AIA College of Fellows
2005 Latrobe Fellowship

Developing an Evidence-Based Design Model that Measures Human Response: A Pilot Study of a Collaborative, Trans-Disciplinary Model in a Healthcare Setting

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Report of Findings

May 1, 2008

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PREFACE

Gordon H. Chong

However measured, by the $441 billion dollars spent annually on non-residential construction, $561 billion on residential construction, or 45% of total energy consumed by buildings, the ongoing fiscal, social, cultural, educational, environmental and health impacts of design and construction on the welfare of our communities is significant. As architects, clients and educational Institutions, we actively participate in defining the quality of these environments. Each of our projects demands significant knowledge for making innumerable decisions on a daily basis. As professionals, we are expected to have the knowledge to make these decisions, gained through education and experience, often verified by examination and licensure.

Why and how these decisions are made is of increasing concern. Clearly, the breadth and depth of circumstances make it unrealistic that academic education alone would ever suffice. Therefore, professional architects, clients, and builders have always depended on our experience and intuition. However, in today's increasingly complex world of decision making, there is a clarion call for better tools, greater rigor in developing knowledge, and a value-based rationale for design decisions. Architects, clients and educators are being called upon to develop knowledge based on research that provides a degree of evidence greater than ever before, and to provide a greater balance of knowledge based on experience, intuition, *and* evidence to inform design decisions that result in high quality communities.

This is easier said than done. The architectural profession has emphasized circumstantial problem solving and the accumulation of prior experience as bases for future decisions, what some characterize as looking back as a means for justifying design decisions for the future. What has been missing is a more generalized knowledge and an ability to predict the effects of environmental design stimuli on human responses.

As important as this seems, why is it, then, that in its 150 years of existence the architectural profession has been unable to embrace a culture of research to inform design? Today, fewer than 20% of 115 accredited Schools of Architecture offer a Ph.D. program, and only a handful more offer some exposure to and experience in rigorous research through building technology centers and laboratories. There remains a significant imbalance in learning between experience, intuition, and evidence-based research.

In 2007, only .2% of federal research funding was allocated to sustainable buildings—which many consider to be highest priority. With this paucity of monies allocated to design research, it is not surprising that practitioners remain unskilled in research.

Worse still, self-promotional information in the name of research reflects poorly on the profession, since it adds no value to the supply chain of knowledge. While this generation of architects has been trained in "problem solving," the world around us has changed to emphasize problem seeking and innovation through exploration and research.

With the 2005 award of the Latrobe Fellowship from the College of Fellows of the American Institute of Architects, Chong Partners Architecture,* Kaiser Permanente, and the University of California, Berkeley have collaboratively explored issues relevant to an evidenced-based research and design model. Working as architects, clients and educators, we analyzed how evidence is developed and what constitutes appropriate evidence to inform design decisions. Additionally, we undertook a pilot study of a trans-disciplinary model in a healthcare setting. We consider Mode 2 research methodology, described more fully later in this report, an appropriate approach, given a desire to build on our past (architectural intuition) and add (unfamiliar) performance measures using established scientific protocols.

Further, the report, like all good explorations, reveals our wanderings, debates, challenges, unanticipated roadblocks, changes in direction, unresolved issues, and our wonderful "ah-ha!" moments. Knowing that our work is but a starting point in our ongoing search and a small contribution to a larger body of professional inquiry of evidence-based design and research, we are more comfortable summarizing our efforts as "lessons learned" rather than research outcomes and conclusions. We learned:

- Historically, architects have been unaware of what to test and how to test for physiological characteristics. Design evidence would benefit if there were greater understanding of the interactions of physiological and behavioral responses to environmental stimuli.

- Evidence that informs design is most useful when a research hypothesis is approached from a combination of (multiple) perspectives: (1) physiological and psychological testing (controlled sampling), (2) observation of social behavior (professional observation, analysis, and interpretation), (3) inquiry and survey (large sampling). While potentially uncorrelated, disparate information can be overlain and interpretations made that would be of benefit to design decision making.

- Architectural research would add benefit if the lessons learned were less explicit (circumstance specific) and more widely applicable as they relate to predictive human responses to environmental stimuli.

- Over the long term, trans-disciplinary, Mode 2 research collaborations hold more promise for true exploration and innovation. The trans-disciplinary process has inherent growing pains, but continuity of effort may be needed to gain full benefit of the relationships between collaborators.

- A research (knowledge development/innovation) culture in architecture will not flourish without the involvement of clients and academia to lengthen the horizon of exploration, to encourage the sharing of findings, and to provide dependable rigor to investigative processes. If the full benefit of research is to be realized, there must be a cumulative, rather than singular, effort on the part of all involved.

Finally, we reaffirm that our goal in undertaking this two-year research effort is not primarily to become researchers, but to inform and enhance the quality of design of our communities.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report to the AIA College of Fellows documents the work of the 2005 Latrobe Fellowship team of Chong Partners Architecture,* Kaiser Permanente (KP), and the University of California, Berkeley.

Purpose

As architects, we struggle continually to create designs that excel in supporting our clients' strategic business objectives. Sometimes these are aesthetic, and our education prepares us well for this challenge. In addition, our core capabilities as licensed professionals must include competence in building technology and regulatory and project delivery systems.

However, the idea that built environments are enablers of organizational performance has not received the same degree of attention in our universities and professional firms. Many of us believe that our work can positively affect our clients' healing, learning, productivity and other business goals relative to their end users. Some of us try to measure the impacts of design; others scoff at the notion, confident in our intuition and vision.

The Latrobe team came together based on the belief that the perspectives, skills and experiences of architects in private practice, facility planning professionals working within client organizations, and scholars in university research communities would enrich an exploration into how to make high value design decisions ("high value" meaning those decisions that can be demonstrated to improve organizational performance). Our goals were to determine what types of information would be useful to clients and designers to inform the design process and facilitate decision-making, and to understand which research methods are most likely to help us predict the outcomes of our work.

What We Did

The report addresses five research endeavors.

- **Literature Review on Evidence-based Practice:** As background, we explored the state of evidence-based practice in design and other professions. We identified some precedents from other professions that we believe could inform architects as we challenge ourselves to resolve a point of view about the role of evidence in our work.

- **Literature Review on Lighting:** We conducted literature reviews on lighting research and specifically the impacts of lighting on health. This became important background and context for our own experimentation. We hope that architects reading this report will find the work of others useful in and of itself.

- **The Natural Experiment:** We pursued a research track aimed at using three existing KP databases as the "tool" for queries about relationships among design attributes, medical outcomes, and patient satisfaction. Because of size and logistical complexity, this became a very large endeavor, and the Latrobe result is the creation of a data model (system), described in greater detail below, rather than specific design outcome queries.

- **The Laboratory Experiment:** In addition to the database, we explored a laboratory experimental approach to test the effects of lighting frequencies on health and cognitive performance. This track's focus was to explore rigorously controlled scientific methods, demonstrate the use of mobile devices that measure environmental conditions, and relate physiological responses to design conditions.

- **Trans-disciplinary Research Lessons Learned:** In parallel with all of the above initiatives, we observed the process itself to make observations about collaborations and trans-disciplinary research as they may apply to the creation of evidence for design in the future.

Evidence-based Practice

The roots of evidence-based practice are widely acknowledged in the healthcare industry, where a strategy of standardization known as "evidence-based medicine" has emerged over the past two decades. A core principle of evidence-based medicine is "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients" (Sackett et al., 1996). The practice of evidence-based medicine means "integrating individual clinical experience with the best available external clinical evidence from systematic research" (Sackett et al., 1996). In evidence-based medicine, the skills and experience of the healthcare provider, the needs and concerns of the patient, and evidence grounded in rigorous scientific methodology stand as the three foundational elements of a model for decision-making.

Variations of the evidence-based medicine model for decision-making have since migrated to other disciplines, including education, social work, software engineering, environmental management, and architecture, to name but a few. While the extent of acceptance and implementation of evidence-based practice varies widely, a common motivation for this migration is the oft-cited observation that current practices in these disciplines are unsystematic, overly reliant upon intuition, prone to undue political influence, or simply ill-suited to enhancing outcomes.

The underlying objective of evidence-based practice is to enhance outcomes by augmenting practitioner experience and skills with suitable evidence. More specifically, evidence-based practice is intended to provide practitioners with the tools and skills necessary to (1) access, assess, and adapt existing evidence for use in specific contexts, and (2) formulate context-specific evidence when existing evidence fails to meet research standards.

What constitutes evidence, and what determines the strength and credibility of data for use as evidence? The literature demonstrates that definitions of evidence and appropriate research standards vary across and within disciplines. In evidence-based medicine, there have been a number of efforts to codify the strength of evidence and its quality as a basis for clinical recommendations. The 2005 Latrobe team acknowledged that different disciplines have adopted different guidelines and that evidence-based design may not conform to the medical model. However, there are also potential lessons learned from medicine and other professions that might help architects understand the intention of evidence-based practice and define a consistent, informed model appropriate for design.

What are some of these guiding principles from which we might learn?

- There may be a variety of types of evidence.

- How "strong" the evidence is, i.e., how powerful it is in terms of predicting an outcome or describing a relationship between two factors (such as "view" and healing"), will depend on the methodology used to create the evidence.

- The basic rules of scientific research do apply. Evidence should be "valid," i.e., it should address the topic it is intended to address (and not be a reflection of another superfluous condition), and it should be "repeatable," i.e., we can feel fairly sure the results will recur. These seems obvious, but how often do we jump to a solution based on a single observation rather than a body of knowledge? As designers, we want answers. But are they the right answers? Was it the "daylight" or the "view" that caused a particular patient response? If we don't know, how can we decide about the size, placement, and orientation of windows beyond merely what feels right?

- Taken together, greater control of potentially superfluous factors, consistency of results across subject groups, and a fairly tight range of responses among research subjects increase the value of research data as a predictor.

- Careful experimental design, including randomization and control, increase the strength of research results, as do large data sets and systemized methodologies.

- There is value in commonly accepted definitions and guidelines for creating and attributing value to knowledge intended to be applied as evidence. This may not be the same for architects and for physicians, but some shared understanding and language allow a profession to move forward with constructive dialogue rather than individual semantic understandings. (We embrace "evidence-based design," but does that mean the same thing to all of us? Not currently.)

- Evidence-based practice does not necessarily remove the soul from practice. The practitioner's judgment and values, informed by experience, are central. A conscientious pursuit of evidence provides a better informed basis for making decisions, but it is not prescriptive.

- Context must always be considered.

- Lastly, a key consideration in evidence-based practice is communication. Architects would not blindly accept technical advice without some combination of data backup and confidence in the source. Why not have a similarly critical standard for assertions about the impact of some aspect of design on human response? When evidence is communicated, we must know enough about the source, the context in which it was developed, and methods used to create it to make a responsible decision about how seriously to trust that evidence and in what contexts we might apply it.

Lighting Literature

The first step in narrowing the scope of research was a broad, multi-disciplinary literature search. Findings were included not only from the environmental design literature that architects most typically explore, but also from sociological, psychological, biological and medical research.

The results of this initial review indicated which of the many topics of the team's interest were most likely to be informed by a rich evidence base. As a result of this exercise, the team chose to focus on the influence of light on health. (Color, another topic the team wished to consider, largely because of its cultural implications, was eliminated because of a weak existing research base, but the team agreed that color, as an aspect of lighting might still be relevant.) This process was important to developing "strong" evidence because good research practice considers each research project in the context of related studies to reinforce or qualify the findings.

A deeper literature review of the most germane issues was then conducted. The National Library of Medicine's PubMed Medline database provided the richest source of information, yielding thousands of references that describe the influence of light on health-related issues. As the specific experimental design was refined, further searches were conducted to ensure that the Latrobe experiment was built on methods that had been demonstrated to be valid and reliable.

The knowledge derived from these incremental, multi-disciplinary literature reviews, together with “new knowledge” from the Latrobe laboratory experiment itself (both led by Dr. Eve Edelstein), combine to produce a strong evidence base from which the outcomes of the Latrobe project can be judged. Reviews of previous research revealed a pervasive influence of light on health and human function. Perhaps even more notable, the literature presents evidence that the quality and quantity of light shown to influence human responses is markedly different than the commonly applied lighting standards designed for visual function. (See LeSourd in the Chapter 2 Appendix; Rea et al., 2006.)

The influence of light on behavior, emotion, function, cognition, and health has been reported in a large body of research that uses either natural or electrical light to alter physiological and/or mental responses (Edelstein, 2006). Written record of the study of biological responses to light dates back at least to the 1800s, when Mairan and Linnaeus recorded plant movement in response to daily lighting changes. Charles Darwin’s work in the 1900s validated the biological response to light in animals.

A myriad of behavioral, emotional, and physiological responses is now associated with exposure to electrical lighting, daylight, and solar orientation. The field has progressed through multiple generations of study, which include the investigation of endocrine changes related to electrical light exposures, such as the role of melatonin in sleep and wake cycles. Seasonal Affective Disorder is now an accepted consequence of seasonal lighting and climactic changes, and electrical light therapies are being actively investigated at major medical centers and the National Aeronautics and Space Administration. Epidemiological studies at the University of California, San Diego, Harvard University, Brigham & Women's Hospital, and Harvard University Nursing Study have explored the relationship between disrupted light patterns and cancer risk.

Complex networks of physiological systems form the biological bases for these responses to light. Commonly known is the release of melatonin from centers in the brain that regulate sleep/activity cycles. Many other cycles and responses are affected, including vasoactive intestinal peptide (VIP), which affects blood pressure and growth hormone. Light also elicits release of serotonin, dopamine, and GABA in the brain, which are associated with motivation, muscle coordination, and focus. In addition, light is associated with increased levels of corticotropin releasing hormone (CRH) associated with stress, gastrin releasing peptide (GRP) related to hunger, and follicle stimulating hormone (FSH) related to reproduction. (For review, see Shanahan & Czeisler, 2000.)

Circadian cycles can be modulated by a variety of external cues, but light is the primary variable that aligns (or entrains) humans to diurnal, nocturnal, and seasonal rhythms. Although decades of research have examined the influence of electrical lighting on circadian entrainment, it was not until 2001 that a new class of cells was discovered in the retina of the eye, thought to be “circadian” receptors that sense slow changes in light levels, rather than receptors for vision. This discovery renewed research to explore the spectrum, intensity, and duration of light that influence biological responses.

Numerous studies have led to the development of “dose response curves” to electrical light that reveal peak sensitivity in the blue wavelength (between 420-470nm) for modulations of melatonin suppression that regulates sleepiness. Bright white light has also been demonstrated to be effective in modulating mood, sleep, and activity cycles (Ancoli-Israel et al., 2003).

The range of spectra that influence the multiple circadian systems is yet to be fully explored. Although research has focused on short wavelengths in the blue range, a broader range of spectra is also associated with biological responses (Revell et al., 2006). Testing of red light has been uncommon, and many researchers have assumed that there is little to no effect of red light on the neuroendocrine or circadian systems. However, Hanifin and colleagues (2005) found that normal healthy humans exposed to 630nm and 700nm elicited small reductions of plasma melatonin levels. These findings are consistent with other studies that reveal the influence of a long wavelength light on cardiac responses (Schafter & Kratky, 2006).

Biological and medical literature reveals many biological functions, diseases and disorders associated with lighting conditions. Basic scientific research has produced evidence about physiological processes in animals, which serves as the basis for discovery about human biological responses to light.

