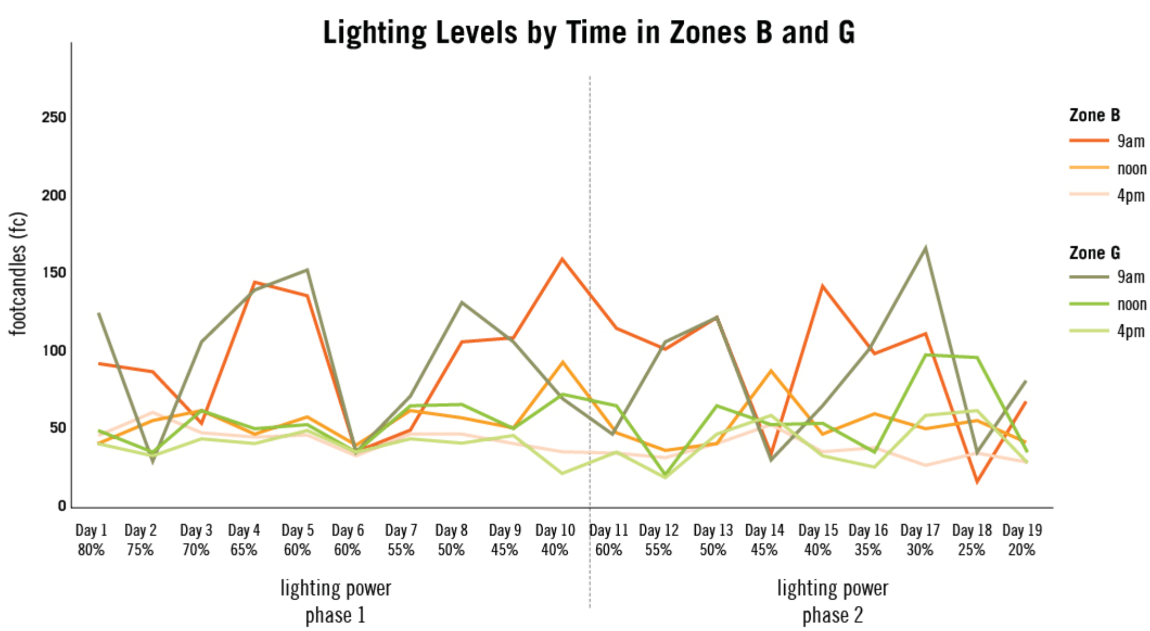


Figure 4: Lighting levels by time of day for Zones B and G for task tuning.

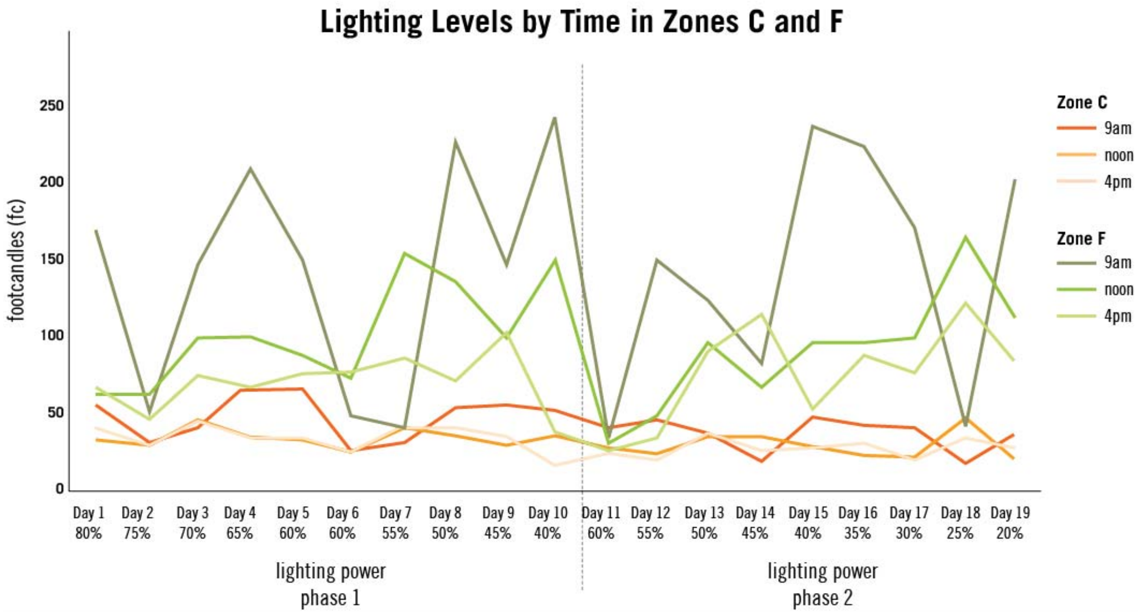


Figure 5: Lighting levels by time of day for Zones C and F for task tuning.

for the surrounding areas. Day 8 and Day 13, both a 50 percent lighting power reduction, provided readings within the ideal range of 30-50 footcandles. Lower lighting power reductions caused Zone C and Zone G to dip below the recommended range.

Light readings in Zone F were consistently higher than their counterparts in Zone C to the north. Similarly, readings in Zone B were higher than their counterparts in Zone G to the south. These readings may be a result of the variables in shading control. The team would still recommend that a lighting reduction of 50 percent be implemented in this area for task tuning. According to an estimate from Lutron, a 50 percent lighting power reduction should result in an energy savings of about 62 percent, based on one CFL 23 watt used 10 hours per day[6]. The lighting power reduction of 50 percent provides a lighting energy use of 264 kWh, which is a savings of about 16 kWh from the baseline.

2.1.7 Recommendations

In an open office environment where the occupants have control over the window shade locations, we would recommend a lighting power reduction of 50 percent in Zones B, C, F, and G in order to maximize the benefits of task tuning without negatively impacting human comfort issues such as task performance, visual comfort, ergonomics, communication, and aesthetic judgment[2].

2.2 Variable Load Shedding

2.2.1 Hypothesis

Prior to implementing variable load shedding in the office, we observed that minimally occupied spaces were maintaining equal light levels as consistently occupied spaces. As a result of this observation, we hypothesized that using variable load shedding in an open office environment results in an energy savings by turning off light fixtures during hours of peak energy demand. The following three hypotheses were tested:

1. Load shedding is an effective way to reduce electrical demand during peak consumption hours.
2. Load shedding has minimal impact on office productivity and comfort.
3. By implementing various forms of outreach and messaging, office employees are more accepting to visual distractions caused by load shedding.

2.2.2 Environment

Variable load shedding is “the automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signal. Load shedding can be done selectively by lowest priority areas first"[1]. Although the Perkins+Will Washington DC office does not currently use a variable load shedding strategy, the tools are in place for a programmed lighting system to be implemented.

The level of light in a space, measured both through electrical lighting and the amount of natural light absorbed through translucent fenestration, changes significantly due to the physical qualities of a space. The load shedding portion of this study reflected a series of physical conditions within the office, that influenced the manner and intensity in which changes in the lights were observed by office employees.

As an open office environment, almost all light fixtures are shared by multiple working parties. Hall lights, which in many office environments could be considered secondary spaces separated from working offices, are adjacent to work stations. Similarly, shared work islands are positioned parallel to bench-style rows of individual workstations. This means that as lighting conditions are adjusted in areas typically conceived of as secondary work areas, common areas, or circulation spaces, they are simultaneously affecting lighting conditions directly connected to primary employee work areas.

The office also uses large, floor-to-ceiling glazing along its east facing perimeter and large punched openings along the north, south, and west perimeter in order to allow generous amounts of natural light to enter the space. The eastern exposure along with a southwest-facing atrium strongly influences the light levels within the office throughout the day depending on external conditions. The solar orientation of the office and its relationship to the program of each space in the office was taken into account during this testing period.

Although the majority of work surfaces and walls throughout the office were designed with white finishes aimed to reflect light throughout the space, the flooring as well as the type of work being performed varies throughout the spaces. For example, one area with the least reported discomfort due to load shedding was the café, a common space with southern exposure and a primarily white material palette, which seem to have mitigated the effects of the reduced light levels. In contrast, the library, with content that reduces the visible white surfaces, received the most complaints for lowered light levels.

2.2.3 Methods

The study period of this testing was divided into two, two-week phases. Both phases were designed to observe, record, and analyze the impact of load shedding on human behavior in an office environment, specifically employee productivity and comfort. In an effort to study the naturally observed impact of shedding lighting loads in specific areas of the office, Phase 1 was completed without informing or engaging any of the employees of the testing. Simultaneously, the team observed energy levels within the office to see if load shedding could result in any substantial energy savings.

For both phases, the team assumed a number of areas within the office in which load shedding may have the least effect on productivity and comfort; these zones included hallways, work islands, and common areas such as the café. Additionally, the team studied energy consumption data for a typical day in the office using the Pulse Energy software and determined a threshold for which was considered – for the purpose of this testing – "peak total energy consumption." This threshold was set at 115kW. After establishing this threshold, it was also noted that the highest energy consumption was occurring between the hours of 11:00 AM – 3:00 PM (most likely due to occupancy and HVAC loads). Throughout both weeks in Phase 1, lights in designated zones were switched completely off during these four hours using the office's lighting control system.

Although we are not currently able to achieve a live link between Pulse and Encelium, the process established for this study was theoretically an automated one as Pulse recognizes that the energy consumption level for the office has reached its predetermined threshold, Encelium automatically reduces lighting loads in specified areas.

For the first five days (Week 1), ceiling mounted lights were shut off in office hallways adjacent to the work stations, and ceiling hung linear LEDs were shut off over work islands positioned between workstations. Week 2 continued to shut off the same zones as Week 1, but also turned off a portion of the ceiling mounted lighting in the library and café (Figure 6). Shutting off lights in the library and the café presented a significant change in the lighting conditions in comparison to the open office due to their spatial separation from other working areas. Unlike the hallways and the work islands, the library and the café are not equally exposed to the open office, resulting in less borrowed light.

Through this technique, the team was able to study a series of questions that ultimately helped us to determine the appropriate relationship between load shedding, energy savings, and human comfort and productivity:

- Is reducing shared lighting a more effective (and less distracting) means of load shedding than reducing light in a separated space?
- Are employees less or more likely to notice lighting changes if they are not expecting or aware of it?
- By including two more zones during the second week, is energy consumption being noticeably reduced (as compared to Week 1)?

During Phase 2, similar methods of testing as Phase 1 were implemented; however, the team used a variety of messaging techniques to inform employees of the expected lighting changes and educate them on the potential benefits of load shedding. This communication strategy allowed for a comparison between the level of impact of Phase 1 (in which employees were unaware of the testing) versus Phase 2 (in which employees were made aware of testing).

The areas tested remained constant throughout both phases. The first week of each phase shed loads over hallways and work islands; while the second week shed loads over hallways, work islands, the Library, and the café. The threshold for peak energy consumption also remained constant at 115kW.

In addition to the implementation of messaging techniques, the primary difference between Phase 1 and Phase 2 was the timing and manner in which lighting loads were shed. During Phase 2, the intention was to more realistically simulate a direct relationship between the peak energy threshold (recorded through Pulse) and the reduction of lighting loads (controlled through Encelium). Rather than turning lights off in the specific zones for a designated four hour period each day, Phase 2 turned lights off only when the office reached the threshold of 115kW; and turned lights back on once the office had cleared this threshold, resulting in a more aggressive visual realization of load shedding.

Figure 6: Zoning diagram for areas using load shedding during the first and second weeks of testing.

2.2.4 Variables
Throughout the testing period, there were a number of variables that were assumed or ignored for the purpose of this analysis. These included:

- Daylight levels/weather conditions (amount of natural light entering the office),
- Additional energy loads that determine the peak energy consumption threshold (as HVAC loads increase, as does the frequency in which the office reaches its peak threshold),
- Occupant views, access, and workstation positions relative to lights (proximity to windows affects awareness of internal light levels),
- Type of work being performed (employees working on a computer reported less effect than those reading, writing, etc.).

2.2.5 Tools
Tools used in various phases of the study included:

- Encelium – Lighting Control System,
- Pulse Energy – Data Collection & Reporting System,
- Electronic occupant survey,
- Physical & digital messaging (signage, emails, announcements, etc.),
- Complaints log.

2.2.6 Results
Hypothesis 1: Load shedding is an effective way to reduce electrical demand during peak consumption hours.

Figure 6 shows the areas designated and affected by the load shedding strategy. The fixtures targeted for the study are a combination of dimmable and non-dimmable fixtures. For the purposes of this study, dimmable fixtures output was reduced to 40 percent of maximum, per Encelium recommended parameters. The study shows load shedding in these areas of secondary work and support spaces can yield up to 0.76 kW of savings when fully activated.

The total load shedding achievable in the space when all fixtures in the open office areas are included is approximately 3.6 kW. The total lighting load is 17.88 kW. The highest peak use recorded was 137 kW and lasted for nine hours. On average, the peak use during the load shedding triggered state was 124 kW and lasted approximately 117 hours over the course of the study period. The load shedding test yielded an approximate savings of 6.85 kWh over the study period.

With the load shedding threshold set at 115 kW, this means that on average the peak use was 9 kW higher. Considering the maximum load shedding of 3.6 kW, this means that full load shedding would be insufficient to clear the threshold. Additionally, the absolute lighting load of 17.88 kW would be insufficient to clear the threshold during the peak recorded use.

The difficulty of using the Encelium system as an effective load shedding tool is attributed to the following factors:

- High efficiency, low-wattage, LED lighting systems are already in use.
- Large windows and mostly white reflective surfaces reduce the need for ambient lighting, therefore, a low ambient lighting requirement to begin with.
- HVAC load is the biggest load and variation exceeds the Encelium Load shedding sapability.

Figure 7 shows the average contribution of each load type to the total consumption. Figures 8 and 9 show the total energy consumption for the office, which includes lighting, and a graph of just the lighting energy consumption for the office to compare.

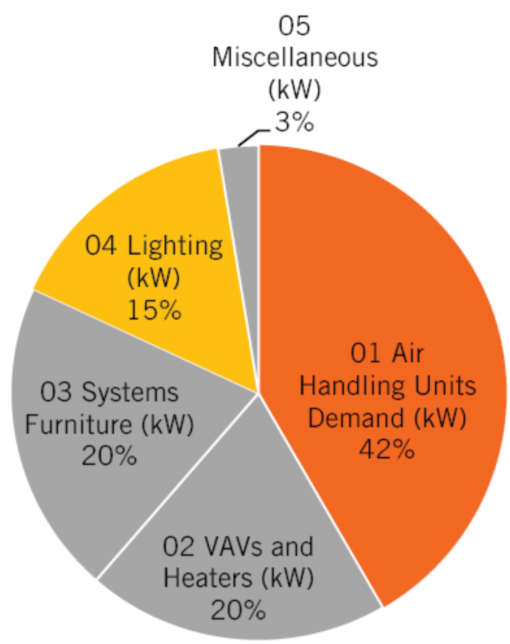


Figure 7: Graph of typical energy consumption breakdown in Perkins+Will Washington DC office.

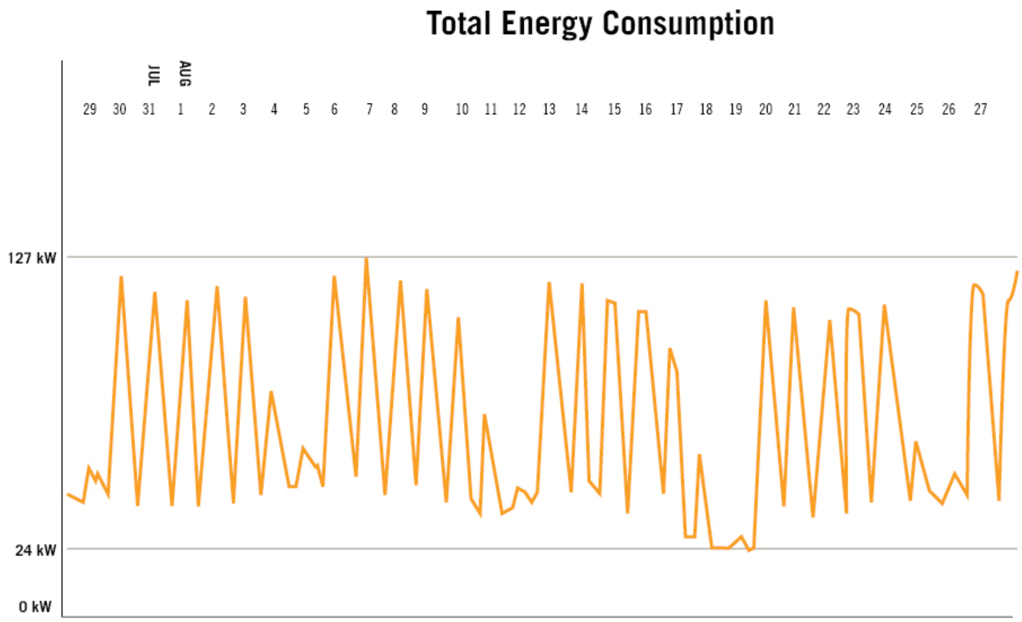


Figure 8: Graph of total office energy consumption provided through Pulse Energy Software.

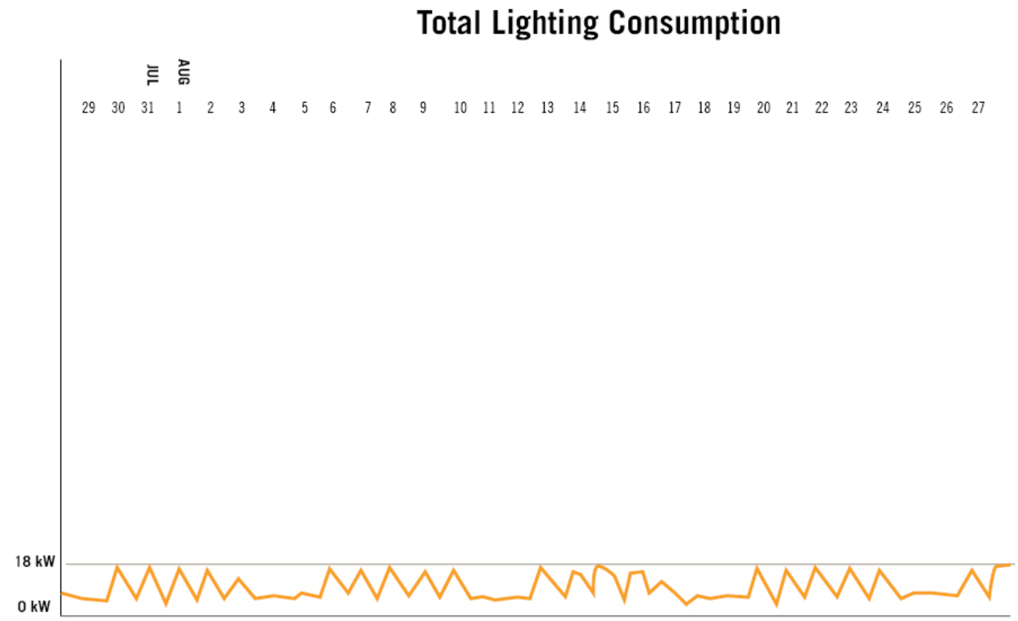


Figure 9: Graph of lighting energy consumption provided through Pulse Energy Software.

Hypothesis 2: Load shedding will have minimal impact on office productivity and comfort.

As part of the analysis, a post-test survey was issued. The survey indicated that the majority of respondents (54 percent) noticed the light fixtures switched off over the work islands, which are part of the target area. Respondents also noticed light fixtures switched off in the café, which was part of the target area in the second week of each phase of testing. However, 40 percent of respondents reported fixtures switched off from the personal work stations, which were not directly targeted during the testing. Two theories are proposed to explain this finding:

1. In a largely open-office environment, light fixtures are readily seen from all areas, both the fixture target area and beyond the affected area identified in the load shedding diagram presented earlier.
2. Respondents are recalling the lighting tests from the other study components, like daylight harvesting when lights were switched on and off to enable lighting measurements.

In the first survey, few respondents found the light changes distracting or uncomfortable. However, in the second set of tests, considerably more respondents found the switching distracting and/or uncomfortable.

Hypothesis 3: By implementing various forms of outreach and messaging, employees are more accepting to visual distractions caused by load shedding.

To mitigate the disruptive effects of the light switching, the study employed and tested four communication strategies:

1. Email communication at the start of the study explaining the load shedding tests and its benefits.
2. Messages prominently displayed on the large monitors in the café area.
3. Small message tents (measuring 8.5" x 5.5") displayed in the vicinity of each of the target areas.
4. Public announcement broadcast over the loudspeaker signaling the beginning of each load shedding event.

At the conclusion of the load shedding study, a survey asked respondents to identify which communication strategy was effective in communicating the Load Shedding study as well as mitigating any distracting effects. Each communication strategy was then evaluated according to the effectiveness vs. effort/cost matrix (Figure 10). These four strategies were selected for the varying degrees of cost or effort associated with their production or execution.

Respondents found the slide on the office café monitor to be the least effective messaging technique employed with a response score of 16.7 percent. When asked to identify the single most effective messaging technique, this strategy received zero percent of the responses. The effort associated with its production was minimal and involved composing a PowerPoint slide to be incorporated into the regular slideshow of office announcements.

Respondents found the email explanation at the beginning of the study as the most effective messaging technique employed with a response score of 94.4 percent. Additionally, 70 percent of respondents chose it as the single most effective messaging technique.

Respondents found the loudspeaker announcements made at the beginning of each load shedding threshold event to be the third most effective messaging technique (22.2 percent). When asked to identify the single most effective messaging technique, this strategy received 15 percent of the responses. The effort associated with its production was minimal and involved composing a brief email for the office manager to read during each load shedding event. Although it proved effective in communicating the event, some respondents said they found the announcements almost alarming and therefore distracting.

Respondents found the printed signage displayed throughout the load shedding testing threshold event to be the second most effective messaging technique (27.8 percent); however, when asked to identify the single most effective messaging technique, this strategy received zero percent of the responses. The effort associated with its production was minimal and involved editing the digital messaging slide to fit onto 8.5"x5.5" card stock. Additional costs incurred in executing this strategy were in the printing, cutting, and displaying of the messages around the affected target areas.

In summary, email was the best communication strategy and print materials were the worst strategy largely because of their higher associated effort and costs (Figure 10). It should be noted though that email was appropriate considering the relatively brief study period of two weeks. In an actual daily use setting or continuous operation scenario, periodic emails may be necessary to remind occupants of the load shedding strategy, its goals, and its benefits.

Although extraneous to the study's hypotheses, the team asked respondents whether seeing the load shedding at work motivated any additional reduction

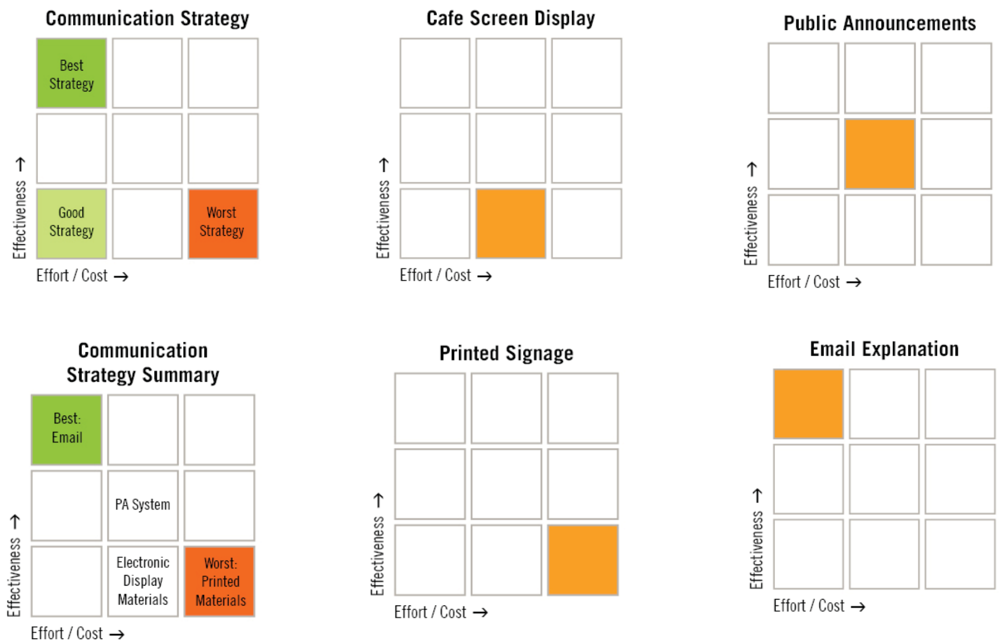


Figure 10: Effort/cost graphic analysis for each communication strategy implemented during the load shedding study.

in personal power use. A majority of respondents (77 percent), reported lack of any impetus to make any changes to their routine or otherwise reduce power use.

Lastly, the study asked respondents to identify areas in the office where it was suitable to shed loads. Minimally used/occupied areas such as back halls were identified by 72.7 percent of respondents and common areas such as the café were identified by 59.1 percent of respondents.

2.2.7 Recommendations

Considering the high efficiency lighting system currently used, its effectiveness in reducing the overall power load is limited especially in the summer months when cooling constitutes the largest share of the electrical load. To be more effective, more aggressive load shedding using more fixtures is necessary.

It can be concluded that the most effective and least costly means of communications for involving occupants in effort to minimize work-place disruption was email. In a continuous operation setting, occupants should consider establishing a schedule to send periodic email reminders to the general office as this engagement can enhance the efforts of achieving load shedding without employee dissatisfaction.

Future load shedding efforts should also explore, when available, technology for using progressive dimming over a length of time. For example, the Encelium system can dim the over-the-workstation lighting fixtures to a predetermined minimum output over a desired time frame. Ideally, the minimum output levels should be set according to available natural light. Consideration should also be given to balancing the decrease in overall ambient lighting with increased use of task lights at the primary work surfaces.

2.3 Daylight Harvesting

2.3.1 Hypothesis

The daylight harvesting testing measures the light levels available from natural light within the open studio space to determine how lighting levels can be stepped down to save energy without sacrificing visual comfort or a change in productivity.

The team hypothesizes that by harnessing daylight and understanding seasonal changes in daylight harvesting ability, a user can decrease lighting energy consumption by at least 20 percent with no decrease in productivity or user visual comfort as well as extend the light fixtures controlled by daylight sensors deeper into the space than the 15’-0” from windows as outlined by LEED[7].

2.3.2 Environment

Encelium defines this strategy as "using photo sensors to automatically adjust light levels to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary"[1].

For the purposes of this test, the team focused on the open studio space that dominates the floor plan. The open studio predominantly has an eastern sun exposure with direct daylight gain into the space in the morning. The glazing portion of the eastern façade consists of 1" thick clear insulated glazing unit, per the building management company's records. Smaller punched, glazed openings on the north and south ends of the open studio along with proximity of neighboring buildings limit the amount of daylight that enters the space from those facades.

Workstations are organized perpendicular to the exterior wall. As installed, daylight sensors control the first two lengths of lamps in the fixtures above the workstations closest to the exterior wall. Other light fixtures above the workstations are dimmable, but currently not controlled via daylight (or other) sensor.

The ceiling in the open studio space is white, which can reflect light farther into the space if used as part of a daylight harvesting strategy. The floor covering closest to the windows is a medium-toned grey carpet tile and does not contribute to daylight harvesting strategies. User-controlled translucent roller shades can decrease the daylight gain in the space.

The adjoining buildings are clad in lighter colored concrete and masonry, which contributes to reflected light and glare issues in the afternoon hours.

Figure 11: Office floor plan showing locations for recording light levels during daylight harvesting testing.

2.3.3 Methods

Due to the plan configuration of the space, it was decided that the middle five rows of workstations in the open studio would be the optimal locations for measuring daylight. The two rows of workstations at the north and south ends of the studio are shaded from the east by conference rooms. The north-most and south-most rows do receive a small amount of ambient light from exterior windows, but the proximity of the neighboring building in each direction hampers quality harvesting.

For each instance of light level verification, lighting measurements were recorded at the exterior end of each row of workstations and at the third workstation in from the exterior (Figure 11).

During the first two week period (Phase 1), employees were notified of testing and asked for patience and cooperation.

During week one, all roller shades were completely retracted. Studio lights were shut off at 8:30 AM for daylight level readings and the weather noted. The lights were turned back on after readings were taken. Studio lights were shut off at 12:00 PM for daylight level readings. They were turned back on after readings were taken. Weather conditions were noted. Studio lights were shut off again at 4:30 PM for daylight level readings. They were turned back on after readings were taken and the weather was noted.

During Week 2, the process described above was repeated, but the roller shades were extracted to 50% (rolled down half way).

During the second two week period, the data from the first two weeks was analyzed to determine the average number of footcandles recorded by location and by time of day.

The studio staff was notified by email that additional daylight harvesting tests would be taking place in the office, and cooperation was again requested. Additionally, staff was asked to direct comments or complaints about visual comfort to the testing team for resolution. The team would be prepared to offer the following mitigations based on the complaint: adjustment of computer monitors, adjustment of roller shades in immediate vicinity of complaint, and/or ordering of a computer glare-reduction screen.

Electric light levels were adjusted twice each day – once in early morning and once during early afternoon. The goal was a combination of 50 footcandles between the average daily daylight reading and that supplied by the electric lighting. Fifty footcandles is regarded by several organizations as a benchmark or threshold for visual comfort at a desk level[3,4].

The team selected the workstation with the lowest average light level readings from the first testing period in creating the lighting adjustment strategy. That workstation was used to target 50 footcandles.

The following information was recorded daily:

- Weather,
- Overhead light level adjustment,
- Window shade adjustments in the morning and afternoon,
- Comments or complaints from staff,
- Actions taken to resolve staff comments or complaints.

Daylight harvesting, perhaps more than the other tested strategies, is directly affected by seasonal variations. Our first round of testing was completed in June, July, and August of 2012, which obviously allows for longer daylight hours. The second round was completed in the winter over two separate weeks. The intent was to see how seasonal change affected the daylight harvesting strategy adopted in the first round.

The second round of daylight harvesting tests was carried out in winter (December 10 – 14, 2012, and again January 21 – 25, 2013). As was done in the summer, the ambient lighting directly overhead of the five middle rows of workstations in the studio was adjusted from a normal 80 percent light level to 53 percent (the level arrived at during the first round of testing). Light levels were reduced at approximately 8:30 AM each morning to take full advantage of the east orientation of the workspace. Light levels were raised back to 80 percent at varying times throughout the testing periods to determine if staff noticed a difference in ambient illumination, though they were always raised back to 80 percent by 4:30 PM, as the sun would set shortly thereafter and the studio space would be noticeably darker.

2.3.4 Variables

The following variables were either out of the control of the testing team or difficult to control on a daily basis:

- Weather patterns (amount of daylight each day),

- Staff interaction with the manual roller shades,
- Type of work being completed at workstations.

2.3.5 Tools

The following tools were used to carry out the observations and testing:

- Encelium – Lighting control system,
- Pulse Energy – Data collection & reporting system,
- Digital light meter.

2.3.6 Results

Based on Phase 1, light level averages were determined and weather patterns discussed and analyzed. The second week of the first period was more cloudy and rainy than the first, and light level readings were noted as a variable out of the control of the testing team. As such, those values brought the average daylight illumination down, but were a more realistic portrayal of actual variations.

Through use of the light meter and the Encelium controls, the lighting levels were reduced in the studio to 53 percent (normally the lights are set at a fixed 80 percent capacity) at 8:30 AM. Direct daylight gain was greatest in the morning hours (due to east orientation of the space), so the studio could take advantage of that increased daylight level.

After analyzing the light level readings for noon and afternoon from the first two week period, it was determined that the lights should be returned to 80 percent capacity at 2:00 PM each day during Phase 2. The lack of direct gain in the afternoon limited how far into the floor plate the daylight penetrated. Reflected daylight in the afternoon (off buildings across the street) also did not have an effect on how far daylight would enter the space. At times even electric light levels at 80 percent did not achieve the 50 footcandle level targeted.

The energy use in Phase 2 can be charted against the energy use over the same period of time in 2011. This comparison removes the seasonal variable from the equation. Plotting the same dates in the Pulse software shows a reduction in the average lighting energy use of 20.36 kWh (including weekends when lighting was not varied). If we compare the average lighting load over a week's time from early June (prior to all testing data), we see a reduction of energy used by lighting of 5.66 kWh.

Based on the testing conditions, the Pulse Energy Monitoring System showed an overall reduction of energy use for lighting of eight percent over the six days the testing occurred compared to the same six days in 2011 (Figure 12).

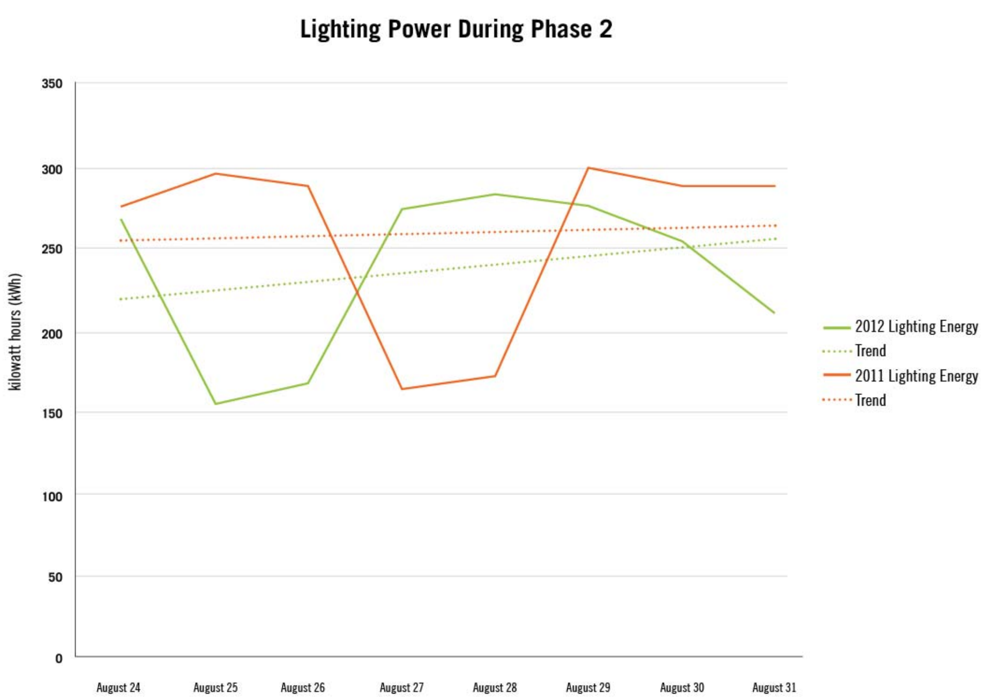


Figure 12: Lighting power measurements from testing in 2012 shown compared to the same calendar dates in 2011.

Figure 13: Diagram for recommended daylight harvesting locations.

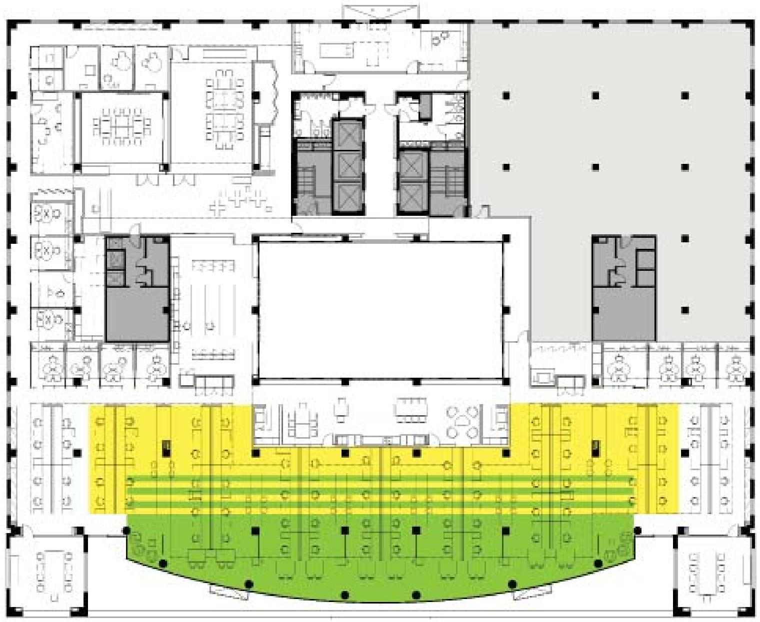


Figure 14: Diagram for recommended combined daylight harvesting and task tuning.

The daily lighting energy use went down during Phase 2 compared to the same dates in 2011, but daily results varied greatly. On August 31, for example, the office recorded a drop in energy use from 287.328 kWh to 212.039 kWh, a difference of 75.3 kWh. That represents a 26 percent reduction over the use in 2011. The reduction in energy use on August 24, however, only represents a two percent decrease. These increments do vary, but since the lighting use is measured by day in these cases, employee work patterns may account for some of the variations. Therefore, the average reduction of eight percent over the six day window will be used as the result of this test.

Comments and complaints from the staff were minimal and mostly occurred during the first few days of Phase 2. Complaints the team received were addressed using the roller shades and had minimal effect on the overall light levels – the complaints were more about glare from the brightness of the window wall and not about inability to see a computer screen. Glare screens were not used. When there was a conscious concern about our attempt to maintain maximum daylighting, the shades were rolled back up when glare was no longer an issue. This is important in noting that the visual comfort of the person sitting at the perimeter workstation directly influences the visual comfort level of the person sitting in a more centrally located workstation. This study did not examine thermal comfort issues relating to the direct sunlight.

During the winter testing, no complaints about glare or illumination levels were registered with the testing team. We observed window shades at varying levels of extraction (we did not fix them at a specific level), and on any given day between one and three task lights would be turned on by staff out of 44 workstations in the testing zone.

While there was a definite reduction in lighting intensity within the studio during the two weeks of testing, energy reporting from the Pulse Energy Management software showed a slight increase in energy use for lighting during each week, compared to a similar week in 2011. This could be attributed to a variety of reasons – staff staying in the office later for work and thus requiring lighting longer into the evenings; more conference room use during that time period and other usage issues. The increase from the December 2012 week over a comparable workweek in December 2011 was an average of 6.8 kWh per day. The increase in the January testing period was an average of 1.04 kWh.

2.3.7 Recommendations

The team recommends that daylight sensors can be used to control the light fixtures within the first 30 feet of the windows for the five rows of workstations along the eastern all-glass facade. This doubles the recommended distance as outlined in the LEED guidelines because of the amount of daylight this office space receives (Figure 13).

For this particular space, a balance between use of roller shades 25-50 percent extracted and reduction in electric light use should be investigated to mitigate direct light glare issues and reduce energy use.

Whatever the reasons for the increase in energy consumption over the previous year's baseline, we would still recommend taking advantage of daylight within a space to reduce overall energy consumption in winter as in summer. With no recorded staff complaints and no glare reduction interventions, we conclude the productivity and visual comfort of the studio staff was not affected by the decreased electric lighting provided. Lighting levels may need to be readjusted earlier in the workday to compensate for less daylight hours, but programmable lighting control software would be able to address that seasonal variation.

3.0 CONCLUSION

3.1 General Observations

The team found lighting to account for approximately 15 percent of the energy consumed in the entire office. However, lighting is a conspicuous component of the open office and directly connected to occupant productivity. As indicated in the variables listed for each test, overall lighting levels are impacted by a variety of factors ranging from weather to occupant behavior. Additionally the architectural elements in the space, such as wall type (opaque vs. glass), finishes (light and shiny vs. dark and matte), views of fixtures (seated at workstations vs. in transit) directly impact how light behaves in a space. For these reasons the team recommends that designers looking to employ an addressable lighting control system as part of their energy management strategy should run a daylight model for the space to inform the proper application of the individual lighting reduction strategies covered in this test.

Building system commissioning is a standard activity at project turnover, but frequently focuses on larger items such as mechanical systems. In performing the tests, the team frequently found many electronic controls to be incorrectly set, such as lighting zones controlling extra fixtures. It is difficult to quantify the effect of improperly commissioned controls. The team recommends full commissioning and ongoing audit of an addressable lighting system when it is used on projects in the future.

The team found task lights to be drastically under-utilized. Although task lighting is required to achieve LEED IEQ credit 6.1 Controllability of Systems - Lighting in the 2009 LEED Reference Guide for Interior Design and Construction, general light levels in the studied office were typically high enough to achieve the recommended 30-50 fc range on a work surface without supplemental light (ANSI, GSA, OSHA). The team hypothesizes that initial costs may be reduced by only offering to make task lights available as they are requested. Savings realized from reduced need for task lighting could then be invested towards occupants in other ways, such as for additional ergonomic products or automated shades. This offers a holistic sustainable approach to lighting rather than a design driven by LEED requirements and credit accrual.

3.2 Messaging Observations

The team found that some occupants did respond positively to messaging related to the testing. A concise email was found to be the most effective means of conveying the testing and any action required by the occupants. However, the team also observed that certain tests and messaging protocol were alarming to some occupants. The team hypothesizes that this was partially due to the fact that the messaging was relating to "tests" rather than describing how an integrated system and conservation strategy work. For future testing, the team recommends concise email as messaging method and to forgo alternate strategies described in previous sections.

3.3 Testing Summaries

3.3.1 Task Tuning

The observations and data resulting from this testing period suggest that in offices with ambient daylight and electric lighting such as the Perkins+Will Washington DC office, a possible reduction in electric lighting of up to 50 percent is achievable. Task tuning is relative to the existing lighting conditions of a space, but is recognized in this study as a highly effective means to reduce lighting loads without negatively impacting employee comfort.

3.3.2 Load Shedding

Load shedding is an effective means of recognizing and immediately responding to issues of peak energy demand during certain times of the day. The challenge of this test was to find areas suitable for shedding lighting loads in an open office. In analyzing the findings from this lighting test, the team found that in order to minimize disruptions caused by switching off lights during hours of peak energy use, load shedding should be confined to secondary, support spaces (not areas of primary work). The team hypothesizes if additional testing were to be conducted, gradual load shedding or dimming may be a more effective means of reaching a similar goal.

3.3.3. Daylight Harvesting

After recording the overall footcandles at different depths of the office and observing the amount of natural daylight entering the space, this report challenges the fifteen-foot distance from the perimeter to control light fixtures through daylight harvesting (USGBC). Rather, the team proposes that through a thorough analysis of a building's orientation, design strategies can be implemented in coordination with efficient lighting design to increase the distance in which daylight may serve as an effective light source within an office.

3.4 Comprehensive Office Strategies

When working to reduce energy consumption of lighting systems in an office environment, it is necessary to maintain adequate lighting conditions that support the work activity. This article determined that the most effective means of achieving this relationship is through a collaborative combination of task tuning, load shedding, and daylight harvesting (Figure 14).

