

Building systems integration for enhanced environmental performance

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ABSTRACT: This paper will provide a summary of ongoing research funded by the US Department of Education's Fund for the Improvement of Post-secondary Education (FIPSE). This research has two significant aspects. The first is the development of interactive digital media through which to teach sustainable design. The primary focus of this paper will be on the second aspect of this research which is the analysis of specific building system integration strategies and how these strategies are related to environmental performance. This is done by the development of a series of examples presented as three dimensional models of well integrated building systems. Each model is composed of two paired integrated systems analyzed with full graphical display, text, analytical drawings, graphs, and tabulated values, to demonstrate the models' performance in a particular environment. A performance metrics provided for each model serves as a basis to evaluate the sustainability of the system based on its performance in the thermal environment, luminous environment, acoustic environment and its ability to address life safety issues. This research intends to serve as a manual for assessing the performance of integrated systems in the conceptual building design stage. The particular focus on the interaction of two paired main building systems aims to filter out the extraneous information and bring coherence to the environmental performance aspect of the systems. This is achieved through explicit presentations of six paired building systems. The pairing is based on four primary systems of structure, envelope, mechanical and interior systems which were identified as sufficient to completely describe a building in the Building Systems Integration Handbook. This book, published by the American Institute of Architects more than two decades ago, pointed out that although there are clearly many more than four systems in the contemporary building, these four are sufficient to completely describe a building and provide a concise starting point for the analysis of combinations.

Conference theme: Innovative approaches to architectural education

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INTRODUCTION

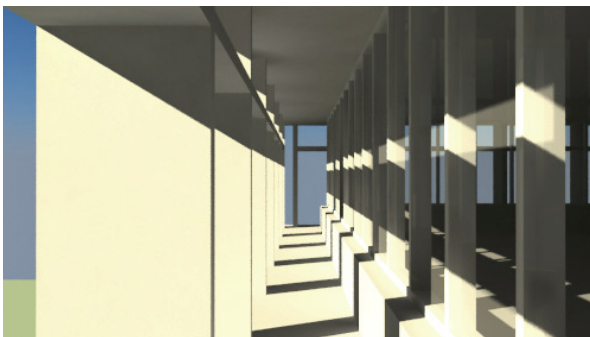


Figure 1. Screen shot from an animation depicting sunlight shading devices (morning)

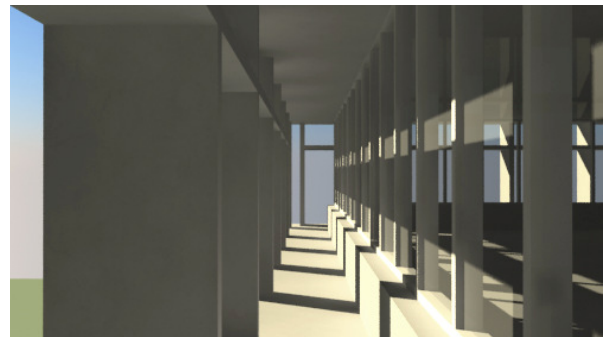


Figure 2. Screen shot from an animation depicting sunlight shading devices (mid-day)

In the practice of architecture an overlap exists in the system aspects of building design, where both architects and engineers develop solutions. Architecture and engineering have been characterized

as two dissimilar disciplines, which must work together due to the vast array of aesthetic and technical needs of a complex modern building [Belcher 1996]. Several writers have emphasized the difference in approach

that engineers and architects take to problem solving. Architects often start with a broad design concept with many different requirements, both functional and aesthetic, while engineers are provided with very focused tasks that may or may not include the broader design scope [Schlaich 1991]. Engineers make decisions regarding sub-system efficiencies most often by focusing on the efficiency of a particular sub-system. However, each of the sub-systems of a building are more malleable than often acknowledged. Each sub-system has its discipline-specific performance criteria and therefore, with regards to design, its own ordering principles. In the building sub-systems are more often than not in conflict, each sub-system using contradictory distribution systems which compete for the same space. Integration of building systems requires the resolution of these conflicts. This conflict raises fundamental questions about the role of architectural design in the process of integrating buildings' systems. If each system in a building has its own ordering principles, and integration inherently requires a compromise among individual systems for a larger whole, what is the basis for making design decisions?