Human studies have disclosed the nature of circadian and circannual rhythms in normal subjects. According to these data, cardiac rhythms, stress, endocrines, hormones, growth and aging, developmental, cognitive, and emotional responses demonstrate circadian rhythms in normal individuals. The evidence base reveals diseases and disorders associated with disruption of circadian or circannual light conditions. For example, hypertension may be related to the disruption of normal diurnal conditions. Cancer risk may be associated with light-induced disruption of melatonin production, which is implicated in the control of cancer growth. Emotional and behavioral disruption has been associated with seasonal lighting changes or climatic conditions where natural solar light is insufficient to maintain biological rhythms. Finally, therapeutic studies explore the use of electrical lighting to modulate circadian responses and ameliorate the consequences of circadian disruption.

The categories below represent a partial list of human responses to light.

- Stress, modulation of cortisol/stress hormones
- Heart disease and hypertension
- Melatonin responses
- Sleep/activity/feeding cycles
- Cancer
- Basal metabolic rate, protein synthesis, and thyroid responses
- Growth
- Aging responses
- Hormone function
- Obstetric

- Neonatal responses
- Ophthalmic development and health
- Hyperbilirubinemia and kernicterus
- Long-term visual function in NICU graduates
- Gastro-intestinal conditions
- Diabetes
- Neural immune responses
- Inflammation and autoimmune disorders
- Brain development and function
- Ataxia, neuropathy
- Concentration
- Alertness
- Attention deficit disorder
- Working memory
- Psychologic and psychiatric conditions
- Decreased memory, dementia,
- Depression, emotional labiality
- Seasonal Affective Disorders
- Pain
- Perception and self-report of pain and pain management
- Medication rates relative to lighting dosage and length stay

The Laboratory Experiment

One of two experimental tracks explored by the team, this laboratory based approach used rigorously designed and controlled conditions to demonstrate specific changes related to alterations of the environment. Measurement methods most likely to yield statistically valid results were selected based on literature reviews. Statistical significance was achieved by minimizing the complexity of the test environment and by testing the influence of one environmental change at a time. (Causal relationships between an environmental change and a person's response often require a larger number of subjects or study sessions.)

This approach also lent itself to an exploration of ways that bio-medical research might facilitate the process of experimentation in functioning hospital settings. Clinical studies often require that a normal study is first conducted in a laboratory setting to demonstrate that the methods used are valid and will "do no harm" to the patient. The results of the Latrobe laboratory study could now serve that purpose, thereby helping to form the next research project with testing in operational clinical environments.

Physiological and cognitive responses to specific light qualities were analyzed and interpreted in the context of an extensive literature base. Scientists from Ohio State University and the University of California assisted in the design of the experiment and provided expertise, resources, and analysis of the results. Scientists from Rensselaer Polytechnic Institute and the National Institute of Mental Health provided advice, technical expertise, and resources.

The Principal Investigator recommended that the experiment focus on light affecting the circadian system because there exists extensive evidence from previous research that the two are related. The experiment examined the influence of specific aspects of light frequency and physiological responses known to relate to health and performance.

The laboratory experiment explored how architecture might influence human exposure to light within built settings, and how varied light levels and spectra might influence health outcomes. Today, medical research acknowledges that chronic stress is a major contributor to heart attack, cancer and diabetes. Additionally, today we are able to alter environmental stimuli, such as lighting, and to measure heart rate variability and EEG as key indicators of stress, in this way linking lighting (as one environmental stimulus), heart rate variability, stress, and health outcomes. The laboratory results went beyond a pilot demonstration, revealing new measurement systems and statistically significant results relating light levels and cardiac health indicators.

Heart rate variability is a sensitive indicator of health status and risk and, as such, is important to all users of all built spaces. The experiment showed that heart rate activation increased and variability decreased during brief exposure to bright white light (with a peak in the blue spectrum) during exposure. These are consistent with melatonin studies using longer exposures at night. Yet more interesting were the results that showed that heart rate responses were highly significantly different in red light conditions than responses in white light, and were associated with situationally appropriate cardiac activation and relaxation during cognitive tasks. Red light has rarely been the focus of circadian research, despite our experience of its role as an indicator of time of day as the sun sets.

Following the experiment, a team of designers and client representatives considered the findings and interpreted how they might apply to design. This step is inductive, and the team does not intend to imply that the design ideas have been rigorously tested and validated. (In fact, a desired follow-up experiment would be to build the proposed designs and measure impacts.) However, the interpretive process illuminates how the design process can come together with scientific evidence to strengthen the creative process.

Several design charrettes were held to discuss the potential impact of introducing biologically relevant light levels on architecture and design. Field measurements were conducted using the new measurement systems to determine the actual light conditions in occupied and recently completed buildings.

The information obtained was considered in terms of principles that might guide design to better serve human conditions. These findings suggest that there is much more to explore about the quality and quantity of light that should be provided to occupants of built spaces; they challenge us to look beyond the typical architectural and electrical solutions in order to better meet human biological and psychological needs.

How did the design team interpret the experimental findings and related survey of the literature? The following design ideas are conjecture, but are informed by specific research evidence. Ideally, they will form the basis for hypotheses for future research studies that directly measure the impacts of design interventions. However, in the spirit of using "best available evidence," they already pose challenges to some conventional hospital design practices and reinforce others.

Evidence: Circadian Systems Need Darkness as Well as Light
The need for light is well known and discussed, but circadian systems also require periods of darkness. In many current hospitals, light intrusion into patient rooms from outside the building, as well as from corridors and other proximate interior spaces, is often at levels sufficient to disrupt the patient's circadian rhythms.

Design Interpretation:

- Patient rooms must have the ability to be darkened. This includes an ability to control light intrusion from both outside and inside the building.

- Accessible controls should provide patients with the ability to adjust light for their individual needs. A single-touch, programmable control for medical staff to immediately establish optimal lighting for assessment and procedures should be provided at bedside and/or at clinical stations.

- Achieving optimal light level starts outside the building, with external shading and shielding devices. A kinetic skin that adapts to seasonal and diurnal light changes (but has manual overrides) may help balance needs for circadian light and darkness, view and glare control.

- Shades should be installed to effectively seal out light around the window perimeter.

- Low intensity lighting on the corridor side of the patient room walls may reinforce pathways for safety while not limiting light pollution into patient rooms.

Evidence: Natural Light Cycles Promote Health; Circadian Systems Need Varied Light Conditions

Natural daylight can be considered the "gold standard." Different frequencies, intensities, and dynamic patterns of light exposure are related to measurable differences in biological responses. Constant exposure to a single frequency and level of light is not ideal for normal circadian patterns. Daylight and electrical lighting that emulates natural diurnal, nocturnal, and seasonal cycles is most likely to support circadian needs and health.

Design Interpretation:

- Brightness and frequency of light should vary throughout the day. The objective is not simply to provide *more* light, but to provide the appropriate cycle frequency of light, including light in the range of spectra and intensities: blue and bright white spectra (shown to influence melatonin-related sleep/wake cycles) and red spectrum, which influences heart rate variability.

- Building footprint should allow for controlled daylight penetration to the central nursing stations or team work areas. Care must be taken to avoid brightness, glare, veiling of electronic screens, and thermal change.

- Atria and light wells might, but do not necessarily, provide sufficient circadian light to interior areas. Orientation, floor level, and atrium proportions should be modeled for circadian light frequency as well as intensity. (The two do not always correspond.)

- Light shelves may be used to introduce daylight to corridors where "borrowed light" to the distributed nursing areas is often blocked by doors, window coverings, and bed drapes.

- Staff should have access to spaces for both darkness and light. There should be a break room with daylight, as well as a separate on-call room to serve different circadian needs, especially for transitioning shift workers.

- Atria and light wells might, but do not necessarily, provide sufficient circadian light to interior areas. Orientation, floor level, and atrium proportions should be modeled and tested for circadian light frequency as well as intensity. (The two do not always correspond.)

- Light shelves and other devices to increase daylight penetration may be needed. This applies to corridors where "borrowed light" to the distributed nursing areas is often blocked by doors, window coverings, and bed drapes.

- For areas where daylight is not feasible or practical (such as imaging rooms), controlled electrical lighting that can be varied according to user, function, frequency, intensity, and distribution may provide useful circadian stimulation.

- For night shift and swing shift workers, daytime patterns of light frequency variation should be recreated and provided to the extent feasible while still supporting patient needs for darkness and staff needs for visual acuity, safety and security. The use of white and blue frequency light augmented by task and safety lighting may support staff circadian sleep/wake patterns. Red light in corridors could be explored as a means to support night time monitoring while minimizing circadian sleep/wake patterns in patients. White lighting at clinical stations would provide for task-related visual acuity. Individual controls at staff stations are essential.

- Localized "light showers" (brief exposure to light that stimulates the melatonin systems) at distributed desks may provide for needed circadian activation.

- Low level ambient light should be complemented by task lighting at work centers for visual acuity. Bright light should be screened so as not to penetrate into patient rooms.

Evidence: Individuals Have Different Light Needs
Lighting needs vary by individual medical condition, visual acuity, preference, and culture. An individual's history of light exposure (over several hours, days, weeks) influences his or her need for circadian light. Swing and especially night shift workers may suffer from stress responses due to misalignment of their sleep/wake cycles and natural daylight and darkness.

Design Interpretation:

- Lighting controls are as important as lighting. Patient and family are often most likely to make preferred adjustments, but they may not know what light is healthiest.

- The ideal system would combine computerized control to provide desirable circadian light (that the patient or staff may not choose) and overrides to adapt to preferences.

- Patient controls must be accessible and easy to use, and should allow control of electric light as well as window coverings.

- Cultural preferences may have a great influence on color choices. Patient control of color through LED lighting may provide a sense of control and ability to easily adapt the environment as the needs and preferences of occupants change.

- Special lighting needs should be considered when setting such levels. For example, elder patients are more likely to need greater light levels, but may be more disturbed by glare and reflection.

The KP Integrated Data Model (IDM)

Much of the existing research about the influence of environmental features on people is based on small studies. As is the case with the Latrobe laboratory experiment, very carefully controlled methods may enhance the significance of findings derived from small samples. Such experiments sometimes provide strong evidence that can be generalized, especially when interpreted in the context of other valid research.

Large sample size is another means to contribute significance and relevance to research findings. Large samples are one way to diminish the impacts of naturally occurring variations that are difficult to control in complex environments, e.g., facilities. In addition, large scale studies have other appealing aspects for corporate decision-making. Executives with decision authority are accustomed to benchmarking and other large survey type research. KP confirmed that their leadership was more likely to be swayed by a large volume of data than by a small sample. The translation from lab to construction program could be a difficult hurdle.

"Natural experiments" are not designed by scientists in the same manner as laboratory experiments, but through systematic observation and analysis of naturally occurring events they yield scientific data. KP's huge data resources were identified as rich targets for this approach.

The team was intrigued by the potential of a large-scale, natural experiment that would mine data about KP facilities and patients to seek relationships between physical design characteristics and patient experience. Envisioned was an integrated database with attributes of 30 hospitals (totaling over 60 million square feet) and perhaps 100,000 patient stays (cumulative over time).

As the owner of both hospital facilities and patient data, KP took the lead in this track of the Latrobe work. The process involved many KP groups for support and advice, but two departments, Service Quality Research and National Facilities Services, collaborated to bring together three data sets—CAFM, HCAHPS and KP HealthConnect.

KP's CAFM system includes information about the physical environment at room, building, and location scales. In addition to existing data that KP routinely captures through CAFM, such as room area, other physical attributes can be added. For a pilot test of the KP IDM, the team added compass point orientation.

The Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey gathers patient satisfaction information, addressing patient experience and social environment. Among these are communication with clinical providers, staff responsiveness, pain control, and environmental cleanliness and quiet. Demographic data, including age, gender, ethnicity and "other," is also collected. The HCAHPS program is sponsored by the Center for Medicare and Medicaid Services (CMS), and the development of the standardized survey instrument is guided by the Agency for Healthcare Research and Quality, working with a public/private consortium.

Patient and staff satisfaction are of great importance to many healthcare client organizations (as user satisfaction ratings are for many other types of organizations), and there is extensive research attempting to link satisfaction to performance measures. The Latrobe team was particularly interested in patient responses beyond satisfaction, specifically physiological outcomes. Patient length of stay is a particularly powerful measure because it is an important indicator of healing, commonly monitored by hospital administrators, and relates to cost and revenue. The KP HealthConnect is a systemwide, integrated, inpatient medical records system. It is, therefore, the critical third component of the KP IDM that permits correlation of physical design data (from CAFM) with the medical history of the patients.

Different numbering systems initially prevented directly relating the three databases, but, through physical surveying and database refinements, fields were added that allow correspondences by room to be defined. The result is a model that can analyze relationships among room design attributes, the medical records of the people occupying the room, and a given person's satisfaction with his/her experience in that room.

Demographic and medical data allow deeper analysis for medical condition and people of different age, gender, etc.

Bringing together three formerly disconnected databases allows design interventions to be conducted in which targeted environmental characteristics can be modified and the resulting medical responses and patient perceptions assessed. Analyses of existing room attributes can also be conducted in a controlled manner to determine correlations of room attributes with medical and satisfaction measures.

The KP IDM has promise as a landmark tool for healthcare research. Because of both its size and the breadth of data types, e.g., medical records and satisfaction surveys, it can now be related to physical design attributes. Beyond creating the data model, KP's contribution to the Latrobe is its stated intention to share the results of research conducted using the tool. A consortium of healthcare providers, professional associations, consultants, and universities is expected to advance the actual use of the IDM through research queries.

The Latrobe Research Model

A primary goal of the 2005 Latrobe Project was to learn about the benefits of a specific approach to research in architectural practice. The observation of the model was carried out to document this process and was treated as its own research track within the Latrobe Project (LP).

All team members contributed to this effort through group meetings, reports, and special submittals about lessons learned, the value of the two research approaches, how each track might affect evidence-based design, and conclusions about what the work means in terms of design performance and design practice.

W. Mike Martin, Ph.D. (UC Berkeley) was the Principal Investigator for this work. The following is an abstract of these components of the process track. The detailed documentation of the process and model development is provided in Chapter 3.

At the core of this model is the agenda of knowledge production intended to address everyday challenges in people's lives, business, education, etc. It is a model whose intent is to make research more accountable to the people it serves. The armature of this approach was grounded in what was referenced as Mode 2 Research (M2R).

As a starting point, the Latrobe Project Team (LPT) agreed that existing cultural practices, procedures, language, and other mores divide the way practicing architects, academic researchers, and clients approach knowledge production and management. These differences in approach are presented in Chapter 1 of this report, but are repeated here to help frame the context of the research process:

- Architects have valuable experience, technical knowledge, and creative skills. However, in the realm of human responses to the physical environment, architects too often turn to intuition, personal experience, precedent, and anecdotal evidence rather than methodologically rigorous research findings. They thereby perpetuate conventional wisdom and fail to provide their clients with the information they need to make design decisions that best support their end users.

- Because experts in research methodology are focused on qualification through scholarly peer review, university research communities possess a critical understanding of scientific protocols that enrich the body of knowledge available for design application. University researchers, however, often discount research conducted outside academia and work within their discipline in isolation from both architects and their clients—the very people who need to utilize the research results. Consequently, many researchers pursue topics of scholarly interest but with limited potential value in actual design application.

- Some people with responsibilities for in-house facilities, real estate, and capital planning in client organizations believe that design has the power to enhance their core businesses, but they lack access to the "evidence" they need to make credible business cases. Unable to find the compelling data they require, interpreted in terms of relevant econometric and other performance measures, some client organizations are conducting their own research, the quality of which varies greatly, depending on the skills of individual researchers.