While task tuning provides an opportunity to balance the needs of work and reducing energy demand, load shedding recognizes the real-time element of energy consumption by responding during peak demand. Therefore, the team encourages combining shedding lighting loads from the overhead lighting with task tuning to establish the minimum lighting level required. To reduce the distraction of suddenly dimmed lights in the open workstation environment, load shedding could act as progressive dimming to lower light levels to 50 percent as suggested by task tuning results.

If a 50 percent reduction is to be implemented at all times, it would not be beneficial to use a load shedding strategy in addition; rather task tuning should be used independently.

Maximizing daylight harvesting through light sensors, however, is recommended in combination with either of the previous strategies.

As a collective system, these three lighting strategies can be combined to not only reduce electrical demand, but also create well-lit working environments with less environmental impacts to the occupants.

3.5 Further Testing

After analysis of the results from the three tests, the team identified a number of recommended adjustments to each test that would help to either refine the data or expand the scope of the test to incorporate additional technologies. It was felt that all three tests should be repeated in additional seasons to determine if the results were consistent throughout the year. It was hypothesized that occupants may react differently during shorter daylight hours, particularly in winter.

For task tuning, the team felt any further tests should attempt to capture occupant feedback on the light levels in real time. While the occupant survey at the end of the test was helpful in understanding general impressions over the testing period, it was impossible to pinpoint exact moments of occupant discomfort in relation to specific footcandle levels. While general light levels decreased over the testing period there were significant variations in weather patterns, resulting in fluctuations in the actual number of footcandles in the studio at any given time. It was hypothesized that real time feedback on occupant comfort would allow the team to pinpoint exactly when footcandles dropped below a tolerable level.

For load shedding, the team felt that any further tests should incorporate dimming, rather than simply turning the lights on and off. The survey results indicated that occupants found lights turning on and off in the middle of business hours to be a distraction, rendering the strategy of limited use in an open office environment. It was hypothesized that a gradual dimming of the lights to partial capacity during peak hours would still realize energy savings without disrupting occupant productivity. It was also noted that since lighting is such a small percentage of energy used in the space there may be other loads that could be reduced or eliminated during peak demand, such as mechanical equipment variations.

For daylight harvesting, the team felt any further tests should add additional positions for the manual roller shades aside from completely rolled up and 50 percent down. It was observed that a 50 percent deployment of the shades was often lower than required to simply reduce glare at the workstations along the perimeter. It was hypothesized that adding additional increments to the shade positions in the study would allow the shades to effectively reduce glare while optimizing the amount of daylight penetrating into the studio. The team also felt that implementation of a light shelf would help to reflect light while acting to eliminate glare along portions of the exterior.

3.6 Future Product Development

While analyzing the test results and variables it became apparent that the more intelligent the system, its capacity to adapt to changes in the surrounding environment also increases. The team observed throughout all three tests, occupants lowered the perimeter shades all the way down early in the morning to block glare from direct sun. This condition typically resolved itself no later than 9:00 AM as the sun's elevation in the sky increased. However, the solar shades remained down for the remainder of the day unless purposely altered by a member of the testing team. Motorized shades with solar tracking software would naturally alleviate this condition. It was hypothesized that if integrated with Encelium, the two systems would be capable of responding in harmony to the changing external environment, effectively eliminating many of the variables that were observed to hinder maximum energy savings during the tests.

The team also observed that the capability to monitor light levels at the work surface was an important factor in assessing occupant comfort. Encelium currently has the capacity to respond to daylight sensors, but the test results showed that these devices had only a limited connection to the amount of light landing on the work surface and only on those within fifteen feet of the building perimeter. While industry standard decrees that fifteen feet is the typical measurement that daylight effectively penetrates into a floor plate, the test results showed that the physical characteristics of this office allowed daylight to affect a much larger portion of the floor[7]. Additionally, shared light from corridors impacted the footcandles at adjacent work surfaces. It was hypothesized that if the lighting control system had the ability to read the footcandles at each individual work surface and dim the overhead lights accordingly, maximum energy savings would be achieved with relatively little impact to occupant comfort or productivity. The team is currently unaware if such a system exists and has identified it as a potential opportunity for product development with systems furniture and lighting control manufacturers.

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02.
A CASE STUDY IN REFLECTIVE DAYLIGHTING

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ABSTRACT
This article focuses on the design of the University Crossing atrium at University of Massachusetts (UMASS) in Lowell, where an innovative way to bring daylight deep into the building's north facing, four story atrium was the primary objective of the study. Using a number of physical and digital tools including Diva-for-Rhino, the design team has explored the invention of reflective building geometry to light the building's interior atrium surfaces throughout the year. Working with Lam Partners and other contributors, the team has iteratively explored how daylight can be efficiently, yet dramatically directed down into a space despite challenges generated by planning constraints, site conditions and formal orientation. The case study documents the team's research methodology, design strategies and technical concepts for executing the work as well as general conclusions on the benefits of the collaborative process.

KEYWORDS: daylighting, energy optimization, computational design, simulation, orientation, sustainability

1.0 INTRODUCTION

Building forms are often driven by conditions that work counter to the ideal geometries of daylighting design. The depth of a building's floor plate, the orientation of the existing urban grid and the shadowing of existing site geometry, among other factors, inform decisions that create unique design challenges when conceptualizing spaces inspired by daylight.

Despite these challenges, the benefits to building occupants and the broader environmental context make finding effective and innovative daylighting solutions an imperative. Developing new design methodologies is crucial to effectively designing day-lit spaces in less than ideal orientations. These new design methodologies require the cultivation of strategic partnerships, the exploration of new computational and physical tools as well as new construction assemblies.

The design of the University Crossing atrium at University of Massachusetts (UMASS) in Lowell has allowed the Perkins+Will Boston office to study an innovative way to bring daylight deep into the building's north facing, four story atrium. Using a number of physical and digital tools including Diva-for-Rhino, a software initially developed at the Harvard Graduate School of Design, the design team has explored the invention of reflective building geometry to light the building's interior atrium surfaces throughout the year. Working with Lam Partners and other contributors, the team has iteratively explored how daylight can be efficiently, yet dramatically directed down into a space despite planning and site related challenges.

Figure 1: Finding inspiring, efficient and innovative daylighting solutions for deep buildings is an imperative for sustainable growth.

2.0 TURNING DAYLIGHTING CHALLENGES INTO DESIGN OPPORTUNITIES

2.1 Drivers of Building Form

Daylighting strategies are often diagrammed assuming the most ideal conditions. The simplest strategies are clear for buildings with an optimal east-west orientation, shallow floor plates, perimeter occupied spaces and a lack of shadowing by adjacent structures. The realities of urban infill sites do not often present the conditions that allow these simple solutions. Often, oddly-shaped, poorly oriented urban parcels are developed when the most ideal sites have been exhausted. The desirability of a site location and prominence may also drive the development of a project with a less than ideal solar orientation. Regardless of the drivers, the principles of sustainable urban growth push us to achieve a density that makes use of challenging sites in creative, thoughtful ways[1].

At the University of Massachusetts in Lowell, the design team was tasked with the design and development of a new student center to be called University Crossing. A number of site-driven and programmatic challenges drove the team to explore a system of reflected daylight within the building's central atrium.

Figure 2: Aerial view of University Crossing looking north over Lowell and the Merrimack River.

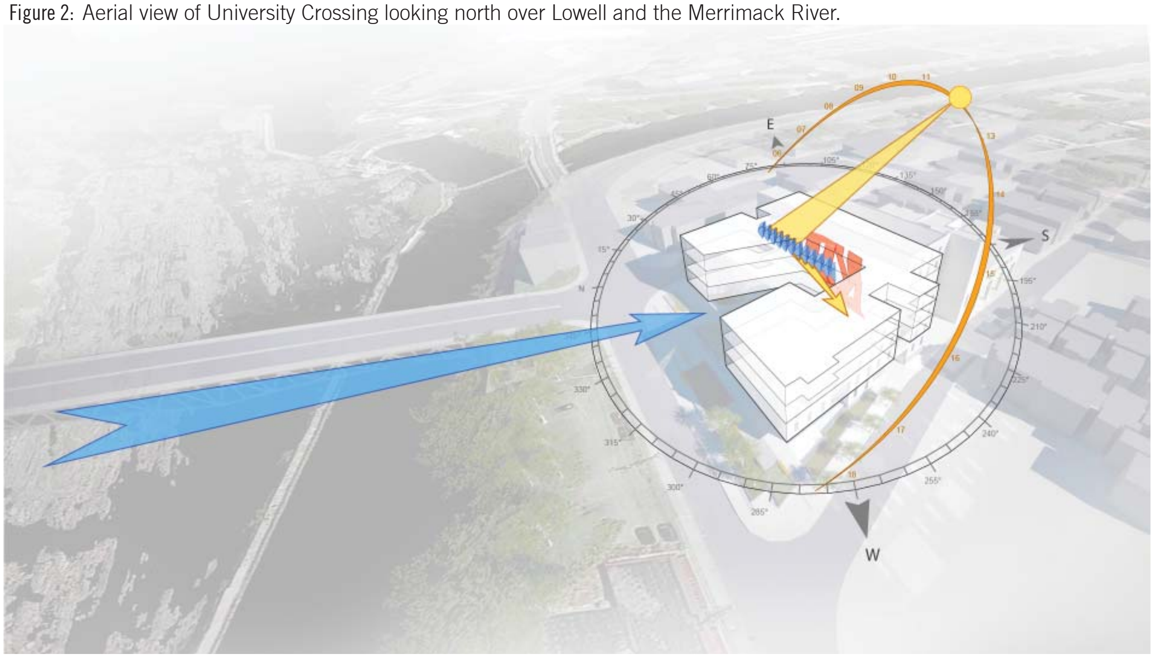


Figure 3: Site and sun path diagram.

2.2 Site Driven Challenges

The project's site is located at the edge of a dense urban neighborhood, remote from the main campus, which lies to its north across the Merrimack River. The primary pedestrian approach to the building is from the new bridge. The location of the building south of main campus and its orientation to the bridge meant that the new structure would be back-lit to students and visitors approaching from the north and that if public spaces were to orient themselves towards the river, they would need to be day-lit primarily from the northern building edge or from above. The dominant urban geometry, 42 degrees off axis from true north, added to the daylighting challenges as traditional horizontal light shelves would prove ineffective for the majority of the day on south-east and south-west facades.

2.3 Existing Adjacent Structures

Adjacent to the site at its southern corner, the six story stair tower of an existing structure stood as a further impediment to a simple daylighting solution. The existing structure and its associated elevator tower would shadow the University Crossing site from the south for the majority of the day.

2.4 Programmatic Requirements

A number of common design pressures drove the architectural scheme towards a solution that can be referred to as a "deep floor plate building". Deep floor plate buildings pose unique challenges when striving to achieve spaces inspired by natural light. Without prohibitively high floor-to-floor heights and large amounts of perimeter glazing, they become challenging to daylight from the building's exterior facades alone.

The scale of contiguous programmatic departments and the functional requirements for their adjacency drove the team to a scheme that maximized the site footprint on four floors and organized the building around a central atrium. The position of the atrium within the building mass was biased towards the northern and most public facade to act as a welcoming space, one that is in scale with the prominent approach axis. By biasing the atrium to the north, the resulting space could be both top lit as well as lit by the northern exterior facade.

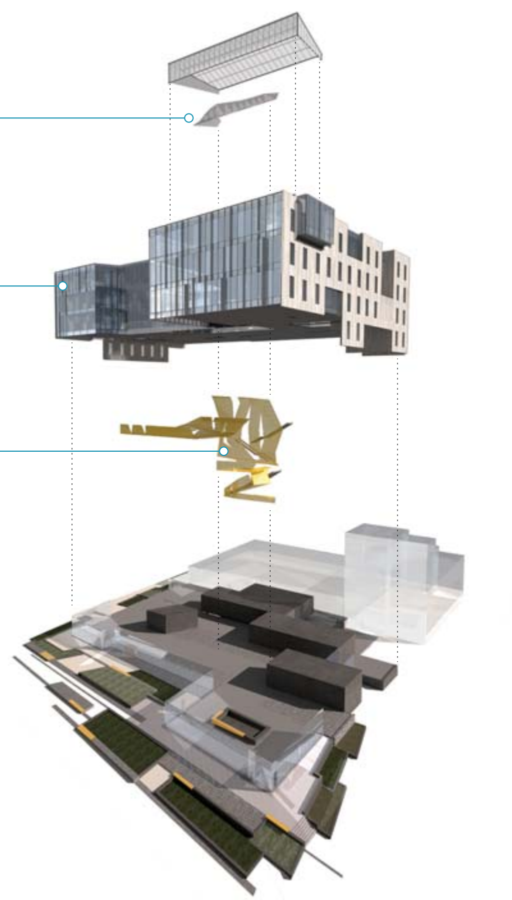


Figure 4: Building massing diagram.

2.5 Balancing Performance and Daylighting

Within a heating intensive climate like the Northeast, a deep and compact building can yield a number of performance advantages[2]. The optimization of the building skin in proportion to the enclosed building volume can yield an efficient mechanical system when coupled with a high performing building envelope. However, this means that daylighting and passive ventilation strategies become challenged by the lack of exterior wall area and general proximity of program to the building's exterior. To further drive down the loads on existing mechanical systems, teams often look to optimizing glazing percentages in relation to the overall envelope area. Similar to optimizing a building's skin to volume ratio, this process tends to drive buildings towards smaller apertures for daylighting.

2.6 Integrated Energy Modeling

As energy modeling progresses in early design and daylighting studies are being performed, the results of reduced lighting loads are typically not accounted for within the schematic energy modeling process[3]. At this point there are few energy modeling tools that account for the benefits of reduced lighting loads by quantifying them within a 8760, hour-by-hour energy simulation. This makes it difficult to account for the advantages of daylighting in energy modeling and has the potential to cause a design team to reduce a project's glazing percentage based solely on the results of early modeling.

2.7 Minimizing the Atrium Aperture

Even without sophisticated energy simulations that tie the performance gains from daylighting and active dimming systems to energy usage, we can make assumptions about effective top-lighting strategies within deep buildings like University Crossing. The first is that the atrium skylight aperture, if sized strictly for daylighting, would require a substantial glazed opening in the insulated roof system. Traditional formulas developed for the calculation of atrium aperture size do little to calculate the effects on a buildings thermal envelope[4]. The weakening of what is typically the most insulated portion of the exterior envelope has the potential to add unnecessary heat gain in the summer and loss in the winter regardless of careful attention to glazing performances. The second assumption is that successful solutions can be found that, at once, minimize the daylighting aperture and maximize the effects of natural light within the building. This is true due to the potency of sunlight. On a clear day the sun's rays offer up to 10,000 footcandles of directional light and on an overcast day can still provide up to a 1,000 footcandles of diffused light. When compared to the 50-150 footcandles necessary for general illumination, it is clear that a small amount of daylight might effectively be beamed into the building through smaller apertures and then spread out or diffused by larger interior surfaces.

2.8 Optimizing Daylighting

Optimization of building envelopes and potency of sunlight suggest that working with minimal, but carefully designed apertures for daylighting can serve as a guiding sustainable design principle[5]. A unique set of strategies present themselves when coupling this principle with the site challenges of orientation, shadowing from existing structures and the directionality of sunlight. This set of strategies involves the reflection or redirection of sunlight through mirrored or highly reflective surfaces. The following section is a cursory review of a number of projects that use redirected daylight in deliberate, yet elegant ways to daylight and animate the architectural environment.

Many of the projects were the products of successful partnerships between Lam Partners Architectural Lighting and their clients.

3.0 PRECEDENTS IN REFLECTED DAYLIGHTING

3.1 Precedent Analysis

There are a wide range of reflective lighting precedents to examine within the history of the built environment. The following precedent study focuses on buildings that take advantage of relatively small, protected apertures to send potent, but focused daylight deep into building environments. Analytical diagrams were developed based on published building sections and photographs provided by Lam Partners to show the basic design concept present in the precedents. The images show how light is reflected or "beamed" into the building through the use of specular surfaces. Working in tandem with these specular surfaces are multiple light-diffusing surfaces. These surfaces serve to spread the highly focused sunlight over a larger area, allowing for effective functional lighting techniques to be used. The range of precedents selected show simple, fixed solutions using flat surfaces as well as complex arrays of operable reflective louvers. Within this spectrum of cost and complexity there are multiple effective strategies that can be scaled up or down depending on the project design goals. Also included are precedents that combine multiple reflective strategies into layered approaches. These layered approaches allow for light to be conceived of as a playful activator of space as well as

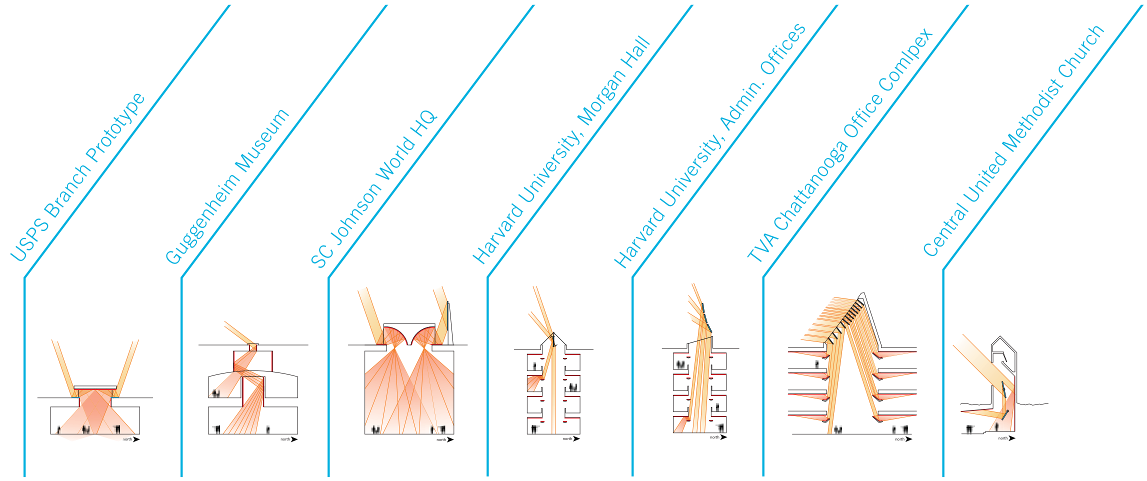


Figure 5: A range of daylighting precedents.

a functional necessity within the same scheme.

3.2 United States Postal Service Regional Distribution Center Prototype[6]

The USPS investigated ways to standardize a new building design for their regional mail distribution centers that would be better organized and more energy efficient. One of the goals was to incorporate daylight as a primary light source. The building design is organized around a series of simple linear bays, with one roof monitor per bay. Through a series of daylight studies, it was determined that the most efficient daylight monitor had a north-south axis with east and west clerestory windows. As an integrated design approach, the roof monitor and ceiling geometry was developed to maximize daylight exposure without allowing direct sun into the building. This was achieved by adjusting the height and position of the clerestory with the shape of the ceilings in each of the bays. By sloping the ceilings up to the monitor opening, the whole bay became a daylight coffer.

The east and west clerestory windows provided ample daylight from sunrise to sunset. The least amount of daylight entered the bays at noon, which coincided with the postal workers lunch break. As part of the integrated design, a spiral duct was placed at the center of each bay below the daylight monitor to condition the space. A simple fluorescent strip fixture with reflector was concealed on top of the duct to provide glare-free indirect illumination on gloomy days and winter afternoons.

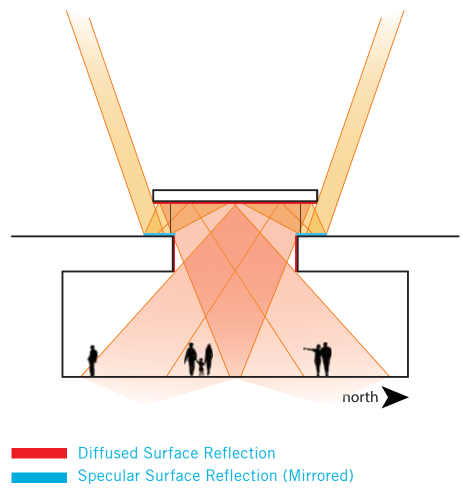


Figure 6: Daylight strategies for United States Postal Service Regional Distribution Center Prototype.

3.3 Guggenheim Museum, Bilbao, Spain[7]

In Frank Gehry's museum of modern art, simple geometric design strategies were developed to bring daylight down through the building to illuminate lower level spaces. One wing of the museum contains the "classical galleries," which are square galleries double-stacked and connected in a row. The upper level of each set of the classical galleries has a skylight centered in a deeply vaulted ceiling cavity. The center of each upper gallery contains a light well that provides natural light to the lower classical gallery. The walls that form the light well create a white box-like element for hanging art. The height of the box walls is set in such a manner so direct sun from the skylight above can never reach the perimeter walls of the upper gallery. Visitors in the upper gallery are not aware that these walls form a light well to the gallery below.

A pair of motorized shades concealed in the top of the light well can be activated to create soft diffuse light to the lower level gallery or close off daylight to the lower gallery when required by special exhibits.

The galleries that surround the central atrium in the museum "borrow" daylight from the sky-lit main space through small openings. Gaps in the floor plates allow daylight to filter down to the galleries and circulation spaces below.

3.4 SC Johnson World HQ, Racine, Wisconsin[6]

This large office building is shaped like a square donut with a litrium at the center. The raised roof over the litrium allows for clerestory windows on all four sides. Curved plaster light scoops behind the clerestory windows redirect sunlight on the east, south and west elevations down to the interior elevations of the central space. Interior light shelves then redirect this sun-light to the open office ceilings. To help balance the daylight on all four sides of the litrium, special "sun catcher baffles" (a term coined by lighting designer William Lam) were installed as outriggers on the north, east and west sides of the upper roof. These architectural baffles are mirrored on the backside and have an architectural finish on the outside face. These baffles function in the following way: when the sun is in the east, the east clerestory admits ample sunlight and on the west side, the suncatcher baffle captures a small band of direct sun and redirects it to the scoop below. This strategy maximizes the daylight potential in the building and creates a more balanced illumination in the spaces. The building also employs exterior light shelves on the east, south and west facades to amplify the natural light at the office perimeter zones.

Upside-down, wing-shaped reflector system was installed on the south side of this high-rise office building to redirect sunlight through a light shaft to a second set of mirrored reflectors on the ceiling of a central atrium. The second array then redirected the sunlight down through the building, through a large glass day light to bring natural light to the public passage under the building.

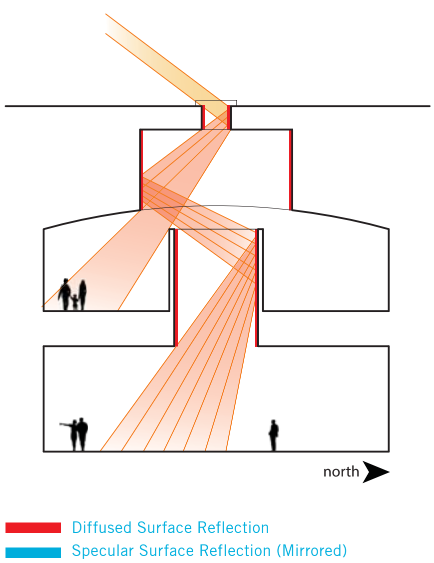


Figure 7: Daylight design strategies for Guggenheim Museum, Bilbao, Spain.

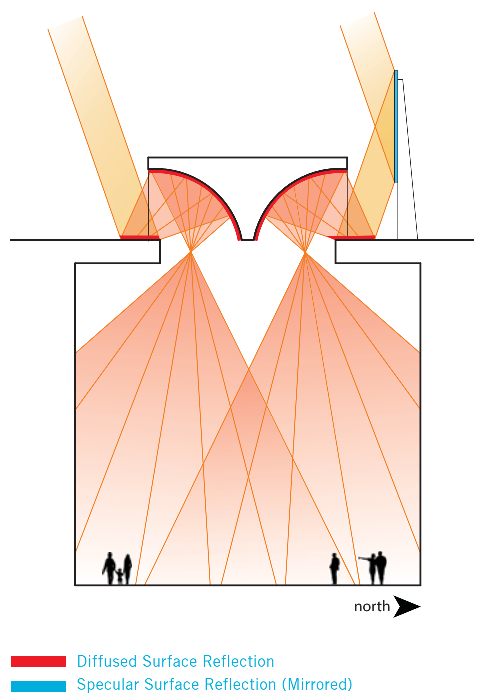


Figure 8: Daylight strategies for SC Johnson World HQ, Racine, Wisconsin.

3.5 Harvard University, Morgan Hall[6]

This building has a small, central sky-lit atrium with two 11' wide light wells on either side. Simple gable skylights cap the four story light wells. The axis of the light well is east-west, which creates a long southern exposure for the skylight. Adjustable mirrored panels below the skylight redirect southern light down the light well to the first floor. Light shelves on second to fourth floor capture a bit of the redirected sunlight and bounce it up to the open office ceilings that flank the light well. The mirrors are motorized and can be adjusted weekly to accommodate changing sun angles throughout the year. As a special feature at noon, the mirrors do a simple rotation to send light down the walls of the light well, across the floor and back up the other side, and then default to their regular position.

3.6 Harvard University, Administrative Offices[6]

This project involved two adjoining buildings embedded within a deep block behind Harvard Square. A full renovation to convert these four and five story buildings into office space was implemented. The buildings have few windows at the short ends and have very little daylight access. A skylight was cut into the center of the roof and a narrow light well was created below to allow daylight into the center of the building. Glass-front offices face the light well to have some connection to daylight. Fixed polished stainless steel reflectors were installed on the roof on the north side of the skylight to redirect sunlight down into the light well. Three reflectors were used and set at different angles to maximize various sun angles. The three mirrored reflectors are set to optimize summer, equinox, and winter sun angles.

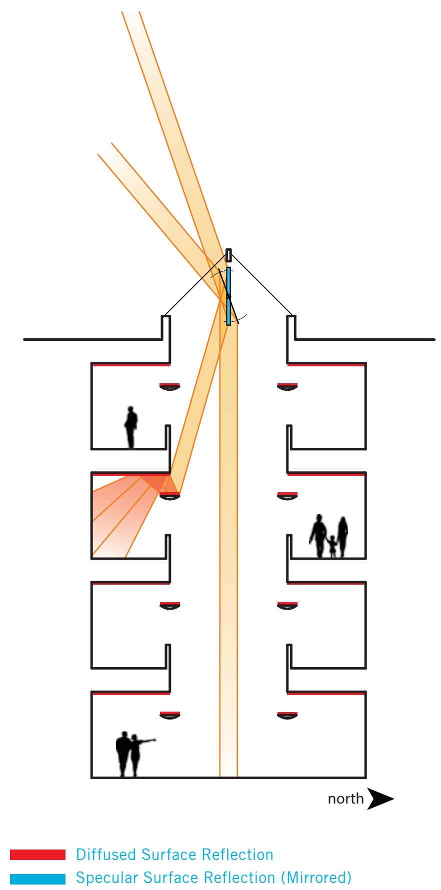


Figure 9: Daylight design strategies for Harvard University, Morgan Hall, Cambridge, Massachusetts.

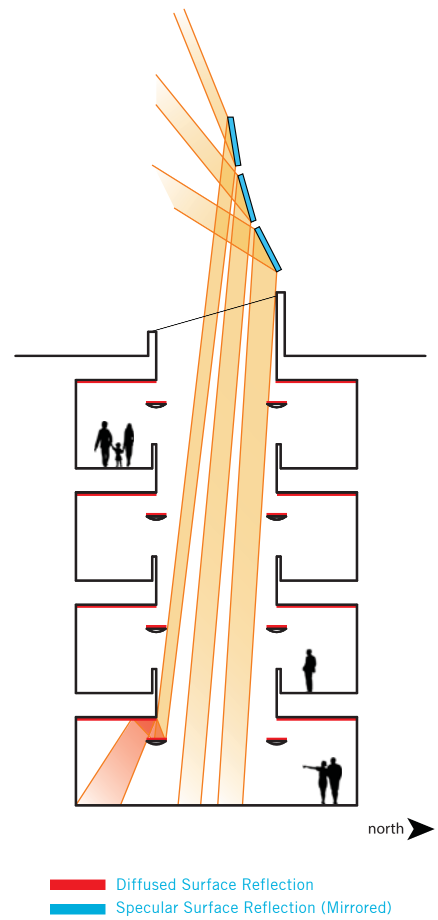


Figure 10: Daylight design strategies for Harvard University, Administrative Offices, Cambridge, Massachusetts.

3.7 Tennessee Valley Authority, Office Complex, Chattanooga, Tennessee[8]

The TVA is a government agency in the energy business. In the 1980's they set out to build a new office headquarters with 1.2 million square feet that would be a model of energy conscious design for all of its facilities. Through a team process, a building design was developed around an array of six to seven story office blocks facing south, with atria and litria in between to maximize access to daylight and natural light in the work environment. The litria concept was further developed to incorporate a strategy of beamed sunlight. This strategy was based on a south-facing litria with sloping glass and an array of one-way tracking mirrored louvers mounted below the glass. The litria were located between two office blocks. The floors of the office blocks were terraced so that they extended into the litria deeper on the lower floors and less on the upper floors in a V-shaped configuration. The edges of the floor slab held a plaster-formed outrigger with a fixed mirror surface facing up at a 45 degree angle. The one-way tracking mirrors below the litrium glass roof were set to beam sunlight straight down. This sunlight was intercepted by the secondary mirrors at the edges of the floor slabs, which redirected the sunlight to the ceiling of the office spaces.

The primary mirror louver system was designed with a white surface on the underside so that in summer, the mirrors could be set to reflect direct sun and create a diffused daylight component off of the white back surface of the mirrors. On winter nights, the mirrors could be closed down to help prevent heat loss.

3.8 Central United Methodist Church, Milwaukee, Wisconsin[8]

Working with the congregation, William Wenzler & Associates developed a new church design that preserved much of the site, and incorporated a special sunlight strategy that served as a practical and metaphorical statement about lighting in a religious facility. The bulk of the church is largely below ground, with berms on three sides, which frees a good portion of the site for a beautiful landscape full of wild flowers. The sanctuary below is oriented with the altar to the north. A large daylight monitor or "suncatcher" rises above the altar and forms a sculptural element in the landscape above. Structural beams gently radiate from the area under the suncatcher to the back and sides of the sanctuary. The south-facing suncatcher concept began as a passive solar strategy to collect solar energy and bring daylight into the altar area.

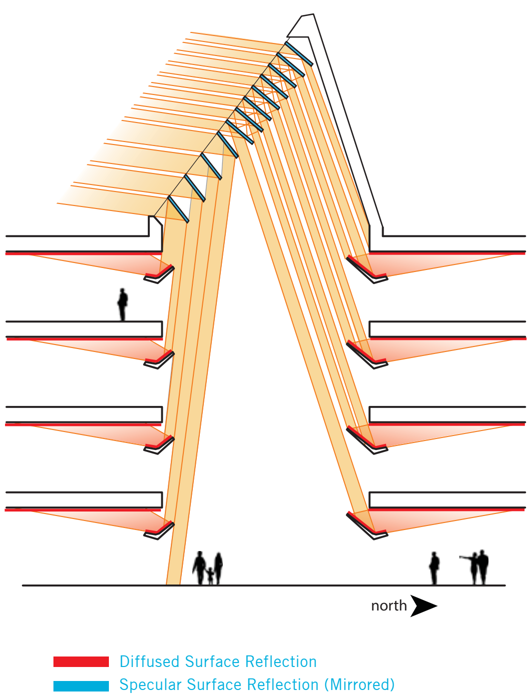


Figure 11: Daylight design strategies for Tennessee Valley Authority, Office Complex, Chattanooga, Tennessee.

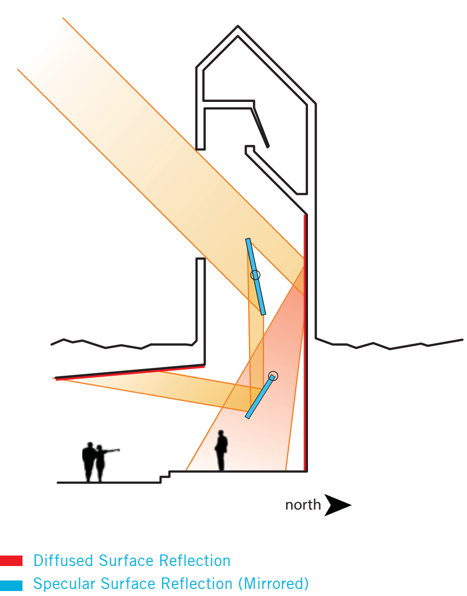


Figure 12: Daylight design strategies for Central United Methodist Church, Milwaukee, Wisconsin.

With its large south facing glass, a shutter was proposed to isolate the upper cavity of this tower from the rest of the church to avoid excessive heat gain in summer. This early shutter concept was modified and transformed into a sunlighting strategy, in which the shutter became a primary tilting mirror to capture as much sun as possible. This primary mirror delivers sunlight to an array of secondary mirrors mounted between the radial pattern of concrete beams below. The secondary mirrors send sunlight streaming down each bay with dramatic effect.

3.9 Additional Precedents

The following are additional precedents that were investigated and discussed during the research process:

Asian Cultural Center, South Korea[6]
This project was a large urban renewal project involving a major site that was cleared and redeveloped as a cultural and innovation center in an urban center. The bulk of the construction is below ground so that the top of the site could be developed as a park, a desperately needed green oasis in an otherwise dense city.

A large cut in the site was created on the south side to expose the new below-grade building to sunlight. A narrow canyon-like cut on the west side opened up the below-grade floors on that side to stepped courtyards for access to daylight. In the center of the development, special skylight wells were created to capture and reflect sunlight down into light shafts that distribute light three levels below grade. The skylight wells, or “light crystals” as they were called, create sculptural objects in the park, with care taken to position adjacent trees to avoid blocking direct sun to the skylights. The light wells are mirrored at the top with diffusing surfaces placed at various levels below for light distribution.

Blue Cross Blue Shield HQ, Connecticut, USA[6]
In this older project, the generous site allowed for proper positioning and massing of the building to maximize sunlight penetration into the office building. The building is organized into two east-west blocks with an atrium in-between. Bill Lam coined the term “litrium” to describe a daylit space that is designed specifically to maximize the capture and redistribution of sunlight as useful illumination. The north block of the building rises above the south block, creating a simple, but effective clerestory window facing south. A scoop-shaped upper wall in the litrium redirects sunlight throughout the space. Interior light shelves at the edges of the office floors facing the litrium capture a bit of sunlight and bounce it up to the open office ceilings for useful ambient lighting. The building also has exterior light shelves on the south side to maximize sunlight penetration on that elevation.

Hong Kong Shanghai Bank Building[9]
This project is an interesting case study of how southern exposure was used to create an active sunlight system for this office building. Norman Foster’s team uses a large, upside down, wing-shaped reflector system installed on the south side of this high-rise office building to redirect sunlight through a light shaft to a second set of mirrored reflectors on the ceiling of a central atrium. The second array then redirected the sunlight down through the building, through a large glass skylight to bring natural light to the public passage under the building.

US Embassy, Ottawa, Canada[6]
This embassy building is shaped like a large boat with a north-south axis. SOM Architects used a central atrium to organize the main public spaces in the building. To the north and south of the building are five story light wells that bring daylight down to the offices on both sides. In essence, this building is similar to Harvard’s Morgan Hall building, except turned 90 degrees. The fact that the skylights over the light wells were facing east and west is critical to the daylighting strategy. Given the high latitude of the site, east and west sun angles play a very important part of capturing sunlight. In this design, a multi-faceted mirror lined the tall upper portion of the light well. The mirrors were set in a splayed position so that with each “bounce” of sunlight, the sun penetrated deeper into the light well. By doing so, sunlight is pushed to both sides of the light well and all the way to the bottom level. The glass handrails of the corridor spaces surrounding the floors below the skylight were made of diffusing glass and set at an angle (rather than straight up and down) to intercept the sunlight streaming down from the mirrors above. This created an ambient glow in the entire light well.

David L. Lawrence Convention Center, Pittsburgh, Pennsylvania[10]
While this large convention center space is not multistory, its design represents one of the largest enclosed daylit convention spaces in the country. Vinoly Architects employed large strip skylights following the curve of the cable suspension roof system to fill the space with natural light. Two motorized shades below the skylights provide a diffusion layer to soften the daylight and a second black-out shade to dial down the daylight to very low levels when necessary. A Bird-Air translucent fabric membrane forms the south facing “clerestory” for a large dose of supplemental diffuse daylight.

4.0 LIGHTING ANALYSIS TOOLS AND METHODS

4.1 UMass Lowell University Crossing

The atrium at University Crossing uses a pairing of two primary daylighting techniques, a large north-facing window for diffused general illumination coupled with a south facing mirrored reflector hung within the atrium skylight. The mirrored reflector is aimed primarily at the north face of the atrium interior. The glazed north face gives effective general illumination to much of the atrium, while the reflector allows for a play of light to activate the primary sculptural surface that defines the space.

The reflector at University Crossing was designed through a highly iterative process between Perkins+Will and Lam Partners. It is composed of a fixed series of surfaces that is calibrated to reflect and aim multiple incident solar rays over the course of the day and year. As in other precedents, there is a diffusing partner to the reflector. At University Crossing a sculptural wood-slat surface is hung on the interior north face of the atrium between the reflector and the primary balcony lounges. This surface acts as a baffled lantern, diffusing and filtering the daylight as it plays off its surface. The result is a play of intense and animated daylight on what would normally be a simple, artificially lit surface.

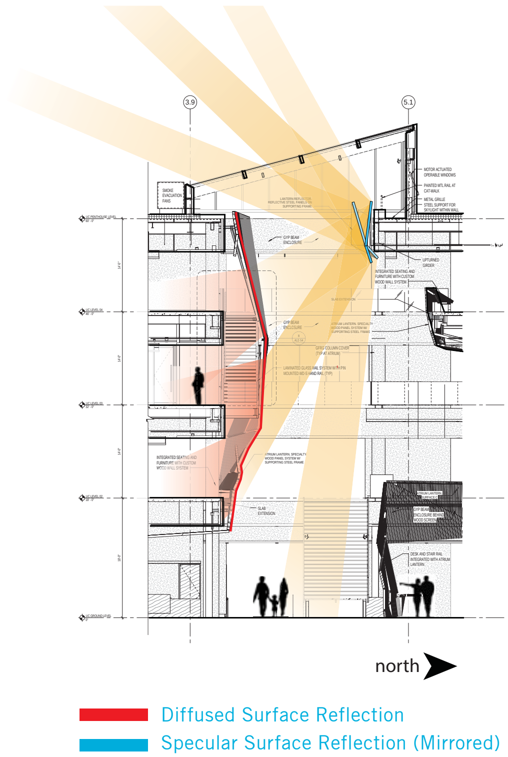
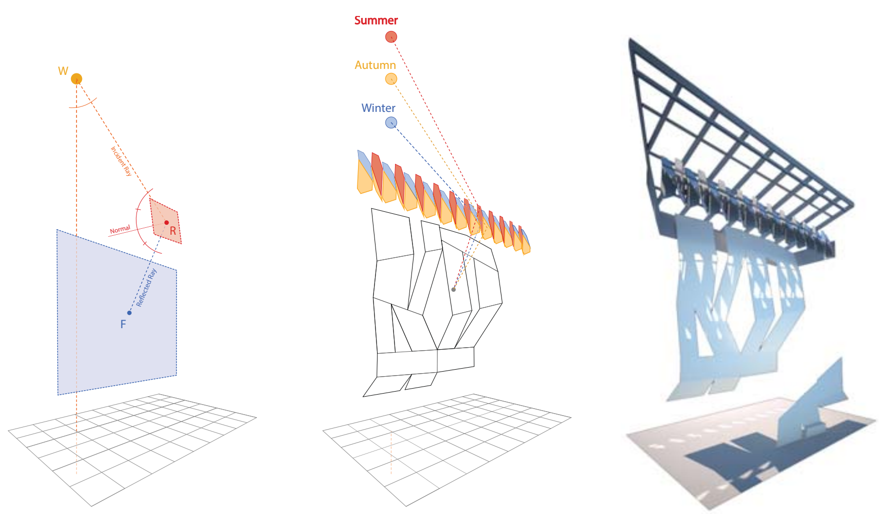


Figure 13: Reflected daylighting parti.



The normal of a reflective surface is derived from the incident solar vector and the focus (F) and reflector (R) points.

Multiple solar positions over the course of the day and year can be used to generate a series of surface normals.

Surface normals can be used to generate a faceted or curved surface that reflects light in a way that can be simulated using rendering engines.

Figure 14: Daylight redirecting strategies at University Crossing.

4.2 Design Process

In studying the reflective and diffusing surfaces of the Umass Lowell Atrium, the team used a number of different tools and processes through the design phases. The following is a summary of the most effective tools used for the design and analysis.

4.2.1 Angular Studies in Reflection

The architecture of the UMASS Lowell Atrium can be conceived of as a “building scale” light fixture. The lighting source, reflective housing and diffusing materials are all present in the design. The source of this fixture is obviously not static. The dynamic angles of solar lighting require a rigorous, iterative and experimental approach to redirect daylight. The process starts with an understanding of the fundamentals of reflected sunlight.

Reflective design surfaces can be angled to aim the most subtle changes in incident vector that result from changing solar position.

Two vectors are needed to define the angle of the reflective surface, the first is the angle of incoming light known as the incident vector. The incident vector of incoming sunlight can be identified through various computer simulation tools or by using the altitude and azimuth from a typical solar chart. The second vector is defined by two points, the target focal point within the building and a specified point of reflection. The bisecting vector between these two lines will be normal or perpendicular to the tangent of the reflective surface[11].

Targeted reflected vectors from multiple days during the year and times during the day must be identified to set loose guiding geometric parameters for the reflective and diffusing surfaces of the space.

4.2.2 Physical Modeling

Early in schematic design the team began studying the design through a physical modeling process. A large scale model was built and placed on a heliodon to simulate real solar angles. Physical modeling of daylighting strategies early on can be an incredibly effective method of exploration for the team. It can provide a rapid design, prototyping and evaluation loop that can be achieved with multiple team members present. The lack of specificity in the process liberates the team from the focus on precision that drives the typical computer simulation process. Video and photography can be recorded from the process and then presented in a way that engages the client without the level of abstraction and technicality associated with computational simulation.

Figure 15: Physical models.