Current guidelines for gauging the environmental performance of buildings are primarily *checklists* and may provide little direction regarding specific design solutions for individual systems. The US Department of Energy's *Smart Schools* program, for example, provides a number of directives for the design of schools which are based on discipline-specific research. *The Advanced Energy Design Guide for K-12 School Buildings* published by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) is one of these references. This document provides *Design Tips* for the school designer such as "provide daylighting to classrooms", "provide lighting systems with energy efficient lamps, etc." The foundation for these suggestions for daylighting is based on an extensive study of the impact of daylighting on student performance [Heschong, 2002]. This analysis included data on over 21,000 students and found better tests scores in daylight classrooms, suggesting an important relationship between daylight availability in buildings and student performance. This study provides a powerful justification for the incorporation of daylight into the design of buildings. However, on closer inspection, this study provides few specific metrics by which to judge the quality of a specific design. Conclusions were based on assigning existing classrooms into one of six categories of a *daylight code* which ranged from *daylight* to *no daylight*. Although this study provides some basis for judging which attributes of a daylight classroom contribute to a daylight effect (enhanced student performance) these attributes are not quantified.

1. ARCHITECTURAL SYSTEMS, BUILDING SYSTEMS, AND INTEGRATED BUILDINGS

1.1. *Building Literacy: The Integration of Building Technology and Design in Architectural Education*

As the environmental impact of buildings becomes increasingly scrutinized, the role of building designers in the initial decision making process and the impact of these decisions upon energy use become more critical. An informed design process merging environmentally responsible practices with advanced technologies can significantly reduce the adverse impact of buildings on the environment. A critical component of an informed design process is a clear understanding of building systems operation, interaction, and the synergetic benefits realized through their proper selection. A consideration of suitable building systems, gauging their interaction, and proposing well integrated systems can lead to producing efficient models of sustainable buildings with minimal adverse impact on the environment. This paper will provide a summary of ongoing research entitled *Building Literacy: The Integration of Building Technology and Design in Architectural Education* funded by the US Department of Education's Fund for the Improvement of Post-secondary Education (FIPSE). This research has two significant aspects. The first is the development of interactive digital media to create a *gaming* environment through which to teach sustainable design. The audience or potential *player* is intended to be as broad as possible. *Building Literacy* is not intended to be developed as a substitute for high resolution analysis tools such as *DAYSIM* or a comprehensive analysis and visualization tool such as *ECOTECT*. Both of these examples require substantial input from the building designer to obtain feedback regarding building performance. Since both are meant to seamlessly integrate into the building design process, each require exterior wall types and building plans (and resultant geometry) generated by the user. *Building Literacy* will allow the user to select from a variety of *pre-constructed* virtual building elements. These will be comprised of element sets as diverse as exterior wall panels (refer to Fig. 1 and Fig. 2 for an example of an *eggcrate* shading device applied to a building envelope), interior room arrangements, floor templates, etc. Admittedly, the assembling of a virtual *kit of parts* can provide only a limited number of possible combinations as compared to the *infinite* possibilities supposedly open to the designer who designs a building from *scratch*. However, the virtual kit of parts provides a platform upon which an entire building can be rapidly assembled, analyzed for environmental performance, re-assembled and re-analyzed. It is believed that this iterative process will accelerate the learning of both the design variables involved in environmental building performance and the potential magnitude of each variable. The *Building Literacy* project does not involve the development of a new tool to evaluate a specific environmental performance (such as the distribution of light in perimeter spaces or the thermal performance of the building envelope) rather; it attempts to teach the performative interaction between different systems incorporated into a building. The desire to compare the performative interaction of various systems has provided an interesting vantage point from which to

assess the various programs that measure specific metrics of environmental performance for individual systems. Two interesting points emerge out of this research. The first is a body of emerging research which seeks to *quantify* what to this point has been discussed in a *qualitative*, largely unquantifiable way. The quantifiable data currently being generated is not precise enough, nor easily tied to performance criteria to be able to make comparison across the systems. The second point is that there are very few metrics for measuring the impact of the integration of building systems upon environmental performance. In fact, this may have always been a relatively little analyzed aspect of building systems integration.