In an effort to illustrate the underpinning issues and values that focused the team's efforts and to demonstrate the nature of the struggle involved in constructing the model, the following is a set of observations about the process of LP interactions. Each of the items listed represents a significant aspect of the research experience. The intent is to provide an overview of the work setting of the process over time and frame the workings of the model.

- **Navigating disciplinary boundaries.** To what extent did the team cross boundaries and approach the LP in a truly integrated fashion? Trans-disciplinary research and what that might mean in our context is still an open question. Because all of the principal investigators of the LP shared a belief in the basic scientific model of research (whether social, organizational, or biological), communication was fairly straightforward. What makes this work interdisciplinary is that the independent variable is design, and the outcome variables are physical, social, and organizational.

- **New ways of knowing.** This project created new knowledge, i.e., the results of the lab experiment, and created knowledge about a "new" way of knowing, i.e., the research model itself and the KP IDM.

- **Agreements are central to progress.** This was an iterative process. Whatever agreements were made along the way positioned challenges and introduced change at every step in the process.

- **Implicit vs. explicit knowledge.** Architectural education and practice center on “problem resolution." In this context, knowledge tends to be “problem specific” and thus not seen as directly applicable to the subsequent problem. With each project viewed as being dependent on the specific context of its application, it is only after many years of practice that a body of knowledge is developed experientially. Additionally, the process of developing knowledge is redundant for the individual and difficult to transfer to others within or outside the profession. Given this culture, it is challenging to conduct research for the purpose of creating multiple forms of evidence and, more specifically, to practice evidence-based design.

- **Language is central to understanding.** The search was for trans- or interdisciplinary (scientific) processes that provided insight into how knowledge is acquired, that added to a practitioner’s typical problem resolution process (context of specific application), and that enhanced predictability of performance. In this case, outcomes were not clear due to language barriers that existed between designers and researcher. Thus, lack of a common language, processes, and protocols made this process slow, difficult, and problematic.

- **Knowledge always in context.** Knowledge produced in context is not new, but it is how context is defined that creates the challenge. The assumption here is that if the knowledge is to be accepted, the parties with a vested interest—architects, clients and researchers—must socially construct it.

- **Tension between agendas of players.** There was tension between the LPT as to what the real opportunities and most important research was relative to the project stakeholders—clients, researchers, designers, regulators, etc.

- **Outcomes to serve the majority.** “Clinical research” is in many ways the healthcare equivalent of “research in context.” It must address the many complex factors that define each individual patient’s condition and his/her unique needs and values, while also investigating specific questions directed toward creating applications that serve to improve outcomes for the majority of people and circumstances.

- **Horizontal consensus building.** The Latrobe proposal initially presented its members with a highly uncertain task. The meetings and interactions were organized to reduce that uncertainty, that is, to define the research question, to mobilize resources, and to develop a structure and a set of operating processes to facilitate the task based on a horizontal organizational structure. The challenge in the process was to reach agreement through consensus. The two concurrent tracks represent a resolution of the process of consensus decision-making.

- **Survival in uncertainty.** M2R research, as noted, guarantees high uncertainty. The ability of a group of people to survive this ambiguity was challenged often in the process. The determination of the quality of the outcomes of this experience of working together will be in the acceptance by appropriate peer groups of the evidence presented in this report.

- **Commitments unquestionable.** The commitment of this team to the project was unquestionable. As noted, the struggles experienced were about language, definitions, roles, outcomes, and resources. Research in context, with diverse disciplinary representation and a lack of a tradition, made day-to-day actions and activities appear fuzzy, but in the big picture significant progress was made in achieving goals. Having gone through the learning process of undertaking research in a M2R model, it is important that there be a longer/term multiple research agenda established. The future of architectural practice will be about knowledge application and production, confirming that the transdisciplinary approach of M2R would work well for a firm committed to a Practice/Research/Teaching model.

Summary of Findings

The LP has provided an opportunity to explore an aspect of the future of architectural practice that is critical to formalizing the format and intentions of the architectural profession's mission. It is clear that the future of the profession is grounded in knowledge management: what do we know; how do we know it; and how do we renew that knowledge in the fast changing world of practice?

As noted earlier, the LP was structured around two commitments to the College of Fellows of the American Institute of Architects: first, in a disciplined manner, to observe, assess, refine, and document the approaches used to create the research in order to allow the architectural profession to learn from it and apply the outcome in future architectural practice settings (The Model); and, second, to conduct a pilot study in a healthcare context to yield immediately applicable data and to construct and test the model (The Pilot).

In its simplest form, the two pilot projects were conducted in a traditional form, Mode 1 Research (M1R) application of the scientific method, but were modified to reflect three primary differences. First, the nature of the research question(s) was defined in the context of application by the three partners to the LP. It was agreed that, when possible, additional disciplinary representation would be brought to the project as needed and, second, that the measure of the quality of the outcomes, in addition to the disciplinary standards, would be judged by their capacity to represent empirical evidence that could inform an evidence-based practice process.

The outcomes of each of the two pilot projects resulted in findings that can lead to future application. The Integrated Database Model (IDM) provides a framework for future research using the IDM to inform specific research questions at a sample scale unprecedented in either healthcare or architectural settings. The Laboratory Experiment provided empirical evidence for various human responses and performance observed when physiological measures, such as heart rate variability, are used under diverse lighting conditions. Outcomes are presented along with a strategy suggested for future use and human performance metrics that imply the need for future explorations in real design settings.

The outcomes represent a starting point for future research rather than a final conclusion or concrete evidence for informing evidence-based practice. These outcomes make a strong case for the capacity to create empirical evidence to inform evidence-based practice if further research efforts engage the IDM and/or apply the methodologies of the physiological measures in actual healthcare settings. The next steps must be grounded in the identification of the metrics for establishing a set of physical attributes of spaces which house human services where human performance can be or is measured. The natural and laboratory experiment arguments suggest (a) the possibility for establishing a robust field of empirical evidence that could inform the outcomes of architectural practice specifically focused on healthcare environments, and (b) that these processes and methods are transportable to other environmental facility types and settings.

In terms of the model, it can be said that the concept of collaborative research is a critical form of inquiry that should be pursued in the discipline and profession of architecture. Did the LP deliver "a model"? Perhaps not, but it did apply the structure and conditions of M2R, providing an important framework for structuring LP outcomes. It is safe to recommend the framework of the five defining elements of the M2R model as important to collaborative research. They are: 1) research should be generated in a context of application; 2) research should be trans-disciplinary; 3) measures of quality should be socially constructed; 4) the effort should be conducted across various knowledge organizations and sites; and 5) the process should be reflexive. These conditions are concurrent with the needs of architectural practice to merge the outcomes of research with design actionability, where design results and the degree of trust in empirical evidence establish an evidence-based design methodology.

It is well understood that our future in architectural practice will be highly influenced by evidence-based practice. It is important to recognize that evidence comes in many forms—from personal experience (intuition), to best practices, to rigorous scientifically established findings. As such, evidence for use in architectural practice does not need to be all in one form or another; rather, as in medicine, practice must use evidence from as many sources as possible to predict the nature of the outcome of specific actions. The critical issue here is not the evidence itself, but the transparency of the evidence so that others can judge and understand the impacts and influences of specific forms of evidence on performance.

The LP has contributed to this dialogue concerning knowledge production (evidence) and its management (evidence-based practice). It reflects more of a beginning than an end, but an important beginning. The partnership and resulting collaboration have exposed numerous issues about the nature of research in practice settings and the conflicts and opportunities in this form of working. But, most importantly, they provided three important starting points for future work. First, the two pilot projects—the Natural Experiment and Laboratory Experiment—contributed fertile arenas for future research and a model for conducting research in practice that appears to map over the needs of the professions and the research community. Yes, there still is work to be done, but a direction has been established and, if pursued, will result in significant results.

ACKNOWLEDGMENTS

The Latrobe Project Team would like to thank the College of Fellows of the American Institute of Architects for its generous support and the opportunity to be the recipients of the 2005 Latrobe Fellowship. The Latrobe Project Team also acknowledges the American Institute of Architects and the leadership, vision, and support of the College of Fellows from 2005-2007. In addition, the Latrobe Project Team thanks all of the people who, over the past two years, have given unselfishly of their time and resources—Kaiser Permanente, Chong Partners Architecture the University of California Berkeley and all of the other people and institutions that supported and contributed to this process**.** The team extends our gratitude to our colleagues, research collaborators, supporters, and advisors who generously contributed expertise, equipment and facilities resources over the past two years. We gratefully acknowledge the work of our research collaborators from Ohio State University and the University of California, San Diego.

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CHAPTER 1 - INTRODUCTION

INTRODUCTION

Robert Brandt and Steven Doctors

Hypothesis

Credible, applicable "evidence" of relationships between design and client organizational performance will result from 1) a collaborative approach that unites the perspectives, skills, and resources of architectural firm, university research community, and client; and 2) use of both scientific research methods and inductive reasoning.

Abstract

There is a movement within architectural practice to inform decisions about design with evidence about the impacts of physical environments on human response and organizational performance. The information currently available to designers varies greatly in terms of its relevance to design practitioners and the reliability of the data in terms of predicting the outcomes of design choices. In large part, both of these shortcomings result from the manner in which research queries are defined and the quality of the methodology used to conduct the research. To advance the practice of evidence-based design, the 2005 Latrobe team explored several approaches to developing knowledge that would be valuable to designers and their clients, as well as defensible in terms of research methodology.

The work builds upon the perspectives of client/end user, university research community, and architectural firm, and it uses methods derived from the behavioral and bio-medical sciences. Pilot studies relating health outcomes to design were conducted as a way to observe the research model in practice. Literature reviews informed and augmented original findings about health outcomes related to physical environment. Conclusions addressed the various research approaches that were utilized, resulting in an assessment of the potential of each to enhance design decision-making.

Background

In 2004, Chong Partners Architecture approached Kaiser Permanente (KP) and the University of California, Berkeley, with the prospect of pursuing the 2005 Latrobe Fellowship, a grant sponsored by the College of Fellows of the American Institute of Architects (AIA) for research to advance the practice of architecture. The three organizations agreed to form a team to pursue a common interest in the development of evidence about the impacts of design on performance, specifically health outcomes in this case, and the application of that knowledge to enhance design decisions.

The team's premise was that cultural mores persist that divide the way practicing architects, academics, and clients approach knowledge creation and management. These differences can be summarized as follows:

1. Architects have valuable experience, technical knowledge, and creative skills. However, in the realm of human response to environment, architects too often turn to intuition, personal experience, precedent and anecdote, rather than methodologically

rigorous research. When architects fail to consider the best available data, they perpetuate conventional wisdom, miss opportunities to innovate, and fail to provide their clients with the information they need to back up design decisions that would best support their stakeholders and business objectives.

2. Expert in research methodology and focused on qualification through scholarly peer review, university research communities have skills that could enhance the level of knowledge about design outcomes. Indeed, there is credible design research that utilizes scientific protocols. However, university researchers tend to discount research performed outside academia. Environmental design research specifically is often conducted in isolation from architects and their clients—the people who need to utilize the research results. Consequently, many researchers pursue topics of scholarly interest, but with limited potential value in actual design application. Moreover, research that could be of use in actual design applications has historically not been readily available to the architectural community.

3. Some people with responsibilities for facilities, real estate, and capital planning within client organizations believe that design has the power to enhance their core business. However, despite their beliefs, they lack access to the "evidence" they would need to make credible business cases to that effect. Not finding compelling econometric and defensible performance metrics coming from their architects, trade journals, and other available resources, some of these clients have turned to conducting their own research. These endeavors vary greatly in quality, depending on the skills of individual researchers.

The 2005 Latrobe team proposed that, despite their differences, the three stakeholders—practicing architects, the clients they serve, and university research communities—together have the perspectives, skills, and resources to enrich the understanding of ways that design influences people in the places that architects create. If this premise is correct, there is an opportunity to significantly improve the contribution that architects make to their clients by increasing the architect's ability to predict how people in different circumstances will respond to specific aspects of physical environments.

The team's shared belief at the outset was that many design professionals want to be able to predict how "end users," e.g., patients, their families, and clinical staff, in the case of hospital environments, will be affected by design, including footprint, color, lighting, occupancy, room spatial configuration, furnishings, acoustic treatments, and other physical attributes. The experience and intuitive understanding of these design professionals certainly provide insights, and there is a body of literature comprising people's opinions about design and its outcomes. However, an approach to design that utilizes both professional experience and scientific evidence could lead to better informed choices, ones that would also be compelling to clients.

The team also knew that each party had experience, skills, and data to contribute that might collectively be more powerful than those held by any one constituent. The question was how to come together. What types of information would lead to the most predictable results? How might diverse skills, especially with regard to research and problem solving, complement each other to produce relevant, reliable, and defensible knowledge for design decision-making? Architects need to know what to build, informed by empirical data, not conjecture, and be able to support their assertions about design impacts in order to garner client approval to implement the most effective, creative design strategies.

Approach

The 2005 Latrobe research proposal framed a research model with three mandates:

- Utilize scientific methods from the behavioral sciences and neuroscience, as well as the inductive reasoning of the architectural design process

- Seek psychological, sociological, and physiological responses to design elements

- Bring together a practicing architectural firm, a university research community, and a leading healthcare provider in a collaborative process designed to utilize the skills and knowledge of all three.

The research proposal comprised two concurrent focal points:

- In a disciplined manner, observe, assess, refine and document the approaches used to create the research, in order to allow the profession to learn from those processes for potential future applications. (The Model)

- Conduct a pilot study in a healthcare context to yield immediately applicable data and to refine the model. (The Pilot)

In the Summer of 2005, the team began the work by refining the intent of the research and the manner in which the team would proceed. In general terms, three questions were posed:

1. What are the characteristics of "evidence for design" that would satisfy architects and clients? Not at all a theoretical question, this query was needed to define the team's intended "deliverable." Success, in a sense, would be measured by producing some findings, whether positive or negative, about which all constituents could say, "I trust that information enough to use it to inform a significant design decision."

2. How might each member of this diverse team contribute to the development of powerful design evidence? As with the question about deliverables, this one was about translating theory to action—our belief that collaboration was fertile to a work plan with defined roles and methods that would utilize our different skills and experiences.

3. What will we study as our pilot topic? To be applicable, the topic needed to be something that the client thought was important, that would actually affect the

architect's design, and that wasn't already fully explored by the research community. In short, the team was defining "How might we affect change in real application?"

Defining the Research Outcome ("What is credible evidence?")

Value

"Today's design and construction environment is extraordinarily complex. Clients have to make an increasing number of decisions that have lasting impact on both their operations and communities. For architects to be of increasing value, we have the opportunity to move beyond intuition and to provide rigorously developed evidence about predictive relationships between design and human response. Our clients will gain the most value from the design process if we inform decisions with credible (scientific) research."

…Gordon Chong, FAIA, Project Director, 2005 Latrobe Fellowship

Evidence-based practice is the context for the 2005 Latrobe research. The goal is not knowledge for knowledge's sake, but rather to add value through design strategies in actual practice. For architects, the opportunity is to add substance to long-standing assertions that the environments they create affect healing, learning, productivity, sales, and other goals of their clients. If the profession convincingly demonstrates these tangible benefits, it might be assumed that the perception of the value of architecture would evolve as well toward design as a business performance enabler.