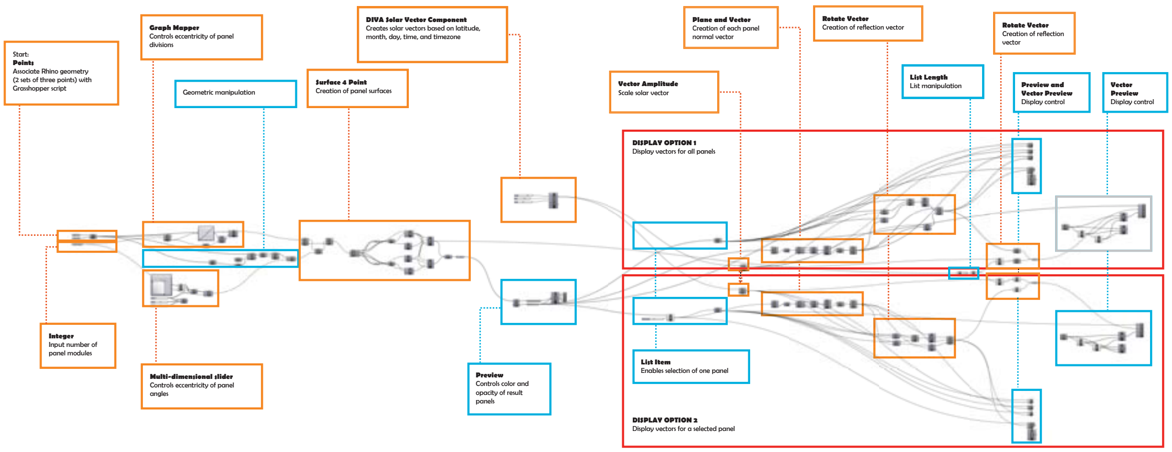


Figure 16: Grasshopper definition parametrically defining reflective surface geometry based on the visualization of solar incident angles.

4.2.3 Parametric Study

After studying potential reflective solutions loosely in physical model, the team moved to the computer to refine the design. At this point, a general scheme had been developed and the next step was to determine the specific panel dimensions and angles that would produce the desired redirection of light onto the lantern. Time constraints required that the team find a quick way to try out numerous variants and test their effectiveness. Lam Partners opted to model the reflector in Grasshopper, a plug-in for Rhinoceros, because the designers could create loose, parametric models that could be used to "sketch" digitally, allowing them to quickly change geometry and generate multiple variants in a short period of time. Grasshopper also allowed for a direct interface between building geometry and incident solar angles through the utilization of DIVA, a daylighting simulation tool built for the Rhino platform. By using a plug-in for Grasshopper, called DIVA-for-Grasshopper, the team was able to visualize the direct relationship between building geometry and the reflected rays of light generated at a given moment during the year.

Having selected this platform, the team needed to determine what simulations to use to evaluate the model. The most typical daylighting simulations' results (values for illuminance and daylight autonomy, which simulate daylighting levels in a space) were less valuable to the study. In this case, the design goal was not to increase overall light levels in the space (light levels were high in general, given the skylight configuration and the north glazed wall). Instead, the objective was to determine which reflector panel orientations would redirect sunlight onto the scrim and balcony lounges beyond. Lam's team might have generated RGB or false color images that would show how the light was redirected with each reflector variant, but these simulations can take several minutes to run for each geometric variant. For this stage of the process, what was needed was to create a model that could give rapid feedback based on what panel orientations were most effective for particular sun angles.

The solution was a Grasshopper-enabled Rhino model, which displayed the direction and angle the sun would hit the panels at any given date and time, and would show the direction and angle of the reflected light. To create this, Lam's designers used the solar vector component in the DIVA plug-in to generate the incident solar vector at any date and time throughout the year, and from there developed the model to generate the resultant reflected vector. The generated script also allowed for the display of incident and reflected vectors. Because this model does not involve light level simulations, the results could be reviewed in real-time as the date, time, or the geometric configuration was changed. There was another important value to developing the reflector model in this way. As integral members of the design team, the daylighting consultants wanted to create a "flexible" model that would be useful to the architectural team as a design tool. The model needed to be sufficiently adaptable so that it was still usable even if the design changed. The model could have been gen-

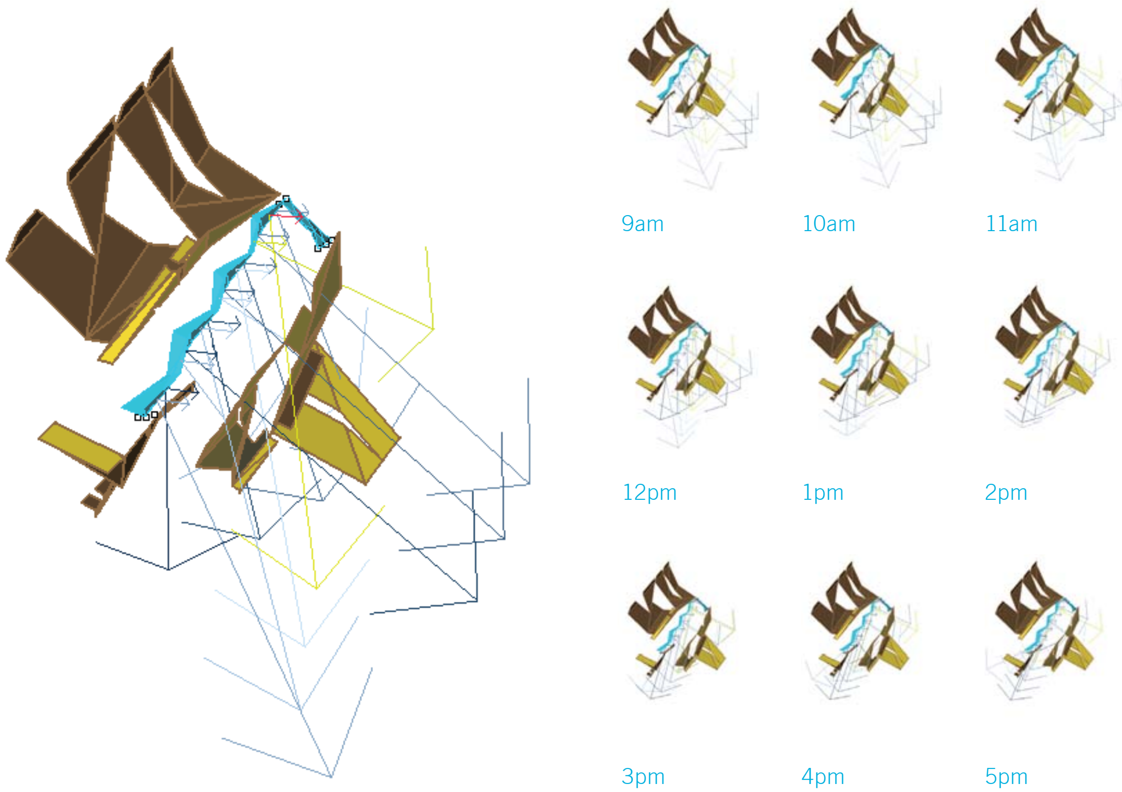


Figure 17: Using the DIVA plug-in, the solar vector component was used to generate and display the incident solar vector as well as the resulting reflected vector in real time.

erated based on a pre-determined time of day or year for the purposes of optimization, but that kind of model would have become restrictive if the design criteria had changed along the way. The team also wanted to maintain freedom in the model to adjust panel dimensions and angles as the process moved into the fabrication and costing stage. In essence, the team wanted to develop a system for collaborative design rather than a set of results. Using this model. both the architectural team and the lighting consultants could work together to determine the most effective and desirable panel angles. The solar vector display model developed here is evidence of a new way for architectural teams to collaborate, in which constraints and parameters are established by one party and modified by the other. Working in this way builds a common model in which the design is informed by the goals and constraints of each team member, but also allows the team members to explore a wide variety of design solutions that satisfy those criteria.

4.2.4 Rendered Prototypes

Once the reflective geometry and the diffusing geometry was modeled and tested using Grasshopper and DIVA, the team used a number of ray-tracing rendering engines to further test the design. In this stage, the team also used conventional rendering techniques to confirm the aiming of the reflector panels. The project had proceeded far enough along to allow for a costing cycle to be complete and the reflector and diffuser geometry was simplified and technically developed.

To confirm the effectiveness of the reflective geometry, the reflector was set to a mirror finish allowing the target of the reflective light to be easily seen in the rendered images.

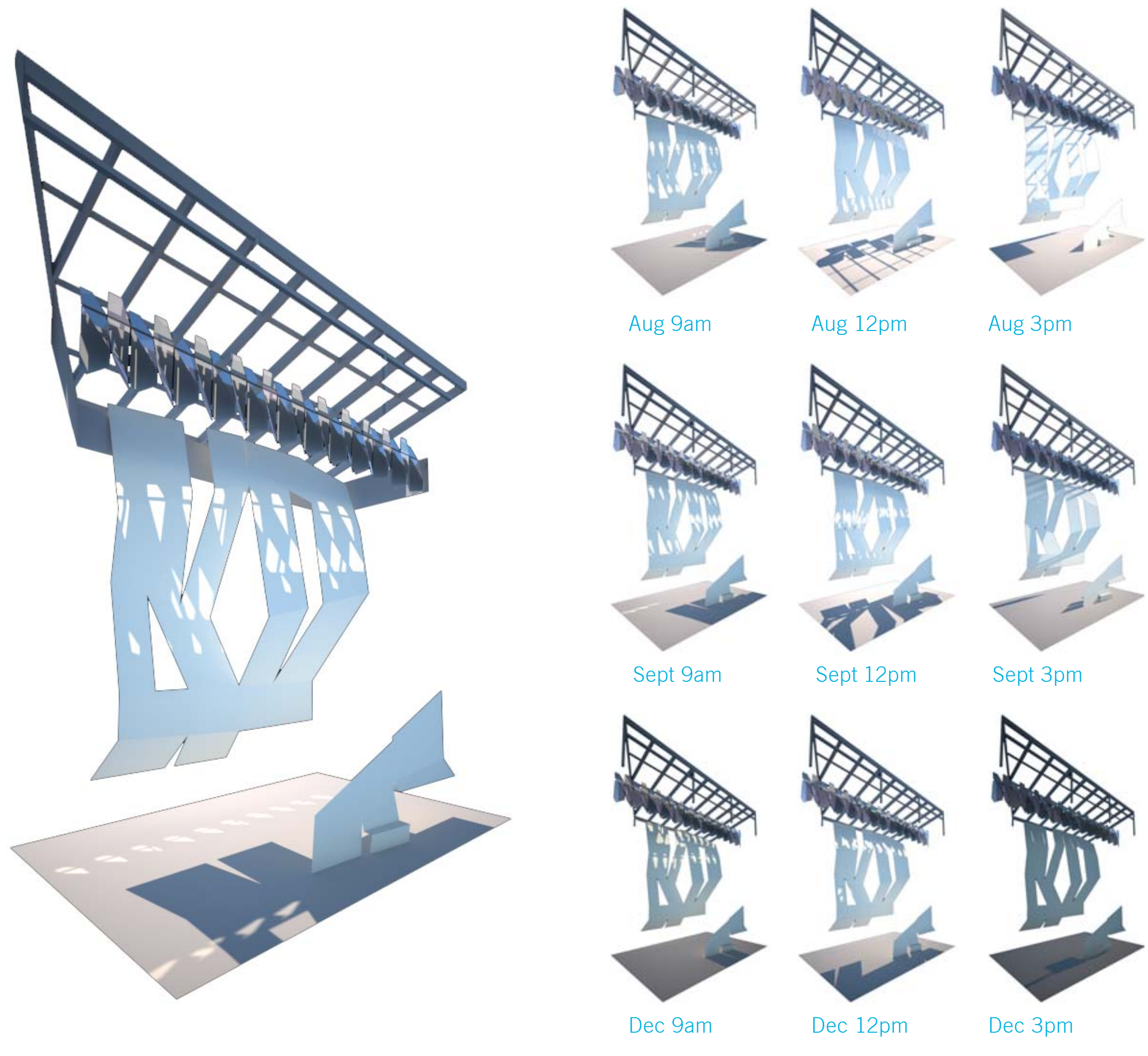


Figure 18: Rendered prototypes allowed the reflected light to be more accurately tuned.

5.0 MATERIALS AND CONSTRUCTION

5.1 Construction

In parallel to the geometric development of the reflector and diffusing lantern, the team explored various methods of fabrication and construction. The following section discussed the critical set of issues evaluated during the design process.

5.2 Reflector Location

Early on in the process, the team discussed the advantages and disadvantages of the physical location of the reflector. Key to this discussion was the building massing and orientation. The reflective geometry was largely driven by the orientation of the atrium and its skylight. Taking advantage of the linear skylight, it was determined that the most effective scheme was a linear reflective surface located on the south side of the atrium skylight. The angular analysis showed that the reflector geometry might have been developed inside of the

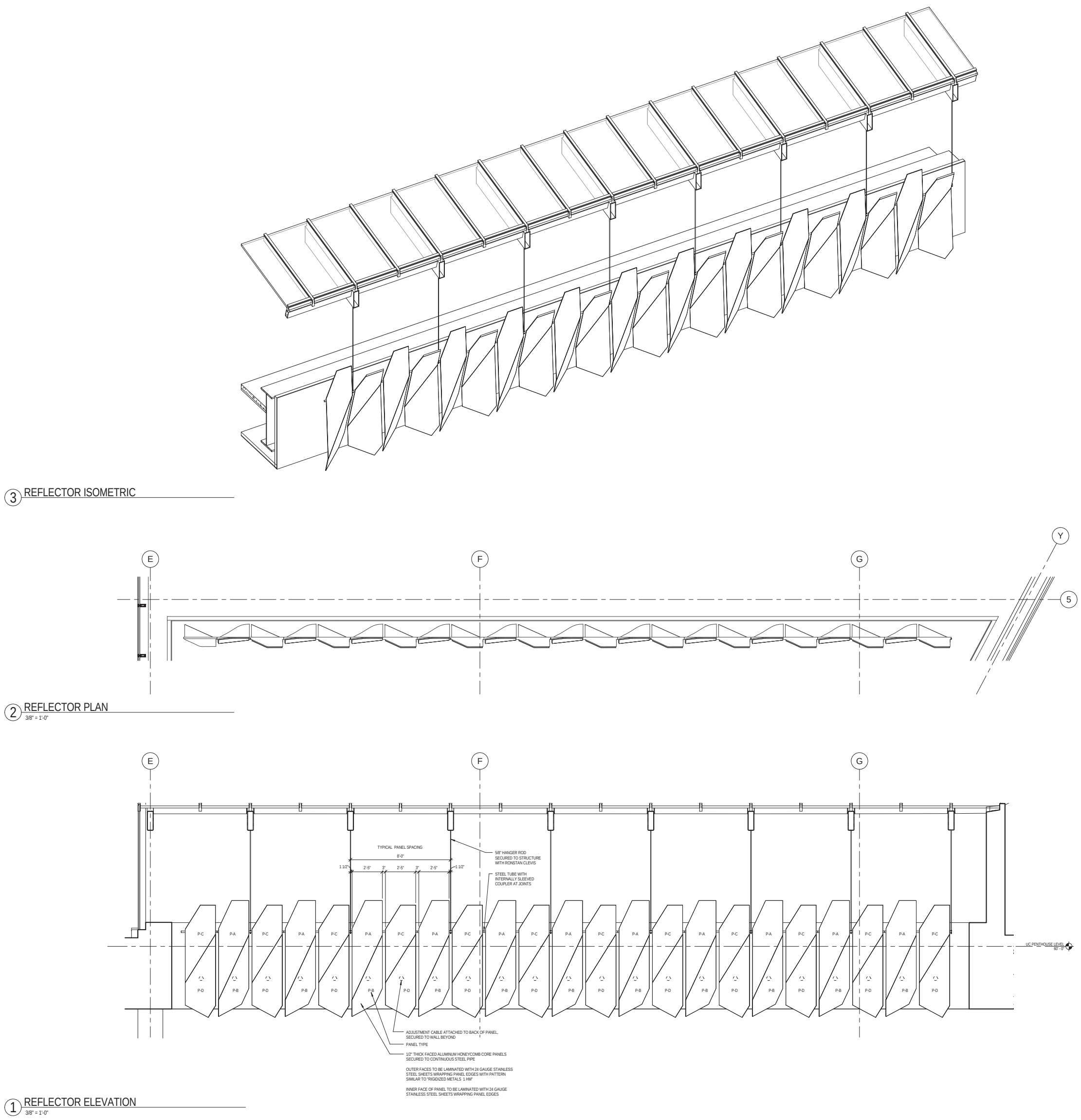


Figure 19: Finalized reflector geometry hung from atrium structure.

building envelope, outside of the building envelope or both to effectively light the diffusing lantern. A number of factors lead the team to the development of a design that is hung from the skylight structure within the building. By taking advantage of the cavity of space required by the smoke evacuation system, the team could explore a wider range of materials due to the location's protection from the elements.

5.3 Reflector Structure

The team conceived of a number of strategies for the construction of the angular geometry of the reflector. Fixed building mounted frames, adjustable hung framing systems were reviewed and priced during the process. Ultimately a series of rigid, faceted panels that could be hung from the skylight framing was determined to be most effective. A lightweight aluminum honeycombed panel substrate was selected to keep the supporting structure as minimal as possible. Operability was unnecessary since the variability of incoming solar angles was resolved with a varied geometry. However, the ability to tune the final angles of the hung structure was important and was accomplished through a simple adjustable horizontal cable system.

5.4 Reflective Materials

The surface of the reflector itself was an important variable within the design. A primary design goal for the reflector was to produce an active play of light over the lantern surface. With this goal in mind, the team selected a hammered aluminum panel with a mirrored finish. The concave, yet specular dimples of the metal surface act like small lenses allowing for a reflection of light that is diffused without a significant loss through absorption. The aluminum was light, inexpensive and could be veneered to the hung honeycomb panels. Aluminum, when polished, reflects the vast amount of the visible spectrum.

Figure 20: Expanded aluminum honeycomb substrate used for the reflectors.

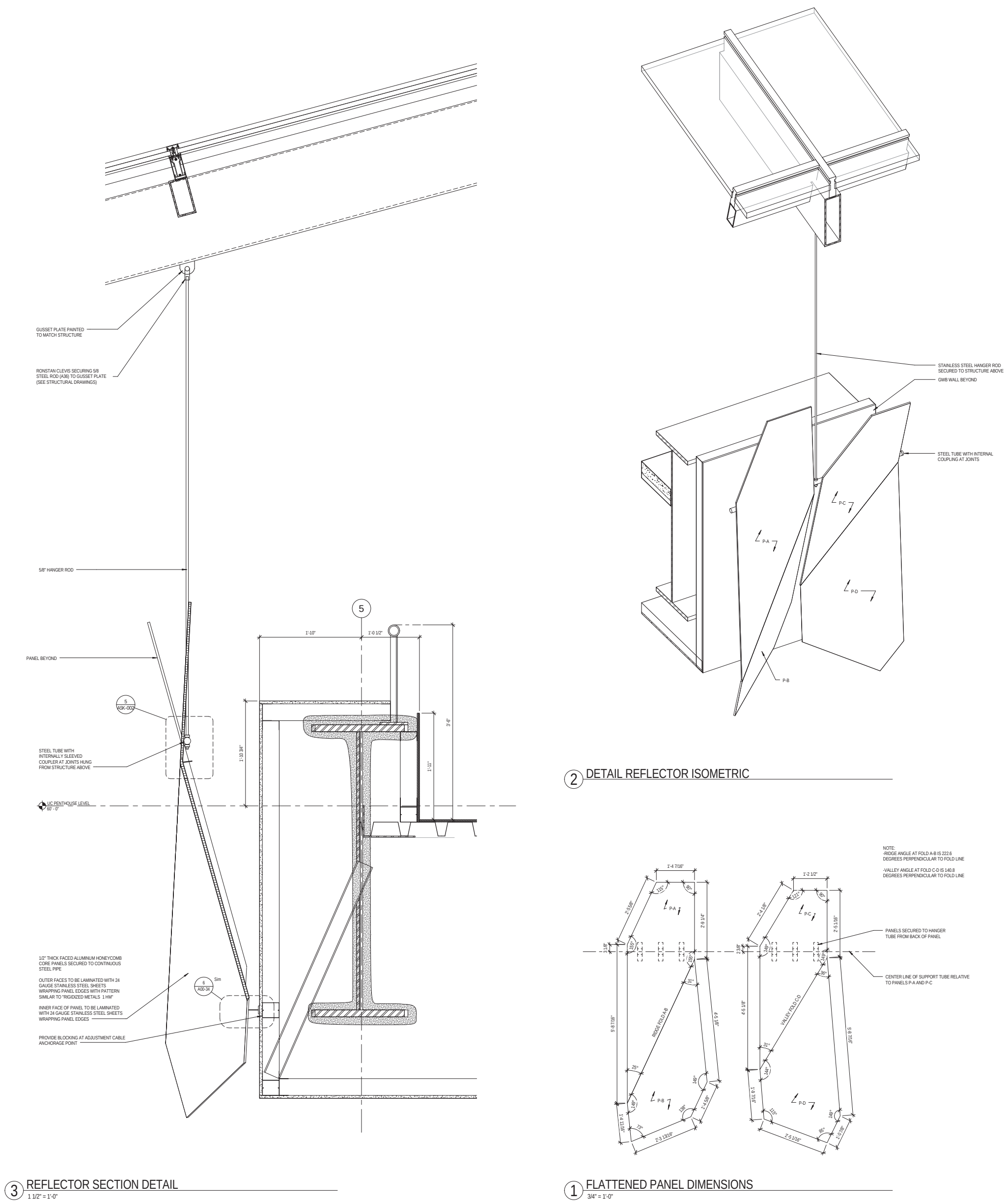


Figure 21: A lightweight panel was selected to keep the supporting structure as minimal as possible allowing for flexibility in final tuning in the field.

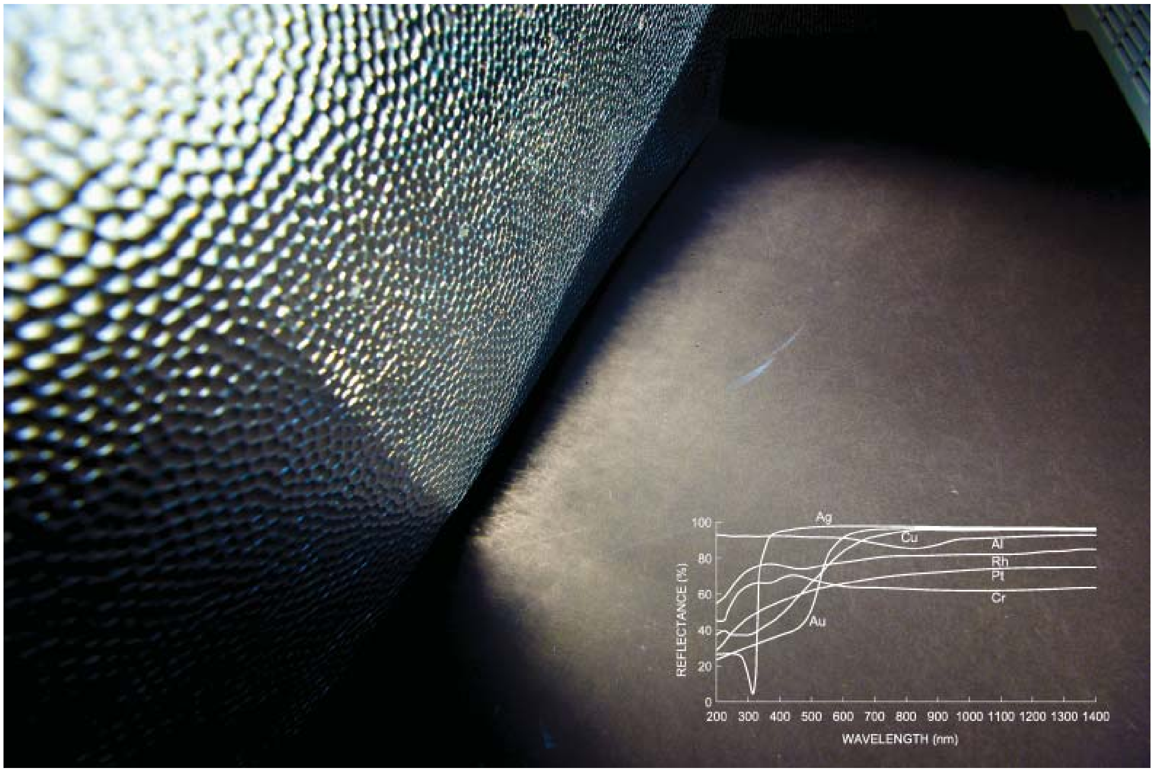


Figure 22: The concave dimples of the polished, then hammered, stainless steel surface act as small lenses allowing light to reflect and diffuse without significant absorption[12].

5.5 Material Considerations

The expansion of the metallic surfaces when heated by the sun was considered in the detailing. Each hung panel was kept isolated to avoid an aggregate of smaller expansions[12]. The panels were designed within the dimensional constraints of typical metal coil widths to minimize waste in construction.

5.6 Diffusing Lantern

The surface receiving and diffusing the redirected sunlight acts in two directions. From within the atrium, the lantern is an architecturally unifying element and receives the play of light over the course of the day. It further reflects diffused light down to the atrium floor. Since the lantern surface is articulated as a visually permeable wood slat system, it allows a filtered patchwork of light to penetrate the balcony lounges. This warm, diffused natural light splashes the north facing student lounges at different times of the day during the year. Alternatively, the team considered stretched fabric panels, translucent glazing, metal mesh and other materials as alternatives for the diffusing lantern. The diffusing material needed only to reflect and scatter light to be considered within the lighting scheme.

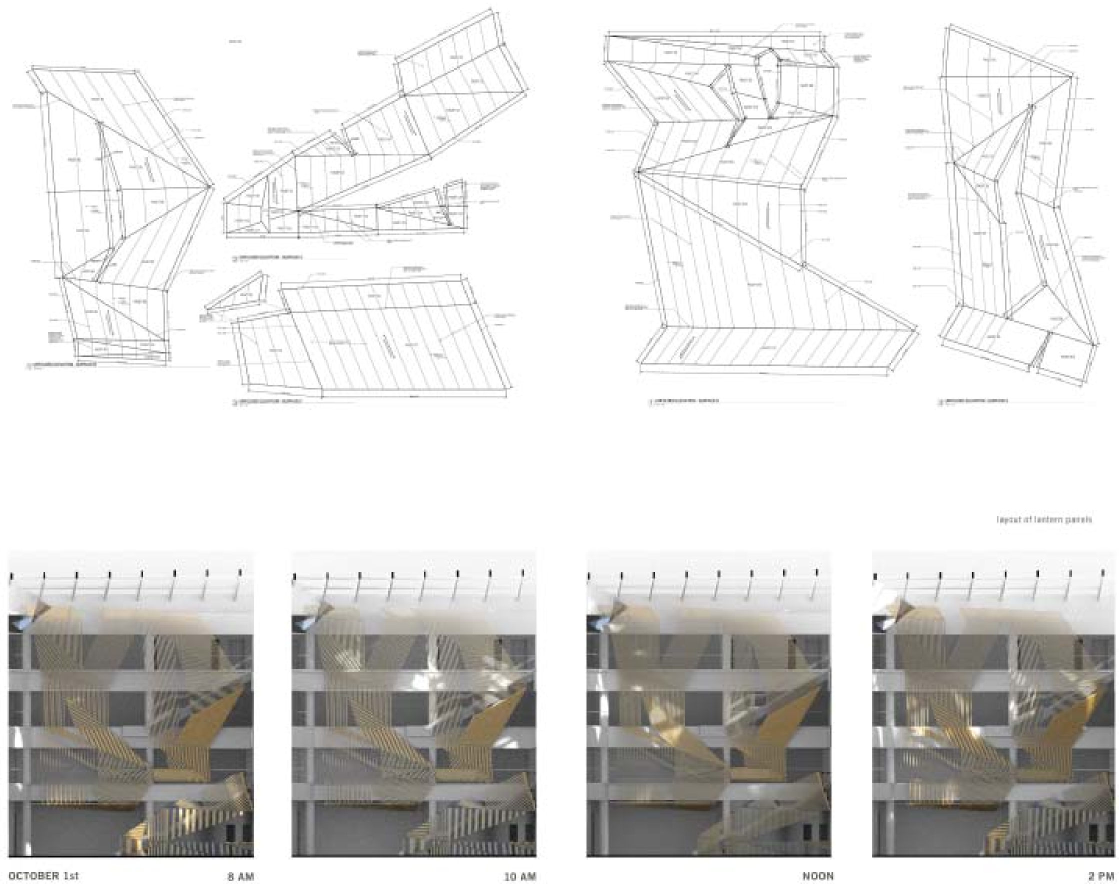


Figure 23: Final studies were rendered to test the reflected light on the lantern.

6.0 DESIGN METHODOLOGY

6.1 Iteration and the Collaborative Design Process

While working on University Crossing, the team engaged in a highly collaborative and highly iterative design process. After the design was complete, it became apparent that the process was crucial to the team's success and key attributes are described in the following section. We start by defining an iterative creative sequence: an iterative design process can be described as having four crucial phases, each phase is present in each successive cycle of non-linear design thinking[14]. The speed at which the team can cycle through a design iteration is crucial to the resolution of the design. The rate of iteration is likely to change over the course of the design, cycling rapidly at first and lengthening as the design becomes more resolved and more complex.

6.2 Iteration and Research

Iterative design is a process-based design methodology. Within an iterative design process, research is embedded and research tools must be invented to help the entire team explore as a collaborative unit. Lam Partner's work in inventing scripted geometry to govern the reflective surfaces of the project was a critical example. As a cycle of iteration moves a concept forward, questions emerge out of the process of design evaluation. These questions alter the concept, defining subsequent design cycles. As a result there is both the opportunity for iterative waste as well as iterative progress in resolving the design. Within this process, waste can be defined as study or studies that fail to inspire decision or redirection. Rapid and direct feedback from Lam's scripted geometry allowed the team to minimize design waste and quickly cycle through effective iterations.

6.3 Iteration and Invention

Crucial to a collaborative design process is the invention of common tools for exploration. Common tools allow for shared experiences, and therefore shared conclusions. They allow for a common and specific language for describing the design, and most importantly, they allow for the cycles of iteration to be started by one mind (or set of minds) and finished by another. In the case of University Crossing, the team used a number of cross-disciplinary tools. Rhino, Grasshopper and Diva were used as a digital platform and physical models were exchanged. This freed the team to allow for multiple minds with different priorities, experiences, focuses and thought processes to iterate on another team member's progress.

Common tools and collaborative teams allow for conclusions to be drawn together rather than separately. Successful teams iterate based on common values, not based on active attempts to counterbalance another's design position.

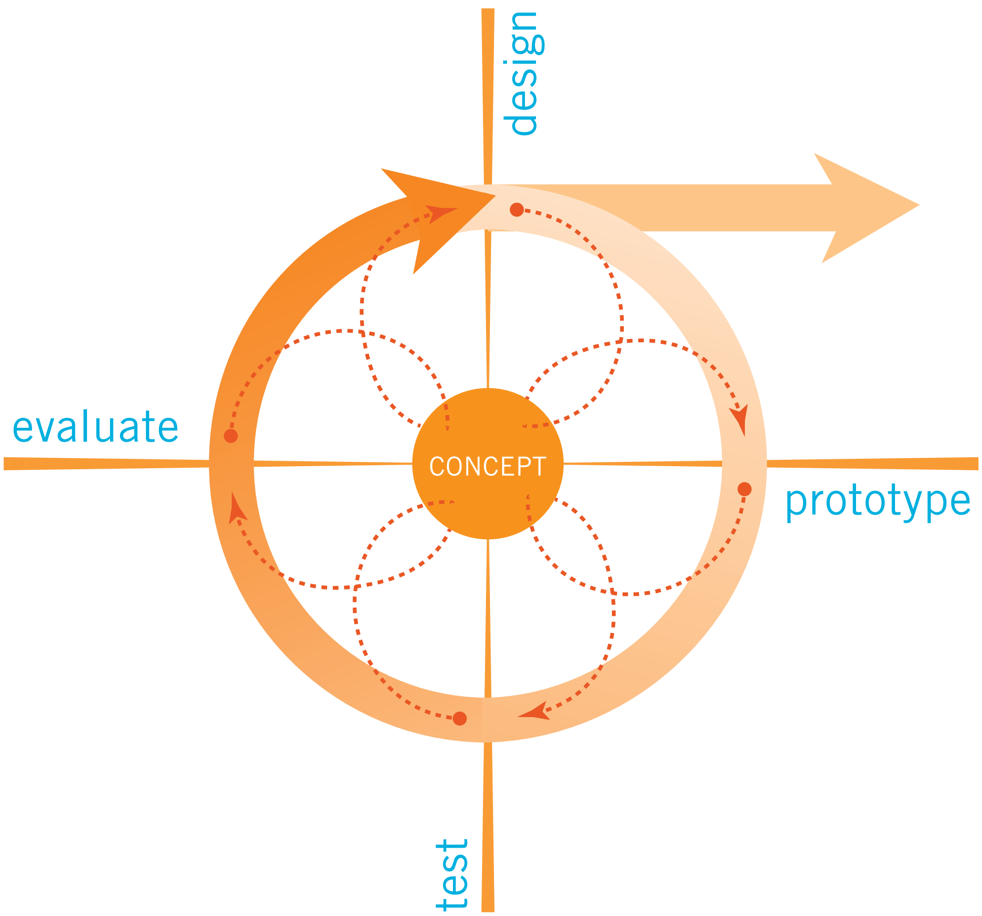


Figure 24: An iterative design process was critical to balance the technical and visual goals of the design concept. Each iterative cycle advances and influences the concept. At times multiple cycles may be running concurrently[13].

Schematic Design

Design- Define the lighting concept and objective for the atrium and surrounding tributary spaces.

Prototype- Model various skylight aperture sizes and configurations based on lighting concept weighing section height, floor plate depth.

Test- Test the skylight aperture sizes through radiance-based simulation and building energy performance.

Evaluate- Evaluate the benefit of reduced lighting loads and quality of environment against heat loss and solar gain through glazing.

Early Design Development

Design- Configure atrium defining surfaces to receive, or further diffuse light. Determine the focus of directed light and propose reflector configurations using angular analysis.

Prototype- Model various skylight aperture shapes and reflector configurations to support earlier evaluations.

Test-Use radiance-based daylighting platforms and physical models to test effectiveness of focus points for multiple dates and times during the year.

Evaluate- Review the daylighting effectiveness and focus of the lighting to validate that it supports the initial design concept.

Late Design Development/ Construction Documents

Design- Begin conceptualization of tectonic approach to reflector language.

Prototype- Build physical models of the reflector and diffuser languages.

Test- Test the diffusion and reflectivity of the materials with realistic distances and lighting levels to confirm earlier simulations at a smaller scale.

Evaluate- Confirm that the physical simulations support the desired effect of the concept.

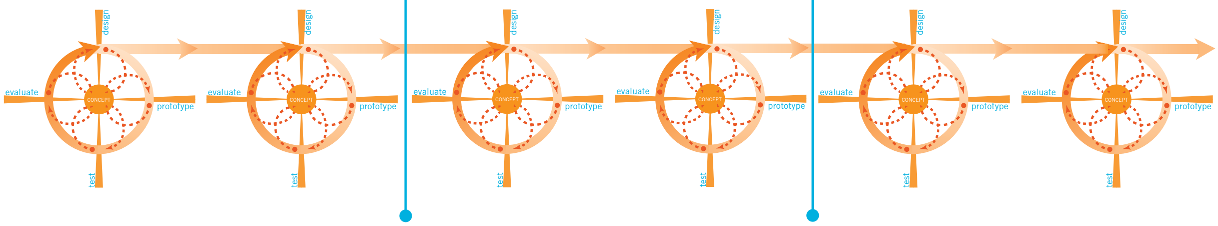


Figure 25: Design studies, prototyping techniques, testing and evaluation methodologies were present in each development cycle.

7.0 CONCLUSION

The design of University Crossing for the University of Massachusetts in Lowell provides a meaningful precedent for daylighting, both in process and in its built form. The team's exploration moved beyond the common simplicity of published rules for daylighting to test an expressive design language rooted in the challenges of sustainable urban growth.

As urban communities continue that growth, pressures will increase the need for sustainable, highly connective sites. Design opportunities like the one at UMass Lowell will become more prevalent and more relevant to the design of daylit buildings. It is imperative that designers explore new tools and new processes to tackle the challenges and complexities of daylighting deep footprint buildings on challenging urban sites.

Fundamental to these processes, is the work of creative, collaborative, multidisciplinary teams. As groups of professionals come together with differing skill sets, vantage points and creative ideas, they must use and invent common design platforms and processes to progress a design language. Advancements in customizable modeling tools, parametric design, rendering and rapid prototyping (as well as the tried and true methods of physical modeling) make true, interdisciplinary daylighting design an achievable goal. The linking of traditional and contemporary daylighting tools allows multiple generations of minds to contribute to the wealth of a design idea by balancing one group's knowledge gap in historical precedent with the other's in digital exploration. Studies of precedents set the creative groundwork for healthy iteration, priming the team with the fundamentals of tested ideas. This process pushes them to expand the architectural dialog with ideas formed from innovation, rather than simple improvement.

Digital daylighting tools continue to evolve. Prototypes built on a platform that can be used between multiple disciplines allows for an iterative process in which designers of each point of view can participate regardless of the specific stage in the iterative cycle. This allows for an efficient, creative exchange of ideas in which variations are prototyped, tested and evaluated against project aspirations in a fluid process. When explored efficiently, ideas that are tested, evaluated, but rejected become crucial to maturing the final design. The digital outcome of a highly iterative design process has the potential for direct translation to the growing computer aided fabrication industry. Physical prototyping along the way allows for practical tests of constructability and helps in finding buildable solutions from traditional and current fabrication technologies. They help dissolve the risk of a complex daylighting solutions failure if the efficiencies of mass-customization do not prove a reality. The goal of smart, dense urban growth coupled with ambitious, varied design aspirations demands an exploration of daylighting that moves beyond the traditional methodology of simple implementation. It propels us to practice in a way that embraces the iterative processes of innovation and engage in the practices of prototyping and digital fabrication. With these aspirations we find daylighting can form the foundation to more expressive, sustainable design.

Acknowledgments

In some cases the creative process might occur as a focused individual study that can be described through monolog. The design of University Crossing at University of Massachusetts Lowell is not the case. It is the result of a passionate collaboration of many minds, many rolls and many disciplines. It follows that this case study represents the product of a large, talented team striving to contribute to an open, collaborative environment. The primary contributing design team members are listed below:

PERKINS+WILL: Dana Anderson (Principal), Brian Healy (Design Director), Patrick Cunningham (Project Designer), James Forren (Designer), David Damon (Associate Principal), Andy Goetze (Project Architect), Christina Long (Project Manager), Emily Lammert (Designer), Jennifer Rheaume (Interior Designer), Christine DiLallo (Designer), Sam Williams (Designer), Jessie Greenberg (Interior Designer), Edward Dudley (Designer).

LAM PARTNERS, ARCHITECTURAL LIGHTING DESIGN: Paul Zaferiou (Principal), Kera Lagios (Designer), Nathanael C. Doak (Designer).

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03.
GAME CHANGERS:
Shaping Learning

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ABSTRACT

New technologies have increasingly moved to the center of 21st century learning inspiring innovative learning concepts and potentially influencing our conception of educational space. This article looks at the connection between game-changing ideas in education and school design. It looks at the benefits and challenges that new technologies bring to the K-12 environment. It describes their connection to inventive pedagogical ideas and their potential effect on the design of physical space.

The research refers to discoveries in neuroscience and cognitive psychology; it introduces theories about the ideal learning environment and takes a look at studies about the influence of the environment on academic performance and behavior. Examples of spaces that respond to inventive educational ideas illustrate the relationship between new learning concepts and physical space.

Data and reports from online and print publications on the subject formed the basis of this research. A number of schools that express the integration of technology and a commitment to new learning styles in their designs were chosen as examples. Site visits allowed to witness the use of inventive learning space first hand and to interview architects, an environmental psychologist, a researcher and educators to gain a better understanding of the learning concepts and the related designs. The fact that many examples are located in Europe does not imply that there are no examples in other parts of the world. The case studies have been chosen based on strength and clarity of design and for their highly experimental quality.

KEYWORDS: K-12, new technologies, games, neuroscience, learning environments

1.0 INTRODUCTION

Traditional educational concepts have been scrutinized in the face of rapidly evolving technology and with the rise of new theories in learning sciences. While traditional education focuses on acquiring basic skills and on content knowledge, many experts believe that success in the 21st century requires the higher order skills as defined by Bloom's taxonomy: the ability to think, solve complex problems, and interact critically through language and media[1].

Alternative learning ideas that build on the availability of technology and on a revised understanding of key skills required for today's global economy have become a central theme among progressive thinkers. Many new learning styles have emerged in recent years as a result. These innovative approaches to teaching and learning question traditional knowledge-based methods in favor of creative, interactive, collaborative, and technology-driven models. Findings in learning sciences often support their validity.

In the context of recent developments in education, it seems surprising that many school buildings are still built the way they were many decades ago. The ConnectED Initiative, introduced by President Obama in June 2013, stated that our schools were designed for a different era. It asserted that the current school system does not sufficiently address the constant learning opportunities of global connectivity, nor does it prepare students for a collaborative and networked economy[2].

This research takes a look at the relationship between innovative learning concepts and the spaces surrounding them. It explores how new technologies in the classroom and innovative educational concepts can drive the design of K-12 spaces. It looks at the manifestation of progressive pedagogical ideas in school settings and investigates the influence of the environment on students.

2.0 SHAPING LEARNING

2.1 New Technologies

A new form of literacy, embracing information, media, and technology, is often named as one of the most important 21st century skills expected of today's students. Consequently, the need to incorporate innovative digital technologies into the curriculum as a learning tool and as subject matter has been a central topic among educators worldwide. With the youngest generation of students and teachers spending more time online than previous generations, it seems only natural to integrate tablet computers, smart phones, the internet, social media and online learning programs into the curriculum. Increased engagement, interactivity, and personalization of learning are among the top benefits expected of the use of mobile devices in the classroom.

Research on the influence of emerging technologies on learning is in its early stages. Advocates say that digital devices hold the attention of a generation raised on gadgets, teach 21st century skills, and allow students to learn at their own pace. Digital technologies are further expected to support collaboration, improve student achievement, allow for innovative forms of content creation, enable increased access to education and virtual learning communities, and facilitate innovative forms of assessments.

Many teachers believe that students' constant use of digital technology affects their attention spans and their ability to persevere in the face of challenging tasks. Other concerns include theft, network security, internet safety, district liability, and the costs of equipping a school with new technology and of training teachers to use the tools effectively. A 2013 Pew Research survey revealed that the majority of the surveyed teachers believe that technology rarely makes a difference in academic performance and that new technologies could widen the performance gap between students from higher-income families and those from lower-income families with limited access to computers[3].