1.2. Building systems and environmental performance

The second aspect of research being conducted for the *Building Literacy* grant is the development of digital learning environments to teach specific lessons about building systems and environmental performance. As opposed to the stochastic environment of the *gaming* environment described above, these lessons will provide an analysis of specific building system integration strategies and how these strategies are related to environmental performance. This is done by the development of a series of examples presented as three dimensional models of well integrated building systems. Each model is composed of two paired integrated systems analyzed with full graphical display, text, analytical drawings, graphs, and tabulated values, to demonstrate the models' performance in a particular environment. A performance metrics provided for each model will serve as a basis to evaluate the sustainability of the system based on its performance in the thermal environment, luminous environment, acoustic environment and its ability to address life safety issues. This research intends to serve as a manual for assessing the performance of integrated systems in the conceptual building design stage. The particular focus on the interaction of two paired main building systems aims to filter out the extraneous information encumbered in the use of the broad term integrated building and bring focus to the environmental performance aspect of the interaction of various systems. This is achieved not through representations of entire buildings but rather by explicit presentations of isolated paired building systems. The pairing is based on four primary systems of structure, envelope, mechanical and interior systems which were identified as sufficient to completely describe a building in the *Building Systems Integration Handbook* [Rush, 1986]. This book, published by the American Institute of Architects more than two decades ago, pointed out that although there are clearly many more than four systems in the contemporary building, these four are sufficient to completely describe a building and provide a concise starting point for the analysis of combinations.

In the past several decades, the terms "architectural systems", "building systems integration" and "integrated buildings" have moved in and out of the lexicon of

architectural discourse. The topic itself and the various approaches are so wide-ranging as to defy an exact definition. One of the most recent texts on building systems integration claimed that the building section of most construction in this country segregates individual sub-systems into horizontal layers to avoid interference [Bachman 2003]. By contrast is the efficiency of the integrated building which by eliminating redundant services will supposedly address issues of sustainability. Bachman's study of integration was a significant step forward from the *Building Systems Handbook* since it provided specific climatic data. It is suggested here that a further development would be the actual analysis of the environmental performance of specific examples to study the contribution of each system.

1.3. An example of integration

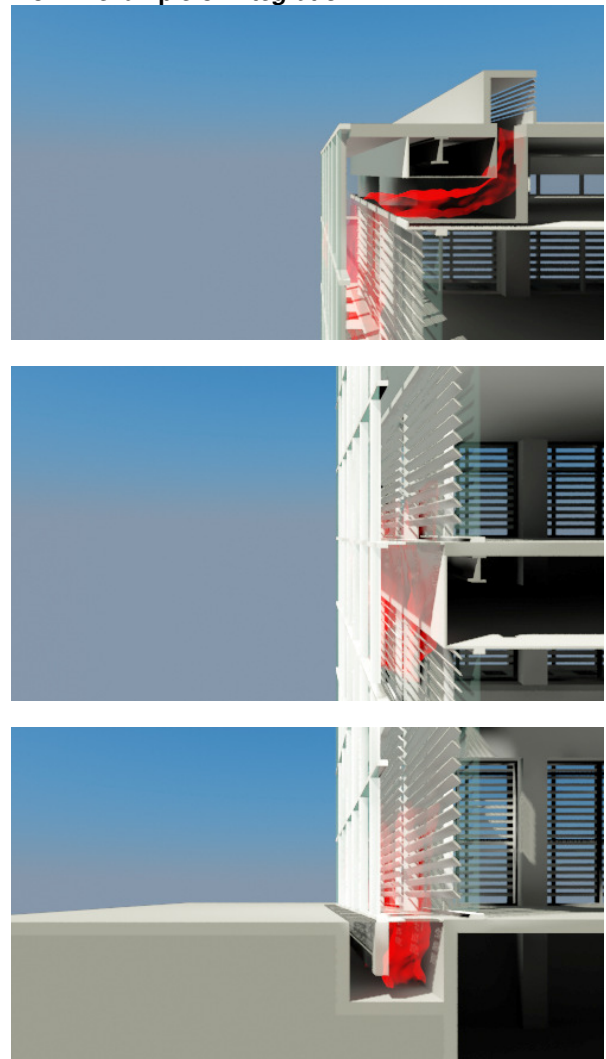


Figure 3. Screen shots of double envelope of the Occidental Chemical Building

Perhaps the potential of studying the relationship between environmental performance and building