Similarly, architects' clients have a great deal to gain from understanding the potential impacts of design approaches on the end users. Reliable performance enhancement indicators would facilitate the client's ability to make sound business choices and to demonstrate a responsible business case for those decisions. Ideally, the data would link environment to outcome and outcome to financial metrics. Conversely, in the absence of credible evidence, especially indicators of measurable impacts, clients might be put in the unenviable position of having to make decisions with significant construction and operational costs based on conjecture.

Because the 2005 Latrobe team's intention was to serve these dual purposes of practitioners and their clients, the team agreed that the research needed to occur in a context of application. The questions needed to address a client's actual concerns. The data produced through the research needed to inform actual design decisions, and they had to withstand the scrutiny of decision makers so they would actually be implemented. In fact, every aspect of the research plan might be affected by the notion of producing evidence for use in real practice.

This is fundamentally different from applied research developed in isolation from an application context and later tested in the field. The approach of the 2005 Latrobe team was to consider applicability while framing the research plan and expected outcomes. What questions matter the most to the client? What types of data would be sufficiently convincing to decision makers to affect their choices? Would the information be meaningful to a designer, given the complexity of physical environments?

The team determined that it needed an operating definition of "evidence" to guide the research activities toward a useful result. A literature search on evidence-base practice was conducted, led by Steven I. Doctors, a Ph.D. candidate at the University of California, Berkeley, and supported by several other team members. The review was used by the team to inform the operating definition of "evidence" and influence the research plan with precedents derived from various professions.

Evidence-based Practice Literature Review

In the broadest context, evidence-based practice may be seen as consistent with tendencies in our information-based society toward the production of knowledge in a trans-disciplinary, socially-relevant context. Its immediate roots are widely acknowledged to be in the healthcare industry, where a strategy of standardization known as "evidence-based medicine" has emerged over the past two decades.

A core principle of evidence-based medicine, as one of its principal proponents has written, is "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence-based medicine means integrating individual clinical experience with the best available external clinical evidence from systematic research" (Sackett et al., 1996). While the use of scientifically-generated evidence in healthcare is not a novel concept from a historical perspective, the scale and scope of its significance in treatment and intervention decisions is new (Timmermans and Angell, 2001). In evidence-based medicine, the skills and experience of the healthcare provider, the needs and concerns of the patient, and evidence grounded in rigorous scientific methodology stand as the three foundational elements of a model for decision-making.

Art & Science
"Evidence-based medicine provides a structure for considering a wealth of knowledge, from rigorously controlled experiments to experiential wisdom. As such, it values both the art and science of medicine. In a similar manner, evidence-based design should incorporate both the art and science of architecture, using rigorous quantitative evidence to inform and support intuitive design creations."

…Eve Edelstein, Ph.D., 2005 Latrobe Fellowship Principal Investigator

Variations of the evidence-based medicine model for decision-making have since migrated to other disciplines, including education, social work, software engineering, environmental management, and architecture, to name but a few. While the extent of acceptance and implementation of evidence-based practice varies widely, a common motivation for this migration is the oft-cited observation that current practices in these disciplines are unsystematic, overly reliant upon intuition, prone to undue political influence, or simply ill-suited to enhancing outcomes. That said, the underlying objective of evidence-based practice is the enhancement of outcomes by augmenting practitioner experience and skills with suitable evidence. More specifically, evidence-based practice is intended to provide practitioners with the tools and skills necessary 1) to access, assess, and adapt existing evidence for use in specific contexts, and 2) to formulate context-specific evidence when existing evidence fails to meet research standards.

Importance of Quantification
"We hope to have sufficiently accurate parameters such that we can quantify the impact of different environmental conditions on important patient outcomes. Quantifying the impacts will make it easier for designers and operations professionals to choose among competing objectives and to evaluate cost/benefit tradeoffs."

…Rob Mangel, Ph.D., 2005 Latrobe Principal Investigator

What constitutes evidence and what determines the strength and credibility of data for use as evidence? The literature demonstrates that definitions of evidence and appropriate research standards vary across and within disciplines. A proponent for evidence-based practice in software engineering, for instance, suggests balancing multiple types of evidence—tangible, testimonial, equivocal, missing, and accepted facts—to construct arguments for decision-making and action (Pfleeger, 2005). By contrast, proponents of evidence-based practice in education emphasize "rigorous, systematic, and objective methods" to generate evidence from randomized experiments, considered the "gold standard" of scientific research (Dirkx, 2006). The United States Department of Education defines "strong" evidence as "well-designed and implemented randomized controlled trials" held in two or more school settings (Whitehurst, 2003). In yet another approach, the definitions of evidence and rigor in librarianship move along a continuum from quantitative to qualitative methods subject to the nature and relevance of the research project (Eldredge, 2006).

In evidence-based medicine, there have been a number of efforts to codify the strength of evidence and its quality as a basis for clinical recommendations. The 2005 Latrobe team acknowledged that different disciplines have adopted different guidelines and that evidence-based design might well not conform to the medical model. However, the availability of information on evidence-based medicine provided an opportunity to the team to consider that model in the research design.

The Oxford Centre for Evidence-based Medicine (CEM) has defined both "levels of evidence" and "grades of recommendation" (Phillips et al., 2001). In brief, these include variations depending on application, e.g., prognosis, diagnosis, and economic and decision analysis, but there is general consistency across uses.

- Level 1 studies = Randomized controlled trials
- Level 2 studies = Cohort studies
- Level 3 studies = Case-control studies
- Level 4 studies = Case-series and poor quality cohort and case-control studies
- Level 5 studies = Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles"

Within Levels 1-3, there are sub-levels, with systematic reviews in each case outweighing individual studies. Homogenous results, i.e., those without "worrisome variations in the directions and degrees of results between individual studies," within each of the five levels rank higher than studies with high levels of heterogeneity. Similarly, results with narrow confidence intervals (a statistical indicator of reliability) are considered more compelling than those with wide confidence intervals.

How a clinician might apply the results of various levels is then categorized by the CEM as "Grades of Recommendation," as follows:

A - Consistent level 1 studies
B - Consistent level 2 or 3 studies or extrapolations from level 1 studies
C - Level 4 studies or extrapolations from level 2 or 3 studies
D - Level 5 evidence or troublingly inconsistent or inconclusive studies of any level

Taken together, greater control of potentially superfluous factors, consistency of results across the subjects, and a fairly tight range of responses among the research subjects increase the value that the research data have as a predictor. In lay terms, after reviewing the evidence and considering its relevance to a specific context, practitioners should be able to say, "We feel reasonably sure we know what were measuring (and not just seeing the effects of some other factor altogether), and we're able to predict with a decent level of probability under what conditions and to which people the results will apply." However, information that is less strong can also serve as evidence but would be applied much more cautiously as part of a recommendation in practice.

The American Medical Association (AMA) published a series of 24 "user guides to the medical literature" from 1992-2000. The guides address specifics, including the AMA's version of a hierarchy of strength of evidence and tools for moving from an understanding of research to a system of synthesizing and applying knowledge in the value-laden context of clinical practice.

The AMA guides specify the following "hierarchy of strength of evidence for treatment decisions." They correspond roughly, but are not identical to, the CEM system.

- N of 1 randomized trial
- Systematic reviews of randomized trials
- Single randomized trial
- Systematic review of observational studies addressing patient-important outcomes
- Physiologic studies
- Unsystematic clinical observations

"This hierarchy is not absolute. If treatment effects are sufficiently large and consistent, for example, observational studies may provide more compelling evidence than most RCTs" (Guyatt et al., 2000). In addition, as per Guyatt et al., even weak evidence can have value. "The unsystematic observations of the individual clinician constitute one source of evidence, and physiologic experiments another. Unsystematic clinical observations are limited by small sample size and, more importantly, by limitations in human processes of making interferences (Nisbett). Predictions about intervention effects on clinically important outcomes from physiologic experiments are usually right but occasionally disastrously wrong." Given these limitations, the hierarchy becomes important, but the clinician's judgment is paramount. The medical practitioner must use experience and professional judgment to determine if a research result that can be predictive in one context should be generalized to other patients. In part, this involves consideration of how societal and personal values affect decisions beyond the research evidence itself.

At the outset, the guides provided the 2005 Latrobe team with some information that was useful in defining what constitutes valuable knowledge for use in evidence-based design. Notable is the premise that "any empirical observation about the apparent relationship between events constitutes potential evidence."

Although not identical, there are many similarities among the guidelines of the CMG, those of the American Medical Association, and others. Writing in the *Journal of the American Medical Association* (JAMA), Janet Torpy, MD, claims that "systematic reviews of the medical literature, large randomized controlled trials (the best way we can assess the efficacy of a treatment), and large prospective studies (followed up over time) . . . can be very helpful in providing evidence about tests and treatments. Reports of the experiences of individual patients or small groups usually provide less evidence, although they may provide important clues about possible adverse effects of treatments" (Torpy, 2006). Therefore, despite differences, the various guidelines used in evidence-based medicine credit value to controlled research, volume, and consistent, reliable results. As Dr. Torpy states, there is some consistency in the qualities promoted in practice guidelines, namely controls in the methodologies to ensure validity and reliability.

Design research poses similar challenges for practitioners of evidence-based design. Research sample sizes are often small. Circumstances are very specific, making generalization potentially difficult. Even research that is strong from a research standpoint may be hard to apply in the complex context of design decisions, which intrinsically consider numerous intersecting physical elements, as well as functional, political, financial, cultural and regulatory influences.

The EBM guides suggest that computer technology may help medical practitioners consider "a whole process of care rather than a focused clinical question. Rather than 'What is the impact of digoxin on my CHF patient's longevity?' the clinician may ask, 'Can I prolong my patient's life?' or even, 'How can I optimize the management of my CHF patient?'" (Guyatt et al., 2000). Perhaps this is also a lesson learned for evidence-based design practice: to most effectively make optimal design decisions, we need systems of information, integrating various influences, rather than bits of data.

A System for Knowledge Development

"Building a body of credible evidence and then applying this knowledge into everyday practice is important to our organization. Preliminary discussions with organizational decision makers indicate that the ideal type of evidence is a body of knowledge and evidence across time and across populations, and guidelines for EBD should include the ability to replicate similar findings across time and population"

…Barbara Denton, 2005 Team Leader, Kaiser Permanente

In very practical terms, the 2005 Latrobe team was able to take away from the review of evidence-based medicine that all information may be considered when making design decisions, but it is important for designers to seek the most compelling results produced using the most compelling research methods. Specifically, what makes research results compelling became a formative influence over the team's research plan, as discussed later in this report. However, there was team consensus, substantiated by the evidence-based medicine model, that quality standards relative to research methodology for evidence-based design were needed and possible. Although any empirical observation about the apparent relationship between events constitutes potential evidence, unsystematic observation, commonly cited as evidence in design practice, would carry little weight.

Defining widely understood and accepted guidelines to assess strength of evidence is but one challenge to the implementation of evidence-based practice. Other challenges the Latrobe team has identified in its literature search include endorsement by researchers and practitioners; concerns about the role of professional judgment and experience; availability of repositories for the collection, assessment, and dissemination of evidence; practitioner resistance to change; and variable incentives for evidence-based practice.

On this last point, the impetus for evidence-based practice varies somewhat for each discipline. In the field of education, it is clear from the literature review that evidence-based practice is driven in great measure by the federal No Child Left Behind Act of 2001, which specifically mandates accountability in the drafting and implementation of educational standards through "scientifically-based research." Scientifically-based research is defined by federal regulations as the application of rigorous, systematic, and objective procedures and the employment of systematic empirical methods based on observation or experiment (Berends, 2002). Similarly, in the field of environmental management, the promotion of evidence-based practice is responsive to laws mandating that environmental regulations be formulated in a "transparent and integrated" fashion (Galloway, 2006). In software engineering, the push for evidence-based practice is linked by one author to the promotion of the discipline as a science, and with it the responsibility for empirically-based engineering leading to "better decision making and higher-quality software products and processes" (Pfleeger, 2005).

An often cited, concern about evidence-based medicine is that it erodes the importance of a clinician's judgment (or undermines the importance of experience). Opponents to the evidence-based practice movement emphasize risks inherent in not understanding context (often complex) and patient values. Advocates counter that the intent is "to integrate clinical expertise with the best external evidence" (Sackett et al.). Sackett et al. also refute that "everybody is already doing it" with claims of "striking variations in both the integration of patient values into our clinical behavior and in the rates with which clinicians provide interventions to their patients."

Communication

"Architects are trained to think critically about building form and technology, but few of us have learned how to evaluate research about human response to design. For us to practice evidence-based design, scientific research needs to be made more accessible, and it must be communicated so that we can assess its validity. We must demand that claims of evidence are backed up by an explanation of their sources—how the research was conducted, the size of the sample and other aspects of context that would allow us to judge quality and applicability to our design circumstances."

…Robert Brandt, AIA, 2005 Team Leader, Chong Partners Architecture

In the interest of supporting the clinician's role as the interpreter of evidence in context of patient needs and values, the literature about evidence-based medicine is clear about the importance of clear communication. The practitioner must determine if the research can be generalized beyond the specific circumstances in which it was conducted to the individual application at hand. To do so requires that the practitioner understand how the research was conducted, what was found, and how the research team assessed the findings in terms of validity and reliability under given conditions.

In considering how the evidence-based medicine model related to evidence-based design, the 2005 Latrobe team agreed that clear communication about the information source, e.g., a randomized controlled trial vs. unsystematic observation, was important so that the architect (like the clinician) could make critical judgment about how strongly to weigh the evidence. This idea was integrated into the 2004 literature review led by Roger Ulrich and Craig Zimring for the Center for Health Design (partly funded by the Robert Wood Johnson Foundation), in which a grading system was used to qualify 600 studies as "rigorous" (Ulrich, Zimring et al., 2004).

The effort to infuse scientific principles into practice has historically characterized the rise and formation of many professions. The architectural profession has not been an exception, with interest in linking scientific research to the design of the built-environment dating to at least the late 19th century, as exemplified by the seminal theorizations of architects Henri LeBroust and Gottfried Semper. This interest continued well into the 20th century, most notably with the 1968 formation of the Environmental Design Research Association (EDRA). EDRA's mission is "the advancement and dissemination of environmental design research, thereby improving understanding of the interrelationships between people, their built and natural surroundings, and helping to create environments responsive to human needs" (http://www.edra.org, accessed 2/15/07). Despite extensive research on the built environment in recent decades, however, this material has for a variety of reasons failed to permeate professional practice, leaving architects reliant upon individual experience, intuition, and readily available information rather than rigorously-formulated research.

Integrating Research & Practice
"Evidence-based design is something that I have been teaching along with my colleagues in the Environmental Design Research Association (EDRA) for over 30 years. Evidence-based design means that the research questions are drawn from practice, not abstract theory. Here, we have done well. Our lament is that architects do not pay attention to our findings. If evidence-based design includes the development of the institutional mechanisms needed to have information flow from research to application (and back again), then it would be something new."

…Galen Cranz, Ph.D., 2005 Latrobe Principal Investigator

There are some indications of a shift toward the application of research and evidence-based practice in architecture, though the focus thus far has been principally on the design of healthcare facilities. This attention to correlating the physical environment with patient medical outcomes and staff satisfaction and performance, exemplified by the work of the Center for Health Design, may be seen as a logical extension of the widespread acceptance of evidence-based medicine in the healthcare industry.

Similarly, the evidence-based urban design efforts of the UK-based Space Syntax design consultancy group on public spaces from London to Shanghai are a natural outgrowth of government-sponsored initiatives on evidence-based urban policy-making (Stonor, 2006). Coupled with the current efforts of the Latrobe research group, these examples suggest that the stage is now set for closing the gap that has historically existed between research and practice in architecture through the broad implementation of evidence-based practice.