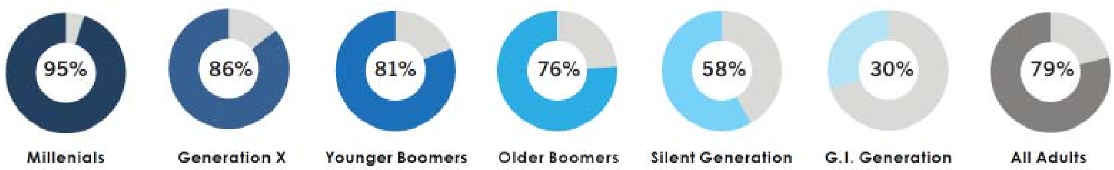

Figure 1: Percentage of online users by generation.

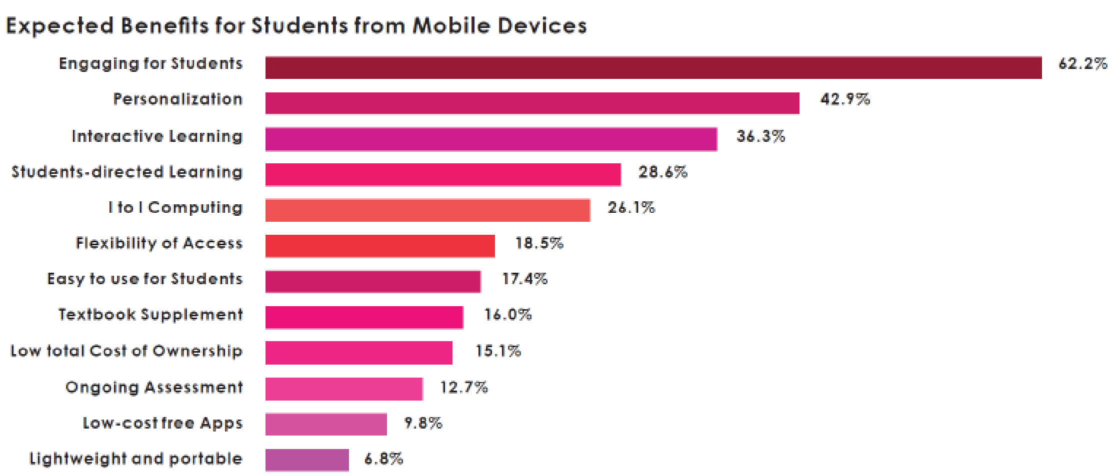

Figure 2: Use of mobile technologies in the classrooms and their benefits (Source: 2013 IESD Mobile Technology for K-12 Survey).

The overall consensus among critics and supporters alike seems to be that the teacher is still the most crucial factor, and that new technologies are just a tool. How they are used is what makes the difference. Many teachers still teach the “old” way with new tools, and as result, do not fully reap the benefits.

Inventive ideas for the use of technologies in the classroom, however, offer possibilities for profound changes in teaching and learning. One method of learning with new technologies that gained attention in the past years is the flipped classroom, where students listen to online lectures at home and use classroom time to do homework. This allows students to learn the new material at their own pace at home and benefit from teacher and peer help to solve problems during classroom time. Some school districts report success with this model. Best known among the providers is the Khan Academy, which offers free online lectures, practice videos and performance summaries.

Critics like to point out that the Khan Academy and similar online learning programs still teach the traditional way relying on lectures and quizzes. TED Prize 2013 winner, Sugata Mitra, promotes an entirely new approach to learning through new technologies based on his beliefs that children are naturally curious and that learning is self-emergent. He suggests “minimally invasive education” where teachers move into the background and watch student-driven learning unfold. He proved his point with the “hole in the wall experiment” in which he installed computers with a high-speed data connection in walls in New-Delhi slums and watched how, within days, children taught themselves to draw on the computer and to browse the net. In his current “school in the cloud” project, children worldwide learn and discover by themselves on a worldwide cloud network.

Salman Khan, founder of the Khan Academy, and Sugata imagine spaces for future learning to be very different from what we see today. Sugata Mitra envisions his “school in the cloud” as a glass pod filled with computers and with one large screen to allow moderators to skype in and play a role in the education of the children. Salman Khan promotes team-teaching and interaction during class time asking “do we have to separate classrooms anymore?”

New technologies and innovative ideas that build on them call for changes in the set-up of learning spaces. With lectures becoming less predominant, classrooms are sometimes complemented or even fully replaced with open learning spaces that foster interactivity and team work. Adaptable and flexible spaces and furniture allow individual and small group learning as well as learning across classes and subjects. Collaborative pods that replace rows of desks reflect the move towards student-directed learning with new technologies. Tablets, laptops, and interactive whiteboards become standard equipment. Learning may not be limited to a specific physical space. Through connectivity and mobility, any space can be a potential place for learning as long as learners and educators effectively connect and collaborate. With the widespread use of new technologies, opportunities to create learning networks that transcend place become available. The immediate environment outside the school can be more easily explored since new mobile devices and apps allow tapping into resources that are available within the community.

Figure 3: Ørestad High School (Photograph by Adam Mørk, courtesy of 3xn architects).

Some progressive schools invest in multifunctional spaces that promote innovative technologies and new ways of learning. One example is Ørestad High School, outside of Copenhagen, Denmark, designed by 3xn architects (Figure 3). This grade level 10-12 school, also known as the "Virtual College," focuses on media, communication, and culture. Almost everything at the school happens online with wireless internet and laptops available for all students. Learning occurs in five stories of predominantly open space. Ørestad High School emphasizes social interaction, interdisciplinary learning and collaboration. The few enclosed team rooms are used mainly for freshmen and at the introduction of subjects.

Acoustics and distractions are a potential issue in this mostly open space. Mille Sylvest, an environmental psychologist whose doctoral studies concern social behavior in buildings, notes that the students at Ørestad High School learn quickly to handle distractions and to adjust their behavior to the environment, occasionally, for example, telling each other to keep their voices down in the open space[4]. Teachers similarly have to adjust their teaching styles to benefit from the open spaces.

The potential noise issues were addressed in multiple ways during the planning phase. A suspended acoustical ceiling made of finely perforated metal provides excellent sound absorption. Walls and floors are acoustically separated. The walls are finished with a multi-layer gypsum system that is particularly effective for medium and low frequency sounds. The rubber flooring compound as well as the carpet in the student islands further help attenuate sound.

Ørestad High School is a fairly radical spatial expression of changes in learning. The open space clearly favors the learning of skills such as the ability to collaborate and interact effectively through language and media in a technology-driven environment.

In 2009, Denmark became the first country in the world to allow students to use the internet during national exams. Educators wanted to move away from memorizing facts, figures and formulas towards testing a student's effectiveness at finding and analyzing material. The Danish Minister of Education Bertel Haarder explained: "our exams have to reflect daily life in the classroom and daily life in the classroom has to reflect life in society"[5].

2.2 The Power of Play

The integration of new technologies in the classroom as a reflection of society goes beyond merely using digital devices. One interesting direction in learning related to new technologies is play and gaming. Research shows that play, more than any other activity, fuels healthy development of children's brains. Play supposedly improves working memory and self-regulation. It allegedly also helps language development and creative problem-solving skills. Stuart Brown, founder of the National Institute of Play and Associate Professor at the University of California San Diego, calls play "the single most significant factor in determining our success and happiness." His book *Play—How It Shapes the Brain, Opens the Imagination, and Invigorates the Soul* describes how play fosters creativity, flexibility, and learning, how it teaches perseverance and how to cooperate with others[6].

A large amount of time on smartphones and even more on tablets is spent with gaming (Figure 4). Some schools use this popular combination of play and new technologies to enhance learning. Proponents of game-based learning like to point out that games provide freedom to experiment and fail. They teach design thinking and problem solving skills, while fostering creativity and the ability to adapt to diverse situations. They reward perseverance and practice. One interesting aspect about gaming is that players willingly accept that the reward for mastering one level of a game is the harder work required to master the next level. This element of self-motivation appeals to many teachers. However, studies show that gaming has not only positive effects on the developing brain. Negative effects can include addiction or decreased attention spans, and the effects depend on how games are used.

Neuroscientists and behavioral psychologists do not yet truly know the implications of the increased use of technology on the developing brain. When neuroscience looked at the overall effect of our constant use of technologies on the brain, the findings were across the board. Some studies say that it hinders deep and creative thinking. Others, including Dr. Gary Small, neuroscientist and professor at UCLA, believe that children immersed frequently and early in technology are digital natives who are wired to use it elegantly. He believes that technology can train our brains in positive ways. A 2004 study at Beth Israel Medical Center, similarly presented the benefits of new technologies on brain func-

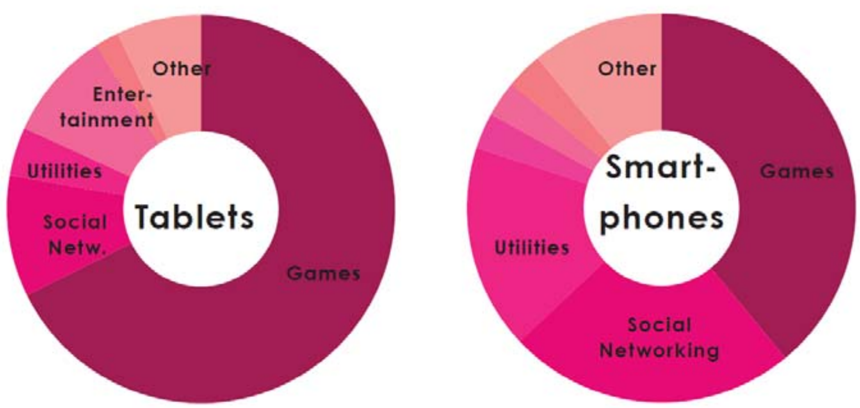

Figure 4: Gaming on tablets and smartphones.

Figure 5: Embodied learning (Photograph by Ken Howie Photography, courtesy SMALLab).

tion, by showing that surgeons who play video games make fewer errors[7].

Quest to Learn (Q2L) Middle Schools in New York and Chicago promote gaming as part of the learning process. The school's support of learning through action manifests itself through their SMALLab space that promotes "Embodied Learning" (Figure 5). Embodied learning brings new technologies, play, and movement together by combining physical interaction with game-based computer technologies. Instead of sitting in front of a screen, students move on interactive surfaces, generating images, graphs, and data through their actions. They can learn chemical titration, for example, by pushing king-size molecules in virtual space or they can study geology by building and shifting digital layers of sediment and fossils on the classroom floor. This model connects the digital and the physical and builds on brain research that shows how merging action with learning results in deeper, longer-lasting memory traces[8].

David Birchfield from SMALLab says that the concept is showing promise when it comes to improving learning results: A 2009 study found that at-risk ninth graders scored consistently and significantly higher in earth sciences on content-area tests when they had also done SMALLab exercises.

Large flexible open interactive spaces are ideal for learning spaces with SMALLab technology. With the mobile technologies generally used in game-based curriculums, learning can happen anywhere. In fact, the shifting boundaries between virtual and physical space and the organization of games around networks may lead designers to question even the need for physical classroom space. Futurelab, a British research organization, states that "rather than continuing to build a system based upon the mega-structures of schools, universities and a national curriculum, we need to move to a system organised through more porous and flexible learning networks that link homes, communities and multiple sites of learning"[9].

Figure 6: Multiple intelligences.

2.3 Learning Sciences

If the setting for learning becomes increasingly interchangeable and less tied to a specific place, what are the characteristics of a space that is conducive to learning?

Research is only at the beginning of mapping the influence of the physical environment on the brain, but safe, social, enriched and stimulating environments show great promise for enhancing learning. Some studies assert that learning in an enriched environment can generate up to 25 percent more brain connections. While research on the effects of the environment on the human brain is still in its infancy, experiments have shown that rats in stimulating environments develop bigger brains. They were smarter and found their way through mazes more quickly[10].

The Academy of Neuroscience for Architecture in San Diego, a collaboration of neuroscientists and architects, claims that there is evidence that certain types of spaces promote the growth of new neurons in humans. Their research looks at how architects could, with the use of color, lighting, and layout, design places that produce improved brain responses. A 2007 study by Joan Meyers-Levey shows how architecture can influence brain process demonstrating that a lower ceiling within a room promotes greater attention to detail by occupants while higher ceilings promoted greater abstract and creative thinking[11].

Discussions in learning sciences about the appropriate learning environment often refer to Howard Gardner and his theory of Multiple Intelligences (Figure 6), which suggests that intelligence is not a static IQ number, but a dynamic collection of talents that is different for each person[12]. Dr. Gardner proposes eight intelligences that all human beings possess in varying amounts, resulting in a unique intelligence profile for each individual. Though disputed among scientists, Gardner's theory has been accepted by many educators who believe that a classroom offering a variety of learning opportunities increases the likelihood of success for students. A number of schools structure their lessons to encourage variety, using music, cooperative learning, art activities, role play, multimedia, field trips, and inner reflection. Thomas Armstrong's book *Multiple Intelligences in the Classroom* describes how classrooms could be made compatible with multiple intelligences[13]. His checklist for classroom space for multiple intelligences suggests, for example, ample space to move around for kinesthetic intelligence, lots of interaction space for interpersonal intelligence and private space for intrapersonal intelligence.

Many visionaries push for a reformed education system based on recognizing students as individuals with diverse talents and based on what they find important to prepare children for the future. Sir Ken Robinson, for example, has harshly criticized the current education system for its lack of creativity. In his humorous and insightful TED Talk “School kills creativity”, the most viewed TED Talk ever, he states that creativity is as important in education as literacy. He suggests that personalizing education, rather than standardizing, allows us to build achievement on discovering the individual talents of each child. This calls for creation of learning environments where students want to learn and where they can naturally discover their talents.

Vittra Telefonplan, a K-9 school in Stockholm, Sweden, is built around the concept of respect for different strengths and learning styles. Many of the ideas regarding technology, the learning sciences, and play are reflected in the schools’ core philosophies and design. Students at Telefonplan work in groups based on skill levels and learning development. The division into groups is made not by age, but by an assessment of which situation would be best suited for the student’s development and level of skill and ambition. Students are free to work independently and grades are not awarded.

The school designed by Rosan Bosch does not have classrooms (Figure 7). The intent is to teach intellectual curiosity, creativity, self-confidence, and communal responsibility by breaking down physical class divisions. Numerous open areas encourage different types of learning. Names such as “The Mountain”, “The Village”, “Tower of Babel”, “Concentration Niches” describe the character of the areas.

Vittra shifted to personal digital learning in 2010. Every student receives a computer for learning. Skills, such as knowing where to find information and how to use it, are as important as students’ sharing what motivates and inspires them on web pages, within the community, in the school cinema, and on stage.

The school’s uncompromising design incorporates many new ideas in education including an emphasis on creativity and personalized, technology-based learning. The playful interior design and the variety of spaces provide a social and stimulating environment. The school offers an enormous amount of freedom to their students and expresses it in the fluidity of space.

2.4 The Open School Concept

The open school concept as seen at Vittra Telefonplan and Ørestad High School is not new. The idea emerged first in the late 60s, in an era that questioned traditional authority, including the way classrooms and schools were organized and students were taught.

Schools that embraced the open concept had no standardized tests and no detailed curriculum. Instead of in a traditional classrooms setting, children learned often at their own pace with the help of the teacher at “interest centers”. Teams of teachers worked collaboratively with one another, using movable dividers to reconfigure the open space for large and small group projects and individual study. Promoters of open education commissioned architects to build schools without walls.

Many open-space schools rebuilt their walls in the culturally and politically conservative 80s. The open classroom experiment was generally considered failed. Noise and distraction were among the main challenges

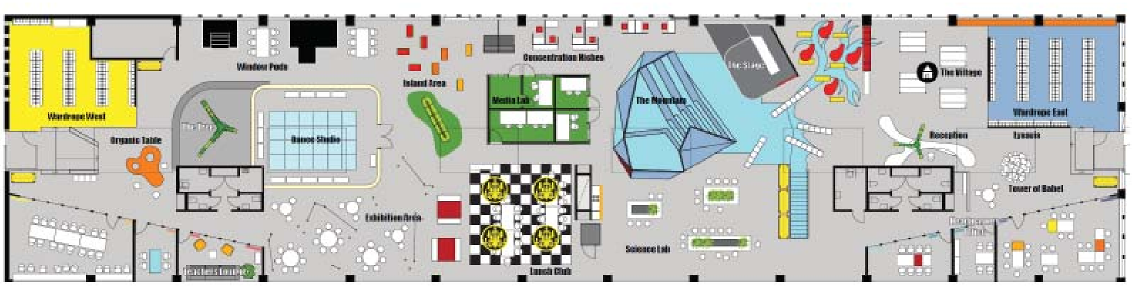

Figure 7: Vittra “Telefonplan” (courtsey of Rosan Bosch Studio).

of open space schools. In many instances classrooms were physically open, but instructors did not adjust their traditional method of teaching. A significant problem was the lack of teacher preparation. Many teachers, who had been trained in a different philosophy of learning, taught as if the walls were still present. This approach did not only complicate teaching, it missed many opportunities that an open learning environment can offer. When the discrete space under the direction of a single teacher is superseded by a more fluid and collaborative plan, however, many new ways of teaching can open up.

As far as distraction is concerned, the arrangement of open space becomes crucial. Many of the failed open schools from the 70s were housed in large undefined spaces. Clever floor plans as designed, for example for Ørestad High School, allow for a more complex layout that provides views and connections, yet semi-privacy in multiple zones. Technology, including building technology, has advanced. Learning becomes less tied to space and new building technologies for screening views and sounds have become more sophisticated and effective.

The open school often did not work as planned in the 60s and 70s. Twenty-first century learning yet calls for team and interdisciplinary teaching, for working in large and small groups. Flexible open spaces can support these ideas architecturally. The revival of the open school idea is no coincidence with the freedom that new technologies offer and the reemergence of student-centered learning.

Though heavily criticized, the open school might have benefits beyond enabling cross-disciplinary learning and team-teaching. Schools nowadays look for innovative solutions to address their budget and space constraints. Open learning space can be easily transformed to larger assembly spaces, reducing the total required area to meet program needs. Flexible arrangement of spaces can facilitate the overlapping of uses and result in building less overall area. Additionally, extending the classroom into the community with support of mobile devices that allow direct access to information could further reduce space requirements by reducing the average number of students in school per day.

The question of how to provide successful spaces for 21st-century learning can become increasingly complex when dealing with existing structures, or historical buildings where limited changes are allowed. School building modernization will be important in the decades to come. With an estimated $542 billion needed to modernize U.S. schools, the majority of school construction will include the renovation and modernization of existing buildings.

Munkegaard School in Copenhagen illustrates a successful modernization by Dorte Mandrup Arkitekter (Figures 8 and 9) that houses inspiring environments for innovative learning in a historical structure striking a deliberate balance between enclosed classrooms and open, collaborative spaces. Originally designed by Arne Jacobsen, Munkegaard School is a protected building that is considered one of the architect's great works. The original 1949 complex is divided into sets of two adjacent classrooms, each with its own courtyard, providing intimate outdoor spaces within a large school. When updates were needed, it was found that the concept did not fit the collaboration-based Danish education philosophy. More open space was needed. Most architectural suggestions were denied due to the school's protected status. To provide open and collaborative learning spaces while leaving the existing structure untouched, a new underground level of wide-open, multi-use spaces was finally approved and built. This space incorporates aspects of learning in a variety of group sizes and introduce a sense of adventure and play into the school environment. Munkegaard School's principal considers the combination of traditional classroom spaces and open learning environments the best of two worlds.

Many school administrators would hesitate before fully committing to nontraditional learning spaces. A long-term commitment to an open learning environment becomes less intimidating if the structural system is planned for both an open learning environment and classrooms. Movable partitions between classrooms, for example, can stay closed for traditional classroom teaching or opened up for team teaching. On a day-to-day level, flexible elements such as movable furniture allow desks and chairs to be rearranged into groups and pods for different learning experiences.

2.5 The Learning Environment and Academic Performance

Often the question is raised if changes or improvements in the physical learning environment can go beyond merely supporting new teaching methods or reflecting changes in society. Could the school environment affect academic performance as well?

Socio-economic status, parents, teachers, the curriculum, and school location are often listed as the key factors to student success. According to the 2007 study, differences in the schools' physical infrastructure, as

Figure 8: Munkegaard School (Photograph by Adam Mørk, courtesy of Dorte Mandrup Arkitekter).

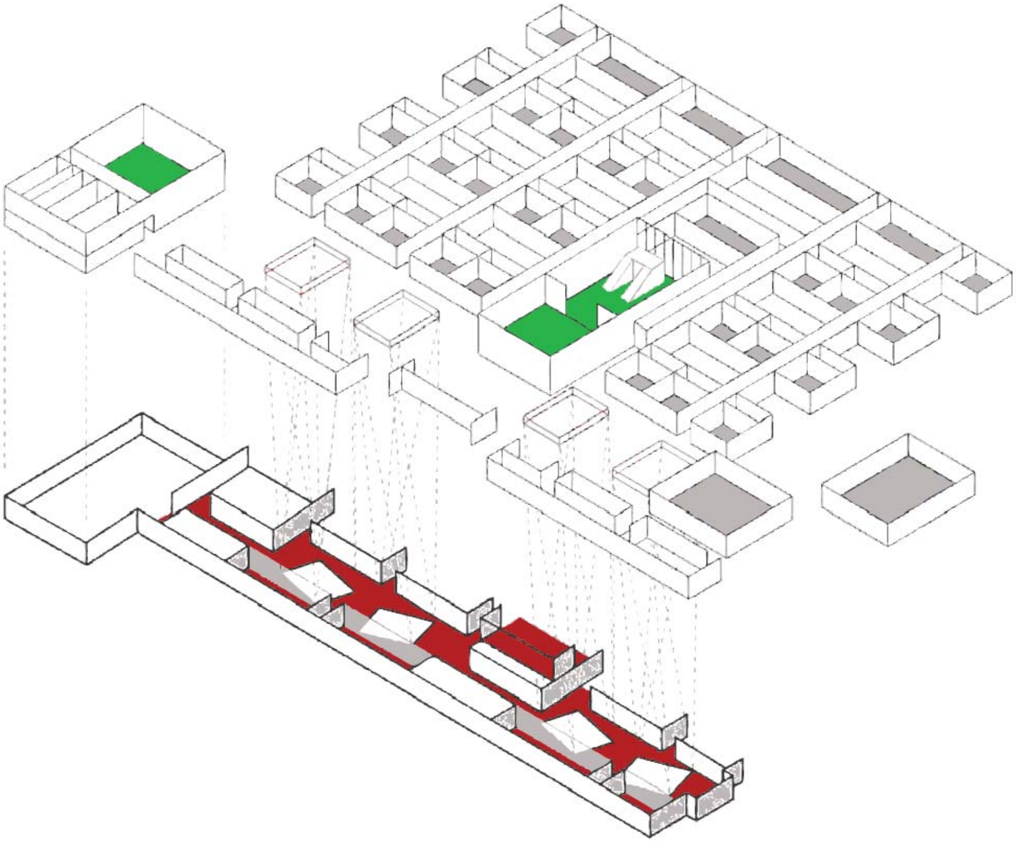

Figure 9: Munkegaard School (courtsey of Dorte Mandrup Arkitekter).

perceived by school principals, have a negligible effect on student performance[14]. On average across OECD countries, the PISA index of quality of the school's physical infrastructure explains only one percent of the variation in mathematics performance. Educational resources, such as computers, software or science laboratory equipment, on the other hand, account for a 2.5 percent performance variation.

A more recent (and ongoing) study, however, by the University of Salford in collaboration with the architecture firm Nightingale Associates, claims that the built environment can considerably affect the academic progression of students[15]. The study looked at 751 U.K. students in 34 classrooms at seven primary schools. Students were assessed for academic performance in math, reading, and writing, while classrooms were rated on six built-environment design variables: color, choice, connection, complexity, flexibility, and light. The proportionate, cumulative effect of these factors on learning progression measured at a 25 percent contribution on average.

The influence of singular factors in the built environment, notably the benefit of daylighting, on people's moods and productivity is well known. However, this is the first time that a holistic assessment has linked the effect of the overall environment directly to academic performance. As the study continues into 2014, it will include 20 additional schools in the U.K.

The direct effect of the built environment on student performance as measured through standardized tests is difficult to assess with so many variables coming into play. This becomes even more complicated when attempting to assess the effect of the built environment on hard-to-measure soft skills, such as creativity, critical thinking, and the ability to collaborate or communicate effectively. Open concept schools frequently focus on these skills. At the time of this writing, studies that investigate the effects of enclosed classrooms on students' performance are not available.

New technologies in themselves similarly have shown little or no direct measurable effect on academic performance. Andreas Schleicher, a veteran education analyst for the Organization for Economic Cooperation and Development (OECD) and Special Advisor on Education Policy, noted that "in most of the highest-performing systems, technology is remarkably absent from classrooms"[16]. He stated that "it does seem that those systems place their efforts primarily on pedagogical practice rather than digital gadgets."

3.0 CONCLUSION

The dominance of the traditional classroom remains an odd constant in planning educational facilities, considering the evolution of learning. The classroom offers many aspects that are beneficial to the learning process: it promotes focused learning in a group, it provides space for teachers to communicate closely with their students, and it creates a sense of home and belonging within the larger school system. The availability of information independent of time and place through new technologies, however, expands possibilities for places of learning. This freedom and flexibility of where learning could take place, inside and outside of school, makes the classroom within a traditional school building only one of many options.

Unconventional concepts for organizing educational space arise particularly with the lecture as the main means of transmitting knowledge moving into the background. Fluid and open spatial arrangements have the potential to foster cross-disciplinary and team-oriented learning models. The open school concept and learning networks, for example, emphasize self-directed learning and collaboration across physical and digital space while benefitting from the students' ability to access information and stay connected beyond the classroom and even beyond the school boundaries through new technologies.

The increased use of technology in itself will most likely not change learning outcomes. If anything, it is a reminder to refocus our attention on making the physical environment most effective for all kinds of learning, with and without digital tools, and on making a school more than a place for acquiring knowledge. Research indicates that safe, social and stimulating environments are best for learning. While spaces that encourage cross-disciplinary communication and interaction as well as impromptu gatherings address the need for social interaction and stimulation, opportunities for introspection and focused work need to be equally addressed in support of personalized and student-centered learning. Students and teachers are diverse and the environment in which each individual might thrive best can be very different. Offering a variety of spaces is crucial to make both students and teachers feel that they are in an environment where they have opportunities to excel.

Neuroscience gains an increasingly better understanding of the influence of space on the brain. Claims that certain types of spaces can foster growth of neurons still need to be proven, but there is evidence that links certain spatial qualities to specific brain processes. An understanding of what environments are conducive to what type of learning needs to form the basis of each design decision.

Although the relationship between learning spaces and academic performance is complex, the environment can certainly incite and support specific behavior. It can make it easier to act in certain ways, and harder to act in others. A learning environment that communicates playfulness might be more effective in teaching exploration, risk-taking and creativity.

The school building is ultimately the body language of a school. What it communicates to students might be subtle, yet powerful. It can make a difference in students' learning if it demonstrates the respect for students and joy for learning.

Designing with various situations in mind becomes even more important as we are planning for future with many unforeseeable innovations to come. Flexibility is, and remains, a key topic in school design not only with regards to rapidly evolving technologies, but also considering the long-term use of school buildings. With a large number of schools closing in some areas while overcrowded schools are an issue in other areas, future adaptability moves back into the spotlight. Abandoned traditional school buildings are difficult to repurpose while more flexible and open spaces can be re-imagined for multiple future uses.

Ultimately, the ideal learning space will be very different for every school depending on the school's pedagogical vision and its context. New technologies and discoveries in learning science open up new possibilities and allow for a fresh perspective on educational space. Re-evaluating space at the inception of each project and fully understanding what learning can offer nowadays is crucial. The possibilities for learning spaces will soon reflect the diversity and spirit of innovation that currently invigorates the educational sector and society as a whole. Finding new and inventive ways to provide spaces that serve students, teachers and the community as a whole best understanding what drives learning today will be the basis for creating successful spaces for the future.

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04.
IS THERE A “THERE” THERE?
Online Education & ArchitectureX

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ABSTRACT
Will online education render the traditional university campus irrelevant? Is there a “there” there when it comes to online education? What makes the flesh and blood, bricks and mortar material realm still relevant – even essential – to education? While online education has brought with it radical transformations to higher education, bringing people together in physical space is and will be essential for student success. The reasons for coming together, however, are changing; institutions must adapt if they are to remain vital. This article examines the risks and rewards that online education presents to the traditional campus as well as the impact that educational models merging online and on-campus learning might have on the traditional campus and beyond. It also identifies potential campus realignments that could bring vitality to a campus through engagement with the regional community, businesses and government as well as the key questions about planning, strategy, branding, and architecture that institutions need to ask themselves in order to determine where they stand in relation to online education.

KEYWORDS: MOOC, competency-based credentialing, flipped classroom, innovation centers, apprenticeship programs

1.0 INTRODUCTION
Is there a “there” there when it comes to online education? If there is a “there” there, what is the architectureX for edX and other online education providers? What are the architectural implications of more and more education materials being placed online for students at traditional universities? These are the questions that sparked this research to determine how architecture might evolve to meet the needs of online education both on the traditional university campus and beyond. In searching for the answers to these questions, it quickly became clear that the “there” in this digitized, dematerialized realm of education is found by looking for what makes the flesh and blood, bricks and mortar material realm still relevant – even essential – to education. So with some irony and a little bit of obviousness, the looking for the “there” in online education became a study of what cannot be done online, or at least not done online well.

These are the early days of online education, even though it started to take root in the 1990s. It has been just in the past two years that the growth of online education has accelerated, fueled by the interest of major universities, venture investors and the growing access to bandwidth. It has also helped that entities such as the Bill & Melinda Gates Foundation and the National Science Foundation have funded online education programs at various colleges and universities so as to study the effectiveness of online education. While these studies are very much in progress, educational leaders already have high hopes for online education. In a 2012 interview, Stanford University’s president John L. Hennessy stated, “I’m a believer in online technology in education. I think we have learned enough about this to understand that it will be transformative. It’s going to change the world, and it’s going to change the way we think about education.[1]” William G. Bowen, President Emeritus of The Andrew W. Mellon Foundation, stated at a recent conference that, “there is real potential for online learning to reduce inefficiencies in teaching, scheduling, and lost transfer credits…[2]” With 31.3 percent of U.S. college students enrolled in at least one online course in 2010, this online education thing might be here to stay[3].

The meteoric rise of – and hyper-enthusiasm for – online education is perhaps most fueled by a hope that it will bring an end to the "crisis" in higher education. This crisis is defined by high student debt that now exceeds the nation's entire credit-card debt, perceived low return-on-investment of a college degree, a drop in state appropriations to public colleges and universities, a drop in median family net worth (resulting in less money to spend on education), and tuition rates rising four times faster than the rate of inflation[4,5,6]. When viewed from the depths of this crisis, the founders of edX and other such massive open online courses (MOOCs) appear to some as oracle-like beings who can show the way to divine salvation for higher education:

> *Already, the hyperventilating has outpaced reality; desperate parents are praying that free online universities will finally pop the tuition bubble — and nervous college officials don't want to miss out on a potential gold rush[7].*

There are a lot of speculations regarding the impact online education will have on the traditional college campus. Some say that online education and the benefits it brings will cause most college campuses to crumble in disrepair as they will be obsolete within 50 years[8]. Others argue that online education is a fad – perhaps even an ineffective educational model – that will not lead to the alteration of a single brick on the traditional college campus. A recent Gallup poll even showed that most college presidents do not expect that online education will bring with it any substantial financial or educational benefits[9]. Problems with Massive Open Online Courses (MOOC) that have recently emerged – such as low completion rates and the inability of MOOCs to reach those who do not already have access to higher education – are interpreted by some as a sign that online education is an inferior education model destined to fail.

However, there are some who see a more nuanced future in which optimal learning occurs in a blended online and on-campus experience. While Sebastian Thrun, founder of Udacity, has been quoted as saying recently that his MOOC is a "lousy product" that is not living up to expectations, he went on to clarify in a subsequent New York Times interview that innovation is an iterative process in which "few ideas work on the first try.[10]" Even Jonathan Rees, a Colorado State University-Pueblo professor who was one of the earlier critics of online education, stated that he sees the convolutions that the much hyped MOOCs have undergone since their inception as something of a maturing process that is taking education into a potentially positive direction in which it is not totally online or on-campus, but somewhere in the middle based on what is best for students. As Rees was quoted as saying, "The MOOC is dead, long live the MOOC.[11]"

While we can only speculate about the future, some of these speculations are grounded in truths about why people will continue to want to occupy physical space with other people to discuss ideas. Certain trends on the ground now, examined in section 4.0, demonstrate that even as there is this rapid shift to the online environment, there is also an emergence of new types of spaces in response to new reasons for people coming together. These spaces represent an online education model that blends the digital and physical worlds. This blended model will not serve everyone. Some institutions as well as some students will reject any forays into the online environment. Some students, out of choice or necessity, will find themselves in an online education model that truly has no "there" there. As explored in section 3.0, these purely digitized models will compete vigorously with some bricks and mortar campuses. For higher education institutions that want their campuses to remain vital centers that succeed in doing what cannot be done online, section 5.0 explores possible directions. Section 6.0 attempts to answer what is architectureX.

2.0 WHAT IS THAT THERE? A BRIEF SUMMARY OF E-LEARNING, MOOCS & SPOCS

Online education fits under a large umbrella called "E-learning." E-learning refers to a full spectrum of activities that leverage educational technologies. E-learning comprises numerous types of media that deliver text, audio, images, animation, and streaming video, and includes technology applications and processes such as audio or video tape, satellite TV, CD-ROM, and computer-based learning as well as local intranet/extranet and web-based learning. Even though the technologies associated with E-learning are essential for online education, these technologies can be – and are – deployed throughout various locations in an academic campus to augment more traditional learning environments.

The online offerings of E-learning come in a myriad of different forms by an increasingly large array of providers. Some are private, some are public and some are not-for-profit. There are the large state university programs such as UMassOnline and University of Maryland University College that have provided online courses for well over a decade; the for-profit providers such as University of Phoenix, StraighterLine and Kaplan; the communal online learning sites such as CodeAcademy;

the not-for-profits like TED Talks and the teacher who teaches math well on YouTube (and now leads the Khan Academy); and of course the MOOCs. Some providers such as UMassOnline have long offered full-fledged degrees for their online offerings. The MOOCs provide certificates for course completion but, some are beginning to provide credits or even degrees from accredited institutions. Some for-profits are regarded as providers of a public good by delivering high-quality education to those who cannot attend a traditional college. Some of the for-profit providers are considered diploma mills.

The Massive Open Online Course, or MOOC, has been getting most of the attention as of late because of the speed of its rise and huge numbers of people who enroll in the courses. Anyone with access to a computer and an internet connection can enroll. At last count, over seven million people were enrolled in Coursera[12]. While there has been much discussion that these free courses would democratize education by reaching out to the underserved throughout the world, a recent survey has shown that most people enrolling in MOOCs are already well educated degree holders[13].

The online class itself typically consists of a short 8 to 12 minute lecture interspersed with quizzes or exercises. Feedback is instantaneous[14]. There are now dozens of MOOC providers, but Coursera, Udacity and edX are the most prominent. Coursera and Udacity are both for-profit and were founded by individual professors from Stanford striking out on their own. EdX is a non-profit that was founded by MIT and Harvard. All three of these MOOCs have now partnered with various other colleges and universities around the world. The MOOC market, already quite large, is only going to get bigger as the MOOC providers set their sights on serving a wide spectrum of people including:

> *… global learners in developing nations who lack higher-education infrastructure and access to the best class opportunities; U.S. college students, particularly at hard-pressed public community – and state – college systems, who need basic courses, who are being shut out of over-enrolled classes required for their degree sequences, or who simply need cheaper alternatives for higher education; and adult learners seeking practical, career-focused skills[15].*

When asked in a recent interview about what sets edX apart from other MOOC platforms, edX president Anant Agarwal responded "we have a fundamentally different mission…. We're non-profit. We're open source. Our technology is for everyone. We have a commitment to campus learning.[16]" While edX is in the MOOC business, their VP Howard Lurie clarified that edX is best described as a learning company that acts as a portal to educational materials offered by its partner institutions including universities and academic publishers. EdX's main mission is to reinvent and enhance on-campus learning rather than replace it. While the MOOC arm of edX already has enrolled almost 700,000 in less than a year, increasing their enrollment is not their primary focus; increasing the quality of education is. To that end, they have launched various pilot programs for research and are engaged in partnerships to customize courses with each of their partner schools. With their partner schools they are in process of establishing research centers for better teaching and learning. These partnerships have led to what Anant Agarwal, edX president, calls a SPOC or "small private online course." These SPOCs blend online materials available only to students enrolled in a class with classroom interaction with professors. Professors can personalize the class with their own readings and assignments[17].

While there are varying opinions about the benefits that come with online education, there seems to be a consensus that the reevaluation of pedagogical methods triggered by the spectacular rise of MOOCs is a good thing. After a recent online education conference, MIT President L. Rafael Reif stated, "I couldn't have imagined circumstances in which you could get all these communities together to discuss education.[18]" People learn by doing and edX is trying to build a platform where students "do," according to Howard Lurie at edX. Even though edX is just one year old, Johannes Heinlein at edX stated that they have gathered enough "Proof Points" to show that an online course broken into segments followed by personal engagement by the student truly can enhance learning. EdX is interlacing homework with attention spans. Such a structure provides personalization, immediate feedback and resonates with the minds of younger people for whom the game-ification of learning is familiar. As Daphne Koller, co-founder of Coursera, recently stated in a New York Times article "we must leverage, not fight against, the changing tide of the preferences of a new generation – the digital natives.[19]"

Long before the rise of the MOOCs and SPOCs, research showed that conventional classroom-based group instruction is the least effective learning condition when compared to one-to-one tutoring and mastery learning. If, as there is strong reason to believe, MOOCs can evolve to become personalized "precision-built courseware" akin to a one-to-one tutoring experience, they will lead to stronger student performance and be a superior method of educational delivery when compared to the traditional classroom[20]. Someday very soon it might be considered irrational for students not to participate at some level in online education if they want the best educational experiences. It might be seen as irresponsible for higher education institutions to not offer an optimized blend of both online and on-campus learning opportunities. It is hard to believe that profound changes in higher education are not underway:

> *MOOCs represent a postindustrial model of teaching and learning that has the potential to undermine and replace the business model of all institutions that depend on recruiting and retaining students for on-campus studies[21].*

3.0 THERE IS NO "THERE" THERE

There are online education models in which students jump back and forth from a digital cloud to a physical classroom or other grounded space. However there certainly do exist other online education models that are untethered to the physical world; there is no "there" there (aside, of course, from the lap in which the laptop is located). Out of choice or necessity, many students will find themselves participating in a pure online education model. This online shift by what is predicted to be a large group of students will be felt most by the middle-tier institutions:

> *Why, after all, would someone pay tens of thousands of dollars to attend Nowhere State University when he or she can attend an online version of MIT or Harvard practically for free?[22]*

No longer do college campuses provide a service that people cannot find at a better price or at a better quality elsewhere. Scarcity of teachers and limited real-time communication options has been the rational for building college campuses since colleges began to appear in the Middle Ages[23]. Scarcity can no longer hold a college campus together. If having a "there" no longer works to attract students and professors, institutions may begin to regret recent campus construction projects and question the need for new construction projects. "There" does not matter anymore for some students.

3.1. StraighterLine to No There

Burck Smith started putting courses online in 2009 when he launched StraighterLine where students can take general education courses such as Econ 101, Psych 101 and College Algebra at substantially reduced rates when compared to a bricks and mortar program. Students obtain credit for their coursework when they enroll with one of StraighterLine's partner colleges and universities such as Thomas Edison State College, University of Phoenix, Bay State College, Kaplan University and Kendall College. These courses will transfer to a wide variety of colleges where students can finish their degrees in person or online.

StraighterLine's goal is less about disrupting the physical campus and more about letting students choose the blend of physical and virtual courses that makes sense for the student rather than what makes sense for the school. Even so, StraighterLine does represent a threat to college campuses: StraighterLine enables students to obtain their degrees without stepping one foot onto a campus. Unlike MOOCs, StraighterLine already has in place a revenue-generating business model where students can get college credits much more cheaply than on-campus options. Testing centers are not even safe from Smith: the StraighterLine proctored tests are observed online using a combination of webcams and screen sharing software called ProctorU. Nor is there a "there" there for even a server room because StraighterLine runs entirely on the Google Cloud Platform. Smith does not see himself as the bad guy here. In fact, he describes the services he provides as part of the solution to the higher education crisis. For a lot of students who cannot or do not find their way to a physical campus, StraighterLine and other pure online providers are the solution.

3.2. No Time (or Money) There

The dematerialization of education is fueled increasingly by growing doubts that time spent sitting in a physical classroom should continue to be the prevailing unit of measure for higher education. For more than a century, the credit-hour has been the universal measurement for the duration of time students occupy a classroom. Also known as the Carnegie Unit, the credit-hour was introduced in 1906 by the Carnegie Foundation for the Advancement of Teaching. Now Carnegie is the main proponent for replacing the credit-hour. What that alternate standardized unit should be is still to be determined, but the current front-runner is some sort of competency measure. For Pamela Tate, president of the Council for Adult and Experiential Learning, this re-evaluation of the credit-hour is long overdue: "We believe strongly that learners should be assessed based on what they know and can do, not just time spent in a classroom.[24]"

Time spent in physical space as a measure of learning is being questioned not just because the measurement of time seems to be an imprecise method of knowledge assessment, but also because many students cannot afford to take the time to sit in a classroom. Time is money and less time in class saves money. Even President Obama recently proposed that colleges consider competency-based degrees as a way of reducing cost[25]. In March 2013 the Department of Education asked that colleges suggest programs for providing financial aid that do not rely on the credit-hour. The response they got was that it is time to embrace competency-based education. A December 2013 report by President Obama’s Council of Advisors on Science and Technology even more explicitly stated that accreditors brandishing the credit-hour not stifle innovation within the nascent online education industry as the industry experiments with ways to provide credit to students[26].