systems integration can be clarified by referring to a specific historical example. The Occidental Chemical Company Corporate Office Building by Cannon Design was included in the original *Building Systems Integration Handbook (BSIH)* [Rush, 1986]. The double envelope of the exterior of the Occidental Chemical Building was intended to act as a *thermal blanket* in the heating season and as an *exhaust vent* during the cooling season with operable louvers which actively respond to climate. The review of this building in the *Building Systems Integration Handbook* praised it as a *meshed* level (the highest level) of integration. However, as with almost all of the examples in this book, there is little quantifiable information as to the environmental performance (refer to Fig. 3 screen shots of double envelope of the Occidental Chemical Building). Ironically, the building was also published the same year in William Lam's *Sunlighting as Formgiver for Architecture* [Lam, 1986]; in Lam's book the building is referred to as the *Hooker Chemical Building*. While Lam acknowledged the success of the double envelope as a solution able to "defy any environmental influence on their form by a technological tour de force" (pg. 201), Lam criticized the louvers relative to views to the exterior as visually confining and distracting. Lam also commented on, but was not able to quantify the potential of the louvers on the distribution of daylight in the perimeter offices. Presumably, this is because of the limitations of the *daylight factor* as a performance metric at the time these books were written (refer to Fig. 4 screen shots of interior of Occidental Chemical Building).



Figure 4. Screen shots of interior of Occidental Chemical Building

The daylight factor has been in use for more than a half century and is defined as the ratio of the internal illuminance at a point in a building compared to the unshaded, external horizontal illuminance under a CIE overcast sky [Moon, P. and Spencer, D.E., 1942]. The daylight factor is the most widely used quantitative measure of daylight [Nabil, A. and Mardaljevic, J., 2005]. A number of different methods have been developed to calculate the daylight factor based on the overcast sky. An underlying assumption is that the overcast sky is a worse case condition and other sky conditions will provide more daylight. The daylight factor does not consider season, building orientation, building location, or direct sunlight. In the absence of these considerations the daylight factor provides little input regarding glare prevention strategies such as vertical and horizontal louvers. To overcome this shortcoming, most designers have historically used direct sunlight studies using simulations or scale models. The goal of these studies is to design facades that prevent direct sunlight on glazing and therefore minimize direct solar gain. The buildings that result from a consideration of both the daylight factor and the blocking of unwanted solar gain exhibit a considerably improved energy balance than a building designed using only the daylight factor. A limitation of this *combined approach* is that only static shading devices and different glazing types can be compared. This limitation has led to recent research which promotes the use of dynamic daylighting performance measured as a way to achieve sustainable design [Reinhart, C.F.; Mardaljevic, J.; Rogers, Z., 2006]. The argument for dynamic performance measures is based upon three shortcomings of the above mentioned *combined approach*; the difficulty of comparing shading devices with manually operated venetian blinds, the lack of consideration for varying daylighting requirements for different building types and occupants and the fact that although the combined approach accounts for building orientation and latitude, the actual climate of a site is not considered. The Occidental Chemical Building is a historical example of an integrated solution in which the contribution of each system was at the time the building was reviewed, somewhat unclear. The use of dynamic daylighting metrics allows an investigation into whether the operable louvers provided a solution to the limitation of static sunshades or simply compromised the distribution of daylight in the interior spaces.

1.4. Conclusion

What is proposed here is the proposition that architectural constructions involve a delicate balance between various systems, each of which has its own logic, indifferent to the other. It is left up to the architect to make sense of these contradictory conditions. The

ability to read the inherent order (and disorder) of each system and to make conscious decisions which recognize the potential conflict and/or coincidence is one of the primary skills required of the contemporary architect. As the ability to measure the actual environmental performance of buildings becomes more refined, it is likely that we will be able to quantify both the specific contribution of each system and the interaction of systems upon each other.

ACKNOWLEDGEMENT

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