An Array of Evidence

"*Design has always been an evidence-based activity. What has changed is what constitutes evidence. This has become even more critical as our profession of architecture has moved from an experientially based practice to a knowledge based set of activities. This project is focused on developing a model for creating an array of evidence through architectural practice that can support evidence-based design action. Evidence from my perspective ranges from highly personal experience to very analytical inquiry grounded in scientific verification. For evidence-based design to be effective it needs to address the full array of evidence available, allowing the designer to make an informed decision that is transparent to the users and clients.*"

…W. Mike Martin, Ph.D., 2005 Latrobe Team Leader, University of California, Berkeley

Following discussion of precedents in evidence-based practice, the 2005 Latrobe team created an "operating definition" to guide the research plan and proposed final outcomes. This was organized around two questions:

- What is "evidence?"

- What is "credible evidence?"

"Evidence," the team determined, could be any observation about the relationship between events, providing it was focused on the specific question at hand, enhanced predictability of the outcome of design decisions, and could be acted upon. In short, it needed to be "a relevant indicator of something."

Further, the team agreed that evidence must be presented in a way that a practitioner could critically and objectively assess its quality and relevance. Therefore, there needs to be transparency in terms of its context and the methodology used to develop it.

What was particularly important to the team about this broad characterization of "evidence" is that it enabled team members with very diverse perspectives and research backgrounds to consider similarly diverse types of data. Information could qualify as being valuable even if it did not conform to the protocols of the individual disciplines, e.g., neuroscience, sociology, ethnography and environmental design, within which the team members were trained and most accustomed to work.

"Credible evidence," the team agreed, needs to be collected using scientific methodology, i.e., good research practices. Further, it must be valid and reliable (basic tenets of scientific research), and it has to be applicable, meaning that it will provide metrics to help the user of the evidence reach an informed decision.

Finally, the team decided to adopt a variation of the definition developed by Sackett et al. for evidence-base medicine. That definition was "Evidence-based design is the conscientious, explicit and judicious use of current best evidence in making decisions about building design."

Mode 2 Knowledge Production

The principles of Mode 2 knowledge production also had a major formative effect on the research strategies employed by the team. In *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies* (1994), Gibbons et al. put forward a thesis that Mode 1 knowledge production, characterized by the autonomy of scientific researchers within academia, was being replaced by Mode 2, which addresses a broad range of interests beyond academia and occurs within a context of application.

The New Production of Knowledge was met with both interest and criticism. The latter included concerns about degrading the quality of research and arguments that Mode 2 is actually not new, but actually the traditional form of science before its academic institutionalization in the 19th century (Etzkowitz & Leydesdorff, 2000). In *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty* (Nowotny et al., 2001), Nowotny, Scott and Gibbons addressed some of these criticisms, acknowledged the complexity of others, and continued the dialogue.

Three trends relevant to research process are "generally accepted to be significant—(a) the 'steering' of research priorities, (b) the commercialization of research, and (c) the accountability of the sciences" (Nowotny et al.). The "steering of priorities" refers to shaping programs and building capacities to meet identified social and economic needs; efforts by industry to identify research needs within the context of economic competitiveness, and top-down management of research themes. "Commercialization" involves increased diversity of funding resources and public:private partnerships and the exploitation of intellectual property for market return. "Accountability" about the management of research is intended to ensure its effectiveness and quality, with intensification of audit, assessment, and evaluation of performance.

Together, these three trends point to an increase in the intention of research toward serving an acknowledged societal purpose with measurable results. This Mode 2 research is more likely now than in many years to involve people across institutions of various types, including academia, government, and the private sector, in identifying the research problem, carrying out the work, and assessing its value.

This Mode 2 paradigm resonated with the Latrobe team. It seemed to be a way to link the interests of client, architect, and university researchers and to lead to standards for research quality as well as applicability. However, the team did not limit the research methodology to Mode 2 principles. In fact, some aspects of the work reflect the scientific methods that characterize Mode 1. This mix is, in fact, consistent with Gibbons' expectation that Mode 2 will supplement and interact with Mode 1, rather than supplant it. It is a trend, not an ideology. The team perceived value in exploring both modes, their interaction, and perhaps some approaches that are not purely mode as much as a hybrid.

Tim Luke, in his paper, "Miscast Cannon? Universities and the Liberal tradition in an Era of Flexible Specialization," addresses the "culture wars" between the canons of traditional western education and the actual application of knowledge in our economy. He asserts that transformation toward more Mode 2 knowledge production is inevitable, but he also claims that there is value in both Modes 1 and 2. "Socially-distributed knowledge . . . is an emergent amalgam of intellectual products now mostly produced and consumed outside of traditional university settings, and quite often in the material context of very short-run corporate outsourcings, task-specific government contracts, or entrepreneurial venture capital start-ups. Such Mode 2 knowledge, ironically, still depends on Mode 1 knowledge centers for many of its constituent elements - trained personnel, physical facilities, research programs, professional networks, or organizing paradigms. Nonetheless, more and more of these resources can be found off-campus or outside of academe" (Luke, 1996).

Joan E. Van Aken addresses a similar concept in the context of management science, concluding that "one should do more prescription-driven, design-oriented Mode 2 research to complement the description-driven, analysis-oriented Mode 1 research" (Van Aken, 2001). Van Aken argues for "prescription-driven" research that focuses on solutions, as opposed to Mode 1 "description-driven" research, for which the goal is problem understanding. According to Van Aken, "Where quality control in Mode 1 knowledge production can be seen as supporting a quest for truth, quality control in Mode 2 knowledge production can be seen as supporting a quest for human performance." Another characterization of this drive for research to support practical decision-making comes from Peltz. The need is for research products that do not just have "conceptual use," but specific and direct "instrumental use" (Peltz, 1978).

The 2005 Latrobe team addressed this by creating a research framework to enhance the ability to be prescriptive, i.e., "if X, then we can predict Y," and to complete a logic chain linking design attribute to metrics of relevance to organizational decision-making. In brief, the logic was as follows: "Design Elements," e.g., lighting spectrum and noise level, elicit "Immediate Physiological Responses," e.g., blood pressure, which in turn influences "Individual Health & Behavior Outcomes," e.g., illness, which result in "Organizational Impacts," e.g. sick days. The premise was that if one can predict a measurable outcome, such as costs to the organization due to employee time away from work, and demonstrate that the outcome is related to a design characteristic, e.g., the amount of daylight in the workspace, then one can rationally assess costs vs. benefits of using that design element.

Gibbons et al. identify Mode 2 knowledge production as having five characteristics, all of which to some degree were considered in the design of the Latrobe research approach.

- It is generated in the context of application. This does not imply certainty about results, nor is it independently conceived and generated Mode 1 research later applied to a real setting. It arises from "the very work of problem solving."

- It is "trans-disciplinary." A range of methods are used which come together often in novel forms to solve a specific problem.

- It is produced across knowledge organizations and at a variety of sites.

- It is "reflexive," in that there is conversation between the researchers and the subjects. The problem solving environment influences the topic, the research design, and the end uses. Consequences are intrinsic to the research process.

- It must accommodate multiple definitions of quality because there are many players and a lack of strict disciplinary criteria with which scientific peers can evaluate.

Defining Team Member Roles

Referring back to the research proposal, there was an assumption that the contributions of individual team members would largely reflect the core purpose of their sponsoring organization. In other words, Chong Partners Architecture would help the team understand the architect's questions and challenges; KP would reflect a client's point of view; and UC Berkeley would add the dimension of research expertise.

Initial team building sessions made it clear, in classic Mode 2 manner, that roles and interest would be far more integrated.

- Respect for disciplined, systematic research was pervasive

- Research experience existed in all three team components

- Biases toward processes and methodologies existed in individuals based on personal backgrounds rather than organization

As originally proposed, the team decided to maintain the model of one project director and a team leader (TL) for each of the three constituents. The latter was to engage internal resources for support and to simplify communication. The team leader role remained throughout the work, although there was a shift from manager to facilitator as the principal investigators pushed to greater autonomy in the pattern of science and away from the project management method more common in architecture.

The concept of one principal investigator (PI) per discipline, e.g., neuroscience and sociology, was also initially maintained from the proposal. However, as the topic was further refined, the PI's and team leaders followed natural inclinations toward their interests that blurred the strict distinctions among disciplines, largely as was desired in the proposed "trans-disciplinary" approach.

The greatest shift in work plan evolved as the research topic was further defined.

Defining The Pilot Research Topic

One of the most important premises for the team was that the research should inform decisions of significance to a design project. In other words, the search for knowledge was not for knowledge's sake alone, but rather to have a real impact on the client organization's performance.

A second premise was that even though our pilot was intended to address a healthcare environment, the outcome could ideally be generalized to other types of facilities. The lessons learned could be applied to education, office, and other settings.

A third requirement outlined in the Latrobe proposal was that physiological methods should be incorporated into the study, testing new concepts about the evidence base available to architects.

The early phases of the planning process, therefore, included extensive outreach to the client organization, in this case Kaiser Permanente. Internal enthusiasm far exceeded the team's capability to address all of the identified issues. Several emerged as potential research topics perceived by the client to be important, but lacking in sufficient data relative to outcomes. Among the major environmental variables for possible focus were color, light and lighting, and acoustics, all of which were suspected of affecting staff and patient experience, but generally lacking in meaningful metrics.

A second question was what population would be studied. Staff performance is, of course, crucial, and equally the patient experience.

Finally, what types of data would be needed to convince the KP decision-makers about the validity and significance of the findings? KP cares deeply about patient self-ratings of experience and surveys perceptions as a standard practice, but how do perceptions translate to health outcomes, as an example?

A framework was developed by the team to give structure to the different types of variables.

Definitions

1. Physical Characteristics/Design Variables – Architectural elements that can be controlled by the designer

2. Intervening Variables – The actual psychological or physiological responses to the Physical Characteristics. Examples might be stress, fatigue, lack of orientation.

3. Measurements/Indicators – The specific way that the research team might identify and quantify what is happening in response to the physical characteristics. Examples might be brain activity that can be monitored with an MRI, heart beat, and blood pressure.

4. Client Outcomes – Things relevant to the client's organizational performance desired to be achieved through the manipulation of physical characteristics. These might be used in a business case to justify design expenditure. Examples might be length of stay and medical errors.

The Framework (Straw Person to Illustrate Examples Only)

Physical Characteristics/ Design Variables	Intervening Variables	Measurements/ Indicators	Client Outcomes
Shape Size Dimension Direction Orientation Light View Air Quality	Stress Fatigue Sense of control Sense of orientation Functional efficiency Cultural sensitivity	Medical data, e.g., Blood pressure Perception survey/ self ratings Observed behaviors/ Trace observations Time/motion studies Bacterial content	Length of stay Retained Plan Members Medical errors Medical condition

What proved most valuable about this way of dissecting the research dimensions was the realization that architects, clients, and researchers tend to focus on different aspects of the chart, depending on their disciplines. Many designers, it was observed, for example, want to know about the physical characteristics, with fairly little concern about what's happening to the affected population psychologically or medically, so long as the design is effective. Clients often seek metrics, such as length of stay, because they directly affect patient experience and costs. From the focus on "evidence for design," however, all team members wanted to be able to say, "This is what the design is really affecting," e.g., stress, and that how that effect is evidenced and that level of understanding of fundamental causal relationships not only explains the design impact, but allows the designer to generalize.

Thus, with topics of interest to the client identified and a theoretical framework for defining a continuum from design characteristic to metric, the team then conducted a first phase literature search to learn what others had previously discovered. More detail about what was found in databases and periodicals is included in other chapters of this report.

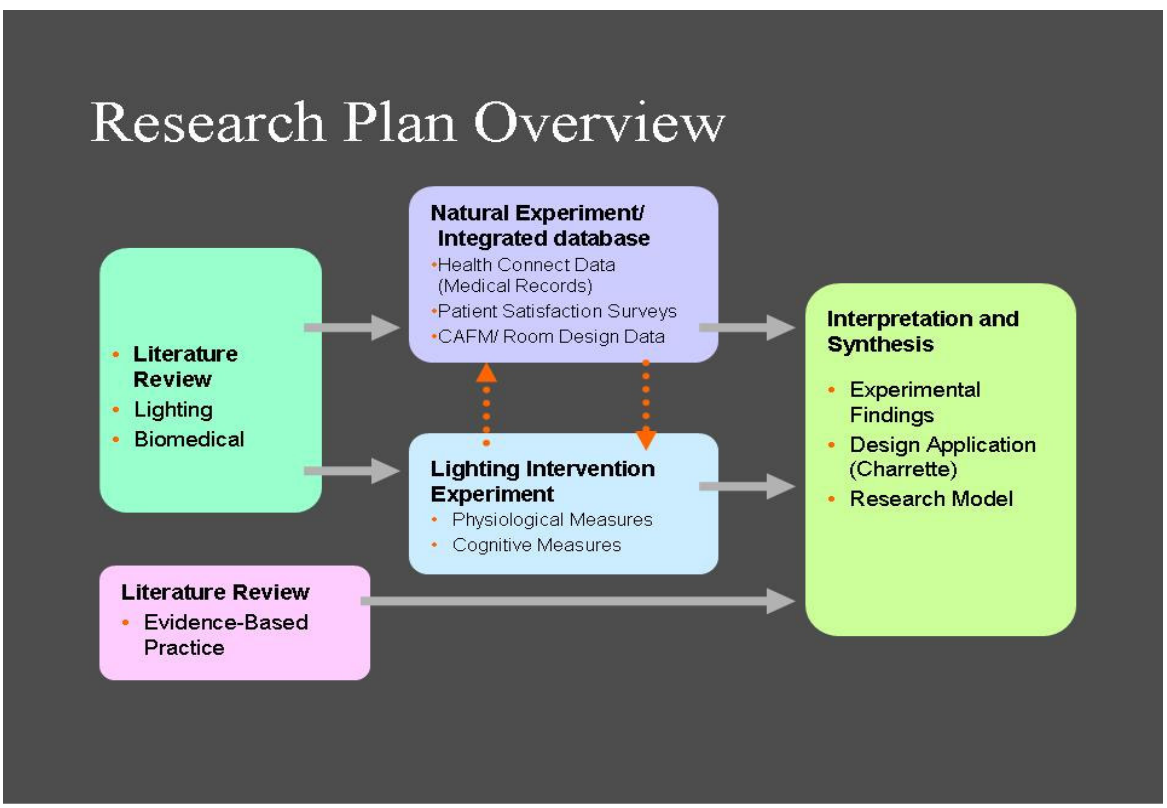
The outcome was a decision to focus the pilot on daylight and electrical lighting, in part because the literature suggested strong significance but did not fully answer the team's questions. Certainly prior research pointed to specific aspects of light, their possible impacts, and the populations most sensitive to the effects. The team felt that the body of knowledge complemented by the pilot would most directly allow designers to understand this important issue.

A decision was also made to focus on patient rooms. Although the team knew that the environments of the medical providers were also of considerable interest and suspected of affecting quality of care, staff retention, etc., the patient room setting seemed to be the more reasonable choice for a small pilot and the one that could be linked to existing available data.

Approximately six months into the research, with framework defined and some literature review completed, the team identified two very different methods for exploring the pilot topic. One related to the design process. A particular lighting condition would be defined that was hypothesized to be significant to patient outcome, a physical setting would be defined, and the effects both pre- and post-occupancy would be measured. Unfortunately, construction time and concerns about patient well-being would not allow this direct an approach. However, a full scale mock-up and/or lab study could achieve a similar result. The degree of control of the design variable appealed to the architects, and this approach also would allow tightly controlled measurements.