All of this pressure on the credit-hour may signal that it is in its final hours. Competency-based programs that save students both time and money are now emerging from all directions. Institutions such as College for America and Capella University have competency assessment degree programs approved by the Department of Education[27]. The State of Texas is working with faculty at South Texas College and Texas A&M University-Commerce to develop an online competency-based degree program costing between $6,000 - $13,000 total. The University of Wisconsin also has a competency-based degree program called the Flexible Option[28]. For even less money than the Texas program, students can obtain a $4,000 M.B.A from the competency-based online UniversityNow[29]. If $4,000 is too much for a degree, there is now the not yet accredited University of the People that offers the only tuition-free online college degree program. Its operating expenses are covered by donations from such entities as the Gates Foundation and the Carnegie Corporation. With just 14 paid staff members, more than 300 volunteers help run the university[30].

In a recent New York Times article, Clayton M. Christensen and Michael B. Horn compared traditional colleges to the 19th century transoceanic sailing ship companies that could not compete against the disruptive innovation of the steamships. While some colleges are now supplementing what they offer with online courses and even flipping their classes with lectures viewed online and class time reserved for higher level engagement with students, this alone is not enough of a change:

> *Like steam, online education is a disruptive innovation — one that introduces more convenient and affordable products or services that over time transform sectors. Yet many bricks-and-mortar colleges are making the same mistake as the once-dominant tall ships: they offer online courses, but are not changing the existing model. They are not saving students time and money, the essential steps to disruption. Though their approach makes sense in the short term, it leaves them vulnerable as students gravitate toward less expensive colleges[31].*

The gravitational pull of competency-based online programs for students with limited time and money is strong. As the availability and acceptability of these time and money saving programs increase, the end of the credit-hour draws closer. Students no longer need to be “there” in a classroom on a college campus as the clock ticks to reach where they are going.

3.3. Networking No There

College campuses have long provided optimum opportunities for socialization and networking, but even these on-campus advantages are being transferred quickly to the online environment. Dates can be found on Match.com and Chemistry.com. Now jobs can be found on MOOCs.com. On-campus networking is being rendered irrelevant as MOOCs can match talented online students with prospective employers[32]. Coursera Career Services, launched by Coursera in December 2012, provides students with an option to appear in a database that employers can peruse. Udacity is also exploring this recruitment model in which companies pay to access high-achieving students as a potential revenue model[33]. Students increasingly will view a “there” on campus irrelevant for their personal and professional networking:

> *If MOOCs can be used to create a system that rewards demonstrable competency, then they will further undermine the value of campus-based networking. When used to connect talent directly to prospective employers, MOOCs can circumvent one of the few remaining rationales for seeking a traditional college experience[34].*

3.4. Not Enough “There” There

Overcrowding and lack of resources at some institutions has meant that there is not enough “there” there for all of their students. When faced with the problem of how to provide remedial courses to 50 percent of students entering the California State University (CSU) system unable to meet the basic requirements for elementary math and English, Gov. Jerry Brown contacted Udacity for help. A pilot program with Udacity and San Jose State was established and so was born the first collaboration between a MOOC provider and a university[35]. Udacity even established a 24-hour online mentoring service to assist these students in these pure online course offerings[36].

California's problems with lack of classroom space extend beyond just the entering students needing remedial courses; existing CSU and community college students are finding that there are not enough seats in courses they are required to take as part of their degree programs. So in hopes of alleviating this shortage of classroom space in these oversubscribed classes, Senate Bill 520 (SB520) was introduced in February 2013 that would allow online education providers including MOOCs and for-profit companies to provide courses for credit to California public college and university students. Not everyone sees SB520 as a good thing. The Berkeley Faculty Association started an online petition against the bill. Robert Meister, Chair of the Council of UC Faculty Associations, stated that "it's the wrong solution to the wrong problem." The real problem is lack of adequate funding[37]. The New York Times Editorial Board also did not think highly of SB520:

> *Online classes are and will be part of the educational mix, in California and elsewhere. But they cannot be counted on to revive a beleaguered public system whose mission is to educate a great many freshmen who need close instruction and human contact to succeed. To broaden access and preserve what is left of the public university, California lawmakers will need to change budget priorities that have been moving in the wrong direction for a long time*[38].

The protests against SB520 worked: the bill has been put on hold until at least August 2014[39]. Proponents of SB520 were also not helped by the poor results of the San Jose State University partnership with Udacity to provide introductory college classes to struggling high school students. With pass rates between 23.8 and 50.5 percent – worse than rates from students in a physical classroom – from the Spring 2013 pilot program, San Jose decided to suspend the program[40]. Whether these setbacks for SB520 and the San Jose State–Udacity partnership are a good or bad thing is hard to determine at this point. Perhaps with some tweaking, the collaboration with Udacity had the potential to provide more CSU students with an opportunity to pass the basic requirements and be eligible to attend classes on a physical campus. SB520 could have enabled more students to graduate on time because they do not have to wait another semester for a seat in a class. It could also have meant that struggling students are not given the personal attention they need and that some students miss out on interaction with faculty. The failure rates of the San Jose State pilot program clearly pointed out that the needs of struggling students were not being met. SB520 most certainly would have resulted in State money flowing to online education providers, leaving less money for the physical campuses throughout California. There is not enough "there" there now and with SB520 there might continue to be less and less there in the future.

While SB520 seems unlikely ever to pass, it already has had a significant impact on the California system. The efforts to pass the bill demonstrated that if an institution cannot provide enough resources to their students, online education providers are poised to fill the gap. Even though the Udacity collaboration ended with a thud in 2013, there might be another online provider in the not too distant future who pushes their way into the university. EdX, for example, is running a separate pilot program at San Jose State that is delivering promising results. So in response to the perceived threat of these external online education providers, University of California System, CSU and the California Community Colleges now plan to launch their own online courses[41]. Perhaps the California system will be able to achieve all that SB520 had set out to achieve while keeping State money within the school system. Such a model has been highly effective for the University of Massachusetts system with UMassOnline pumping millions of dollars into the UMass system every year. If, however, California fails to resolve their classroom shortage problems either through the development of their own online program or even through construction of more physical classrooms, external online providers will be quick to offer solutions to the lack of "there" there.

4.0 THERE IS A "THERE" THERE

While there are providers of online education that have no need for the physical world, let alone the college campus, there are others who view the intertwining of online education with the physical campus as a way to bring success not just to the individual student, but also to the institution as a whole. Their aim is not to replace the campus with the computer. Jack M. Wilson, the founder of UMassOnline and President Emeritus of the University of Massachusetts, has shown in his professional life that a commitment to both online education and the campus leads to successful outcomes at multiple levels. After serving as CEO of UMassOnline for several years, Wilson went on to be the President of the University of Massachusetts for eight years during which he approved numerous new construction projects for the university. These were construction projects that still made sense to an online education leader. Wilson noted that online education is changing the campus, but it will not destroy the campus. The campus still matters.

So it is proposed by some that an optimum blend of both on-campus and online learning experiences gives the student the best opportunity for success. While edX hopes to attract many students to its online offerings, edX also promotes the campus as a place of learning. In a March 2013 interview, Johannes Heinlein, Director of Strategic Partnerships and Collaborations at edX, stated that there will always be a value in face to face interactions. Campuses are places to come together to engage with intellectually driven people. Engagement has proven to be crucial for student retention[42]. Great facilities encourage students to spend time on campus, which leads to greater engagement with others, which leads to greater student retention and greater student success. As purely online programs grapple with poor completion rates, institutions should capitalize on the power of the campus to facilitate student engagement and student graduation. To highlight this advantage that campuses have over purely online programs does not mean that campuses should not change; online education can bring with it a much needed enhancement of the student experience on campus. For example, online education can positively transform the way students and professors use the classroom. Salman Khan, founder of the online Khan Academy, highlighted this potential at a recent conference:

> *Khan believes that online learning will allow professors and teachers to leverage the physical space better. When rote learning can be replaced by online technologies like those provided by Khan Academy, the classroom can be used for more high level discussion*[43].

At the level of the institution, successful outcomes can be achieved through a holistic view of online education and the mission of the institution. The University of Massachusetts is a success story when it comes to this very kind of holistic thinking. Jack M. Wilson noted that online education provides another way for UMass, a public institution that emerged from the Morrill Land-Grant Act, to fulfill its mission to bring education to the people. Providing courses online has enabled UMass to reach students beyond Massachusetts. This broader reach has led to the lowering of costs to all students as the university has been able to distribute their product more widely. UMassOnline has allowed the university to scale up their course offerings without expanding the physical campus. The additional courses offered online have enabled UMass to hire more faculty. These additional faculty members in turn bring in money from research grants or in some cases money from the commercialization of their research. This money generated by the faculty has made investments in research buildings viable because of the revenue generated by those research buildings. Beyond just research buildings, Wilson noted that UMassOnline has been very good for the physical campuses of the University of Massachusetts. UMassOnline has created a revenue stream of $70 million per year. Before UMassOnline, UMass had not built a residence hall in more than 30 years and they had deferred maintenance on many of their campuses. UMassOnline enabled UMass to focus on their physical campus infrastructure. According to Wilson, UMassOnline supports a traditional campus environment and enables UMass to become a major research institution all while bringing the cost of education down for students.

Success for both students and the university is also what some universities are hoping for with programs that convert online students to on-campus students. In their MOOC2Degree program, these universities are using MOOCs as part of a way to lure students to their bricks and mortar campuses. These universities offer free introductory for-credit online courses with the expectation that if a student passes one of these free courses, they will want to complete the degree program on campus[44]. If the MOOC2Degree program is a success, it will convert digital students into flesh and blood students occupying real campuses. Such a conversion of digital students to physical students was part of the rationale for the Udacity-San Jose State partnership. In providing online remedial classes to high school students through Udacity, those students – it was hoped – would transform into full-fledged, college-ready students occupying the very real San Jose State campus. Sebastian Thrun, founder of Udacity, argues that through such a program, MOOCS actually will increase enrollment at traditional physical campuses by increasing the number of students eligible for college:

> *There's a distinction that people often don't make… which is whether these classes reach existing students and take away business, or whether they reach new students and add to the business?*[45]

The merging of online and on-campus learning has the potential to bring forth successful outcomes for both students and institutions. With the merging of the digital and physical, a wide spectrum of physical transformations can come to the college campus and beyond. Some blended models are successful without any changes to the traditional campuses. Other models comprise an infusion of technology and more flexible furnishings into existing campus spaces. Some have led to gatherings of people in spaces beyond the campus. In all of the blended models, there is a "there" there by definition.

4.1. There are Flipped & Blended Classrooms

The blended classroom is one that straddles both the online and on-campus worlds. In most cases, these blended classrooms are considered “flipped” because students first absorb new information through online lectures and exercises, then come to class for discussions and to apply what they know in project-based learning exercises. The professor can tailor the class based on the feedback of how students performed on their online assignments. Blended classrooms are growing in appeal and, according to Johannes Heinlein at edX, they represent the future for edX. Howard Lurie at edX explained that the lecture hall is the 14th century model of education; the blended classroom is what makes sense now.

Positive results are emerging out of the blended and flipped classrooms such as the edX pilot program at San Jose State University (not to be confused with the Udacity-San Jose pilot program). San Jose students viewed online materials for this “Circuits and Electronics” pilot class and they also participated in classroom-based instruction led by their San Jose professors. San Jose saw the fail rate drop from 40 percent to 9 percent for this class[46]. Positive results also are being reported out of Clintondale High School, the first entirely “flipped school,” with failure rates dropping and graduation rates rising. As with the San Jose program, Clintondale students view lectures at home and then come to class to do projects and exercises with other students. Flipping is “a potential model of how to use technology to humanize the classroom.[47]”

EdX has other small private online course (SPOC) pilot programs featuring the blended model at MassBay Community College and Bunker Hill Community College. In these two programs, community college faculty are adapting edX courses for their students who, when compared to typical MIT or Harvard students, are generally older and are working full-time. Students access the course material online and then come to class to discuss the materials with their MassBay or Bunker Hill teachers. Such a model has required no physical modifications to these community college classrooms. Here a new model of learning can be applied to the existing physical campus of a community college without any large infrastructural investment. As with the San Jose pilot program, the MassBay class is already seeing positive results: 18 out of 19 students passed the midterm and 16 of those students received an A. In the purely online version of the class, only 22 percent of students passed the midterm[48]. Clearly it helps to have a “there” there.

4.2. There are Team-Based Project Rooms

Burck Smith, founder of StraighterLine, stated in a recent interview that the blended classroom is not the answer because it is still predicated on the fact that the class is the organizing force. With the rise of online education, Smith argued, the class no longer offers a strong justification for gathering people in space; everything typically conveyed in a class can now be transmitted online. Instead of the class, Smith suggested the group project be what pulls people together in space. Smith envisions an environment where students are committed to working on these projects and are reviewing other students’ projects. Everyone is evaluated by their mentors. There are already several examples of successful project-based learning in action: Franklin W. Olin College of Engineering’s project-based curriculum challenges students to solve real-world problems posed by corporate sponsors; Hampshire College’s students develop their own projects based on issues they decide they want to explore alone or in groups; Harrisburg University of Science and Technology works with corporate faculty to provide students with project-based experiential components.

4.3. There are Active Learning Classrooms

Traditional classrooms are being overshadowed now by active learning classrooms (ALC). Unlike the traditional classroom that is unidirectional with rows of student desks facing towards the teacher’s desk or podium at the front of the room, the new team-based project rooms are multidirectional with groupings of students working together. A typical student grouping could be formed by a round table seating several students and within each student’s view are screens for students to share images. This arrangement not only encourages face to face interaction, but also facilitates technological interaction. It is a return to Socratic learning with technology as part of the discussion. These new ALCs can be defined by the following characteristics[49]:

- Tables arranged to support groupings of students
- Technological infusion of projectors, video, accessible outlets, data ports and WIFI
- Multidirectional focus (projection screens and whiteboards could be on multiple walls)
- Layout fosters inclusion of every student
- Flexibility of space facilitates movement and energizes students (everything has wheels)
- Writable surfaces everywhere (tables, walls).

Recent studies show that the active learning classrooms are having a positive impact on learning when compared to the traditional classroom: students in ALCs have higher grades, teachers and students in ALCs have more discussions (instead of lectures), the ALC teachers move around the room more, and writing surfaces in ALCs are used more by both teachers and students[50]. That these ALCs are proving to be successful educational spaces is evident by the multiple consulting companies such as Strategic Workplaces and Wave Guide that specialize in their layout. Furniture manufacturers such as Izzy+ have whole lines geared towards distance learning and active learning classrooms.

4.4 There is Technological Infrastructure

As the MassBay and Bunker Hill Community College-edX pilot programs show, institutions do not need to invest in a lot of technological infrastructure for their students to participate in online education. The institutions that deploy E-learning activities – including online education programs – throughout their campuses have had to make substantial investments in technical infrastructure and the spaces to house that infrastructure. Control rooms full of equipment racks are needed for supporting various campus locations and beyond with content. Studios are needed for the production of the content. HarvardX, the University's operating entity for the edX initiative, is in the process of hiring production staff such as course-development managers, media mangers and video managers. HarvardX is also constructing new video facilities[51]. As UMassOnline's founder and UMass President Emeritus Jack M. Wilson pointed out in a recent interview, much of this technological infrastructure supports the ethereal cloud rather than the computer labs of yesterday. Wilson stated that the personalization of computing should be the focus for institutions as they move forward.

Recently there even have been large technological investments at the K-12 public school system. Approximately 11 million tablets were sold to schools in 2012. In a pilot program at Barron Park Elementary School in Palo Alto, California, every fifth-grader has an iPad. In one Texas school district, $20 million has been allocated to provide mobile computers to almost all of their 25,000 students[52]. If these sorts of investments are becoming common place in public K-12 schools, those students – "the digital natives" – will expect a technologically infused environment when they attend college[53].

The there "there" is wired… or wireless.

4.5. There are Informal Technologically-Infused Spaces

In addition to the new video facilities, control rooms and high-tech classrooms, A/V consultants such as Wave Guide are also helping their clients develop technologically-infused informal student collaboration spaces. These informal spaces could be the break room, lunch room or any sort of spill-out space. Wave Guide is equipping these spaces with flat screens, recharge stations and wireless connections that can connect to the flat screen in the space. Even when students are "there," they can also be online.

4.6. There are Meet-Ups

Many MOOC students – particularly those who are taking online courses without any connection to a physical university – want the camaraderie and discipline that comes with a study group. Organically these study groups, or "meet-ups," have sprouted up independently from the MOOCs themselves using social media. They could occur in a pub or a Starbucks or just about anywhere else that people can find chairs to sit down in a group. The value of these study groups is becoming evident: students are saying that they are more likely to finish an online course if they are part of a study group that comes together for meet-ups in actual physical places[54].

When asked if edX had any plans to start organizing formal meet-ups for their course offerings, Howard Lurie at edX stated that it is good that these meet-ups happen without edX involvement; edX does not want to be presumptuous about how people in Thailand or Brazil might best study. While edX might help establish study spaces in partnership with NGOs, they do not want to overextend themselves to be organizing world-wide study groups. Regardless of who organizes a meet-up, they are a "there" that has developed in direct response to MOOCs.

4.7. There are Testing Centers

Testing centers have become a major player in the rise of online education. Without proctoring, it is very easy to cheat on an online exam. Pearson's testing centers, located in more than 100 countries, now provide students at edX, Coursera and Udacity with a place to take a proctored exam. However, just when it looked like online education could not be completely untethered from the physical world, ProctorU appeared. ProctorU uses webcams and screen-sharing software to oversee online exams[55]. Physical testing centers are where the three main MOOCs have turned to enable students to validate what they have learned online. Testing centers help to ground an online student's work with the legitimacy that sometimes only a "there" can provide.

4.8 There are Community Center Learning Environments

In his January 29, 2013, State of the City address, Mayor Thomas M. Menino announced the launching of a pilot program with edX. The initiative, called BostonX, would provide free online courses to Boston's community centers:

> *Imagine a day when our community centers are little campuses in their own neighborhoods, full of vibrant groups of neighbors, exchanging ideas and making progress together. This initiative is a first, important step in that direction. We must connect adults in our neighborhoods with the opportunities of the knowledge economy*[56]*.*

Not only would the BostonX project provide the community with access to computers and the internet, but also to professors and students from Harvard and MIT. These Harvard and MIT people potentially would lead discussion groups at the community centers. According to Howard Lurie at edX, the BostonX project is still very much in the design stages, but edX is committed to developing a relationship with their community and helping underserved members of that community. Hopefully this will lead to economically challenged students discovering that if they can do the work of a Harvard class, they should feel like they could go to Harvard. As Anant Agarwal, the president of edX, was recently quoted in the Boston Globe, BostonX could just be the beginning of this wave of CityX's around the world:

> *The sky is the limit as far as the possibilities here…. My hope is that this idea pioneered in Boston may spread to other cities. One could imagine it all around the world. NewDelhiX. San FranciscoX. I guess LAX is already the airport*[57]*.*

The United States government is also thinking big about creating centers for learning around the world. The Bureau of Educational and Cultural Affairs' "MOOC Camp" is described on their website as a new initiative "to host facilitated discussions around massive open online courses at U.S. Embassies, Consulates, American Spaces and other public spaces around the world.[58]" Operating now in 40 countries, the mission of the program is to not just provide learning opportunities for people around the world, but also to facilitate the funneling of students into United States colleges and universities with a network of student advising centers called EducationUSA. These MOOC Camps have the potential to resolve two of the biggest problems with MOOCs: "the lack of reliable Internet access in some countries, and the growing conviction that students do better if they can discuss course materials, and meet at least occasionally with a teacher or facilitator.[59]"

The fact that the U.S. government is creating physical learning spaces around the world shows that it is not enough simply to broadcast free information on the Internet; there needs to be a "there" to truly reach out to people. While the BostonX project is not yet physically "there," the fact that it is in the real planning stages means that this is a "there" that is almost here. These community center learning hubs – along with the flipped and blended classrooms, active learning classrooms, new technological infrastructure, informal technologically-infused gathering spaces, "meet-ups," and testing centers – demonstrate the genuine need for a "there" to be integrated with an online world in order to achieve success for students and the institutions serving those students.

5.0 THE "THERES" THAT COULD BE THERE

Despite online education – or even because of it – academic campuses have the potential to remain vital. In an optimal learning model, bringing people together in physical space will continue to be essential for student success. The reasons for bringing people together are changing and institutions will need to adapt or fade away.

In a recent interview, Johannes Heinlein at edX predicted that online education will replace non-value-added activities that occur on campus: the 800-person lecture hall will no longer provide as high a value as spaces that facilitate closer engagement with faculty and are enhanced by technology. In a separate interview, Nader Tehrani, the Head of the Department of Architecture at MIT, anticipated that because space is expensive, a lot of things that happen in lectures may migrate online. Class time will become the time for valuable face to face contact in seminars or discussion groups. Tehrani predicted that institutions will decide to phase-out some lecture classes so that their budgets can be applied to better learning experiences in smaller groups. Tehrani added that the spatial needs for interfacing with others will vary from discipline to discipline. Some areas of study are easily translated to the online environment. Others require a high level of student engagement in a physical space perhaps equipped with resources available only in that space. There will continue to be needs for science labs, art studios, and music rooms on college campuses.

In addition to the educational merits of campus learning, EdX’s Lurie argues that the developmental value that comes from 18 year olds being away from their parents and surrounded by their peers will ensure that there is a future for residential life on campuses. Eighteen year olds probably will still want to live with other 18 year olds 50 years from now. Therfore, the educational and developmental merits of campus learning will continue to be powerful reasons for bringing people together on campuses. However, it cannot be ignored that online education is changing the dynamics of why people come together. Higher education institutions will need to look to what cannot be done online – or at least what cannot be done online well – if they are to remain vital centers. Thomas L. Friedman wrote a hopeful opinion piece on the future of the academic campuses, but he also concluded that universities will have no choice but to change in response to the rise of online education:

> *There is still huge value in the residential college experience and the teacher-student and student-student interactions it facilitates. But to thrive, universities will have to nurture even more of those unique experiences while blending in technology to improve education outcomes in measurable ways at lower costs. We still need more research on what works, but standing still is not an option*[60].

This section explores some of the possible “theres” that could be there on the college campus of the future.

5.1 There Could Be an Entrepreneurship Campus

Centers to encourage student entrepreneurship and innovation have begun to crop up at some leading universities. These centers serve as examples of the “theres” that could be there for campuses struggling to figure out how to remain vital in the face of rapid technological changes. Entrepreneurial projects need physical space and that physical space needs to facilitate connections between students and private enterprises. As Cornell University President David Skorton stated in the Wall Street Journal when discussing the temporary Cornell NYC Tech space in Google’s Chelsea headquarters, “We need to create a new academic model for this time and this place and this industry…. The key, we believe, is engagement between world class academics and companies and early stage investors. Co-location is critical to connecting academic research and industry in a sort of a mixing bowl and seeing what happens.[61]” Even when Cornell NYC Tech moves out of its temporary location at Google, its main mission will continue to be to foster a seamless connection between the university and industry. In this new model, “Cornell NYC Tech is not just a school, it is an ‘educational start-up’, students are ‘deliverables’ and companies seeking access to those students or their professors can choose from a ‘suite of products’ by which to get it.[62]”

Cornell, of course, is not alone when it comes to fostering collaboration between students and professionals. Rensselaer Polytechnic Institute’s Lally School of Management established a center for technological entrepreneurship in 1988 that was then renamed The Severino Center for Technological Entrepreneurship in 1999. More recently, Harvard University launched the Harvard Innovation Lab (HI) in 2011 in part to keep up with MIT’s Entrepreneurship Center and Stanford’s “d.school.” Even law schools are opening their own law firms essentially to become “teaching hospitals” for law students with close supervision by professional lawyers and faculty[63].

The interior design of some of these innovation centers aims to foster creativity by conjuring a “start-up” atmosphere. For example, the Harvard Innovation Lab was designed with “exposed ceilings, ventilation, and wiring; bare concrete floors; surfaces coated with whiteboard paint to accommodate free-form sketching and recording of ideas; a kitchen stocked with refrigerated sodas and candy, and an adjoining large-screen television with an Xbox Kinect game controller.” In order to promote “structured spontaneity,” wheel-mounted furniture and flexible ceiling-mounted electrical connections in common areas were chosen[64].

The impact of these entrepreneurship centers extends far beyond the walls of the institutions that house them. Jack M. Wilson, the co-founder of The Severino Center for Technological Entrepreneurship and President Emeritus of The University of Massachusetts, has long professed that such centers of collaboration play a pivotal role in economic development for entire regions. As Wilson has stated in his October 2012 presentation at the White House, “The path to economic and social development in Massachusetts goes through the University.[65]” According to Wilson, innovation occurs when universities collaborate with industry and capital. From this innovation springs new jobs, new companies and perhaps even new industries.

The emergence of these innovation and entrepreneurship centers and law school “firms” illuminates a path forward for other academic institutions looking to use their physical campuses in meaningful ways that are distinct from the online environment. Students and professionals need a "there" to work together on entrepreneurial endeavors.

5.2 There Could Be an Apprenticeship Campus

It is time for a reinvigoration of the vocational college to shake it free of the stigma of vocational training as something less than desirable. This is necessary not only for the millions of people out of work, but also for the employers who cannot find skilled people and the country who cannot compete on a global level. Sebastian Thrun, founder of Udacity, is shifting the focus of his MOOC to address the very real need for vocational training by partnering with companies in need of skilled employees. With the corporations not only helping to tailor the training, but also sponsoring it, this partnership is the first viable money making model for Udacity. According to Thrun, this partnership represents the future of college education:

> *At the end of the day, the true value proposition of education is employment…. If you focus on the single question of who knows best what students need in the workforce, it's the people already in the workforce. Why not give industry a voice?* [66]

Industry has been given a very loud voice in helping South Carolina to develop a skilled workforce. A dearth of skilled workers was what prompted both Tognum America and BMW, two German companies with major facilities in South Carolina, to develop apprenticeship programs in partnership with several area high schools and technical colleges. These programs are good not just for the college offering the training, but also for the entire state. South Carolina clearly knew this when they started their Apprenticeship Carolina program in 2007. The program now includes more than 4,500 students working in over 600 companies[67]. Now South Carolina's main employers are European companies that have been lured to the area in part because of the support the state's colleges have provided in training.

There needs to be a "there" there to train the country's youth if the United States is to grow its industrial capabilities. Even President Obama noted the importance of developing more apprenticeship programs such as those in Germany in his 2013 State of the Union address. However, the number of apprentices has actually been falling instead of rising in recent years. Obama's $100 million grant program to advance technical training in high schools unveiled in November 2013 might not be enough to turn things around[68]. American colleges and universities have an opportunity here to provide a "there" for these programs that require space for students and industrial experts to come together to work on real life machines making the real life things people need.

5.3 There Could Be a Lifelong Learning Campus

Academic institutions struggling to find new markets in this digital age could look to serving the working and retirement populations in their region. As with the need for more vocational training of the country's youth, there is both a need and a desire for older populations to continue their education. George Mehaffy, the Vice President for Academic Leadership and Change at the American Association of State Colleges and Universities (AASCU), is urging AASCU institutions to reposition themselves to be campuses for lifelong learning, further reinforcing their bond to their respective communities. This makes sense in light of rapid technological advances as well as the fact that people are working later in life:

> *Given the pace of technological change and the evolution of the business world, skills obtained early may become obsolete. The new model for workforce education and training is predicated on the need for continuous learning throughout the working life, a process of lifelong learning involving training and retraining that continues well past initial entry into the labor market.*[69]

Facilitating the working population's access to the campus would be essential for an institution that wants to be a lifelong learning campus. In addition to providing courses on nights and weekends, an institution could provide episodic educational experience lasting just a few days for particular training needs. In order to compete with online education providers, discounts on courses to regional businesses could also be provided. Such discounts on courses are already provided to Walgreens employees by the University of Phoenix.

Mehaffy highlighted that learning does not stop when people retire. There is a growing desire within the senior citizen population to participate in college classes. Institutions could consider constructing residence halls for senior citizens who want to relive days at their alma mater or just want to live in a vitality-filled campus where they can continue to grow. People will want to be "there" on campus, but institutions need to recognize that these people are increasingly at various stages in their lives.

5.4 There Could Be a "College Experience" Campus

Burck Smith, founder of the online education company StraighterLine, does not think online education will lead to the end of campus learning. Smith still sees value in the campus experience, but this "experience" needs to be redefined and accentuated. In a recent interview with Smith, he suggested that now that courses can be stripped out of the campus and put on the web, campuses need to offer a "college experience" instead of a selection of courses. The price for this "college experience" could be set based on a time period (term, year) instead of credit hours. The experience would include interactions with intellectually curious people and access to a network of students and professors. College would be about bringing people together rather than bringing people into a room to be lectured to.

The transformation – from a place where courses are provided to a place that offers an experience – would necessitate a redefinition of how spaces are used throughout the campus. For example, a professor's office would no longer be a space for the professor to work alone on research; it would instead become a space for student-professor interaction. A classroom would no longer be a space for a unidirectional exchange of information; it would be turned into a space allowing meaningful interactions between people working on projects together.

For this "College Experience" to be a true departure from traditional educational models and to have a true impact on a student's life, it should be about providing students with their own optimized personal experience. The educational institution could be a place that facilitates a customizable path for a student as they move through their studies with the guidance of faculty who are given the time and space to know the student. While online education providers are busy developing software to provide students with self-paced, personalized courses, campus leaders could be creating malleable, customizable spaces where the student experience is something unique and meaningful.

5.5 There Could Be a "Stewards of Place" Campus

The very fact that colleges occupy a place is what separates them from online educational options. That place in which a college occupies is a specific place in the world. That specific place is what makes a college unique from all other colleges. These are simple facts that George Mehaffy at AASCU has been trying to highlight to AASCU's 415 public four-year institutions.

In a recent interview with Mehaffy, he stressed that these middle-tier institutions are most at risk now in the face of online education and must, therefore make the most of their uniqueness of place. Mehaffy said that AASCU has taken on a Paul Reveresque roll recently by trying to impress upon their member institutions the British-are-coming-type situation they face: state funds are declining, expectations are growing, and technology is changing the entire balance of education delivery. Mehaffy is encouraging institutions to remake themselves as "Stewards of Place," a role that would be defined by a strong connection to their surrounding communities, a connection to their region, civic engagement, and local economic development initiatives. A college can no longer be just a place for the storage of 18 year olds; a college must become a steward for the community in which they are located.

It is especially critical to AASCU institutions that colleges play a greater role in their community and region; most of AASCU students come from less than a 100 mile-radius to their college. For most state colleges, their region provides them with a steady stream of students. These students hopefully will graduate and work in the same region as their college. A college needs to invest in the physical place that they occupy because a thriving local economy is mutually beneficial to both the college and the community. Emphasis and reinvigoration of the "there" there is, according to Mehaffy, essential to the survival of middle-tier institutions.

5.6 There Could Be a Migrating Campus

When a university sends their researchers to swim all around a shipwreck in wetsuits and fins, they essentially are creating a temporary satellite "pocket" research campus. Howard Lurie at edX suggested in a recent interview that the shipwreck "campus," linked to the world online through a live video feed, could serve as a model for a future university system composed of connected pockets of activities. These activity pockets could be located anywhere from that shipwreck deep underwater to a corporate headquarters in a Shanghai high-rise. Unlike the typical branch campuses built in communities throughout a university's region, these pocket campuses would be nimble, temporary research sites that would follow the action. These sites would be tied to the university system through online connections.

Such a nimble campus that follows the action is close to becoming a reality when The Minerva Project opens for business in the fall of 2015. Minerva students would migrate to a new city – Hong Kong, Rio de Janeiro, Sydney, London, Cape Town – every semester. As noted in the Minerva website, "The City is the Campus.[70]" While Minerva students will do their coursework online, they will be grounded in urban life. Even though students will have no student center or quad or sports facilities, they also will be grounded in shared housing facilities in each city[71]. As The Minerva Project matures, it will be interesting to follow what emerges as the essential elements of the Minerva "campus." What are the physical components that remain the same as students move from city to city?

With a "Migrating Campus," the university would be defined by its reach to pockets of activity around the world rather than by the walls of a campus. The "there" there would be ever-shifting, but it would be there.

5.7 There Could Be a Porous Campus

A porous campus is one that allows a high conductivity of people in and out of its spaces. All of the possible campus types explored in this section share a high level of porosity. Both the "Entrepreneurship Campus" and the "Apprenticeship Campus" require a porous environment to allow for exchanges between the business world and the academic world. The "Lifelong Learning Campus" must have a porosity that helps students in all phases of life to find their way to the campus. The "College Experience Campus" requires porous spaces that facilitate interaction between students and faculty. The "Stewards of Place Campus" needs to be porous so as to enable connections with the surrounding communities. The "Migrating Campus" has a porosity that enables researchers and students to connect to activities all over the world.

The porosity of an institution will, according to George Mehaffy at AASCU, determine its success in the future. The online environment excels in the facilitation of the flow of ideas and data. The campus environment must excel in the facilitation of the flow of people. If the campus is infused with technological infrastructure, the campus will be an exceptional place that facilitates the flow of ideas, data and people.

Porosity, however, can be at odds with the exclusivity that is so much a part of the value of some institutions. These institutions will need to reevaluate their levels of openness versus selectiveness. Online education brings with it a democratization of education, but some people will still want to obtain a stamp of approval by being selected by a particular elite group. The acceptance letter to elite institutions is "proof" to many students of their worth. Membership in an elite college or internship program creates social networks that can lead to career and personal success. Architecture has often been used to define these spaces of selectivity. These spaces are designed to exclude thereby creating status thereby creating demand. While Harvard and MIT have opened education to millions around the world through their founding of edX, they are careful not to open the flood gates to these millions at the Harvard and MIT campuses. This limited porosity of these campuses as well as those of their edX partner institutions is spelled out in the edX Terms of Service on the edX website:

> *When you take a course through edX, you will not be an applicant for admission to, or enrolled in, any degree program of the X University as a result of registering for or completing a course provided by such X University through edX.You will not be entitled to use any of the resources of the X University beyond the online courses provided on the site, nor will you be eligible to receive student privileges or benefits provided to students enrolled in degree programs of the X University.*

6.0 CONCLUSION

There is a "there" there. There will be a "there" there. There is an architectureX emerging in response to edX and other online education platforms. Classrooms are no longer unidirectional with focus on the lecturer; they are multidirectional with focus on each team member as well as shared display screens. Hallways are no longer conduits for getting from point A to B; they have nooks and crannies for informal technology-infused gatherings. Libraries are no longer warehouses for books; they have meeting spaces with access to technology. Community centers are no longer just places for Girl Scout meetings; they have spaces equipped with online learning resources for the entire community. Hoever, these examples of technologically-infused spaces for blended learning experiences do not fully define architectureX. ArchitectureX encompasses all of the spaces for learning activities that are not easily replicated online. It is the spaces that an institution preserves and accentuates as part of a reassessment of their core values and mission in relation to the online environment. It is the small seminar room with just a simple wooden table and chairs overlooking the tree-filled quad. It is the turpentine-scented art studio and black countered laboratory. It is the music room with a gaggle of sheet music stands.

The definition of architectureX is ever-evolving because the very definition of "education" is rapidly changing. StraighterLine's CEO Burck Smith argues that the definition of education has in fact never been clearly defined. Is education defined as a process of content transfer? Or is it about socialization or networking? Is it experiential? Or is education defined by all of the above? Up until now, it is the government sanctioned accreditation of colleges that has defined education. This, as Smith points out, has meant that the definition of education has been self-referential: "Education is What Colleges Tell Us it is." As online providers are pulling chunks of "education" out of the college sphere, the definition of education is undergoing an uncontrolled metamorphosis. This means that the reasons for bringing people together for "education" are also rapidly changing and those reasons will vary from institution to institution. Even though the definition of architectureX will continue to be in flux as the definition of education continues to morph, right now campus leaders could be asking themselves important questions that might point to what architectureX could mean for them. These questions touch upon issues spanning from planning to interior design considerations.

At the planning and strategy level, the rise of online education makes it even more critical that institutions assess the ways in which their assets may best support their mission, vision and values while at the same time ensure the greatest return on capital investments. With the fragmentation of the traditional college experience, most academic institutions will need to streamline their capabilities. How will online education impact the way an institution will optimize their portfolio of properties? Should an institution think of creating satellite campuses around the world? Should branch campuses be closed? Should branch campuses be opened? Should low-ranked university programs be phased out? How will the institution's expansions or contractions impact the economy of their surroundings? What sort of alliances could be made with the regional business community? Questions regarding urban design also come into play at this level. How might urban design projects funded jointly by a city and a university reinforce connections with the community? How might urban design bring students into a city?

At a landscape architecture level, an institution might ask if outdoor spaces encourage interaction and flow. Does the campus landscape design create a porous perimeter that is welcoming to the outside community? Does the landscape design inspire people to gather for outdoor work sessions or private studying? Is there access to technology at these outdoor spaces where people might work? Does the exterior lighting and landscape make the campus safe for people walking to classes in the evening?

At an architectural level, the first question institutions might want to ask is which spaces should be preserved and accentuated as part of their core values and mission in an increasingly digital world. Do they need a new building or can they renovate and adaptively reuse what they already have? What are they going to do with that 800-person lecture hall? Does flexible technological infrastructure need to be interwoven through all of the campus buildings? Are there spaces for intimate personal interaction to counterbalance the massiveness of the MOOCs? Are there places for students to gather for blended learning experiences? Are spaces easily accessible for older students?

At an interior design level, again, considerations need to be made about what needs to be preserved and what should change. Do all the existing chairs with tablet arms encourage collaboration amongst students? Are there loose furnishings throughout campus buildings that encourage people to sit and chat for impromptu conversations? For new Active Learning Classrooms, do the furnishings allow for flexible arrangements? Does a tech start-up-like interior actually foster innovation?

At every level of design, considerations about the institutional brand also come into play. With the fragmentation of the college experience, a strong brand identity will be essential to making physically whole the increasingly atomized, virtual student body. Does an institution's approach to planning, strategy, landscape design, architecture and interior design reinforce the brand identity? Do students feel engaged with the university when they come on campus? Does an institution's online presence weaken their brand identity? Does an online presence strengthen an institution's brand identity? Is the institution's brand based on a level of exclusivity? If so, how much should the institution open itself to the online world beyond its gates? Or is it critical that the exclusivity of the physical campus be reinforced as a way to attract people who want to be stamped exceptional by way of access to this exclusive physical space?

It was questions about brand identity that strongly contributed to Amherst College's recent decision not to join edX. The Amherst faculty asked "why a prestigious liberal arts college devoted to 'learning through close colloquy' should put its name on courses attempting to teach tens of thousands of people at once.[72]" Many other universities are asking themselves these important questions about their mission as it relates to online education and have decided that online education could enhance not only their pedagogical efforts, but also life on their physical campus. When advocating for bringing online education to UMass, UMass-Online founder Jack M. Wilson convinced faculty that academic standards would remain high; the admissions process and curriculum for UMassOnline would be the same as UMass. The online programs would not be a watered down version of UMass.

It is the positing of questions such as those covered in this section that could help campus leaders discover what architectureX means for their institution. As with Amherst College and UMass, this could mean very different things. Regardless of the answers, it is essential that academic institutions at least be asking. Change is coming if not already here. In a 2012 interview, Stanford University's president John L. Hennessy offered advice to other universities grappling with the answers to these questions:

> *… universities have to be willing to change. Universities build on tradition and history, but they also have to be dynamic. And I think that struggle to balance those two opposing forces – to not become too attached to the past in such a way that you can't do something new, or to become too faddish in such a way that you lose your core values – is an ongoing challenge for all institutions. But online education is going to happen; it's not going to wipe everything else out, but it is going to happen. We have to embrace it.*[73]

Institutions need to know where they stand. What is their "there"? What can they do "there" that cannot be done online?

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05.
BETWEEN LABORATORY AND FACTORY:
A British Model for Innovation in Manufacturing and Applied Technologies

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ABSTRACT
In late 2009, the University of Virginia Foundation consulted with Perkins+Will to help develop a program brief for a different kind of research facility: a hybrid of laboratory and factory that would offer a new model of collaboration between universities and industry that would be called the Commonwealth Center for Advanced Manufacturing, or CCAM. The CCAM initiative envisioned a non-profit institution, housed in a purpose-built facility, which would promote faster and more effective translation of laboratory discoveries into products and processes for commercialization.

One of these new collaborative models has been innovated in the United Kingdom. These centers, generally called "Technology Innovation Centres," each focus on a particular research "theme" that, though specialized, has relevance across a wide range of aerospace, power systems, electronics, and other technology-intensive industries. This study aims to provide an understanding of the "British Model" for university-industry collaborative research centers at several levels—development history and government policy; business and operations; and planning and design, in order to understand this important emerging building type. The objective of the article is also to provide applicable lessons that may empower U.S. universities and companies to collaborate under similar organizational principles as the British Technology Innovation Centres and its new American counterpart, CCAM.

KEYWORDS: collaboration, research and commercialization, building typology, manufacturing processes, hybrid facility

1.0 INTRODUCTION

The competitiveness of U.S. high technology manufacturing in the global marketplace has become an increasingly serious topic in current political and economic debate. Meanwhile, while still ranking number one in many measures, U.S. universities see declining trends in research grant funding, and are urgently searching for new models of collaboration with private industry.

We worked closely with CCAM's founding partners—the University of Virginia, Virginia Tech, and the Rolls-Royce Corporation--in programming and eventually designing the new facility for such collaboration. As the project developed, we were made aware of an important precedent to the CCAM concept – not in this country, but in the British city of Sheffield.

The Advanced Manufacturing Research Centre (AMRC) became operational in 2008, and pioneered the model of a membership-based research institution that bridges the gap between laboratory and factory. In the British model, universities and companies commit to becoming dues-paying members in an independent research consortium, equipped with purpose-built facilities to accommodate investigations jointly agreed by the membership. We also learned that the AMRC would soon be joined by several other "Technology Innovation Centres" (TIC's) to establish a network of similarly organized facilities, all pursuing complementary themes in materials science and engineering, product development, and manufacturing technology. CCAM will informally associate with these centers, as its primary research themes in surface engineering and manufacturing systems are intended to complement the research efforts of its British cousins. The aim of these centers is to accelerate the transition of laboratory discoveries into manufacturing techniques and processes in an environment that has attributes of both laboratory and factory.

In helping the Technology Innovation Centres achieve this goal, a common planning and design approach has evolved, which draws from a shared programmatic kit of parts and a consistent strategy for assembling these elements into a coherent architectural statement. In short, we are seeing the emergence of an important new building type.

In order to gain a deeper understanding of the British TIC's, key Technology Innovation Centres were visited in February 2012 in order to conduct an observational study. The study consisted of touring the facilities and conducting interviews with the senior administrative staff as well as with the architects who designed them (see Figure 1). Preceding the visits, a detailed questionnaire was submitted to each of the centres, which set the agenda of the interviews and facilitated the discussions.

Figure 1: Location map of British TIC's that were part of this study.