A second approach, however, was too compelling to ignore. KP has a vast real estate portfolio, documented in a CAD/CAFM system. It also has patient medical records and patient experience survey data. The PI's suggested that data could be mined for correlations between existing room design characteristics and the medical outcomes and experiences of patients in those rooms. Even though the rooms would not be redesigned for the experiment, rooms could be sought that had the design characteristic in question and compared with rooms with different characteristics in terms of medical and survey data. This analysis could be done systematically and controlled for possible confounding variables, such as medical condition and patient age and gender. The shear volume of data was unprecedented in evidence-based design, and the size of the database also provided the analyst with a level of statistical significance, even though each variable and measurement might not be as controlled as in a laboratory study.

The team chose to split the pilot into two tracks—a laboratory study (complemented by field measurements and design interpretation), and a natural experiment based on bringing together the continually refreshing KP databases. By pursuing two contrasting approaches, the team hoped to have two results that could be evaluated in terms of their strengths and weaknesses. Further, the goal was to be able to pilot related topics using the two approaches and then be able to compare and contrast the results. To date, the natural experiment has not yielded environmental design findings to relate to the laboratory findings on circadian light. However, as per the Executive Summary, the KP Integrated Data Model (IDM) is posed to address the circadian issue as well as many others and, therefore, is a valuable Latrobe result in itself.



The Structure of This Report.

Chapter 1 – Introduction: An overview of the team's intent, problem definition and research plan is covered in this introductory chapter. This includes an annotated literature review about the state of evidence-based practice by Steven Doctors, Ph.D. candidate (UC Berkeley). That document and commentary by Robert Brandt (Stantec) pose a challenge to the profession to rethink how we define and practice evidence-based design and to move forward to an approach that benefits from the perspectives and skills of practicing architects, clients, and university researcher communities, as well as the lessons learned—both pro and con—from other professions.

Chapter 2 - The Laboratory Experiment: Addresses what we know about light and health from the literature; how this experiment was conducted and what specific aspects of lighting were studied; what new findings we now have; and how these new data can be applied in design. The Principal Investigator for this work was Eve Edelstein, Ph.D. (Chapter 3). Dr. Edelstein and her team used bio-medical and cognitive measurements as well as field tests using a beta test version of a mobile light measurement device. Her findings were interpreted for design application during charrettes by medical planners and interior designers.

Chapter 3 – The Natural Experiment: Describes the primary research strategy the team at Kaiser Permanente used to create a tool, the Integrated Data Model, that can be used to answer important, current questions about the impact of design elements on patient well-being in hospitals. This tool integrates three classes of data never before connected—physical design features, patient experience, and patient medical outcomes. Broadly speaking, this original coordination allows planners and architects to understand the effect of architecture on health. The tool is especially powerful because of the enormous size of the sample, which allows fine discrimination between the effects of one variable versus another.

Chapter 4 - The Model: Includes an analysis of what was done, lessons learned, and the team's reflections on how future research might be affected by the experience provided by this Latrobe Fellowship to improve the quality of evidence-based design. W. Mike Martin, Ph.D. was the Principal Investigator for this work.

References

Berends, Mark, & Michael S. Garet, "In (Re) Search of Evidence-Based School Practices: Possibilities for Integrating Nationally Representative Surveys and Randomized Field Trials to Inform Educational Policy," *Peabody Journal of Education*, vol. 77, 2002, 28-58.

Dirkx, John M., "Studying the Complicated Matter of What Works: Evidence-Based Research," *Adult Education Quarterly*, vol. 56, no. 4, August 2006, 273-290.

Eldredge, Jonathon, "Evidence-based Librarianship: the EBL Process," *Library Hi Tech*, vol. 24, 2006, 341-354.

Etzkowitz, H., & Leydesdorff, L. (2000). "The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations," *Research Policy*, vol. 29, 109-123.

Galloway, Tamara S., Rebecca J. Brown, Mark A. Browne, Awantha Dissanayake, David Lowe, Michael H. Depledge, & Malcolm B. Jones, "The ECOMAN project: A novel approach to defining ecosystem function," *Marine Pollution Management*, vol. 53, 2006, 186-194.

Guyatt, G., Haynes, R., Jaescheke, R., Cook, D., Green, L., Naylor, C., Wilson, M., & Richardson, W. (2000). "Users' Guides to the Medical Literature," *JAMA*, September 13, 2000. vol. 284, 1290 - 1296.

Luke, T., (1996). "Miscast Canons? Universities and the Liberal Tradition in an Era of Flexible Specialization," Presented at "The Future of Higher Education," California State University, Oct. 18-20, 1996.

Nowotny, H., Scott, P., & Gibbons, M. (2003). "Introduction. "Mode 2" Revisited: The New Production of Knowledge." *Minerva* 41, 179-194.

Pfleeger, Shari Lawrence. "Soup or Art? The Role of Evidential Force in Empirical Software Engineering," *IEEE Software* 22, no. 1 (Jan/Feb 2005), 66-73.

Phillips, B., Ball, C., Sackett, D., Badenoch, D., Straus, S., Haynes, B., & Dawes, M., (2001). "Oxford Centre for Evidence-based Medicine Levels of Evidence (May 2001)."

Sackett, D., Rosenberg, W., Gray, J., Haynes, R., & Richardson, W. (1996). "Evidence-based Medicine: what it is and what it isn't," *BMJ*, Vol 312, 71-72.

Timmermans and Angell, 2001.

Torpy, J. (2006). "Evidence-based Medicine." *JAMA*. vol. 296, 1192.

Van Aken, J., (2001). "Mode 2 Knowledge Production in the Field of Management," Eindhoven Centre for Innovation Studies, The Netherlands, Working Paper 01.13.

Whitehurst, Grover J. "Identifying and Implementing Educational Practices Supported by Rigorous Evidence: A User Friendly Guide," U.S. Department of Education, Institute of Education Services, National Center for Education Evaluation and regional Assistance, December 2003.

Literature Review on Evidence-Based Practice

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Prepared for: 2005 Latrobe Fellowship Research Team

Date: September 5, 2007

Categorized by profession:

- Architecture (non-healthcare) and Urban Design
- Education and Child Development
- Environmental Management
- Librarianship and Information Systems
- Social Work
- Software Engineering
- Miscellaneous

Architecture (non-healthcare) and Urban Design

Badland, Hannah and Grant Schofield. "Transport, Urban Design, and Physical Activity: An Evidence-Based Update," *Transportation Research*, Part D, vol. 10, 2005, 177-196.

In this article about the complex interrelationship of urban design, transportation facilities, and public health, the authors employ an evidence-based approach to their study. Their argument is that current research is predominantly discipline-specific and lacking the multi-disciplinary approach necessary to understand the complex cause/effect relationships in the urban environment. They comb existing literature in a "systematic" review of these interrelationships, seeking evidence to be used in improving health outcomes through "suitable" urban environments and transportation. The article exemplifies a literature review form of evidence-based practice, which can be accomplished when available evidence is deemed to meet suitable disciplinary standards.

Bradley, Stephen and Christopher Hood. "Delivering Minimalist Workplaces that Improve Corporate Agility," *Journal of Facilities Management*, vol. 2, no. 1, 2003, 68-84.

To ensure flexible workplace environments responsive to variable work practices and changing technologies, the authors promote the assemblage of evidence from systematic evaluations of facility usage. They suggest that various research tools, including time-lapse photography, visual observation, and digital tools, are available to enhance an understanding of how space is used. The evidence generated by such systematic inquires, the authors suggest, will enhance user performance and space efficiency over time, more so than continued reliance on older workplace models.

While promoting a specific view of the "minimalist workplace," the article more broadly suggests that the introduction of scientific-based research methodologies into the design process, in this case by way of evaluating existing spaces, will enhance the outcomes of architectural practice.

Echenique, Marcial, Alan Short, and Koen Steemers. "What is Architectural Research," *ARQ*, vol. 9, no. 1, 2005, 13-15.

Stemming from a conference at Cambridge, the authors ask: What is architectural research? Does it exist as a field distinct from others (such as building science and art history), or does it merely draw upon research in other fields? For a research university such as Cambridge, the implications are enormous since government funding is at stake. If architecture is not a field of research, it is, by some measures, merely a field of vocational training and not a true academic discipline. Some argue that the design process is research, with the study of prototypes and precedents comparable to a literature review in research-based disciplines. John Worthington (partner at DEGW) notes that the challenge is to reaffirm the integrating role of architecture, using research to underpin evidence-based practice and to give practice "academic relevance." The article asserts that there was consensus amongst conference attendees that "architectural research is an interdisciplinary field where all kinds of fundamental research in other disciplines come together in the generation of form." While the article focuses on architecture as an academic discipline, the questions raised relative to design and research are equally relevant to architectural practice.

Heerwagen, Judith H., Kevin Kampschroer, Kevin M. Powell, and Vivian Loftness. "Collaborative Knowledge Work Environments," *Building Research & Information*, vol. 32, no. 6, November-December 2004, 510-528.

The authors emphasize the importance of employing research-based evidence to understand and design for effective "knowledge work" spaces that balance the different physical and cognitive requirements for collaborative and individual activities. Available literature shows that the requirements for successful collaborative spaces can negatively impact individual activities, while spaces designed to enhance individual activities are not conducive to the open communication opportunities required in a collaborative work environment.

Horwitz, Jamie. "Beyond Net-to-Gross: Analog Tools for Thinking with Non-Architects about the Design of Circulation and Other Shared Spaces," *AIA Report on University Research 2005*, 119-131.

The author acknowledges a "growing public interest" in evidence-based design based upon available user-oriented literature, and that the "authority" of scientific-based methodologies may well be the next "qualifying standard" in architectural practice. The author further acknowledges a desire on the part of architect and client alike to minimize risk and increase accountability in the design and construction of facilities.

Yet the author cautions against any strict application of scientific-based methodology that might cause evidence to "trump" the synthetic attributes of architectural thought. For this article, the author retroactively constructs evidentiary arguments in support of the design outcomes for a completed project to demonstrate how evidence concerning patterns of human interaction and circulation might have contributed to (but not serve as the sole basis for) certain synthesized design decisions by the architect.

Jones, Phil. "Safe Streets: Challenging the Principles," *Proceedings of the Institution of Civil Engineers, Municipal Engineer 156*, issue ME3, September 2003, 191-195.

The author criticizes prevailing "rule-based" traffic engineering techniques as "less rational as might be assumed." He argues that such techniques are based more on intuition than scientifically formulated evidence, and that they give primacy to vehicular movement while failing to assign sufficient value to pedestrian requirements. The author suggests that evidence-based practice would more accurately consider the complexity and multi-functionality of the streetscape, thereby offering a better balance amongst safety and aesthetic factors.

Macmillan, Sebastian. "Added Value of Good Design," *Building Research and Information*, vol. 34, no. 3, 2006, 257-271.

This article summarizes a literature review conducted by a number of public and private commissions and other entities in the United Kingdom of recent research on the social and economic benefits of a "well-designed built environment." The literature review includes studies of commercial office buildings (linking, for instance, spatial layout to teamwork and personal thermal/solar controls to productivity); education buildings for which research questions focused on the relationship between physical environment and learning; healthcare facilities; and a blended category of urban design, housing, and open space. The author suggests that such research overlooks the variable values associated with good design for stakeholders and is thus not useful in the design process. With the inclusion of values by way of various statistical methodologies, research and practice will be linked and evidence-based design will represent a more realistic proposition for practitioners.

Raman, Baranidharan and Jody R. Naderi. "Decision Tree Templates for Interactive Evidence-Based Design of Site-Specific Use-Specific Pedestrian Environments," Texas A&M University, working paper, March 2004.

Rather than address overarching questions about incorporating research and evidence into the design process, the authors propose a decision-tree design methodology based on a database of physical attributes deemed to be historically associated with "good pedestrian landscape design." According to the authors, such a methodology allows professionals to incorporate evidence into the design process. They define landscape architectural design as a "creative process of applying learned knowledge to achieve meaning in the manipulation of the environment."

The authors observe that experienced designers are able to draw upon knowledge gained from past experience to predict the outcome of the design effort. Their objective with the design-tree methodology is to enhance both the learning and predictive capabilities of the designer by providing a tool that "inductively" models human experience.

Stonor, Tim and Chris Stutz. "Toward Evidence-based Urban Design," working paper, Space Syntax, December 10, 2004, 1-6.

The authors note that the stimulus for evidence-based practice in the United Kingdom stems from government mandates that promote the sustainability of communities. These mandates include standards for the formulation and incorporation of evidence in urban policy-making. The authors propose to extend the government's promotion of evidence-based urban policy-making to evidence-based urban design. The article cites evidence-based medicine as a model for such practice, while recognizing that the complexities of urban space may require different approaches to the formulation of evidence and multiple standards of evidence to support design. The authors acknowledge as well that urban planning practitioners will need to acquire new research and interpretative skills to incorporate evidence-based design into the profession.

Stonor, Tim. "An Evidence-based Approach to Spatial Planning and Design," white paper publication, Space Syntax Limited, October 2006.

The author continues his argument in favor of evidence-based design in this promotional piece, repeating his observation that prevailing practices are "simplistic" and "unsophisticated," leading to "greater damage than benefit." He argues that incorporating evidence about urban patterns and behaviors into the design process will enhance outcomes.

Van Aken, J. E. "On the Design of Design Processes in Architecture and Engineering: Technological Rules and the Principle of Minimal Specification," working paper 03.08, Eindhoven Centre for Innovation Studies, June 2003.

The author observes that the scale and complexity of certain design problems warrants a design process that is "fully organized and disciplined." The design process, however, is more likely to be based on the designer's experiential knowledge (Polanyi's tacit knowledge) rather than the inclusion of evidence in a systematic fashion. Harking back to the design methods movement of the mid-twentieth century, the author argues for the reconsideration of technological, engineering, and evidence-based rules to enhance the design process and the outcome of practice.

Education and Child Development

Berends, Mark and Michael S. Garet. "In (Re) Search of Evidence-Based School Practices: Possibilities for Integrating Nationally Representative Surveys and Randomized Field Trials to Inform Educational Policy," *Peabody Journal of Education*, vol. 77, no. 4, 2002, 28-58.

The authors promote the integration of two modes of inquiry—randomized field trials and nationally representative surveys—to enhance school interventions. They argue that scientific-based research methods do not in isolation ensure value to educators. Methods must be coupled with a sound set of questions that can be studied empirically, research methods must be appropriate for the specific context, and results must be reported for public review and analysis. Reference is made to No Child Left Behind regulations that require scientific research principles be employed in the development of educational programs. "Scientifically-based research," as defined in NCLB policies, is research based on the application of rigorous, systematic, and objective procedures and employment of systematic empirical methods that draw upon observation or experiment.

Browder, Diane M. and Karena Cooper-Duffy. "Evidence-Based Practices for Students with Severe Disabilities and the Requirement for Accountability in "No Child Left Behind," *The Journal of Special Education*, vol. 37, no. 3, March 2003, 157-163.

The authors link evidence-based practices in education to federal No Child Left Behind (NCLB) regulations that mandate accountability in the formulation and assessment of educational standards and annual assessments based on rationalized standards. This highlights the political context of evidence-based practice, that is, the promotion of a methodology within a discipline triggered by a political initiative. The authors note that there are over 100 references in NCLB regulations to "scientifically-based research" and that recipients of federal funds must use that funds on evidence-based strategies and interventions. The authors observe that there are challenges to the implementation of evidence-based practices—namely, the availability of time for teacher practitioners and a general lack of familiarity with research practices. Additionally, the authors note that there is very little literature that demonstrates the efficacy of mainstreaming children with special needs under NCLB, thus giving it the appearance of being more of a value-based than evidence-based policy.

Carey, John C. and Carey Dimmitt. "Resources for School Counselors and Counselor Educators: The Center for School Counseling Outcome Research," *ASCA Professional School Counseling*, vol. 9, no. 5, June 2006, 416-420.

The authors summarize efforts of the Center for School Counseling Outcome Research (CSCOR), founded in 2003, to promote research-based decision-making in the field of school counseling. The Center conducts research studies, disseminates research outcomes, reviews current literature, and sponsors annual gatherings on evidence-based practices. The formation of CSCOR was prompted by a ten-year trend toward standards-based educational policies and the resulting need for accountability in identifying and closing gaps between standards and performance.

School counselors' needs are identified in the article as: research demonstrating that counseling services can positively impact student behaviors; training in use of data in counseling services; research on how interventions can affect outcomes; and evaluating interventions and programs to comply with accountability requirements. The authors highlight differing purposes of intervention research and intervention evaluation—generalizable research based on hypotheses of interest to researchers; evaluations based on objectives of stakeholders and specific program standards. The article reiterates the benefit of centralized repositories for discipline-specific research, as with the Cochrane and Campbell Collaboration, to facilitate practitioner access to research materials.

Collins, Shawnee and Charles Salzberg. "Scientifically Based Research and Students with Severe Disabilities: Where Do Educators Find Evidence-Based Practices?" *Rural Special Education*, vol. 24, no. 1, Winter 2005, 60-63.

The authors discuss scientifically-based research (SBR) as mandated by federal No Child Left Behind regulations (2001) and the What Works Clearinghouse, established in 2002 by the federal government to disseminate evidence-based practices to educators. They define SBR as research involving "rigorous, systematic, and objective methods, and rigorous data analyses to justify conclusions." The authors suggest that public policy initiatives are the impetus for evidence-based practices and that government participation in the articulation and dissemination of such practices provides credibility to an otherwise complex and "potentially controversial" process. These practices are problematic for students with severe disabilities and for rural schools, according to the authors, due to a reliance on randomized controlled trials on large, homogenous populations. This suggests the need, the authors observe, for more flexibility in the interpretation and implementation of evidence-based practices in specific contexts.

Cook, Bryan G., Timothy J. Landrum, Melody Tankersley, and James M. Kauffman. "Bringing Research to Bear on Practice: Effecting Evidence-Based Instruction for Students with Emotional or Behavioral Disorders," *Education and Treatment of Children*, vol. 26, no. 4, November 2003, 345-361.

While they focus on the sub-discipline of special education, the authors highlight two prevailing obstacles to evidence- or research-based educational practices: first, the tendency toward personal preferences in teaching and, second, the inaccessibility of available literature to practitioners. The authors recommend the use of teacher-educators to synthesize and disseminate research findings to teacher-practitioners and increased attention to linking research to interventions and practices.

Davies, Philip. "What is Evidence-Based Education*?" British Journal of Educational Studies* 47, no. 2 (June 1999), 108-121.

In the face of increasing top-down educational policymaking in England that suffers from unselective and non-systematic research practices and political-bias, the author proposes an adherence to evidence-based education (terms used by other authors include research-based, literature-based, and context-sensitive practice). This occurs at two levels: access to existing scientific-based literature and its use in specific applications and, secondly, the process of establishing new evidence when existing evidence is inadequate. The author's view of evidence-based education is derived directly from the evidence-based healthcare program at the University of Oxford. He reviews questions raised in the debate over evidence-based practices in education, such as applicability, nature of evidence, the process of using and developing evidence, and the quality and accessibility of research databases.

Davies, P. "The Relevance of Systematic Reviews to Educational Policy and Practice," *Oxford Review of Education* 26, no. 3 and 4, (September-December 2000), 365-378.

The author promotes the use of systematic reviews to enhance formulation of educational policy and practice. Systematic reviews represent, according to the author, the accumulated knowledge base of the profession, and afford researchers and practitioners access to broader data sets and syntheses not available from individual studies. The author discusses the attributes of the Campbell Collaboration as a repository for research materials, which would be the humanities equivalent to the Cochrane Collaboration for the healthcare field.

Dirkx, John M. "Studying the Complicated Matter of What Works: Evidence-Based Research," *Adult Education Quarterly*, vol. 56, no. 4, August 2006, 273-290.

In the face of widespread efforts to further evidence-based practices in education, this article emphasizes the need for an education knowledge base rooted in pragmatic issues of practice. The author sets his recommendations against the backdrop of ongoing polemics over evidence-based practices and their efficacy and suitability as a cure for pervasive problems in the educational system.

Elliot, John. "Making Evidence-Based Practice Educational," *British Educational Journal* 27, no. 5 (2001), 555-574.

This article draws attention to the philosophical debate about the definition, development, and implementation of evidence-based practices in education. The author notes that David Hargreaves receives much credit among scholars for his promotion of evidence-based practices in education. Subsequent scholars, such as Peters and Stenhouse, have challenged the Hargreaves approach as overly outcomes-based, and have promoted as an alternative "research-based teaching" that encourages a closer linkage between "educational aims and process," ostensibly missing from Hargreaves' approach.

This author promotes a theory of evidence-based practice that draws upon the differing but overlapping positions of Hargreaves and Peters/Stenhouse, thereby demonstrating that for all the discourse about evidence-based practice in education, the theories and methods are very much in flux and subject to ongoing polemics.

Gertsen, Russell, Lynn S. Fuchs, Donald Compton, Michael Coyne, and Charles Greenwood. "Quality Indicators for Group Experimental and Quasi-Experimental Research in Special Education," *Exceptional Children*, vol. 71, no. 2, Winter 2005, 149-164.

Prompted by the transition to rigorous, scientific-based research in special education, and empowered by a 2002 National Research Council report suggesting that education should be subject to the same methodologies as science-based disciplines, the authors propose a set of quality indicators to assess the merits and integrity of research reports. These quality indicators, the authors suggest, can also be used to formulate and assess new research questions and proposals. The quality indicators are presented as a series of interpretative questions categorized by underlying conceptualization of the study, nature and extent of the sampling pool, implementation of the intervention, outcome measures, and data analysis. According to the authors, implementation of the quality indicators will increase the likelihood that research employed by practitioners and developed by researchers will meet appropriate standards of rigor, with a resulting overall improvement in the state of education.

Greenwood, Charles R., Yolanda Tapia, Mary Abbott, and Cheryl Walton. "A Building-Based Case Study of Evidence-Based Literary Practices: Implementation, Reading Behavior, and Growth in Reading Fluency, K-4," *Journal of Special Education*, vol. 37, no. 2, Summer 2003, 95-110.

In this article, researchers document a three-year investigation into the efficacy of evidence-based practices in education, focusing specifically on the outcomes of a literary reading program. Observations include sustained use of evidence-based practices by teachers and improved behavior of students under study. For the purpose of the study, evidence-based practice is defined as drawing upon at least one empirical study, with "preferred" practices supported by experimental or quasi-experimental studies when possible. Practices varied over the three-year study as teachers experimented with, adapted, or abandoned reading practices as appropriate to their interests or objectives.

Hammersley, Martyn. "Educational research and teaching: A Response to David Hargreaves' TTA Lecture," *British Educational Research Journal* 23, no. 2, April 1997, 141-161; and Hargreaves, David H., "In Defence of Research for Evidence-Based Teaching: A Rejoinder to Martyn Hammersley," *British Educational Research Journal* 23, no. 4, September 1997, 405-419.

The two articles represent a dialogue between two of the most prominent players in the British discourse on evidence-based practice in education. Fundamentally, Hargreaves and Hammersley share the view that prevailing educational research methods do not provide a solid evidence-based foundation for the teaching profession, that these methods do not "generate a cumulative body of knowledge" nor address the fundamental issues of concern to teachers. Beyond this common ground, the two scholars diverge on several key points. First, Hargreaves' proposals for evidence-based education generally adopt evidence-based medicine as a model and include more teacher participation and more guidance for teachers in research activities. Hammersley resists evidence-based medicine as a precedent, arguing that the pervasive tendency amongst professions to model themselves after the sciences does not mean such a model is necessarily suitable for education. Secondly, the two scholars have different views on the standards to be employed in the formulation and assessment of research, with Hammersley arguing that Hargreaves is too vague about how research is to be applied to practical problems in the field. The third primary area of divergence concerns the relationship between research and practice. While Hargreaves expresses great faith in the efficacy of research, its relevance to education, and its capacity to positively influence practice, Hammersley takes a more nuanced position by arguing that research can, indeed, contribute to the identification of solutions, but that its effectiveness should not be overrated beyond realistic expectations. given the enormous complexities of the educational field.

Lerman, Dorothea C., Christina M. Vorndran, Laura Addison, and Stephanie Contrucci Kuhn. "Preparing Teachers in Evidence-Based Practices for Young Children with Autism," *School Psychology Review*, vol. 33, no. 4, 2004, 510-526.

This article demonstrates that while debates continue about the efficacy and methods of evidence-based practices, efforts are underway to implement such practices through the training of practitioners. The authors discuss the implementation of evidence-based practices in a special education environment for children with autism. They propose an instructional model that teams teachers with outside researchers and other practitioners in a continuing education program to expose teachers to evidence-based practices that will enhance outcomes for both teachers and students.

Luckner, John L., Ann M. Sebald, John Cooney, John Young III, and Sheryl Goodwin Muir. "An Examination of the Evidence-Based Literacy Research in Deaf Education," *American Annals of the Deaf*, vol. 150, no. 5, Winter 2005/2006, 443-455.

The authors note increasing expectation for high levels of literacy in the current "service- and knowledge-driven economy," leading to an increased demand for rigorous scientific methodologies in the educational environment. This attention to scientific methodologies is notably augmented by federal No Child Left Behind regulations that specifically mandate the employment of "scientifically based research" in the formation and implementation of educational policies. According to the authors, such "scientifically based research" includes experimental control groups, generalizable results replicable through multiple studies, and "convergence" of results and studies. The authors' objective was a literature review and meta-analysis of available research on deaf education studies.

Odon, Samuel L, Ellen Brantlinger, Russell Gersten, Robert H. Horner, Bruce Thompson, and Karen R. Harris. "Research in Scientific Methods and Evidence-based Practices," *Exceptional Children*, vol. 71, no. 2, Winter 2005, 181-194.

This article furthers proposals made in the Gersten et al. article regarding quality indicators by suggesting three tiers or stages of research: initial "descriptive" research activity (preliminary hypotheses, observations, and pilot work), experimental causal research (controlled laboratory experiments and classroom-based demonstrations), and research on processes that are generalizable and applicable in practice (randomized classroom trials studies). This staging of research, the authors suggest, allows for the phased formulation of questions and for methods that are context-specific.

Simons, Helen, Saville Kushner, Keith Jones, and David James. "From Evidence-based Practice to Practice-based Evidence: The Idea of Situated Generalization," *Research Papers in Education* 18, no. 4 (December 2003), 347-364.

The authors document a British evidence-based education program intended to provide teachers with the skills and tools necessary to conduct research. As the program evolved, the practices most prone to being adopted by teachers were those most closely linked to the practical realities of everyday classroom activity. The authors propose the notion of "situated generalization" pertaining to the assessment and generation of evidence. More specifically, "situated generalization" emphasizes teacher interpretation and judgment rather than strict compliance with rule-based methodologies. It is, as the authors state, "a process of recognition and adaptation, on the basis of similarities and differences, to one's context." Such an approach, they claim, is consistent with what they argue are the three key characteristics of evidence-based practice: teachers need to interpret evidence on a case-by-case basis; evidence needs to be closely linked to the specific context of practice, and evidence is most credible to teachers when interpreted and analyzed collectively with peers.

Environmental Management

Galloway, Tamara S., Rebecca J. Brown, Mark A. Browne, Awantha Dissanayake, David Lowe, Michael H. Depledge, and Malcolm B. Jones. "The ECOMAN Project: A Novel Approach to Defining Ecosystem Function," *Marine Pollution Management*, vol. 53, 2006, 186-194.

This article recounts a research effort focused on the development of an evidence-based approach to environmental assessment through an integrated series of laboratory and field studies. The authors assessed the condition of coastal areas using a set of cost-effective health indicators, or biomarkers, tested initially in the laboratory and subsequently employed in the field. The value of the research, according to the authors, is its contribution toward an evidence-based definition of "ecological quality." The promotion of evidence-based practices, they suggest, is at least partially in response to laws mandating that environmental regulations be formulated in a "transparent and integrated" fashion.

Mathevat, Raphael and Andre Mauchamp. "Evidence-based Conservation: Dealing with Social Issues," *Trends in Ecology and Evolution*, vol. 20, no. 8, August 2005, 422-423.

The authors ground their remarks in the observation that environmental conservation interventions are commonly undertaken in the absence of sufficient scientific evidence to support them and rely more on anecdotal evidence or precedent. The outcome of such interventions can be enhanced if consideration is given to the full range of ecological, social, and economic issues. The complexities of such issues, the authors argue, require a broader evidence-based conservation strategy to better understand the problem and viable value-based solutions.

Pullin, Andrew S., Teri M. Knight, David A. Stone and Kevin Charman. "Do Conservation Managers Use Scientific Evidence to Support Their Decision-making?" *Biological Conservation*, vol. 119, no. 2, September 2004, 245-252.

Based on their study, the authors argue that environmental conservation interventions tend to be based on experience and past practices rather than on context-specific evidence. This, they contend, is attributable to evidence not being readily available, non-existent, or, as is frequently the case, conservation managers and planners not making "full or systematic use" of the evidence even when it is readily available. They suggest that the adoption of evidence-based practices employed in other fields, such as medicine, would enhance the outcomes of conservation practices. The authors highlight two key points regarding the adoption of evidence-based practices: the intent of evidence-based practice is to generate more and higher quality evidence, but decision-making should not be stalled in the absence of good evidence; and the promotion of evidence-based practice does not suggest that current conservation interventions are wrong, rather evidence-based practice represents an opportunity to enhance the outcome of future conservation interventions.

Roberts, Philip D., Gavin B. Stewart and Andrew S. Pullin. "Are Review Articles a Reliable Source of Evidence to Support Conservation and Environmental Management? A Comparison with Medicine," *Biological Conservation*, vol. 132, no. 4, October 2006, 409-423.

The focus of this article is on enhancing evidence available to practitioners rather than a broad argument for evidence-based practices. On the premise that evidence-based medicine is an appropriate model for evidence-based practice, the authors compare the rigor of review articles in environmental management, a key and often sole source of evidence for environmental managers, with systematic reviews in the fields of medicine and public health. Their observations—that environmental reviews are of lower quality, are more subject to bias, and are less synthesized than those in medicine and public health—lead to their recommendation that environmental journals should mirror the systematic review guidelines in medicine and public health so as to improve the "impact, quality, and power of review articles." This, according to the authors, would improve the basis for adopting evidence-based practice in environmental management.

Librarianship and Information Systems

Dickenson, Gail K. "How One Child Learns: The Teacher-librarian as Evidence-based Practitioner," *Teacher Librarian*, vol. 33, no. 1, October 2005, 16-20.