From these interviews, this study aimed to answer the following:

- Where is the gap between research and commercialization, and how did certain key universities, private companies, and public agencies come together to bridge this gap with the Technology Innovation Centres?
- How are the organizations of the centres structured, and how do they conduct the business of research?
- What are the planning and design commonalities—and differences—between the centres as well as CCAM? Is this an emerging building type that begins to set a standard for such buildings around the world?
- What is the U.K.'s policy moving forward in supporting these centres, and enlarging the network and the types of technologies that they address? How does this policy compare to that in the United States?

2.0 THE TECHNOLOGY INNOVATION CENTRES: A BRIEF HISTORY

In the world of high-tech industry, somewhere between basic discoveries in the laboratory and full-scale production of profitable and reliable products, lays a graveyard of promising ideas that lacked the right resources for successful translation into commercial reality. Meanwhile, production difficulties plague the manufacturing of high-tech products because problems were not solved at a smaller scale before massive investments in the equipment and processes of commercial-scale production.

The metrics of how basic research evolves into commercializable reality has long been identified, and has developed into such sophisticated rubrics as the Manufacturing Readiness Level (MRL) scale, the Technology Readiness Level (TRL) scale, and its variants. These frameworks describe the attributes of each step along the way as processes are defined, refined, and scaled up to production levels (see Figure 2).

MRL 4-6 is the zone of development that institutions such as the British Technology Innovation Centres, and its American counterpart at CCAM, are targeting. They aim to achieve this goal by creating purpose-built facilities where universities and private sector companies can collaborate on shared problems of translating laboratory discoveries into technological innovation.

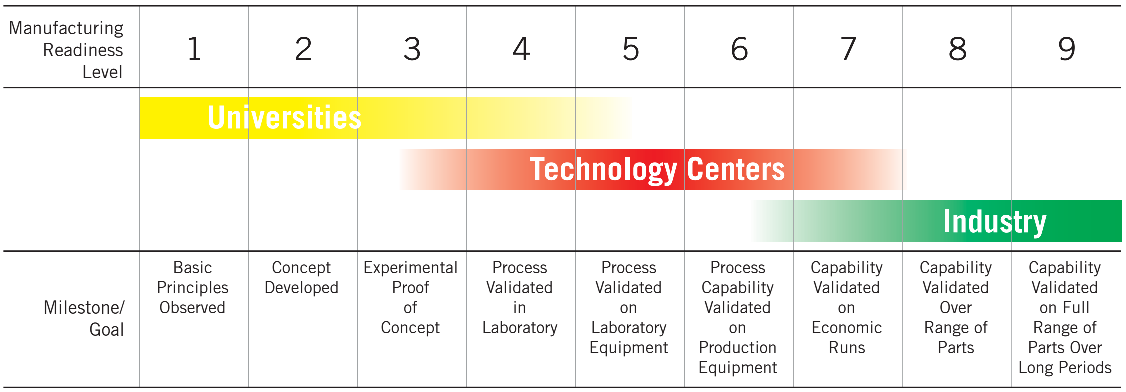


Figure 2: Manufacturing Readiness Scale.

2.1 Advanced Manufacturing Research Centre (AMRC)

At the beginning of this century, on a reclaimed brownfield near the city of Sheffield, England, a novel experiment began in how universities and industries could collaborate in manufacturing research. The Boeing Corporation sought new breakthroughs in machining technology; the University of Sheffield was particularly renowned in research in machining and metallurgy, owing to centuries of expertise that made the Sheffield region famous for metalworking. Boeing and the University partnered in the traditional way in the 1990's, with Boeing directly funding research projects, but, set out in an ambitious new direction in 2001. Working at a larger political scale, and gaining funding and support from regional development agencies (Yorkshire Forward) as well as the European Union (European Regional Development Fund), the founding partners created the Advanced Manufacturing Research Centre (AMRC), a new institution that would be housed in a purpose-built facility where multiple industrial companies and the university could collaborate on projects within the general theme of machining technology.

The organizational breakthrough was the membership model: participants would be members of a research "club", paying annual dues that would cover the operational costs of the centre. All research conducted at the centre would fall into one of two categories: "generic" (projects of common interest amongst the various members, funded by the membership dues) or "directed" (projects of particular interest to a particular member or subset of members, funded by the participants). Another key aspect of the model would be the disposition of intellectual property (IP): all members would share in the IP resulting from generic research, while the results of directed research would become the IP of the particular sponsors. This approach to intellectual property within a collaborative environment ensures continued interest in shared research and also incentivizes investments in directed research; indeed, it is the fundamental key to the financial success of the centre.

The AMRC completed its initial 1200 m^2 (13,000 SF) facility in 2004, on the reclaimed site of a former coking works just outside of Sheffield. Very quickly, the increasing roster of members and projects began to outgrow this modest first building. About that time, Rolls Royce, as a member of AMRC, championed the development of a much larger facility, dubbed the "Factory of the Future", that would more capably support the potential of the AMRC model. Understanding the level of ambition for this project, the members carefully set the vision and goals for the facility, an effort that included a charrette facilitated by the Rocky Mountain Institute. The programming effort pointed towards a building almost four times the size of the original, at 4,500 m^2 (48,500 SF).

The functional realities of collaborative research in machining technology demanded a very large high bay space; the relatively small available site area suggested that any program areas that did not need to be on slab-on-grade—that is to say, virtually everything besides the high bay, certain specialty laboratories, and the entrance lobby—needed to be elevated. The solution was “the office over the workshop”—all the office and meeting areas are on top of the high bay, resulting in the equivalent of a three story building. Acknowledging the functional demands, and honoring the idea of “factory” as a theme for the project, Bond Bryan Architects embraced a simple, rectangular box as the outward form of the building, but developed it with great sophistication in its detailing.

The founders desired a workplace culture that would reflect and support the collaborative mission of the centre; the design supports this goal by an open and airy office floor with a flexible workstation environment interspersed with glass-walled team meeting rooms (there are very few private offices). At the same level, on the other side of the high bay, is a conference area with meeting rooms of various sizes as well as the main employee canteen. Connecting the office and the meeting areas are bridges that cross over the high bay, which, together with generously large windows from offices and meeting rooms that look down into the space, visually link the activities on the office level (computational research, analysis, administration, meeting) with the “factory floor”, where research is applied in actual processes with real factory equipment.

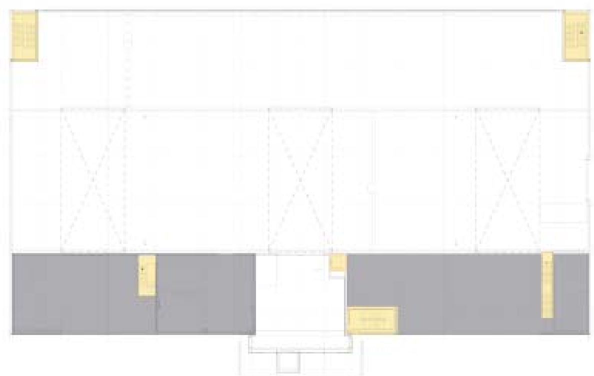
The theme that links the functional and cultural goals of the project is sustainability, which was a very high priority from the inception of the project. Features include ground source heat pumps, and effective daylighting strategies (Buro Happold confirmed 98% of the floor area is naturally lit), natural ventilation in most areas, and solar shading. Most iconic is an 86 meter wind turbine, which offsets approximately one third of the building’s annual electricity usage. The building was awarded the highest Building Research Establishment Environmental Assessment Method (BREEAM) rating, “Excellent”.

Opened in 2008, the AMRC “Factory of the Future” is a showcase building in at least three ways – as a venue for putting the latest technologies in machining processes on display for the large number of visitors who tour the building every year, as an architectural expression of “industrial elegance” that pays homage both to its factory roots as well as to the progressive goals its mission, and, finally, as a demonstration that industrial progress and sustainability are not necessarily contradictory goals.

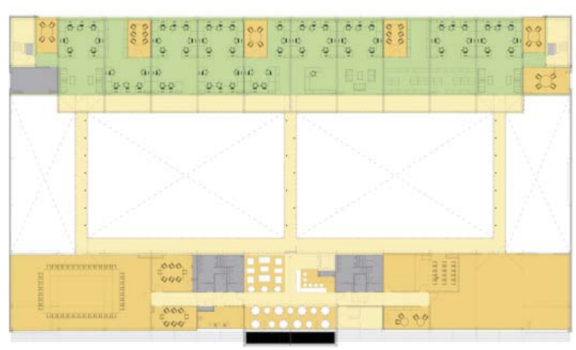
Figure 3: AMRC "Factory of the Future."

Figure 4: AMRC high bay.

AMRC ground floor plan



AMRC mezzanine floor plan



AMRC first floor plan

0 10m 20m

Figure 5: AMRC floor plans.

2.2 Advanced Forming Research Centre (AFRC)

Recognizing the success of AMRC, other partnerships of regional development agencies, universities, and high-technology companies (many of whom were already members of AMRC) began initiating projects modeled after this new building type. The first of these was the Advanced Forming Research Centre in Glasgow, Scotland. The synergy here was the strength of the University of Strathclyde in metallurgy and manufacturing technology (a talent that draws from Glasgow's historic leadership in shipbuilding and other heavy industries), and the innovations sought after by Rolls-Royce, Boeing, Mettis, and other companies having an interest in forging and forming of precision components for critical applications in diverse fields such as aerospace, marine propulsion, and oil exploration.

Like AMRC, the third leg of the stool was participation by a regional development agency, in this case, Scottish Enterprise. With their commitment of public funds for the construction and the initial equipment, the AFRC project could move forward, beginning with the development of the functional program in 2008 (about the time the AMRC Factory of the Future was coming online).

Although the research theme was different, the functional considerations for the AFRC were broadly similar to those at Sheffield: a high bay where very large tools and equipment could be moved with relative ease; laboratories that could support sensitive specialty activities such as surface characterization and metrology; and an open, flexible office environment. However, program and budget pointed to a building only approximately half the size of its sister facility in Sheffield, on a larger site—thus, a single-story solution made the most sense. Hypostyle Architects, of Glasgow, gave the building a memorable form by bifurcating the building with a central "street" feature that functions as entrance lobby and break-out space from adjacent meeting rooms, and (using some specifically aeronautic imagery for inspiration and deliberately avoiding the appearance of a box) endowed the office and high bay zones with expressed shed roofs that are as striking on the exterior as they are on the interior.

Sustainable features included enhanced air tightness and insulation in the exterior envelope, maximization of natural light and natural ventilation, and sophisticated energy control systems. The project achieved a BREEAM "Very Good" rating. The AFRC opened its doors in the summer of 2010.

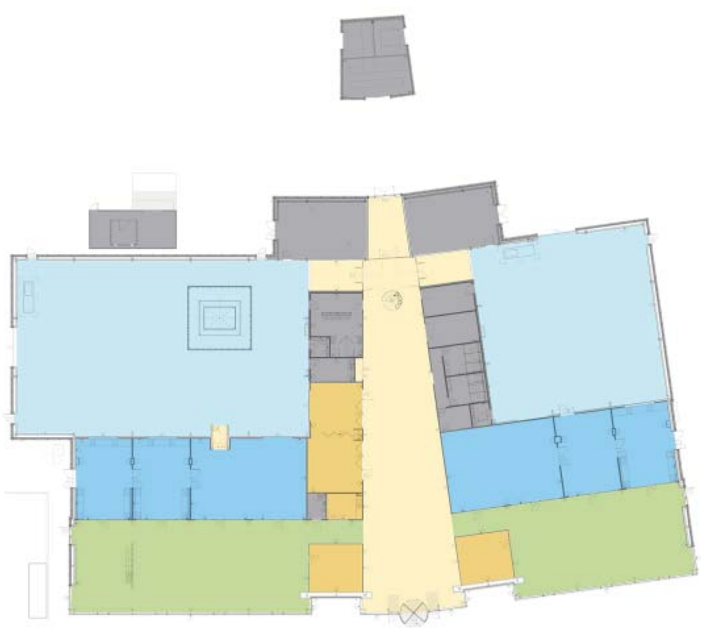


Figure 6: AFRC ground floor plan.

Figure 7: AFRC exterior (Photograph courtesy of Hypostyle Architects).

Figure 8: AFRC office & break Area (Photograph courtesy of Hypostyle Architects).

2.3 Manufacturing Technology Centre (MTC)

While the AFRC project was just getting underway in Scotland, two other partnerships in England formed to develop institutions that would explore other distinct themes in materials engineering and manufacturing innovation. In Coventry, three regional universities, together with Airbus, Rolls-Royce, and the East Midlands Development Agency, founded the Manufacturing Technology Centre (MTC), whose main mission would be to explore advancements in assembly and joining technologies. At 12,000 m^2 (129,000 SF), it is by far the largest of any of the centers that are the subject of this study. The expansive floor area was in part driven by the requirement for three very large high bay spaces, each capable of accommodating complete production-scale assembly cells (indeed, one of the high bays was

Figure 9: MTC public exterior.

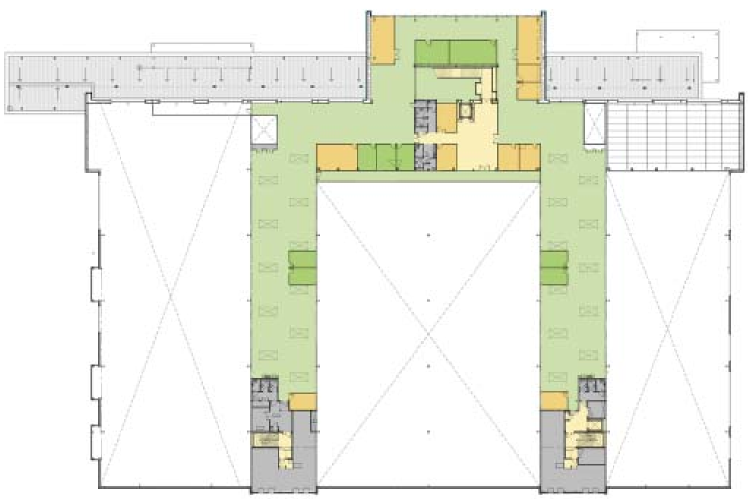
Figure 10: MTC lobby concourse.

required to be able to accommodate the wing of an Airbus A-380 super-jumbo airliner). Broadly similar to the AMRC in the arrangement of the major functional pieces, the MTC was also programmed with an exceptionally spacious and architecturally memorable "public" space, a 3-story high concourse that connects most of the major program elements including the employee café and large meeting rooms. The investment in this amenity reflected a realization, based on the experience of the AMRC, that these centers will host large meetings and see a surprising amount of visitors—everyone from elementary school field trip students to political leaders—and that significant break-out space is a critical necessity.

Although lacking something as conspicuously iconic as AMRC's wind turbines, the Manufacturing Technology Centre achieved a BREEAM Very Good rating. The MTC began research operations in the summer of 2011.

MTC ground floor plan

0 10m 20m



MTC first floor plan

0 10m 20m

Figure 11: MTC floor plans.

2.4 National Composite Centre (NCC)

Meanwhile, the University of Bristol, with its noted reputation in composites research, teamed with the Southwest Regional Development Agency and with additional funding from the European Union, launched the National Composites Centre (NCC). For this project, the critical founding industrial member was Airbus, who was outgrowing its existing composites research facility nearby and was anxious for additional research capacity as efforts for its first all-composites airliner, the A-350 XWB, were ramping up.

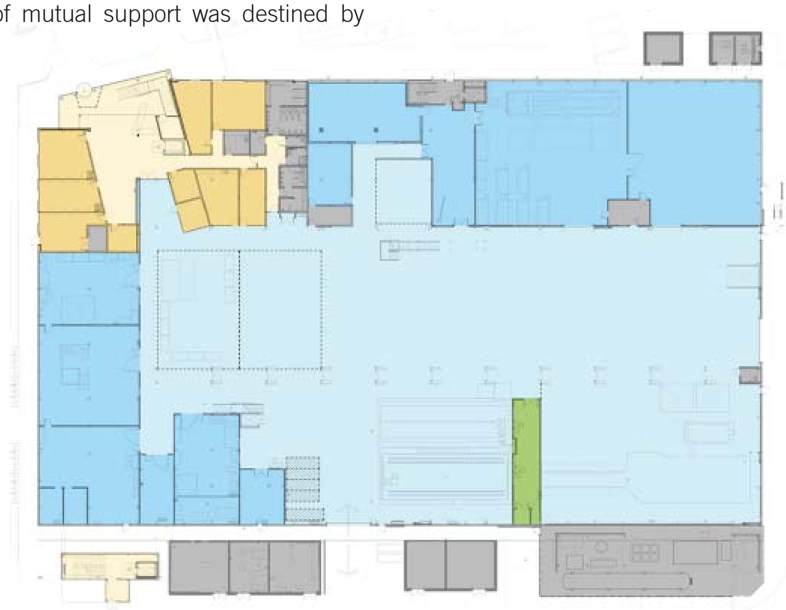
At 8,500 m^2 (91,000 SF), the NCC is physically organized along similar lines as its cousins in Sheffield and Coventry, but with a somewhat larger proportion of the program given over to closed-wall dedicated special-purpose rooms having unique requirements for cleanliness and controllability of environmental conditions, appropriate to the nature of composites production and assembly.

Consistent with the precedent set by the AMRC, the National Composites Centre achieved a BREEAM Excellent rating. Notable sustainable design features include an aggressive daylighting scheme in the high bay, photovoltaic arrays, and rainwater harvesting. Like the MTC, the NCC began research operations in the summer of 2011.

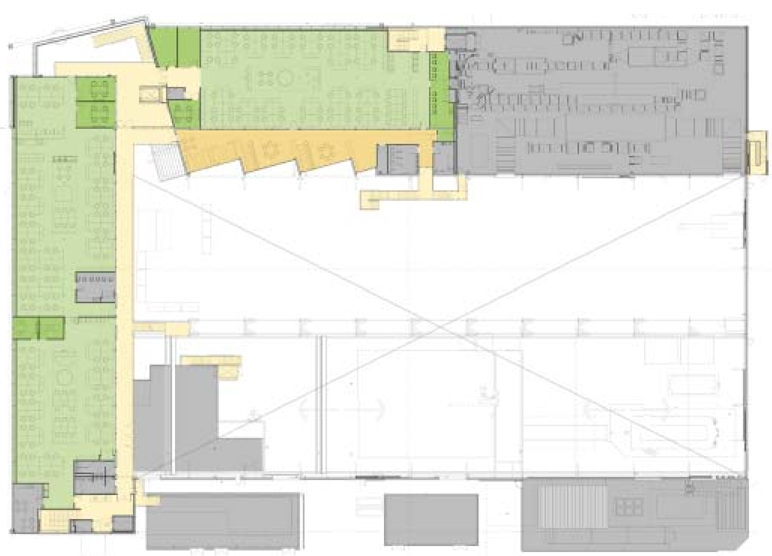
Figure 12: NCC main entrance.

Figure 13: NCC high bay.

Far from being isolated institutions, the AMRC and the four other U.K. research centers that followed in its path quickly evolved into an informal association regularly taking counsel with each other on recruitment of new members what projects would be pursued at the respective centres, and other topics of joint interest. This atmosphere of mutual support was destined by two important facts: first, several key companies (most notably Rolls-Royce) are members of many or all of the centers, and second, at the behest of these members, the research themes of each centre were chosen to be complementary with, rather than duplicative of, the themes of the others.



NCC ground floor plan



NCC first floor plan

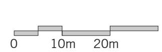


Figure 14: NCC floor plans.

2.5 Commonwealth Center for Advanced Manufacturing (CCAM)

Certain key industrial members of the TIC's in the UK recognized, given the nature of their global supply chains, the importance of expanding the TIC model to other countries including the United States. Building on particular strengths of the affiliated universities, University of Virginia and Virginia Tech, the new center in the U.S. would have a theme that none of the U.K. centers had yet emphasized: surface engineering, a specialty in materials science that pertains to coatings and other surface manipulations of materials that alter their fundamental properties. This center, called the Commonwealth Center for Advanced Manufacturing (CCAM), is located near Petersburg, Virginia, not far from the recently completed Rolls Royce North American Rotatives Factory, which manufactures jet engine disks.

CCAM had its first programming effort in the fall of 2009; the project was completed in October of 2012. This 62,000 SF facility has a similar mix of basic program components as has been described for the AMRC and its cousins; but, in organizational strategy, more closely resembles the AFRC (the diagrams in the latter part of this study illustrate the relationship). Drawing on reported lessons from the operational life of the AMRC, a deliberate visitor pathway ("parade route") is hardwired into the planning of the building. Like the NCC, the design offers plenty of closed-wall laboratory spaces to accommodate processes that will need unique environmental conditions, a consequence of the surface engineering research theme. Like the MTC, a generously sized lobby that offers independent access to a dedicated conference area anticipates the center as a busy venue for meetings, seminars, and presentations.

Figure 19 illustrates the commonalities and differences among the five centres observed as part of this study. Notable factors include private or university ownership of the centre; 100 percent funding of construction cost from the government for examples in the U.K.; complementary (not duplicative) research themes; and a mostly 1:1 ratio of general to directed research.

Figure 15: CCAM west exterior (Photograph by Alan Karchmer).

Figure 16: CCAM high bay (Photograph by Alan Karchmer).

Figure 17: CCAM east exterior (Photograph by Alan Karchmer).

CCAM first floor plan

CCAM second floor plan

Figure 18: CCAM floor plans.

	AMRC	AFRC	MTC	NCC	CCAM
Location	Sheffield, England, U.K.	Glasgow, Scotland, U.K.	Coventry, England, U.K.	Bristol, England, U.K.	Petersburg, Virginia, U.S.A.
Building Owner	University of Sheffield	Strathclyde University	Manufacturing Technology Centre, Ltd.	University of Bristol	University of Virginia Foundation
Construction Cost (£)	£6.5m (2008)	£6.3m (2010)	£23m (2010)	£11m (2011)	£8.1m (2012)
Construction Cost (2012 adjusted)	£5.8m	£6.2m	£22.8m	£11.3m	£8.1m
Construction Cost (2012, in U.S. $, ($1.60/£)	$9.3m	$9.9m	$36.5m	$18.1m	$13m
Building Gross Area (m^2)	4,500 m^2	2,600 m2	12,000 m^2	8,500 m^2	5,700 m^2
Building Gross Area (gsf)	48,500 gsf	28,000 gsf	129,000 gsf	91,000 gsf	62,000 gsf
Construction Cost / sf	$192	$353	$282	$198	$210
Public Funding of Construction Cost	100% (Yorkshire Forward RDA, European Union)	100% (Scottish Enterprise)	100% (East Midlands Development Agency, Advantage West Midlands)	100% (Southwest RDA, European Union)	28% (U.S. Economic Development Agency)
University Members	University of Sheffield	University of Stratchclyde	University of Birmingham, University of Nottingham, Loughborough University	University of Bristol	University of Virginia, Virginia Tech, Virginia State University
Research Themes	• Machining & Milling • Composites	• Forming • Forging • Tool design	• High integrity fabrication • Net shape • Intelligent automation • Tooling • Manufacturing simulation & informatics	• Composites manufacturing • Preform technologies	• Surface engineering & coatings • Manufacturing systems
Ratio of Generic to Directed Research	1:4	1:1	1:1	1:1	1:1

NOTE: Adjusted construction cost based on Faithful & Gould construction Inflation Reports of March 2010, April 2011, and October 2011, reflecting annual construction cost deflation/inflation of -10% in 2009, -3% in 2010, and +2% in 2011.

Figure 19: Technology Innovation Centres – comparison at a glance.

3.0 THE TECHNOLOGY INNOVATION CENTRES AS A BUSINESS PROPOSITION

The TIC's, along with their American cousin CCAM, share the same basic organizational scheme that was established at AMRC in Sheffield. In summary, private sector companies are dues-paying members of a non-for-profit research organization; this organization is affiliated with one or more research universities; and, most critically, the member companies share in ownership of the intellectual property that results from generic research projects.

All of the centers have at least two tiers of membership. Members at the top level typically pay between £200,000 and £300,000 in annual dues ($320,000 - $475,000). These members are typically large, well-established Original Equipment Manufacturers (OEMs) with a wide range of technological interests. Their membership includes a seat on the board of directors, which, besides having oversight on the operations of the center, also determines which projects will be pursued as generic research. These Tier I members share in the ownership of the intellectual property (IP) stemming from the generic research.

Second (and in some cases, third) tier memberships are generally aimed at smaller companies, or companies whose interests are focused on a single area of technology. Benefits for the lower tier members are correspondingly more limited; for example, they may not share in the IP of generic research outside of their particular project involvement.

Members typically must commit to a minimum time duration for their membership, for example five years for Tier I, three years for Tier II, etc. In some cases, a member may provide in-kind donations, such as major equipment, to satisfy its dues to the center in whole or in part.

Major OEM's such as Boeing, Airbus, and Rolls-Royce were major players in the establishment of the centers; however, beyond the founding members, a center's financial success relies on having a critical mass of Tier I members. Thus, recruitment is a critical activity, particularly in the first few years of a center's existence. While many members consist of companies with an aerospace focus, the research themes tend to cut across all industries that rely on innovations in materials science and engineering and their related manufacturing technologies. Thus, the membership profiles of the centers can be rather ecumenical: besides aerospace, members are coming from fields as diverse as electronics, imaging, medical equipment, robotics, industrial tooling, and power generation, to name a few.

The founding of all of the Technology Innovation Centers had roots in existing relationships between certain major OEMs and particular universities. For example, Boeing's collaboration with the University of Sheffield, building upon that university's noted accomplishments in machining technology, paved the way for the establishment of the AMRC. In some cases, the relationship can be with multiple universities – for example, with its multi-themed research agenda, the MTC involves a consortium of universities in the East Midlands region, each bringing different talents to the centre including the University of Birmingham (net shape manufacturing), the University of Nottingham (advanced tooling), and Loughborough University (electronics manufacturing).

The structural relationship between the universities and the centers is variable. In some cases, the Centre is a wholly owned subsidiary of its affiliated university (as is the case with the AMRC and the University of Sheffield). The MTC, on the other hand, is an independent non-profit corporation (in the U.K., a "Company Limited by Guarantee", roughly equivalent to a 501(c) organization in the United States).

AMRC established the concept that collaborative and proprietary research could co-exist in the same institution. In fact, the business model depends on the additional revenue that proprietary research brings, in addition to the annual dues paid by the members. As mentioned previously, "generic" research are those projects jointly agreed by the top-tier members to be of interest to all; the cost of this research is part of the operating expenses of the center; and the intellectual property accrues to all the top-tier members.

"Directed" research are those projects commissioned by an individual member, or group of members, who pay additional fees for the research and enjoy exclusive rights to the I.P. Similarly, an entity completely outside the membership of a center may commission research, and pay fees to the center for this effort.

Directed and commissioned research are a substantial revenue stream for all the centers, and can comprise anywhere from 50 percent to 80 percent of the research volume at the centers.

The presence of proprietary research poses a dilemma in buildings that are otherwise intended to be hotbeds of collaboration, with physical transparency as an architectural goal across all the centers. However, the centers seem to have had few challenges in being able to create necessary security – physical and or visual – in certain areas where particularly sensitive work is in progress. Occasionally, a “room-within-a-room” may be constructed to provide the necessary barrier. More challenging, in some cases, has been the setting up of the information technology infrastructure in the buildings to allow secure data to be handled and stored within what is otherwise a collaborative network.

4.0 AN EMERGING BUILDING TYPE: LABORATORY AND SHOP FLOOR UNDER ONE ROOF

Although these five technology Innovation Centres were designed by separate architectural firms, with limited awareness of each other while the program briefs and designs were being developed, it is remarkable how a comparison of the centers reveals many more similarities than differences. Partially, this is a result of the example set by the AMRC. It is also a result of all firms embracing the functional logic of the building as a giver of form, and of having separately arrived at a common set of goals.

The high bay (or bays) are the most critical program element, needing at once to be both like a true factory floor, but also not setting up obstacles for change. Once set up, a factory floor may remain unchanged for many years; in a research environment such as at these centers, large equipment gets moved in, moved around, and moved out with much higher frequency. Thus, the high bays generally feature large undifferentiated floor space with at least 8m overhead clearance, large access doors from the exterior, generous daylighting, a modular approach to delivering utilities, and (in most cases) a very strong floor slab capable of supporting extremely heavy equipment. Most of the high bay spaces in these centers are equipped with traveling bridge cranes.

Laboratory spaces supplement the high bays, providing enclosed environments for specialty and sensitive work that requires acoustic separation from the generally noisier high bay, or that have unique environmental requirements. Mechanical systems serving high bays generally recycle some proportion of the high bay air, and these spaces can have a relatively large range of temperature and humidity. Sensitive instrumentation and activities such as metrology (precision measuring), surface characterization (involving very sensitive tools such as scanning electron microscopes), metallurgy, chemistry, and many other specialty activities usually require air systems meeting laboratory criteria in terms of temperature and humidity range, air change rate, and ability to handle heat loads. In these spaces, all air once exhausted from the lab is not recycled.

Office areas are open plan; private offices are very rare. A variety of teaming and meeting spaces are distributed in the office areas to provide venues for collaborative project work. In all cases, open workstation areas are positioned to allow views into the high bay area, or the labs, or both.

In the U.K., conditioned air and power and data cabling are provided by a raised flooring system, thus allowing higher ceiling heights and advantages in energy efficiency.

In most of the centers, some of the large meeting rooms are separated from the office areas and are more directly connected to the building lobby. Together with the lobby, which serves as break-out space, these meeting rooms create a miniature conference venue for lectures, seminars, and symposia that have become commonplace in the centers.

All of the centers recognized that despite the very practical and functional imperatives of these buildings, the image of the building and the visitor’s experience would be critical for successfully conveying the mission of the centers to the broader public. This was recognized at the AMRC, but even they did not anticipate the volume of visitor traffic that would eventually be flowing through their facility. The designers of the subsequent centers took this lesson to heart, carving out more generous lobby spaces and sometimes incorporating “parade routes”, i.e., designated walking routes that choreograph the experience of typical visitors who are escorted through the building.

In every case, the founding partners of the various centers requested their designers to develop an “iconographic” image of the building, recognizing the importance of these new institutions in their literal as well as political landscapes. The designers, including Perkins+Will at CCAM, found an architectural voice that while unique to each center, were all within a certain bandwidth of formal simplicity and what one might call “industrial elegance”.

Finally, as mentioned in the individual descriptions of the centers in previous sections, all of these projects recognized the resonance between sustainability and fundamental goals of the research that the centers are meant to support: striving for manufacturing techniques and processes that are more efficient, less energy intensive, and less wasteful of materials. To that end, all of the projects employed an array of energy efficiency strategies, some of which were imaginatively leveraged into becoming a part of the building image (for example, the wind turbine at AMRC, or the serrated profile of the clerestory windows at the NCC). All of the U.K. projects achieved either of the top two ratings available under the BREEAM system.

Together, as the following diagrams and floor plan comparisons show, the Technology Innovation Centres have invented what is essentially a new building type, not quite resembling a typical engineering lab at a University, nor a factory either, something that, quite appropriate to the research it supports, is somewhere between the two.

High Bay Heavy Equipment Labs
Securable Enclosed Labs
Open Workstation Environment
Enclosed Teaming, Meeting or Seminar Rooms; Cafe
Circulation and/or Display/Exhibit Area
Core and Support Areas

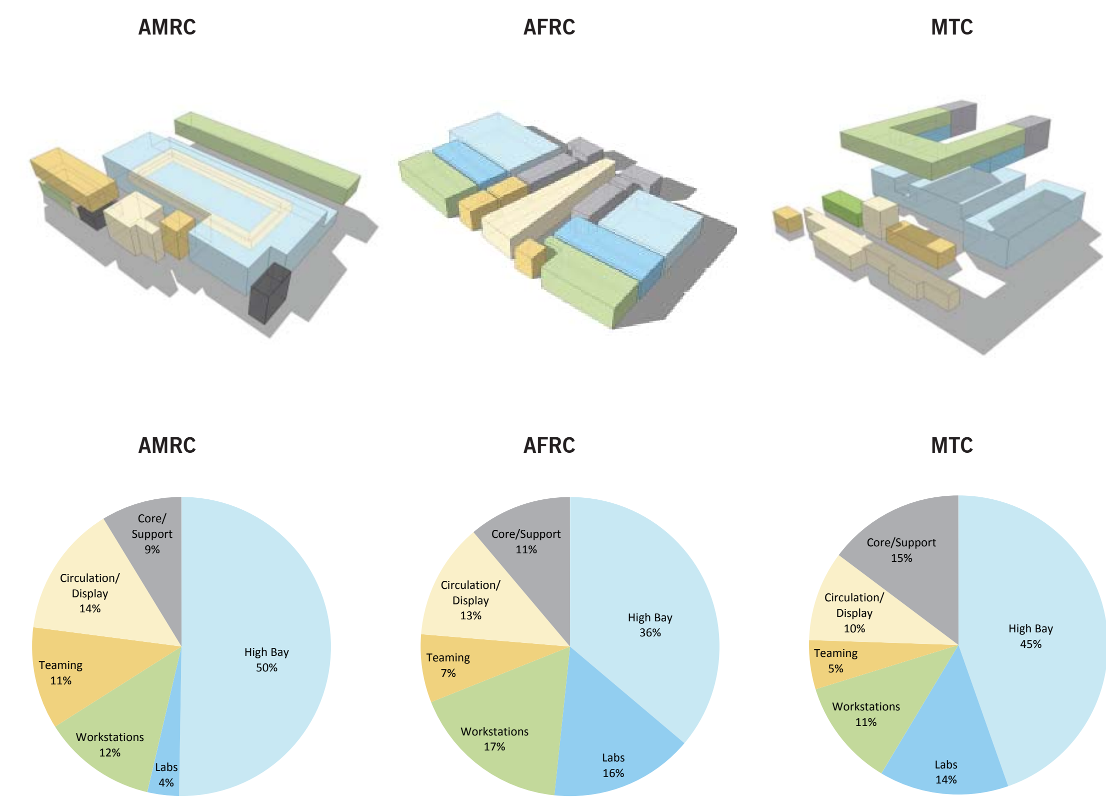


Figure 20: Massing and location of program areas in proportion to other centres.

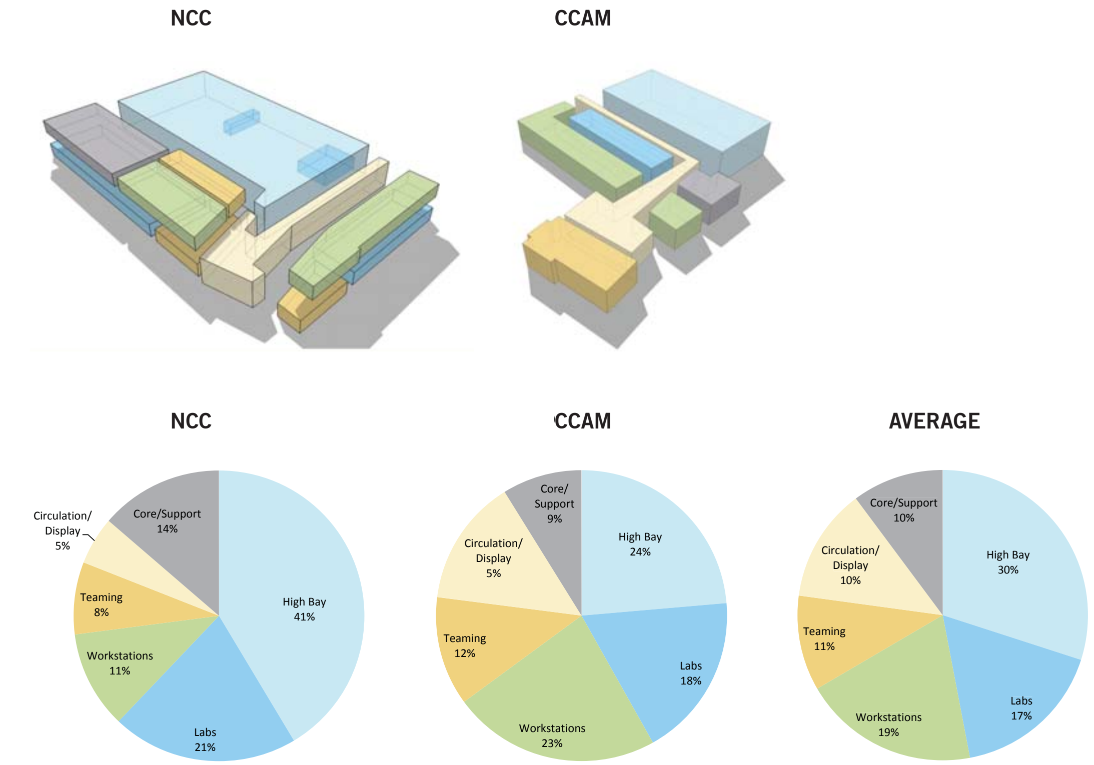


Figure 21: Massing and location of program areas in proportion to other centres.

5.0 U.K. GOVERNMENT POLICY AND INDUSTRIAL REVOLUTION: THE CATAPULT CONCEPT, AND IMPLICATIONS FOR THE UNITED STATES

5.1 The Rise, Fall, and Recovery of Manufacturing in the U.K.

Recent years have seen a decline of the UK's share of manufacturing in the world economy, as summarized in the following points extracted from the House of Commons Library report International Comparisons of Manufacturing Output (updated January 2014)[1]. As of 2011 the UK ranked:

- 7th in terms of manufacturing output ($233 billion),
- 26th in terms of manufacturing output per head ($3,700),
- 108th in terms of manufacturing output as a share of national economic output (11 percent).

While statistical evidence was piling up that the U.K.'s competitive world advantage in manufacturing was beginning to erode, particularly in the high-value, high-technology industries that had been its traditional strength, there was attendant concern that shifting the economy more towards financial and service industries would not realistically solve long-term unemployment problems. As Lord Mandelson, Business, Innovation and Skills Secretary in the Labour governments of Tony Blair and Gordon Brown, remarked in late 2009, the UK needed "less financial engineering and more real engineering", recognizing that broad-based prosperity could not be achieved without a healthy, growing manufacturing sector.

5.2 Diagnosing the Problem: The Hauser and Dyson Reports

Earlier in 2009, Lord Mandelson had commissioned a report to identify what the U.K. could be doing better to compete more effectively in high-value manufacturing. Dr. Hermann Hauser, a noted entrepreneur and venture capitalist in Britain, was asked to lead the effort; the resulting report, The Current and Future Role of Technology and Innovation Centres in the UK, focused on research and development as the key area needing improvement[2]. Dr. Hauser succinctly framed the global competitiveness situation:

> *". . . it has become clear that the leisurely translation of scientific discoveries into new industries has been replaced by a race between nations to take advantage of these discoveries and translate them into economic success stories before others do so."*

The Hauser Report identifies current UK policies regarding public support of scientific and technological innovation and commercialization including a variety of national and regional boards and agencies, but concentrates on a specific aspect of these policies, the Technology Innovation Centres (TICs). At that time, TICs such as the AMRC existed in several technological arenas with various measures of government support and guidance. The Hauser Report recognized the importance of the existing TICs in promoting the activities that characterize the financially risky middle ground of the Manufacturing Readiness scale: providing a setting for companies to share the cost and risk of applied research and process scale-up, co-locating access to equipment and skills that might otherwise be beyond the reach of individual universities or companies, and matching technologies to markets.

The Hauser Report goes on to compare the British Technology Innovation Centres with peer institutions in a dozen other countries, such as the Industrial Technology Research Institute (Taiwan), the Carnot Institutes (France), and the National Institute for Advanced Industrial Science and Technology (Japan).

The most cited point of reference, however, both in the Hauser Report as well as elsewhere, is the network of TICs in Germany known as the Fraunhofer Institutes, consisting of more than 80 research units operating in 60 institutes across a broad range of topics in science, engineering, and medicine. Founded in 1949, the Fraunhofer Institutes are by far the most developed network of TICs in any country, and are often credited with a key role in the success of the German economy and its extraordinary share of high-value manufacturing in the world economy. In the Hauser survey of TICs around the world, it is noted that the Fraunhofer system is in the median range in terms of direct government funding of operations, at about 30 percent, with the remainder of their budget coming from government-funded research grants, usually won on a competitive basis, and from privately commissioned research projects.

In contrast, the UK TICs were generally expected to be financially self-supporting, without any direct contribution of public funds to operations, within a few years of their founding. The Hauser Report saw this as unrealistic expectation that promoted short-term thinking in setting the research direction of the centers. The Report also noted that, to the extent the UK had been investing in its TICs, it did not have "clear prioritization, long term strategic vision, or coordination at a national level." The Report concluded with a series of recommendations, such as better networking of existing and future TICs, criteria for establishment of new centers, and, most importantly, establishment of a consistent funding program that could help ameliorate financial uncertainty and promote long-term, strategic planning amongst the centers.

Almost simultaneous with the Hauser Report was a report commissioned by the conservative party from Sir James Dyson, noted industrial designer and inventor of, amongst other things, the eponymous cyclonic-separation vacuum cleaner. Dyson's report, Ingenious Britain: Making the UK the Leading High-Tech Exporter in Europe, took a more sweeping look at the challenge of effective technological innovation, including cultural and educational factors[3]. The Dyson report, citing the AMRC as a positive example, reached a similar conclusion as Hauser in recognizing the importance of the Technology Innovation Centres and recommending a firmer policy and funding structure to support them.

5.3 The Catapult Program

In 2010, the conservative government under David Cameron acted upon the recommendations of the Hauser and Dyson reports, and established a national program to guide and support the development of TICs in the U.K. Favoring the brand name of "Catapult Centres", the program largely follows the roadmap put forth in the Hauser Report. The stated mission of the Catapult Program is to develop "centres of excellence that bridge the gap between business, academia, research and government."

Administered by the U.K.'s Technology Strategy Board, the Catapult program encompasses the existing TICs discussed in this report – AMRC, AFRC, MTC, and NCC – under the title "High Value Manufacturing Catapult", with an annual funding contribution of approximately £4m annually to each center. It also is launching "catapults" in other topic areas including cell therapy, offshore renewable energy, satellite applications, connected digital economy, future cities, and transport systems.

5.4 The Future of Technology Innovation Centres in the United States: the National Network for Manufacturing Innovation

Meanwhile, recent developments in the political and policy arenas here in the United States reflect an increasing awareness of the importance of high-value-added manufacturing in a vibrant, growing economy. For decades, as in the U.K., conventional wisdom had rationalized the decline of manufacturing in the United States with the concept that the economy's shift of emphasis to services would be a higher and better use of the talent of the citizenry, and assure the preeminence of the U.S. economy on the world stage. A corollary to this reasoning was the belief that while low-tech and commodity manufacturing might be moving to foreign countries, the U.S. would always maintain dominance in the production of high-tech, high-value-added goods. However, the experience of the first decade of this century tells a different story: the U.S. share of high-technology exports declined from around 20 percent of the world total in the late 1990s to about 11 percent in 2008, as illustrated in Figure 22.

Trade balance in high-technology goods for selected regions/countries: 1995-2008

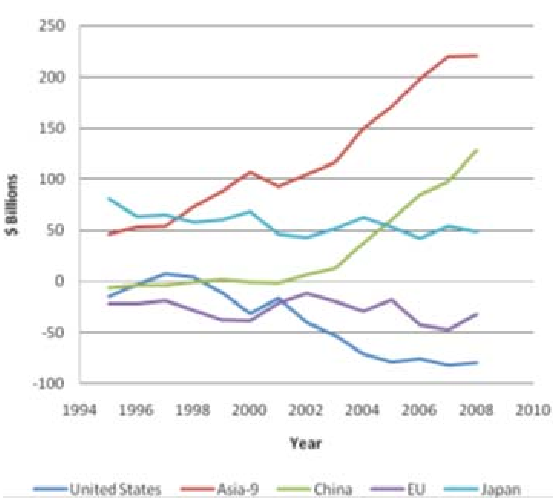


Figure 22: Trade balance in high-technology goods for selected regions/countries: 1995-2008 (Source: National Science Board's Science and Engineering Indicators 2010).

In response to this and other statistical evidence that a fundamental and disturbing shift is occurring in the competitiveness of U.S. technology, the President Council of Advisors on Science and Technology (PCAST) released a report in June 2011, Ensuring American Leadership in Advanced Manufacturing, which presents the following three points to make the case of why high-tech or high-value manufacturing matters[4]:

- "Manufacturing, based on new technologies including high-precision tools and advanced materials, provides the opportunity for high-quality, good-paying jobs for American workers;
- A strong manufacturing sector that adapts to and develops new technologies is vital to ensure ongoing U.S. leadership in innovation, because of the synergies created by locating production processes and design processes near to each other; and
- Domestic manufacturing capabilities using advanced technologies and techniques are vital to national security."

The over-arching concern is that as high-value manufacturing moves overseas, with it goes the innovation chain: basic research, primarily from universities; applied research, proof-of-concept, and scale-up (the middle part of the MRL scale); and the feedback of the commercial sector back into the research stages. Like the Hauser and Dyson reports, a key recommendation of PCAST is to improve, with federal participation, the research infrastructure that supports the middle levels of the MRL scale.

The United States does not lack programs that support R&D and innovation in manufacturing technology; however, as Figure 23 shows, these programs tend to be either focused on earlier or later stages of the MRL process, or are relatively small-scale programs.

In March 2012, President Obama announced the implementation of the key recommendation of the PCAST report, a national-level infrastructure of manufacturing research comparable to the Catapult centers in the U.K. With a somewhat less poetic, but typically American name, the National Network for Manufacturing Innovation (NNMI) is envisioned as establishing as many as fifteen CCAM-like centers across the country. Appropriately, the president chose as the setting for the NNMI announcement the new Rolls Royce manufacturing facility at Crosspointe, Virginia—which is, not coincidentally, also the home of CCAM. The president also cited CCAM as a model of the sort of university-industry collaboration that the government expects to be typical of NNMI; few may realize that, as this report shows, the

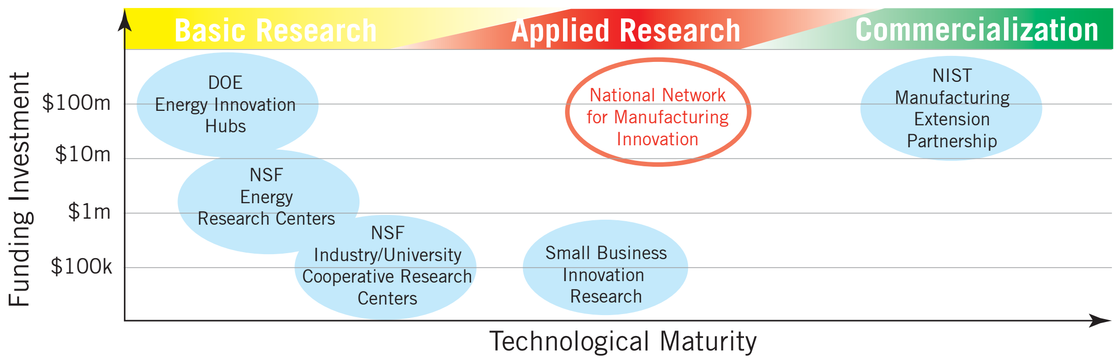


Figure 23: The National Network for Manufacturing Innovation fulfills a role similar to CCAM and other centres between laboratory and factory.

model owes much to forward-thinking academics, business people, and policy makers in Britain.

6.0 CONCLUSION

As universities in the U.S. struggle to find new mechanisms for supporting research in the face of stagnant or declining governmental funding, high technology industries are actively looking for and investing in new pathways for innovation in a time of fierce global competition. Centers dedicated towards advancing technology through a collaborative hybridization of laboratory and factory, such as the British TIC's and America's CCAM, provide a solution.

By bringing together both private industry and university research programs, a group of such centers having specialized, but complementary research themes promotes faster and more efficient translation from research to commercial application than the typical model of industry-funded university research because the resulting innovations are simultaneously leveraged across multiple technologies and market sectors. These Technology Innovation Centers provide an unprecedented hybrid building type, a mix of laboratory and factory, to support these new pathways from discovery to application.

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06.
THE RESOURCE INFINITY LOOP:
Ecoshed Planning for Resilient Cities

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ABSTRACT

Nature has been recycling water within the Earth's closed ecosystem since the very beginning of time. Humans, although a part of the ecosystem, have misappropriated this precious reserve, severely imperiling the availability of freshwater for future use for all life on Earth. Civilizations have thrived or collapsed because of water. The restructuring of our established water and food systems is urgently needed in order to eliminate the constant waste inherent to present systems, and to reverse the detrimental impact they have had on our climatic system. Global warming, water scarcity, food insecurity, and social inequity are just some of the myriad problems facing cities globally. The decrepit state of much existing infrastructure provides a unique opportunity to implement major change. This research focuses the discussion on ecoshed planning - a new paradigm that conveys a multitude of benefits to humankind's physical and social health, cities' environmental and economic health; and above all, the health of the planet's ecosystem. Ecoshed planning closes the loop of water and nutrients – the Resource Infinity Loop – by reclaiming wastewater through natural processes and reusing it for urban farming. San Francisco is well suited for implementing ecoshed-based planning, as shown by the system envisioned for one of the city's watersheds. Arcata, a real-life, built example of these processes in use, which is now almost 40 years old, demonstrates how such a system can succeed. With rigorous multidisciplinary research and collaboration, and progressive policies that push boundaries, it is possible to build the ecologically-regenerative, resilient cities that the future requires.

KEYWORDS: water scarcity, food security, wastewater treatment, urban agriculture, ecological processes, regenerative landscape

1.0 INTRODUCTION

In nature's hydrologic cycle, water is not lost nor created. The volume of water in our ecosystem has always remained constant. Humans' lifestyles, however, have resulted in the decrease of readily available surface freshwater, the less than one percent out of the total volume of water in the ecosystem that is available for all life on earth[1]. Used water, commonly but shortsightedly referred to as wastewater, is pumped daily into saltwater sinks of the world at a pace far greater than nature can replenish freshwater bodies. If we were to mimic nature and recycle used ("waste") water to form closed loops that are a source of freshwater, we could help keep the freshwater-to-all-water ratio from decreasing any further. Recycling urban used water not only reduces the volume of freshwater being discharged into saltwater bodies, but also minimizes the need to draw freshwater from nature's dwindling reserves. Over time this will effectively allow nature a chance to regain ecological balance as well as capture otherwise-squandered nutrients, rehabilitate decrepit or disused post-industrial landscapes, and revitalize communities. Taking this strategy a step further, the article gives a practical examination of the reuse of urban used water to illustrate the concept of an ecologically resilient food and water infrastructure for cities.

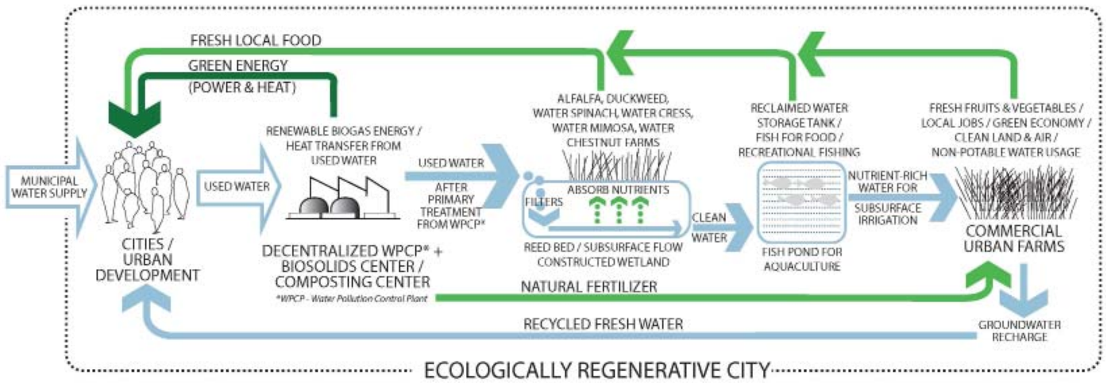


Figure 1: The Resource Infinity Loop concept.

2.0 RESILIENT CITIES CAN SAVE PLANET EARTH

The fast-paced lifestyle of city-dwellers is powered primarily by tapping into an inordinate proportion of fossil fuels, burning through the carbon reserves of our ecosystem. Most transportation, heat, and electricity needs are met by burning fossil fuels, which releases sequestered carbon into the atmosphere as carbon dioxide—a primary component of greenhouse gases (GHGs). Once covered with mature trees, vast land areas that acted as sinks for GHGs have been cleared to make way for cities. With limited opportunity for carbon capture and sequestration that would have contributed to future fossil-fuel reserves, these emissions have instead increased the concentration of carbon dioxide (CO_2) in the atmosphere. Increased levels of greenhouse gases trap heat within the earth's atmosphere, resulting in a gradual rise in our planet's temperature. This steady warming of the globe has had a major impact on the climate already. Recent crippling storm surges, coastal inundation due to sea-level rise, and severe disruption of weather patterns affecting everything from Alaskan glacier melt and Atlanta's schools running out of snow days to zebra migrations and Zimbabwean food security are all effects of global warming. California declared drought this winter while the rest of the country was lashed with severe rain and snow-storms, often where such weather is very far from the norm. Patterns of extremes, as a result of global warming, are a living reality.

In nations across the world, the agriculture economy is giving way to technological- and service-based economies as once-reliable rainfall patterns disappear and agricultural land is consumed by cities. Rapid migration from farms to cities and reduced farm areas will burden remaining agricultural lands with the colossal task of sustaining an ever-growing global population. How we feed our billions, with more than 70 percent of the world's population living in cities by the year 2050, poses enormous challenges to our food system – its production, transportation, storage, distribution and disposal[2]. It threatens our food security and demands a plan of action.

The world will not go hungry for lack of food, but rather waste of food. Nelson (1996) makes the argument that the world's farms produce enough food to provide the world with an adequate diet, attributing food scarcity to a disconnect between places of production and place of consumption[3]. United Nations Food and Agriculture Organization (FAO) studies illuminate the alarming worldwide state of affairs[4]:

- Every year, about one third of the food produced in the world for human consumption, approximately 1.3 billion tons, is either wasted or lost to natural forces,
- Every year, rich nations waste almost as much food (222 million tons) as the entire net food production of sub-Saharan Africa (230 million tons),
- Every year, 40 percent of all food in the United States is thrown away. It is estimated that about half of the water used to produce this food also goes to waste.

Food waste is economically and environmentally disastrous. It encompasses unjustifiable squandering of the tremendous amount of water necessary for the food's production; increased use and misuse of the high-embodied-energy chemicals in fertilizers and pesticides;

and unnecessary contribution to global warming due to factors ranging from the extra fuel consumed in transportation to the methane emissions from food rotting in landfills. All of this food waste is wasted, yet again, when it is not reclaimed and recycled back into the land to be used as nutrients to grow more food. In the United States, organic waste is the second-biggest component of landfills, which are the largest source of methane emissions[5]. Methane is the most harmful component of greenhouse gases. It is 23 times more potent than CO_2 as a greenhouse gas[6].

Food production accounts for 70 percent of global fresh water needs (in United States agricultural demands constitute 80 percent of water needs), an onerous demand on a rapidly dwindling resource[7]. Extreme weather patterns due to global warming will result in dry regions getting drier and wet regions getting wetter. Half the world's population will live in water-stressed regions by 2025[8]. How we conceive (or re-conceive) the urban water infrastructure and how we spatially organize our cities is the key to tackling water scarcity; to succeed we must maximize the capture, use, and reuse of every precious drop.

To mitigate some of the irreversible changes our present city systems have inflicted on our ecosystem, and to begin to have a net-positive impact on the planet, we need to fundamentally rethink the way we plan and build our cities.

3.0 The Resource Infinity Loop

Cities are under growing pressure to determine and deploy optimum water and food infrastructure systems in order to reduce waste; this raises the all-too-immediate question of how we intend to tackle our present overly centralized, overly mechanized, and now crumbling infrastructure. According to the U.S. Environmental Protection Agency's report "The Importance of Water to the U.S. Economy," released November 2013, an investment of an additional $84 billion between now and 2020 is needed, mainly in three areas[9]:

- *Water Treatment Plants* – Upgrading and replacing old plants.
- *Pipes* – The EPA reports that 60 percent of drinking water needs and 28 percent of wastewater needs are pipe-related (51 percent of wastewater pipe-related needs are repairs).
- *Wet Weather Management* – The EPA reports that 772 cities are working to prevent untreated sewage from entering waterways when sewer systems are overloaded.

These anticipated infrastructure improvements are a big investment. At a time of large-scale replacement, it is irresponsible to maintain or reinstate what has contributed to the crisis in the first place. We have the opportunity to introduce a transformative solution to water infrastructure that simultaneously addresses issues of global warming, food security, and water scarcity. The moment begs us to explore the immense potential of reusing our urban wastewater in an infinite loop, using processes that mimic nature, only on an accelerated timeline.

The Resource Infinity Loop upends the way we think about and build our cities. At present we seem to have been accustomed to the idea of the city as a consumption powerhouse with a challenged food system, water-polluting waste streams, and outdated infrastructure transporting large-carbon-footprint food and water resources. The concept of the Resource Infinity Loop, on the other hand, rests on our acceptance of the integral role human beings can play in re-establishing the regenerative ecological flow of our ecosystem; it offers a way to reassert the progress of humankind, to take ownership of our fates, and to be responsible to ourselves and the future.

City dwellers tend to think of the urban ecosystem as birds and critters, trees and gardens, and parks and ponds. We believe that by nurturing these non-human, natural elements within our cities, we can address the ailments of the urban ecosystem to create a healthier city. Though an honest start, this solution is incomplete. Humans are the predominant species in the urban world and the critical link in repairing the ailing urban ecosystem, and can be an active force for renewal. To find regenerative solutions for our cities, we need to step into the ecosystem and take our place in nature's cycle.

The Resource Infinity Loop is a new ecological and social paradigm that uses urban wastewater as a renewable and reliable resource for urban farming, thus closing the water and nutrient loop within the urban environment. Largely unexploited in the more developed economies—but used to great advantage in water-scarce parts of the world—it directs nutrients in human waste for urban farming, thus constantly renewing the food and energy resources being consumed. The used water (it is wastewater only if we let it go to waste) contains vital nutrients - phosphates and nitrates - that are essential for farming, and are the chemicals applied in conventional agricultural practices. Used water is the inexpensive, renewable resource for nutrients and water. The Resource Infinity Loop envisions urban open

Figure 2: Celebrating the abandoned grain silo as a cultural landmark and a place making opportunity.

spaces as productive landscapes that engage natural processes; put fresh food closer to consumers; enhance biodiversity; act as a catalyst for an agriculture-based green economy; and provide a nexus of education and community-building, a framework for social interaction across the food system within the confines of a city.

The Resource Infinity Loop is a cost-effective, low-energy, low-maintenance, resilient approach for replacing the traditional expensive, energy-intensive, centralized infrastructure for water, food, and energy needs. It treats wastewater locally through ecologically advanced treatment processes and reuses it in food-producing constructed wetlands, aquaculture ponds, and urban farms. It successfully creates and embeds decentralized water and food resource-recovery ecosystems within the fabric of the city. Unlike the current systems, it has the capacity to self-renew in the wake of disruptions, and as a modular, decentralized approach, has an infinite capacity for expansion. Cities will keep growing, and humans will continue to cluster there; the fundamental ways in which we plan, design, and build our cities should be redefined to include the infinite resource loop of used water to feed every city.

4.0 DESALINATION, A RESOURCE-INTENSIVE DEPENDENCY

In contrast to the Resource Infinity Loop, desalination of ocean water is a hasty and short-sighted solution that has been adopted by countries with limited access to fresh water, despite its tremendous negative environmental impacts. The chief ecological detriment is the brine disposed back into the ocean after the desalination process, which increases the salinity of the ocean bed, resulting in loss of habitat for marine life—essentially, stretches of dead ocean.

Desalination systems are already in use, and despite the very significant environmental costs associated with this process, the body of local and international environmental law regarding disposal of brine back into the sea does not yet include a single stringent policy. Another drawback is that: the pre-treatment level of salinity of sea-water makes desalination an extremely energy-intensive and an expensive solution from the beginning. In comparison, as indicated in Table 1, although the Resource Infinity Loop concept does entail a kind of desalination process, the removal of salts that are ben-

Table 1: Salinity level comparison of fresh water sources.

FRESH WATER SOURCE	AVERAGE SALINITY (mg/L)
Rainfall/Snowfall	5-10
Potable Water	<100
Waste (Used) Water	500-2,000
Ocean Water (source for desalination)	35,000

eficial nutrients for plants from urban wastewater is far easier and less energy-intensive than from ocean water, and the salts can be retrieved for application in farms.

Although desalination is an early water-supply solution for some water-stressed regions, it cannot be a solution for places with challenging geographical conditions — at high elevation, or deep in the interior away from the coast; nor is it a solution for economically challenged nations. More often than not, places facing the most acute water shortages have these challenges. Desalination also fails the tests of scalability, resilience to adverse weather events and operability in emergency conditions, environmental responsibility, long-term sustainability, economic sense and social progress. In the long run, any true solution must address every stage of the water-use cycle including stemming the flow of waste and reconnecting infrastructure to community and landscape, none of which desalination can accomplish.

5.0 ECOSHED PLANNING TO ENABLE CLOSED WATER AND NUTRIENT LOOPS

5.1 Defining an Ecoshed

Ecoshed signifies the extent of the physical area of a city within which all systems—the natural watershed, the water-treatment and waste-reclamation catchments, the food supply-chain—could work in concert as a closed cycle of use and reuse. Ecodistricts, a recent coinage in contemporary thought on cities, are neighborhoods committed to accelerating sustainability that integrate building and infrastructure projects with community and individual action. Ecosheds take that concept a step further; each ecoshed's distinct boundary is established by the natural topography, like the watershed of a creek, in order to take advantage of the inherent ecological systems within its extent, and to integrate the infrastructure framework with the natural systems already present. The Resource Infinity Loop is such a decentralized framework for water and food infrastructure that we can build ecoshed by ecoshed. The goal is to install productive landscape systems that allow natural processes to operate as infrastructure at an urban scale. Reducing the quantity of mechanized infrastructure and embracing ecological processes will create resilient systems that possess the capacity to renew themselves in the wake of a stormwater surge or other disruption. This is a major advantage over the conventional, centralized, mechanized water infrastructure that alienates itself from the natural landscape and then has to build barriers to protect itself from natural forces. The Resource Infinity Loop paradigm rests on the optimization of capture, distribution, and recapture of the water, food, and energy within the extent of an ecoshed—in essence, ecosheds are the units or building blocks of this new paradigm, each one a place of self-sufficiency and renewal.

5.2 Theoretical Planning of an Ecoshed

San Francisco's topography lends itself easily to this theoretical exploration. Due to its fortunate topography, San Francisco can boast of an extremely low-energy waste-disposal system, wherein all the combined stormwater and sewer lines transport wastewater to the seven receiving pumping systems along the water's edge using only gravity; energy is then used to pump it to San Francisco's two wastewater treatment plants: Oceanside Water Treatment Plant and the Southeast Water Pollution Control Plant. The city, thus has nine natural watersheds that drain either into the bay (eastern San Francisco) or the Pacific Ocean (western), but only two mechanized wastesheds. This following exploration brings back to the fore the underlying topography of the city, to propose each watershed as the basis for an individual ecoshed that would close the loop of water and nutrients within its boundaries.

The Islais watershed, along with the existing Southeast Water Pollution Control Plant (WPCP), is the focus of this study of ecoshed potentials. The Islais-Agro-Park plan, described here, repositions the Southeast WPCP as a catalyst for economically and physically revitalizing this under-utilized and neglected industrial neighborhood of San Francisco. While maintaining the current

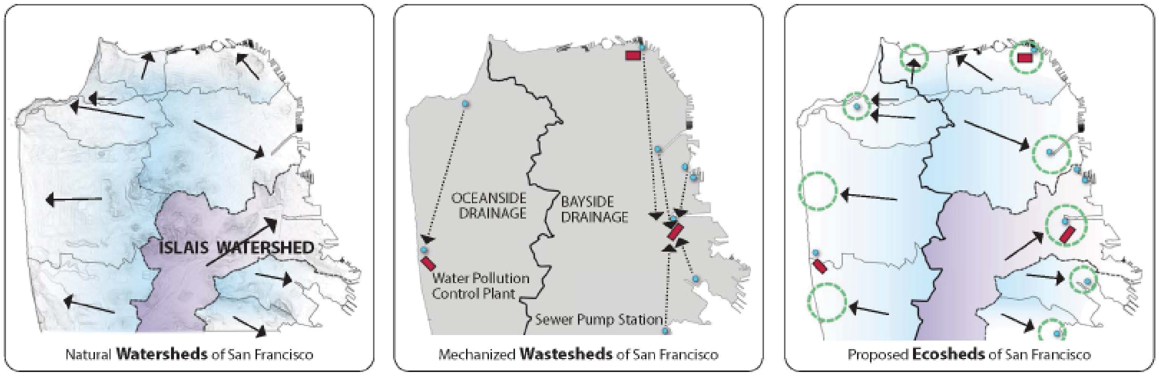
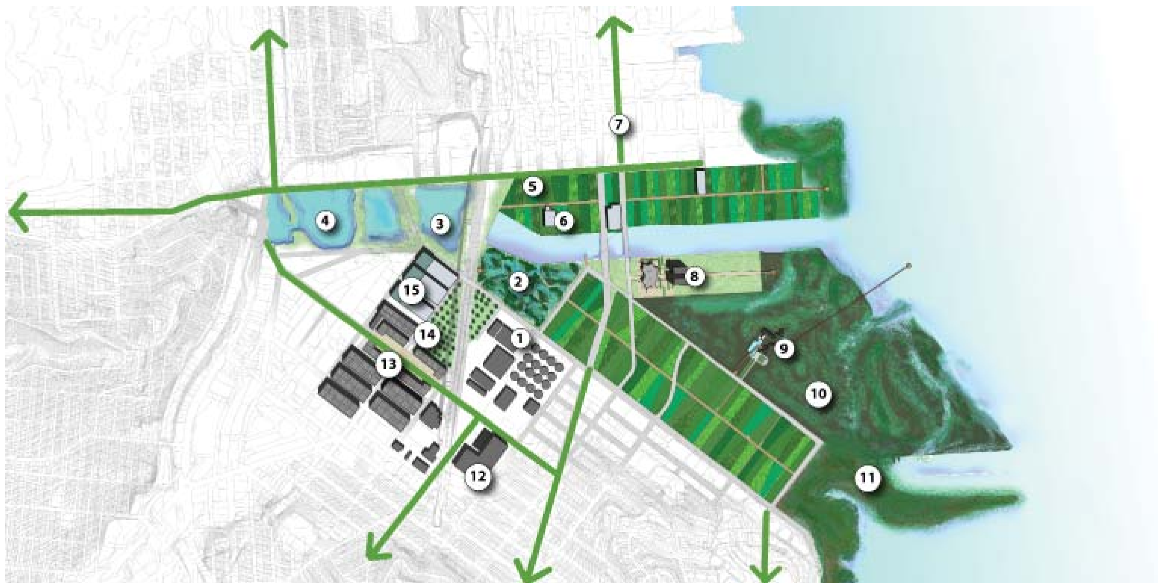


Figure 3: Adapting to San Francisco's drainage pattern for decentralized ecosheds.

job-centric use of the neighborhood, the plan proposes a clean, green, agro-based economy. The San Francisco Wholesale Produce Center is located immediately adjacent to the WPCP (Figure 5), making this ecoshed well-positioned to build on some of the existing uses for the greater economic, environmental, and social good of the neighborhood.

The effluent discharged from the WPCP system following conventional secondary treatment is our starting point. Under the new system, this waste-turned-resource will be tapped and redirected to flow through areas of reed beds for tertiary treatment. Nutrients are absorbed by plants growing in the reed bed (a source of food and biofuels), making this water fit for collection in large tanks for the next step: a controlled-environment aquaculture. Wastewater-fed aquaculture, if the right techniques are used, reduces the E. coli count of the water entering the wetlands from about 10 million organisms per milliliter to only 10 to 100 per milliliter[10]. The idea is akin to the East Kolkata Wetlands in Kolkata, India, where the sewage of the entire metropolis is fed into engineered wetlands that are one of the largest and most productive aquaculture systems of the world[11].

As long as there is a constant slow flow of water through the system of constructed wetlands and aquaculture ponds, this already nutrient-rich water, further nourished by droppings from the fish, can be reused once more in raised-bed urban farms. These urban farms would replace some of the land-intensive light-industrial uses that are, for the most part, growing obsolete. Runoff from these raised-bed urban farms can be recaptured and channeled back to the reed-beds / constructed wetlands. The Resource Infinity Loop, thus recovers water, nutrients, and energy from wastewater; replaces land-intensive, obsolete industrial use with ecologically regenerative food-production use; and creates job—reconnecting urban dwellers with their ecosystem and manifesting and inculcating values of social and environmental responsibility. Other cultural educational and recreational activities can be layered on top of this ecological framework to make it a true model of an ideal ecoshed. This functional unit of the Resource Infinity Loop would lend balance to San Francisco, giving the eastern half of the city its own amazing open space amenity—Golden Gate Park—a distinct, functional, and productive landscape called the Islais-Agro-Park.



1. Southeast Water Pollution Control Plant (WPCP)
2. Used Water, after primary treatment from the WPCP, is filtered in the constructed wetland for secondary treatment. Constructed wetlands produce edible plants like alfalfa, duckweed, water spinach
3. Nutrients get added back into the water during its flow through the acquaculture pond and is recycled on to the urban farm
4. Stormwater biofiltration ponds, a working landscape of ecological stormwater measures are integrated within the city's open space framework
5. Urban farms irrigated by recycled water from aquaculture ponds
6. Existing warehouses adapted to be greenhouses + urban farm tool shed or food-processing centers
7. A new, high-functioning streetscape, the result of overhauling the existing street surface to install functional and visible landscape infrastructure that collects, filters, and transports stormwater run-off
8. Silo Food Museum + Urban Agriculture Center, with its existing iconic silo structures, preserved, reimagined, and adapted to acknowledge the history of the site, showcase the present, and help imagine the future
9. Wetland Center, a visitors' center educating visitors about the wetlands
10. Saltwater wetlands provide flood protection while helping treat the high volume of runoffs during unpredictable wet weather; besides promoting biodiversity within the city
11. Ecocenter at Heron's Head Park is an educational community center
12. Cogeneration Plant + Composting center. Cogeneration Plant recovers heat from WPCP. Composting Center recycles organic waste from the WPCP, nurseries, produce market, urban farms, and the surrounding community
13. Wholesale Produce Market, after its early morning activities, transforms into a Bargain Produce Market that sells produce unfit for supermarkets and restaurants to the local community
14. Horticultural nursery + agricultural experimentation laboratory captures and utilizes excess heat from WPCP
15. Food innovation center + agro-business incubator spaces that train community members and promote entrepreneurs to target a food-based economy in "Islais-Agro-Park"

Figure 4: Ecoshed planning in the Islais watershed of San Francisco.

Heron's Head Park in the Bayview-Hunters Point Shipyard neighborhood adjacent to the Southeast WPCP, is a 24-acre thriving wetland restoration/nature preserve recently created in the Southern Waterfront. It was the result of an abandoned shipping terminal construction that was taken over by nature, and then in the 1990s, was improved with funding from the City and County of San Francisco Public Utilities Commission, the Port, the California Coastal Conservancy and the San Francisco Bay Trail Project to enhance the emergent wetlands. This peninsular park is home to salt marshes and upland restoration activity, walking trails, bird-watching, environmental education activities and the EcoCenter. The EcoCenter at Heron's Head Park (for location see label 11 of Figure 4), is an educational community center that uses sustainable on-site power, water and wastewater systems. Nearly every feature of this facility is designed to educate the public about renewable energy, pollution and greenhouse gas reduction, wastewater treatment, sustainable building materials, rainwater harvesting and the green economy. In July 2013, the EcoCenter was certified by the United States Green Building Council as a Leadership in Energy and Environmental Design (LEED) Platinum building. It was the first LEED Platinum - Zero Net Energy Building in San Francisco. This recent effort in this ecoshed has already set a precedent for natural, restorative interventions that will heal the community and the land.

5.3 Ecoshed Thinking Required to Revolutionize Planning Policies and Programs

City agencies need to restructure their policy creation environment to foster multi-departmental collaboration that synergistically looks at goals and targets of different departments to promote "ecoshed thinking." We urgently need progressive policies and innovative programs that reveal the concealed and invisible underlying natural systems of our cities and emphasize the need to harness the messy, though highly beneficial, regenerative capacity of natural processes as urban infrastructure. These policies will require:

- Developing a stronger nexus between urban health policies, urban agriculture policies, and policies on the reuse of urban used water, in order to remove unnecessarily stringent regulatory barriers and encourage innovation in all fields;
- Establishing an integrated framework addressing water reuse, urban agriculture, and public health goals and targets;
- Identifying and protecting areas of wasted interstitial public land – along freeways, rail lines, airports, and utility easements, for example – and capturing them as opportunities for city-scale strategies for this framework;
- Decentralizing the implementation of this framework by establishing a network of individual ecosheds, in order to allow close monitoring, periodic follow-up of performance, and active local community engagement in the process; and
- Partnering with institutions and organizations that provide sound technical know-how and educational support for implementing waste-to-fork programs.

Urban environmental policy should mandate that all new urban developments, whether private or public, must neither damage nor deplete the natural environment, but rather start a positive cycle of regeneration and resiliency, with projects required to:

- Develop an environmental stewardship action plan to increase awareness of and participation in proactive management of natural resources;
- Identify land for regenerative uses and develop a biodiversity plan contributing to a targeted increase in landscape biodiversity;
- Identify areas and opportunities to enable urban farming - small or large scale, on individual private property or as a community activity;
- Allocate land for landscape-based solutions, or develop building-design strategies, for on-site capture, treatment, and reuse of wastewater; and
- Develop action plan to promote local, small-scale agro-businesses, to support local entrepreneurs, boost local economies, and develop a resilient food infrastructure.

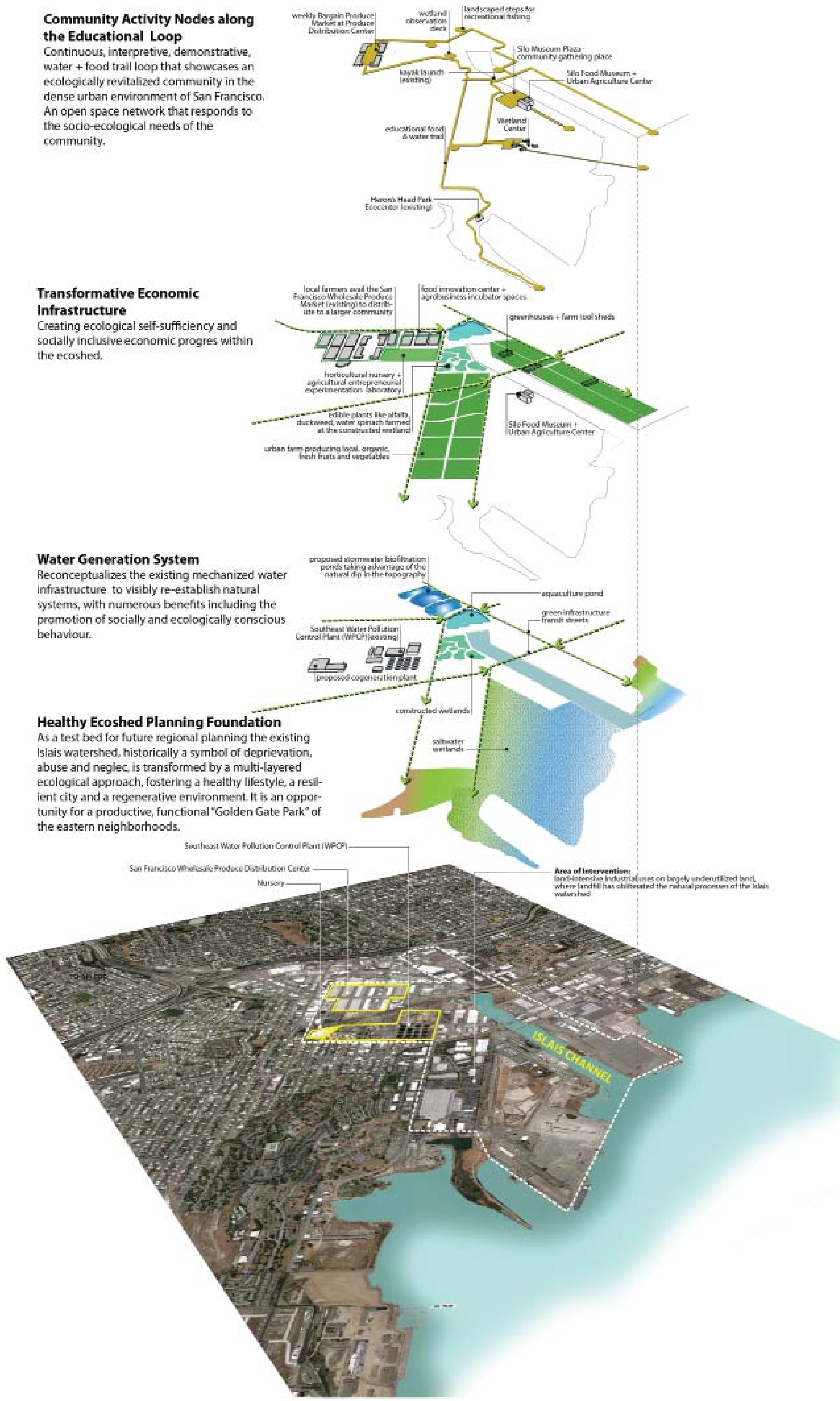


Figure 5: Significant components and benefits of the ecoshed plan.

6.0 CASE STUDY: ESTABLISHING THE TREND IN THE RIGHT DIRECTION

Arcata Marsh and Wildlife Sanctuary + Wastewater Treatment Plant in California is world-famous as an innovative, integrated wetland wastewater treatment system that has repurposed a degraded landfill area and transformed it into a 154-acre valuable resource. The town treats the wastewater of its 17,000-person community in this facility, which provides a popular tourist destination. It is a small-scale, decentralized system that combines the process of a conventional treatment plant with an ecological process, not just to restore, but also to use the restored marshes for the purpose of tertiary treatment and enhancement of the treated water. The plants in the marshes absorb nutrients, cleaning the water before it is discharged into Humboldt Bay. The facility has proved to be an economic boon to the local community; has replaced a landfill with a bird and wildlife sanctuary, now well established; and, with its five miles of trails, has become a recreational destination for locals and tourists. In addition, the Arcata Marsh Interpretive Center is an educational resource for the community.

The City of Arcata established this innovative treatment system as a reaction to an expensive regional wastewater treatment plant being proposed to comply with California's Bays and Estuaries Policy in 1974; the policy states its purpose as, "to provide water quality principles and guidelines to prevent water quality degradation and to protect the beneficial use of waters of enclosed bays and estuaries"[13]. The active wastewater treatment plant had experienced an event of discharge of unchlorinated effluent into Humboldt Bay in 1970, and needed an effective and efficient solution to prevent any future reoccurrence.

Figure 6: Arcata Marsh and Wildlife Sanctuary + Wastewater Treatment Plant, Arcata, California[12].
Area: 154 acres of freshwater and seawater marshes, tidal mudflats, and grasslands.
Design Population: The facility was designed to handle wastewater for up to 19,000 people.
Year Completed: The Arcata Marshes were added to the active Wastewater Treatment System in 1986.

The Arcata marshes comprise three two-acre constructed wetlands that treat all the wastewater generated from the existing wastewater treatment plant through the natural processes of wetland ecosystems. The marshes are planted with thick bulrush and cattail vegetation that slow the flow of water, allowing suspended material to settle and preventing growth of algae due to absence of sunlight reaching the surface of water. The water is then pumped into a chlorination facility to kill any viruses. It is further processed naturally through 31 acres of additional constructed wetlands called the enhancement marshes. At this stage it is clean enough to be released into the bay; however, it is required by regulation to go through a second chlorination process because fecal matter from the birds in the marshes technically violate the regulations.

Innovations and benefits that are associated with the Arcata Wastewater Treatment plan include:

- A low-energy, low-maintenance, decentralized wastewater treatment facility, as compared to conventional treatment facilities.
- Ecological transformation of a landfill and an industrial site into a restored marshland.
- Early wastewater aquaculture experimentation project (since discontinued) that raised Pacific salmon and trout in ponds mixed with partially treated wastewater and seawater, demonstrating wastewater as a resource to be reused.
- Public access to the shoreline of Humboldt Bay (previously inaccessible to the public due to the lumber mills, the landfill, and the wastewater treatment plant) and emergence of a regional destination for bird-watching and natural recreational trails.
- A successful attempt to limit expensive infrastructure investment by adding a cost-effective natural process to wastewater treatment. The cost of the Marsh and Wildlife Sanctuary was half that of its proposed alternative regional sewage processing plant. Moreover, the annual maintenance cost is about $500,000 instead of the $1.5 million the conventional plant would cost.
- Effectively prevented the sprawl that might have

occurred as a result of the pipe network expansion needed for the centralized regional sewage processing plant that had been proposed.

By constructing a cost-effective and environmentally sound wastewater reuse and treatment solution, the facility has received international recognition and numerous awards for municipal planning design, cost-effective public utility operation, an urban redevelopment plan, and natural resource project design.

Arcata is not a holistic example of a Resource Infinity Loop, but it went a long way in demonstrating the scientific and ecological integrity (and multiple benefits) of using cost-effective natural processes.

7.0 MULTIPLE AND MULTI-SCALED BENEFITS OF THE RESOURCE INFINITY LOOP

7.1 Access to Fresh, Local, Organic Food

Providing easy and regular access to fresh produce and other food addresses one of the most prevalent problems in the city: food deserts. A food desert is a large area of a city with no access to grocery stores that stock fresh fruits and vegetables. Growing food within cities and distributing locally through mobile vendors/food trucks or to stores and food hubs eliminates this situation. It gives all city dwellers the choice to adopt healthy food habits and live a healthy lifestyle, thus reducing the likelihood of health issues like malnutrition, obesity and related ailments, and even heart disease. This is a boon

Table 2: Beneficial impacts of the Resource Infinity Loop.

BENEFITS	Local / Community	City-wide	Regional	Global
Access to fresh, local, organic food	✓	✓		
Strong local economies / economic drivers	✓	✓	✓	
Educational amenity established at water treatment plant	✓	✓	✓	
Reconfigured streets with visible water infrastructure and reduced stormwater runoff	✓	✓		
Renewable energy from urban waste	✓	✓	✓	✓
Reducing the 'heat island' effect	✓	✓	✓	✓
Changes made to 'urbanscape' / institution of productive landscapes	✓	✓	✓	✓
Improved water quality in our rivers, bays, and oceans	✓	✓	✓	✓
Biodiversity promoted and flooding reduced through wetland restoration	✓	✓	✓	✓
Phosphorous recycling	✓			✓
Social equity	✓	✓	✓	✓

Figure 7: Reimagining city infrastructure: an urban landscape that closes the cycle of water and nutrient use.

Figure 8: Access to bargain produce at the wholesale produce market/food distribution hub.

for the public as well as for cities' often over-subscribed neighborhood clinics and hospitals. Establishing a balance of commercially viable farms and ensuring access to affordable fresh produce will require further investigation into successful urban agriculture typologies and models.

7.2 Strengthening Local Economies with New Drivers

The Resource Infinity Loop introduces opportunities for commercial organic urban farming and aquatic ecologies within the city that generate and support an aquaculture economy. This creates new local economies that are fundamentally structured around the environmental and economic health of a city and the physical and social health of its residents. In addition, ancillary support businesses focused around urban agriculture – such as a food distribution hub, experimental nurseries and laboratories, urban agriculture-focused training center, and agrobusiness incubator spaces – further boost the economy with clean, green jobs.

7.3 Renewable Energy Created from Urban Waste

Bio-methane is an extremely potent GHG emission. Bio-methane, unlike fossil fuels, is produced from fresh organic matter like manure, sewage, and organic waste, which means that it is a renewable source of energy that can be produced rather inexpensively worldwide[14]. Studies have shown that bio-methane, if captured and used as biofuel for powering light vehicles, can actually produce a negative GHG emission, which will result in the long run in reduction of GHG emissions and a positive impact on the environment[15]. Bio-methane is also used in larger-scale energy production: heat, a by-product of the gas, is converted into electricity—another way in which bio-methane can be a responsible source of energy.

7.4 Educational Community Amenity Established at Water Treatment Plant

Given the innumerable benefits from urban used water, water treatment facilities deserve better status within our urban fabric. These should be places of education and community pride, with careful thought given to their aesthetics and the opportunity for placemaking. A wonderful precedent can be found in the recently built Omega Center for Sustainable Living (OCSL) facility, also known as the Eco Machine. OCSL is not just a wastewater treatment plant that treats water through biological process to recharge the acquifer, it is also a demonstration project and an education center orienting visitors to a regenerative future.

7.5 Reconfigured Streets with Visible Water Infrastructure and Reduced Stormwater Runoff

We now have the advantage of a growing repertoire of tested best practices that offer ways to reconfigure street cross-sections to reduce unwieldy, hidden infrastructure with visible functional landscape features. For example, bioswales that provide attractiveness to land-

Figure 9: Public access with interpretive signage provides an immersive educational experience.

scapes can dramatically reduce sewer overflows during severe wet-weather events; they treat storm-water run-off either by infiltration or by conveyance to other water collection/treatment locations.

7.6 Reducing the "Heat Island" Effect

The open space and greenery that are part and parcel of the various natural processes introduced by the Resource Infinity Loop have a positive impact on the problem of heat islands (excessive buildup of heat in cities). Heat islands affect communities by increasing energy demand, air conditioning costs, heat-related illness, and mortality, particulate air pollution and greenhouse gas emissions as well as decreasing water quality. Having nature-scape open spaces is one of the most effective ways to reduce the urban heat island effect within cities.

7.7 Changing Urbanscape to Institute Productive Landscapes

Given the development pressures on any available land within a city, it is immensely beneficial to initiate a strategic framework of streets, easements, open spaces, and under-utilized areas, which together establish a valuable integrated green infrastructure as well as provide productive landscape opportunities allowing natural processes to aid in the functioning of the city. Parcels adjacent to such landscape greatly benefit from an increase in property values.

7.8 Improved Water Quality in Rivers, Bays and Oceans

Agricultural run-off is one of the largest sources of non-point-pollution affecting freshwater bodies. Chemicals added in fertilizers and pesticides are only partially absorbed by crops, and much of it drains away as run-off, seeping into our rivers, lakes, aquifers, and oceans. This practice is financially unsound and a huge loss of finite resources, in addition to the fact that when these resources drain away, they become pollutants. This pollution endangers aquatic life, due to eutrophication causing algal bloom. It is difficult to control non-point-source pollutants like this. Removal of chemicals is currently achieved largely by chemical precipitation, which is expensive. A less-expensive, environmentally friendlier alternative is biological control and removal through buffer zones like wetlands, riparian zones, and aquatic ecotones (transition zones) that filter and retain the nutrient elements from agricultural runoff.

7.9 Establishing Wetlands to Promote Biodiversity and Reduce Flooding Events

Wetlands serve as detention ponds during a storm surge, drastically reducing run-off into water bodies, and infiltrating it over time to recharge the ground water. These functions buffer adjacent communities from inundation during a heavy storm event and serve as natural flood control. Wetlands also promote biodiversity. The wetlands environment has a distinctive vegetation pattern of hydrophilic plants, which in turn provides important habitat that attracts local water-fowl and migratory birds, making constructed wetlands a successful way to welcome larger diversity of nature into our cities. In addition to these benefits, some hydrophilic plants are edible including alfalfa, duckweed, water spinach, watercress, water mimosa and water chestnut. These wetlands, thus constitute an added source of fresh food.

7.10 Phosphorus Recycling

Phosphorous in chemical fertilizer is mined from finite, shrinking phosphate reserves, the majority of which are in Morocco and South Africa. Fabricating and transporting phosphorous is an energy-intensive and expensive process. There are large environmental and cost-saving benefits achieved by replacing chemical fertilizers with phosphorous recycled from human waste.

7.11 Addressing Social Equity

Historically, large parcels in low-lying areas of the city have been zoned for industrial uses. With the changing economy these industrial parcels have remained vacant or under-utilized, failing to repurpose to more relevant, job generating economies. Oftentimes these sites are environmentally degraded, requiring expensive clean–up before reuse. Residential neighborhoods adjacent to these industrial areas have been generally under-served communities, impaired by poverty, and lacking the most basic social infrastructure and community amenities. The Resource Infinity Loop provides the framework to provide for the social needs of these communities and enable a livable environment.

Repurposing these sites for controlled-environment agriculture could heal blighted sites and convert them into an economic and environmental asset for the owner and the community. The Resource Infinity Loop, by its very nature, favors sites where communities are most in need, and therefore, inherently promotes social equity through the elevation in quality of life for the immediately surrounding community; an urban farming setting (as compared to an industrial environment) has long-term economic, social, and health benefits to the communities that need them most.

8.0 CHALLENGES IN IMPLEMENTING THE RESOURCE INFINITY LOOP

8.1 Public Health Regulations

Applying wastewater in agricultural fields is an age-old farming tradition practiced by civilizations across the globe. Since the 1800s, farmers in California have used wastewater for irrigating crops. Of all the various uses, agriculture irrigation accounts for almost half of the use of treated water available annually in California. California is the national leader in use of treated water for both agriculture and landscaping. Despite its benefits, however, wastewater contains pathogens and poses a risk to public health, especially in urban areas.

California's Department of Public Health Services determines the permitted use of recycled water. Listed in Title 22 of the California Code of Regulations for recycled water use, these regulations are among the most stringent in the entire country. Table 3 shows the permitted irrigation use of the three main reclaimed water types - secondary treated recycled water, tertiary treated recycled water, and advanced water purification recycled water.

Current inconsistent policies and regulations, in addition to a cumbersome permitting process, have hindered the large-scale use of recycled water. By adopting uniform health standards, the Department of Public Health will be able to provide project designers with the direction needed to cost-effectively design for water recycling facilities that are fully protective of public health and provide ecological benefits to the city.

Water-abundant nations, like Sweden, have experimented since the 1990s with eco-sanitation in an effort to protect the water quality of the Baltic Sea. Recycling and reuse of nutrients in wastewater is promoted in their various legislation pieces and environmental policies.

Table 3: Permitted use of recycled water by type under Title 22, California Code of Regulations.

TYPES OF RECYCLED WATER	PERMITTED REUSE
Secondary Treated Recycled Water	Surface irrigation of orchards, vineyards, landscaping areas not subject to constant human use
Tertiary Treated Recycled Water	Spray irrigation on recreational venues –parks, golf courses school yards; industrial uses; irrigation of edible food crops
Advanced Water Purification Recycled Water	Replenishment of potable water sources – groundwater and surface reservoirs

8.2 Cost of Water

Subsidized farm irrigation and the cost of transporting water to farms from distant sources have undermined the push to look for sustainable new freshwater sources. The perception that water is relatively low-cost has been exacerbated by water utility rates that are set substantially below their true values. We have been slow to respond to our many drought cycles. We need to reassess the cost of water and adjust our water rates. The increase in price of water in Australia has, over the years, contributed to an overall decrease in water use[16]. Australia is one of the global leaders in water responsiveness because of its undeniable reality of being a water-scarce region.

8.3 Land Availability

The idea of a functional landscape serving as an infrastructure on an urban scale conjures an image of vast expanses of expensive land unavailable for real estate development. The need for large land area that engage natural processes is a potential deterrent to the implementation of the Resource Infinity Loop. Further research is required to determine the size and scale of such a landscape infrastructure, however, advancements in technology (with Worrell Water Technologies' Living Machine® system that uses living plants and beneficial microorganisms to turn wastewater into clean water) make one hopeful of future possibilities of a compact land-engineered solution that minimizes land requirement, keeping urban land available for high-intensity urban development.

8.4 Societal Perception

There is a preconceived, emotion-driven, public perception of risk that weighs against the reuse of urban wastewater for food production in many developed countries. Mainly, this seems to be a psychological barrier, which is to say, a matter of public education and political will. However, with growing awareness of the fact that water is a limited resource, and with increasing demand, societal perception of wastewater is changing. Treating and reusing water locally has the potential to win over a community when proposed as an alternative to using a conventional, mechanized, large-scale facility built for a region of which the community is a small part, especially as it also gives the community a chance to come closer to meeting its local environmental and economic goals.

9.0 CONCLUSION

In order to make ecologically-sound design and engineering decisions when planning our cities, it is imperative to understand wastewater ecology. Efficient, aesthetically appealing, decentralized, natural treatment features within urban developments are the energy-passive, community-engaging, resilient, and scalable solutions that will help maintain the water balance of an urban watershed and serve as one of the many regenerative solutions essential to the survival of cities. Complementing a basic treatment facility with additional natural treatment, as in the case of Arcata, avoids expensive, high-maintenance, conventional infrastructure solutions. Cities stand to gain manifold benefits from such an ecological process within an urban development. These solutions still have challenges to overcome, and will need to be adapted to specific local context as well as local policies and regulations—but the stage is set and there has never been a better time to act.

Issues pertaining to water access are issues of basic human rights and of social justice. Around the globe, water concerns are contentious across political boundaries, determine national security policies, and have enormous consequences to world economies. There is no overstating the fact that water issues are fundamental issues of survival to any and all species. We need to protect our water reserves and design for resilient cities.

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07.
LABOR-DELIVERY-RECOVERY ROOM DESIGN THAT FACILITATES NON-PHARMACOLOGICAL REDUCTION OF LABOR PAIN:
A Model LDR Room Plan and Recommended Best Practices

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ABSTRACT
Epidural analgesia is the most popular method of controlling pain in labor in the United States today, but it has serious side effects and risks for both mothers and babies. Though most laboring American women choose epidural analgesia, it is important not to confuse a hospital's failure to provide options with patient preference. Few large obstetrical units offer LDR rooms that facilitate non-pharmacological pain relief through comfort measures, and more women would choose these methods if they were readily available. Moreover, patients who have the opportunity to choose non-pharmacological pain relief techniques report higher satisfaction with the birth experience. The architectural design of an LDR room can greatly facilitate the use of non-pharmacological techniques for effective pain relief through two primary mechanisms: relaxation through a calm, supportive physical environment, and labor in water. LDR rooms should be designed to incorporate best practices to ensure that laboring women are able to be relaxed and comfortable, that their movement is not restricted, and that their privacy is guarded. This study applies best practices to develop a model LDR room that takes into account current American codes and standards and includes features that facilitate non-pharmacological pain relief techniques.

KEYWORDS: Evidence-based design, patient satisfaction, birthing pools/tubs, unmedicated birth, labor aids

1.0 INTRODUCTION
The objective of this research was to produce a model patient room design and recommend best design practices for Labor-Delivery-Recovery room (LDR) design, which facilitates the use of safe and effective non-pharmacological pain relief methods during labor. The methodology for this research included a lengthy interview with an experienced birth educator and doula, a review of existing data from journal articles, books, and online publications, and a comparison of current typical LDR plans from domestic and foreign hospitals.

1.1 Background
In many hospitals, epidural analgesia (pain relief delivered via epidural during labor) is routine and is provided to approximately two thirds of all women who are in labor. It has become the most popular and common labor pain management option for women in North America. At some institutions, greater than 85 percent of all women in labor request and receive analgesia for labor and delivery[1]. However, epidural analgesia produces common untoward effects on labor (including a drop in blood pressure, decreased blood supply available to the baby, slowed labor, increased risk of needing a caesarean section, and neonate lethargy and difficulty in breastfeeding) and can cause serious or life-threatening complications (including difficulty breathing and permanent nerve damage)[2]. One in 4,000 women will experience a life-threatening side effect from her epidural analgesia, and one in 2,800 experience a serious side effect[2]. Safe and effective non-pharmacological alternatives to epidural analgesia exist and are frequently used by midwives and doulas. One example is the Bradley Method, which aims to reduce pain in labor through relaxation. Another technique is laboring in water. Studies have shown that non-pharmacological pain relief can be as nearly as effective as epidural an-

algesia, but carry none of the health risks to mother or baby. However, contemporary LDR room architecture often does not facilitate the use of these methods[3]. For example, laboring in water has been clinically shown to significantly reduce pain, however, most LDR rooms do not include a labor pool[4].

Epidural analgesia rates are highest in high-volume obstetric units. Designers have the opportunity to positively impact the rates of epidural analgesia through the design of LDR rooms. LDR rooms are already being designed to limit medical errors, and this article explores how we can design them to reduce medication risks by facilitating non-pharmacological pain relief strategies.

1.2 Patient Satisfaction

Many doctors and nurses believe that pain is the foremost concern of laboring women and that pharmacological pain relief will ensure a positive birth experience and improve patient satisfaction. It is important not to confuse institutional standards with women's preference; in fact, there is evidence that the opposite may be true[3]. Several studies have shown that women who use no labor medication are the most satisfied with their birth, both initially and over time. In a British survey of 1,000 women, those who had used epidurals reported the highest levels of pain relief, but the lowest levels of satisfaction with the birth, probably because of the higher rates of intervention[2]. Another study that compared women who labor in water to those who do not, showed that women who labor in water have a significantly higher level of satisfaction with the birth experience[4]. Competition for maternity patients among hospitals is intense and hospitals are looking for ways to improve their patient satisfaction scores. Offering non-pharmacological options for pain relief is a good business strategy.

1.3 Scope

This study focused on the Labor-Delivery-Recovery (LDR) model in large American hospitals. LDR rooms accommodate the birth process from labor through delivery and recovery of mother and baby. They are equipped to handle most complications, with the exception of cesarean sections. This architectural model was selected because it is the contemporary standard in large hospitals.

Outside of the scope of this study are the traditional obstetrical model with separate labor, delivery, recovery, and postpartum rooms (this model is widely considered to be obsolete), birthing centers, labor & delivery C-section rooms and C-section operating rooms, and Labor-Delivery-Recovery-Postpartum rooms (LDRP's). Although the LDRP model is similar to the LDR model, it includes special provisions for postpartum care - this study is focused only on the labor and delivery phases of childbirth. However, many of the design ideas from this study can be applied to the LDRP model.

1.4 Minimum LDR Code Requirements

LDR rooms must have a minimum clear floor area of 340 square feet with a minimum clear dimension of 13 feet (15 feet minimum is preferred to accommodate the equipment and staff needed for complex deliveries). This includes an infant stabilization and resuscitation space with a minimum "clear floor area" of at least 40 square feet. The dimension and arrangement of room must be such that there is a minimum clear dimension of three feet between the sides and foot of the bed and any wall or any other fixed obstruction[5].

"Clear floor area" is defined as the floor area of a defined space, which is available for functional use exclusive of toilet rooms, closets, lockers, wardrobes, alcoves, vestibules, anterooms, general circulation, and auxiliary work areas. Floor space below sinks, counters, cabinets, modular units, and other wall-hung equipment mounted to provide usable floor space counts toward "clear floor area." An alternate definition is provided by the Illinois Department of Public Health: clear area shall include only useable space within the patient room and shall not include entry or vestibule areas, space required for door swings, or space for fixed, immovable furniture. The bathroom shall not be included in calculating the clear area of the patient room[5].

1.5 The Physiology of Labor, Hormones, and Perception of Pain

During natural labor, the human body produces three main hormones that regulate the progress of labor and birth and influence the perception of pain: oxytocin, beta-endorphin, and adrenaline. Too little or too much of any of these hormones can create a slow, painful labor (Figure 1). Production of all three of these hormones is strongly influenced by the emotional state of the laboring woman, therefore, relaxation is critical to controlling labor pain.

Darkness spurs the body to produce melatonin, which in turn increases the production of oxytocin. This is why so many women go into labor at night and why labor so

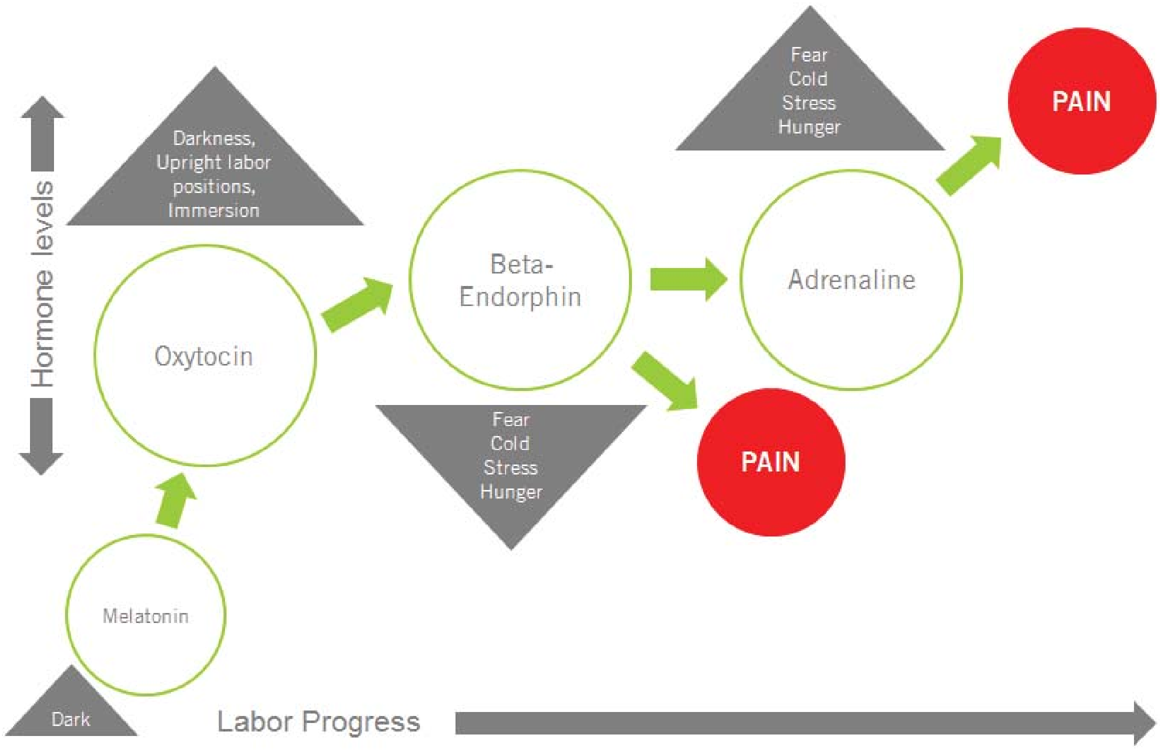

Figure 1: Physiology of labor, hormones and pain.

often stalls in a brightly lit clinical setting[6]. Oxytocin is the hormone that causes the uterus to contract during labor. Levels of oxytocin gradually increase throughout labor and are highest around the time of birth, when it contributes to the euphoria and receptiveness to her baby that a mother usually feels after an unmedicated birth. To promote oxytocin levels, it is important for the mother to stay calm, comfortable, confident, and to avoid upsetting disturbances. Upright labor positions increase the pressure on the pelvis, which increases oxytocin production. Dim lighting is also linked to oxytocin production. The presence of oxytocin influences the production of endorphins.

Beta-endorphin is the stress hormone that builds up in a natural labor to help the laboring woman transcend pain. Low levels of endorphins can cause labor to slow and become excessively and intolerably painful. A laboring woman can enhance her production of endorphins by staying calm and comfortable and avoiding upsetting disturbances.

Adrenaline is released under stressful conditions and levels naturally increase during an unmedicated labor. At the end of an undisturbed labor, a natural surge in these hormones gives the mother the energy to push her baby out and makes her excited and fully alert at first meeting with her baby. However, excessive levels of adrenaline caused by hunger, fear, cold, or a perception of danger actually inhibit labor and exacerbate the perception of pain[2]. In North America, mortality rates for both mothers and babies demonstrate that it has never been safer to have a baby[7]. However, it appears that many women have never been more frightened of the process[3]. Adrenaline levels can be kept in check by staying well-nourished, warm, calm, comfortable, and relaxed; by being in a peaceful environment; and by being supported by people who can suggest comfort measures and offer positive encouragement. A review of 51 studies including 3,663 subjects found that music reduces pain and reduced the need for pain medication, though the magnitude of the benefit is small[8].

1.6 Effect of Laboring in Water on Pain

While immersion in any depth of warm water (such as in a bath tub) is associated with comfort and relaxation, only deep immersion (such as in a laboring pool) produces significant pain relief through the physiological response of a redistribution of blood volume which stimulates the release of oxytocin and vasopressin, a hormone that regulates pain. Amazingly, this physiological response can produce pain relief that is as nearly effective as an epidural analgesia[9]. The reduction in pain is so similar to the effects of an epidural that some doulas refer to immersion as an "aquadural." A 2004 British study showed, for women with dystocia (slowed labor), laboring in water for up to four hours reduced the need for epidural analgesia from 66 percent to 47 percent[10]. In a 2009 survey of 12 trials including 3,243 women, the Cochrane Database of Systematic Reviews found that "water immersion during the first stage of labour significantly reduced epidural/spinal analgesia requirements, without adversely affecting labour duration, operative delivery rates, or neonatal wellbeing"[4].

Laboring under the pressure of a warm shower is also correlated with pain relief. According to the Gate Control Theory, put forth by Ron Melzack and Patrick Wall in 1962, pain can be reduced by "closing the gate," blocking a painful stimulus. This theory draws from the presence of two different types of nerve fibers. Fast-responding long nerve fibers transmit signals of pressure and warmth. Slow-responding small nerve fibers transmit signals of pain. The Gate Control Theory proposes that pain can be reduced by activating the long nerve fibers and preventing the smaller nerves from sending pain signals. The continuous pressure stimulation of skin by the warm water of a shower blocks the pain transmissions of the small nerve fibers. Anecdotal evidence by doulas indicates that the pain level of laboring women is reduced by a warm shower[11]. The drawback to this techniques is that the nerves habituate (get used to) the sensation in about 15 to 20 minutes. Therefore, a shower alone is not adequate for continuous pain relief.

1.7 The Needs of Laboring Women

Women in labor have specific physical, emotional, and mental needs in order to master the ability to relax completely as a pain relief tool. In his 1965 book, *Husband-Coached Childbirth,* Dr. Robert A. Bradley originally categorized these needs including deep and complete relaxation, quiet, darkness and solitude, physical comfort, closed eyes/the appearance of sleep, and the assistance of a birth partner[12]. A British survey in 2005 further itemized the environmental needs that women rated as important[13]. The three things that women wanted most commonly during labor were: having a clean room, being able to stay in the same room throughout labor, and being able to walk around. Most women also wanted the use of an ensuite toilet, space to move, and a comfortable chair for their birth partner. More than 50 percent of women said that having a birth pool available was at least moderately important, and 30 percent said that it was of high importance[13]. Many of these needs have architectural implications, itemized in Table 1.

Table 1: Needs of laboring women, comfort measures, and associated architectural implications.

NEEDS OF LABORING WOMEN	Comfort Measures	Architectural Implication
Relaxation	Massage (hand or back)	Provide a comfortable chair, and a shelf for massage/aromatherapy oils
	Clean room	Non-staining, scrubbable interior finishes
	Attractive room and views of nature	Attractive, coordinated finishes and furnishings; abundant windows with views of refuge and prospect nature imagery
Quiet	Control over music	Wire room for digital sound dock
	Reduce noise coming from corridors, and nurse work areas	Excellent Sound Transmission Class (STC) of corridor walls
	Reduce noise coming from other patient rooms (feeling that one isn't being overheard by other patients)	Excellent STC of walls between patient rooms
Darkness & Solitude	Control over visual access to their room	Provide blinds at corridor windows, curtains at doors
	Privacy when people enter the room	Provide curtains at doors
	Control over lighting (on/off/brightness)	Provide dimmable lighting in patient room and toilet room; provide darkening shades at exterior windows
Physical Comfort	Walking/stair climbing during labor	Provide space for walking in room (furniture including bed should be moveable) and in patient corridors; provide therapy stair in patient room
	Hydrotherapy (shower)	Provide ensuite shower with provision to keep birth partner dry
	Hydrotherapy (labor pool)	Provide space in room for labor pool; provide slip-resistant flooring; provide self-serve access to warm dry towels
	Labor aids (birth stools, birth balls, mats, pillows)	Provide ensuite storage space for equipment in a variety of sizes
	Labor aids (rebozo, a traditional Mexican shawl)	Provide grab bar with blocking behind wall for looping a rebozo
	Easy access to a toilet	Provide ensuite toilet
	Access to nourishing food and drink	In-room mini-refrigerator
Birth Partner	Comfortable chair for partner	Provide space for a reclining chair for a support person
	Access to nourishing food and drink	In-room mini-refrigerator

2.0 CURRENT LDR ROOM DESIGN

2.1 Current LDR room design in America

Two typical examples of contemporary American LDR room plans are illustrated below in Figure 2. These rooms are designed to accommodate the laboring woman and her medical attendants as well as the equipment. They do not provide adequate space or provisions for non-pharmacological pain relief techniques.

Figure 2: Plans of typical LDR rooms in the United States.

The typical LDR room provides storage space for medical equipment, but frequently not for labor aids. If labor aids are available, they are often stored remotely, in corridor closets that may not be accessible to the laboring woman. The equipment is usually shared between rooms, so labor aids in the correct size or quantity may not be available to each woman[14]. When labor aids are present in the birth room, they may take up so much of the available space that they become a problem. One woman remarked, "…my birth room…made me nervous because it was so full of people and equipment"[15].

Most LDR rooms do not include a labor or birth pool. Some ensuite toilet rooms include a shallow bathing tub, but this is meant for bathing only and does not provide the same physiological pain relief as a deep laboring pool. Some LDR rooms allow floor space for a portable laboring pool, but the requirements of a mobile pool (remote drains, tangled pump cords, slippery floors) create dangerous conditions for patients and staff, causing staff to limit their use. When a permanent laboring pool is provided it is typically accessible on only one side. This prevents it from being used as a birthing pool which is required to be accessible on a minimum of three sides[14].

Ensuite toilet rooms are standard in new construction, but are not yet required for older facilities[5]. The toilet rooms typically include a shower, but do not include provisions to keep birth support partners dry[14]. Night lights in toilet rooms are not currently required by code so they are typically not provided[5]. The toilet room offers space for several comfort measures such as a warm shower or privacy, but without a nightlight, these activities must either be conducted in darkness with the door closed, in the bright light of the toilet room, or in semi-darkness with the door ajar, lacking privacy.

LDR rooms are designed to be as compact as possible to maximize patient capacity while reducing nurse travel distances. However, these rooms do not provide adequate space for laboring women to move. As a result many women walk in institutional-style corridors that do not allow privacy and relaxation. Almost 85 percent of women surveyed said that "being out of sight of others" while walking was important. One woman commented, "…there was nowhere in the busy wards to walk. I felt in the way, but my room was so small, I could only do three paces back and forth"[15].

Since the 1980's, there has been a trend toward attractive, hospitality-type finishes in LDR rooms, so most LDR rooms today are designed with a home-like feel[16]. This contributes to a feeling of comfort and familiarity and is excellent for relaxation during labor. There has been a recent trend toward making food and drink available to laboring women, but in-room refrigerators are not typically provided. Refreshments for birth partners are typically located in a remote lounge or cafeteria.

2.2 Current LDR Design in England

Two typical examples of contemporary British LDR room plans are illustrated in Figure 3. LDR rooms in England, even in large institutional teaching hospitals, often include a permanent birth pool that is accessible from three sides. These rooms tend to be smaller than their American counterparts and do not generally meet American code requirements for size. British maternity units are commonly staffed with midwives and doulas that are trained in non-pharmacological pain relief techniques. The LDR rooms usually provide in-room storage for both medical equipment and labor aids and have access to an ensuite toilet room. Due to the small size of the patient room, the patient bed is sometimes stored outside the room when the birth pool is in use.

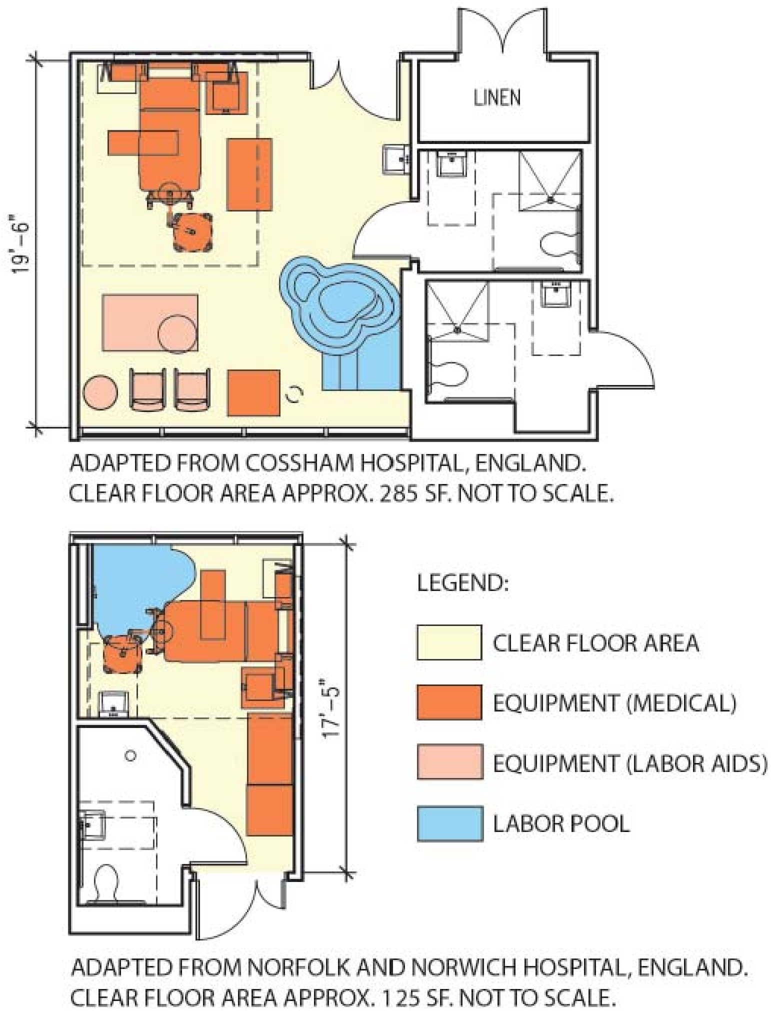

Figure 3: Plans of typical LDR rooms in British hospitals.

3.0 BEST PRACTICES & MODEL LDR DESIGN

3.1 Best Practices

LDR rooms should be designed to meet standards that incorporate best practices to ensure that laboring women are able to be relaxed and comfortable, that their movement is not restricted, and that their privacy is guarded. Women should have every opportunity to ease the pain of contractions without using an epidural analgesia as a first resort because pharmacological methods of pain relief carry additional risks and adverse effects for the baby and mother[15]. Specifically, an LDR room should include:

- An ensuite toilet and shower with dimmable lighting
- Access to a permanently-installed labor/birthing pool
- Sufficient space to accommodate medical equipment, a variety of labor aids, and staff, while leaving room for the woman to walk and try various labor positions
- Attractive, home-like finishes, artwork in a soothing palette, and adjustable lighting
- Privacy features including curtained doors and windows and walls that do not transmit sound
- Access to positive distractions including food, drink, television, and items from home
- Access to comfort items such as warm towels, clean linens, and aromatherapy/massage oils
- Support for birth partners including food and drink, comfortable seating, and dry space in toilet rooms
- Abundant windows with refuge and prospect nature imagery, and room darkening shades.

3.2 Model LDR Patient Room

By applying the best practices categorized above to the plan of a typical LDR room, a model LDR room was developed that takes into account current American codes and standards and includes features that facilitate non-pharmacological pain relief techniques.

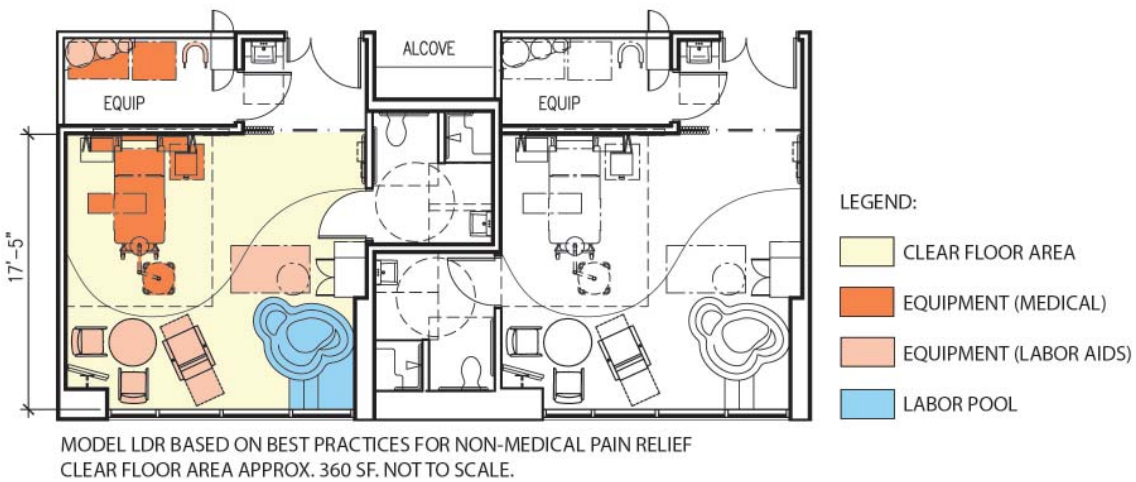

Figure 4: Plan of a pair of model LDR rooms.

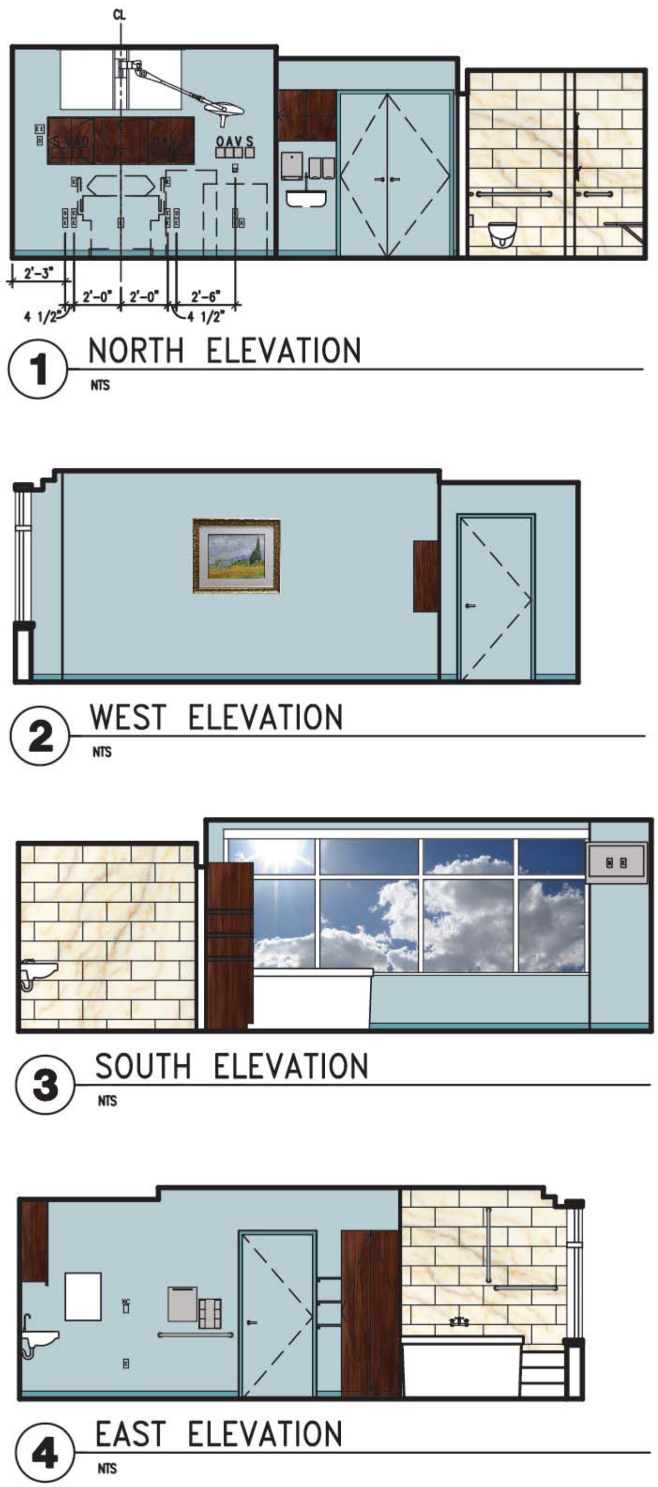

Figure 5: Elevations of a model LDR room and ensuite toilet room.

The model LDR includes a permanently installed, deep labor/birth pool that is accessible on three sides and has permanent plumbing connections. A wardrobe fitted with a blanket warmer is located adjacent to the labor pool for storage of warm, dry towels. A variety of stock and custom labor pools are available and this model includes a built-in access stair alongside the pool. The stair doubles as a therapy stair and can be used as a labor aid to reduce pain.

The finishes in the model LDR room have been selected for attractiveness and safety. The pool and toilet "wet area" is demarcated with attractive, slip-resistant flooring for safety, while the patient area at the bed is defined by durable and attractive wood-look product. At the headwall, the medical gasses and equipment are readily available, but concealed behind an attractive cabinet. Furnishings, artwork, and curtains have a home-like feel to create a welcoming space. A safe and attractive room reduces the stress response in laboring women and reduces the perception of pain.

The model LDR room has plenty of space for staff, medical equipment, labor aids, and space for the woman to move about. Rhythmic movement and upright postures help women cope with the pain of contractions, so there is space to walk around[17]. A grab bar mounted on one wall can be used for tethering a rebozo (a traditional Mexican woven shawl). Gentle movement with a rebozo can be used to ease severe back pain during labor and provide comfort during natural birth[18]. The presence of a birth partner is critical to many comfort measures during an unmedicated birth so variety of comfortable seating options have been provided[12]. The recliner and chairs provide space for relaxation, massage, and rest for a birth partner.

The exterior wall has plenty of windows. If an attractive view of nature can be created outside, this too can reduce pain. Studies have shown that nature images that combine a mix of refuge (imagery that communicates a place to hide in a potentially dangerous situation) and prospect (imagery that offers a view into the distance) yielded the lowest pain response among surgery patients[19]. Room-darkening shades and dimmable lighting are provided to allow the laboring woman to choose darkness to increase her body's production of melatonin and oxytocin and as a comfort measure to reduce pain.

Storage has been provided inside an ensuite storage room for both traditional medical equipment as well as a variety of labor aids. Storage space dedicated to each LDR room ensures that clean labor aids in the correct size and quantity will be immediately available to the patient. The portable labor aids depicted in the storage room include a floor mat, therapy balls on a wall-mounted ball rack, and a birth stool. A pass-through linen/supply nurse server has been located along the corridor wall to allow self-service from inside the room and easy restocking for hospital staff. Access to clean, dry linens preserves a woman's comfort and dignity and allows her to relax. The storage room also has space to accommodate a small dorm-style refrigerator for snacks and drinks. Familiar foods serve as a comfort and a positive distraction that reduces the perception of pain. Further, having on-demand access to foods prevents a laboring woman from becoming overly hungry and triggering an overproduction of adrenaline that increases pain.

Other positive distractions that have been provided in the room include a wall-mounted television and space in the wardrobe to store familiar items from home. There is a small shelf for aromatherapy/massage oils or other comfort items. The room is wired for sound from a portable music player, allowing the patient to control the selection and volume of music.

The patient room includes an ensuite private toilet with a hand-wash sink, toilet, and stand-up shower. Laboring women often need to void their bowels frequently, and it can be difficult to distinguish between pressure in the bowel and pressure from the baby's head as delivery approaches. Immediate access to an ensuite toilet enables a woman to remain relaxed without fear of soiling herself or her room. One study showed that 70 percent of women rated the presence of an ensuite toilet as "highly important"[15]. The design complies with the standards of the American Disabilities Act (ADA). Although not all LDR toilet rooms are required to be accessible, the standards are intended to accommodate a patient and a support person, which is how even able-bodied patients frequently use this room. Further, many women find the toilet to be a comfortable place to labor, and the accessible grab bars can be helpful with positioning. Therefore, it is good practice to comply with the ADA requirements in the typical LDR toilet. The shower design incorporates a linear drain at the threshold and a shower curtain, allowing a support person outside the shower to keep dry. The toilet room is equipped with dimmable lighting to create a private, safe, and nurturing environment.

Auditory and visual privacy are critical to non-pharmacological pain relief during labor. Relaxation during labor is difficult to achieve if the woman feels her vocalizations are being overheard in the corridor or adjacent rooms. To create privacy, the walls between the patient room and surrounding areas are designed with double layers of gypsum board, metal studs located 24” on center, and sound absorptive material on both sides. This assembly provides the highest Sound Transmission Class that can be achieved with gypsum board construction[20]. For relaxation, a laboring woman also requires direct control over visual access to her room and privacy when people enter the room[14]. To meet these needs, a vestibule with cubicle curtain is provided at the entry. This allows the visitor to enter without exposing the laboring woman.

3.3 Architectural Trade-offs

As with any design decision, there are architectural trade-offs associated with the best practices recommended above. Larger LDR rooms create longer travel distances for staff and reduced floor plate efficiency. The model room plan above occupies only approximately 20 square feet more clear floor area than codes require. Permanent birth tubs occupy costly floor space and may not be used by all patients. However, by providing a labor pool in the LDR room, a bathing tub can be eliminated from the patient toilet, reducing the floor space required by the toilet room by about three square feet. Ensuite storage rooms require additional area in LDR rooms. However, because an equipment storage room has been provided ensuite, a separate unit equipment storage room can be eliminated or reduced.

4.0 CONCLUSION

Epidural analgesia is the most popular method of controlling pain in labor in the United States today, but it has serious side effects and risks for both mothers and babies. Yet, greater than two-thirds of women who labor in hospitals choose this option while a mere 10 percent choose a natural birth with non-pharmacological pain relief. However, it is important not to confuse a hospital’s failure to provide options with patient preference. Few large obstetrical units offer LDR rooms that facilitate non-pharmacological pain relief through comfort measures, and surveys show that more women would choose these methods if they were readily available[12]. Moreover, patients who have the opportunity to choose non-pharmacological pain relief techniques report higher satisfaction with the birth experience. The architectural design of an LDR room can greatly facilitate the use of non-pharmacological techniques for effective pain relief through two primary mechanisms: relaxation through a calm, supportive physical environment, and labor in water.

This approach is an example of evidence-based design (EBD), a burgeoning trend in healthcare design. Hospitals are increasingly demanding that architects think about physical environments in the same way that doctors think about medicine and base design decisions on sound evidence.

While trade-offs exist, particularly with regard to the increased size of the model LDR room, the benefits are enormous. The model patient room and recommended best practices require a modest increase in floor area. In return, they can reduce medical risk for patients, improve patient satisfaction, and create unique and valuable marketing opportunities for hospitals and the architects who design them. In the competitive environment of healthcare, obstetrical units would do well to incorporate these best practices into their LDR rooms.

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NEXT STEPS

Going forward in the continuing evolution of the Innovation Incubator, the program will continue to focus primarily on promotion, distribution and increasing the overall exposure of the remarkable projects that emerge each cycle. We are always looking for ways to connect Incubator participants to one another, to others in Perkins+Will with similar or complementary interests, and to outside experts or groups who share our goals and enthusiasm for pushing creative thought forward. From the inception of this program, the committee has felt that our greatest challenge is not finding or giving voice to the creativity that exists throughout Perkins+Will, but rather in spreading the word about the amazing work that results.

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