The author explores the prospect of applying evidence-based practice to librarianship to mirror the benefits of similar practices in the health industry. Evidence-based librarianship is defined as a systematic (as opposed to intuitive) process of framing a question, investigating the existing body of literature, identifying and implementing a solution, and concluding with an assessment of the outcome. The author reviews current best practices for each of these tasks and concludes that implementation of these practices will achieve the dual objective of enhancing the professionalism of librarianship and improving student performance.

Eldredge, Jonathon. "Evidence-based Librarianship: The EBL Process," *Library Hi Tech*, vol. 24, no. 3, 2006, 341-354.

This article describes evidence-based librarianship as a systematic, five-step process: framing a "defined, relevant, and answerable question"; researching available literature and "authoritative" resources; analyzing the "evidence"; performing a cost/benefit analysis of prospective action plans; and assessing the outcome and "effectiveness" of the implemented action plan. To contribute to the formation of a body of knowledge for the profession, the author proposes the collection and dissemination of evidence generated by its practitioners in the course of evidence-based practice.

Gallagher, John, Kathleen Bauer, and Daniel M. Dollar. "Evidence-based Librarianship: Utilizing Data from All Available Sources to Make Judicious Print Cancellation Decisions," *Library Collections, Acquisitions & Technical Services*, vol. 29, 2005, 169-179.

This article is a focused study of evidence-based practice applied to the management of library periodical collections. The authors demonstrate a systematic methodology that captures data from multiple internal and external sources for the purpose of identifying cost effective management strategies and facilitating decision-making in this area of concern.

Social Work

Bruder, Mary Beth, Gloria L. Harbin, Kathleen Whitbread, Michael Cinn-Powers, Richard Roberts, Carl J. Dunst, Melissa Van Buren, Cindy Mozzarella, and Glenn Gabbard. "Establishing Outcomes for Service Coordination: A Step Toward Evidence-based Practice," *TECSE*, vol. 25, no. 3, 2005, 177-188.

Given the historical ineffectiveness of service integration, defined as a coordinated effort of multiple providers, resources, and agencies bearing on the needs of any given client, the authors explore evidence-based practices as a means of enhancing outcomes. Drawing upon four national studies, the authors propose a set of achievable outcomes of practice to be employed as a "logic model" for assessing the effectiveness of service integration. While aware that further studies are needed given the complexity of service integration attributable to multiple stakeholders and variables, they suggest that logic models, and by extension evidence-based practices, show some promise for enhancing the outcome of practice.

Crisp, Beth R. "Evidence-based Practices and the Borders of Data in the Global Information Era," *Journal of Social Work Education*, vol. 40, no. 1, Winter 2004, 73-86.

The author argues that advancements in information technology facilitate the incorporation of evidence-based practices in social work. This article serves as a primer for defining and expanding the parameters of acceptable evidence, and for assessing available evidence and its suitability to the specific context of practice.

Gambrill, Eileen D., "Evidence-based Practice: Sea Change or the Emperor's New Clothes?" *Journal of Social Work Education*, vol. 39, no. 1, Winter 2003, 3-23.

The author methodically lays out arguments for incorporating evidence-based practice into social work. Challenges, according to the author, reside principally amongst practitioners resistant to change. Key changes include the adoption of evidence-based practices employed in other disciplines, and accepting the patient/client as a key participant in the decision-making process.

McNeece, Aaron C. and Bruce A. Thyer. "Evidence-based Practice and Social Work," *Journal of Evidence-Based Social Work* 1, no. 1 (2004), 7-26.

In this inaugural issue of a journal devoted to evidence-based social work, the authors describe the fundamental characteristics of evidence-based practice as they apply to social work. Consistent with the motivations of the journal, the article seeks to promote evidence-based practice as a new paradigm that will enhance the outcome of social work services and, by extension, assert social work as a profession legitimized by rationalized and empirical-based processes.

Software Engineering

Dyba, Tore, Barbara A. Kitchenbaum, and Magne Jorgensen. "Evidence-based Software Engineering for Practitioners," *IEEE Software* 22, no. 1 (Jan/Feb 2005), 58-65.

The author turns to evidence-based medicine as a model for decision-making in software engineering, suggesting that the application of scientific techniques will minimize the economic risks of software development and increase the quality of the end product. As in other fields of endeavor seeking to adopt evidence-based practices, the fundamental methodology proposed by the author includes formulation of an "answerable" question, investigation into available evidence, assessment of that evidence, application of findings to the specific context of practice, and a performance evaluation of the final product.

Pfleeger, Shari Lawrence. "Soup or Art? The Role of Evidential Force in Empirical Software Engineering," *IEEE Software* 22, no. 1 (Jan/Feb 2005), 66-73.

A recurring theme in the literature on evidence-based practice is how to define credible evidence for decision-making. The author proposes that software engineering practitioners can strengthen their arguments for action by balancing four types of evidence—tangible (documents such as lines of code or procedures), testimonial (equivocal/probabilistic; unequivocal on direct observation), missing (does not occur in testing), and accepted facts. The outcomes of this broad view of evidence, according to the author, include more credible hypotheses and more effective decision-making about product development.

Miscellaneous

Armstrong, J. Scott and Robert Fildes. "Making Progress in Forecasting," *International Journal of Forecasting*, vol. 22, 2006, 433-441.

The authors discuss a divergence between evidence-based findings and prevailing beliefs among academics and practitioners, leading to resistance to adopting evidence-based practices in forecasting. They propose various methods to bridge this theory/practice gap and overcome what they perceive to be a resistance to change. The proposals, premised on the considerable influence journals maintain in the forecasting discipline, include: more frequent publication of papers that contest current beliefs; more disclosure of experimental data to facilitate replication; and improved availability, readability, and usefulness of journals. The authors also propose that evidence-based forecasting methodologies be incorporated into software and Internet-based decision-making products for wider access and enhanced functionality.

Aspinall, W. P., G. Woo, B. Voight, and P. J. Baxter. "Evidence-based Volcanology: Application to Eruption Crises," *Journal of Volcanology and Geothermal Research*, vol. 128, 2003, 273-285.

The authors promote evidence-based practice to improve the accuracy of risk analyses over that of "conventional scientific" approaches. The authors set their argument for evidence-based practice in the context of rationalized problem-solving promoted under the broad auspices of Evidence Science.

CHAPTER 2 – THE LABORATORY EXPERIMENT

THE LATROBE LABORATORY EXPERIMENT

Eve A. Edelstein, Ph.D.

Summary

1. Literature reviews, the first stage in evidence gathering, provide strong and compelling findings that suggest that a change in current lighting and daylighting practices are warranted.

   - Reviews revealed a great deal of evidence from scientific studies that suggest new lighting strategies.

   - Specific literature reviews revealed a pervasive influence of light on human function, outcomes, and health risk.

   - While some of the evidence is rigorous and strong, and some is soft and anecdotal, there are compelling reasons for designers to more carefully program and design around access to controlled daylight and electrical lighting.

   - Current understanding of circadian rhythms suggests that the typical building's lighting conditions do not emulate the light that a body needs.

   - Short wavelength light (420-460nm) is indicated as the most effective at modulating melatonin related sleep and wakefulness. Broader spectra (bright white light) modulate melatonin responses, but require greater intensity or length of time to be as effective as blue light.

   - Time of day, length of time, intensity, distribution and spectrum of light—all interact to influence human responses.

2. The body has many circadian responses in addition to melatonin cycles, which may be modulated by a different range of spectra. This has been little investigated to date.

   - New wearable technologies enable architects to gather evidence in operational built environments without intruding on users.

   - Field studies demonstrated the use of personal logging systems to measure circadian and photopic light, which can easily be used in most architectural settings. Future development of micro-technologies will facilitate pre- and post-occupancy studies. (See Daysimeter, RPI).

3. Controlled experiments can test ideas raised by the client, the designer, the literature, or by users in the field.

    - The Latrobe laboratory experiment tested a concept put forward by designers that brief "light showers" may be a useful means to modulate circadian responses when access to daylight is not feasible (due to architectural constraints, climate, or time of day).

    - The study demonstrated that the use of "off the shelf" lighting devices was associated with stress related changes after only 5 minutes of light stimulation.

    - Heart rate variability measures during relaxation and working memory tasks showed that brief exposure to bright light (with a blue peak) was related to activation, as predicted by circadian research.

    - Red light was associated with significantly different responses. Heart rate reactivity changed appropriately with the situation. Variability was high during relaxation, but reduced during memory tasks as appropriate.

4. Bringing together the literature reviews, IDM database, and results from the laboratory findings, new information based on trans-disciplinary approaches developed.

    - Wearable micro-technologies for evaluating environmental conditions (circadian light levels and/or sound measures) and human measures (e.g., stress, cardiac, cognitive responses, satisfaction, medical conditions) could be used in real operational or mock-up environments to assess the actual level of individual exposure that occurs in each design and for each function (shift work, dark rooms, procedure rooms, etc.).

    - An IDM system could be used to relate the individual user, visitor and staff responses and outcomes to specified locations and designs.

    - Time series of measurement of light (and sound) conditions in particular environments will add greater clarity to understanding the influence of the design on responses and outcomes.

5. The final stage in evidence-based design is to create a design intervention based on the principles developed from the literature reviews, experimental findings, and field studies.

    - New lighting interventions could be tested in operational or mock-up environments.

- Important outcome measures, including heart rate variability, in addition to traditional survey and observation methods, could assess the influence of the lighting interventions.

- Lighting interventions should reflect specific issues. A combination of lighting designs is most likely to meet such varied needs and should provide access to controlled daylight and individual task and circadian lighting that can be controlled per individual, role, and time.

Abstract

The Latrobe Fellowship proposal committed to the inclusion of scientific methods and physiological techniques as part of a trans-disciplinary approach to explore the influence of architectural environments on human responses. The intention of the Latrobe Laboratory Experiment was to conduct a pilot study to explore how the rigor of the scientific method and physiological techniques might enhance the quality of evidence available to designers. The premise was to apply rigorous methods that might provide a new means to gain information to better support design decisions.

The Latrobe Laboratory Experiment explored how architecture might influence human exposure to light within built settings, and how light level and color might influence health outcomes. The laboratory results went beyond a pilot demonstration, revealing new measurement systems and statistically significant results relating light levels and cardiac health indicators. Heart rate variability is a sensitive indicator of health status and risk, and as such is important to all users of all built spaces. The experiment showed that heart rate variability decreased during brief exposure to bright white light over the course of the experiment, consistent with circadian activation. Yet more interesting were the results that showed that heart rate responses were highly significantly different in red light conditions than in white light. Appropriate cardiac activation was observed during cognitive tasks, but cardiac relaxation during rest. Red light has rarely been the focus of circadian research, yet we are familiar with its role as an indicator of time of day as the sun sets.

In order to stretch beyond the laboratory into the realm of design application, design charrettes were held to discuss the potential impact of introducing biologically relevant light levels on architecture and design. Field measurements were conducted using the new measurement systems to determine the actual light conditions in occupied and recently completed buildings. The information obtained was considered in terms of principles that might guide design to better serve human conditions. These findings suggest that there is much more to explore about the quality and quantity of light that should be introduced in built spaces. The results challenge us to look beyond the typical architectural and electrical solutions in order to better meet human biological and psychological needs for light.

Experimental Approach

Scientific Methodology

The scientific method provides a successful model for investigating complex questions, such as the influence of built environmental variables on human psychological and physiological outcomes. The method defines how questions should be framed in the form of hypotheses that can be tested, and how data should be collected and analyzed to demonstrate that the observations and measurements are reliable (accurate), repeatable (reproducible), and meaningful (valid). By carefully controlling the experimental design and the environmental variables in the test setting, statistically significant findings can be obtained from a relatively small number of subjects.

Comparison with findings from other rigorous studies provides a powerful means to demonstrate that the experimental results are repeatable, that they reliably reflect the phenomena being studied, and that they are valid in the context of the experiment and their application. The conceptual framework for applying such findings requires that the results are conveyed with information about the context and limitations of the research so that appropriate generalizations can be made. This approach is different than practices often employed in evidence-based design, in which the results of a single experiment or case study are generalized beyond the levels that science would allow.

The scientific process begins with a definition of an observation or problem, followed by information gathering that informs the development of a testable idea (or hypothesis). The experiment is a cornerstone of scientific methodology that defines a problem solving process for testing the hypothesis. The process requires that objective measures be used to gather data that describe a feature that exerts influence (the "independent variable") on another feature (the "dependent variable"). It also requires that valid measures be used that accurately describe changes that occur and that truly reflect the phenomenon being studied. Experimental "rigor" is provided by using accurate, repeatable, and reliable (low measurement error) methods. Following critical analysis of the findings, conclusions are formed that can be used to develop new or more accurate hypotheses related to the findings.

Critical analysis of the methods, validity, and applicability of the results is also required for the success of the scientific problem solving process. The design of the experiment itself determines if data will actually (and accurately) measure the features that are being tested. The research methods chosen must be suited to the location and conditions under which the measurements will take place. Just as a single design does not answer all issues, a single research method does not answer all questions. Careful design of experimental methods, location, and approach yield valid data.

Since valid scientific studies require that evidence is demonstrated to be repeatable before hypotheses are supported or refuted, and before generalizations are applied, it is rare that an intuitive thought or single case study will be used as proof, and unlikely that a single piece of research will inform all cases, hypotheses, theses, principles or laws. Instead, research relies on a very broad and deep information base.

The complexity of a real-world environment introduces "confounding" factors that make it difficult to determine the causal relationship between an environmental feature being manipulated and an outcome. Potentially confounding factors can be minimized by controlling human variables (age, gender, vision, medical condition, number of procedures, acuity, length of stay, etc.) and by studying a "normal" subject group and providing a baseline for comparison with other human factors, e.g., aging, culture, or medical condition. Normal studies also provide "pilot data" needed to show that the experiment induces no harm, and proof of principle that the experimental methods work. Such information is typically required before an Institutional Review Board (IRB) approves the study of patients or staff. The study of normal subjects also provides great relevance to architects, as they describe the users of the broad range of architectural types. Confounding environmental variables (noise, architectural features, indoor air quality, etc.) can also be controlled by careful experimental study design.

A myriad of novel technological and conceptual advances offers new opportunities to incorporate scientific methods. For example, neuroimaging and wireless electroencephalography (EEG or brainwave) techniques are being used to explore how cognitive maps are formed in subjects' minds as they freely navigate virtual and real spaces. Heart rate responses can be recorded unobtrusively in office environments, indicating changes in stress levels (Thayer et al., 2006). Using such methods, new information can be generated that addresses many design questions and problems that have to date been impossible to answer in operational built settings.

The final stage of the scientific process requires verification that the application of a design solution performs as hypothesized. The repetition of multiple investigations in multiple sites, using multiple methods provides the evidence-base from which specification of general principles and predictable performance criteria can be developed. The scientific process discourages overstatement of results or overgeneralization that asserts causal relationships between environment and outcome. As the database of information derived from repeatable, valid information grows, new design solutions may be generated and new trans-disciplinary methods developed.

Despite this requirement for repeated research, existing evidence can be used while waiting for additional findings and further understanding to develop. The key is to apply the findings carefully, respecting the extent of knowledge and limitations to its interpretation. Indeed, this system fails when the scientific process is ignored, outcomes are overstated, or incidents are unreported. Translational science provides an excellent example of how knowledge at the bench may be carefully applied to the development of discoveries and therapies (Edelstein, 2006).

These basic principles of the scientific method ensure the value and applicability of evidence-based design, even when the research team is working beyond the strictures of traditional scholarly research within one discipline and in the formation of a trans-disciplinary design process. The value of evidence so acquired is based upon an understanding of the evidence-building process on the part of the practitioner, who must critically assess the risks and rewards of applying the evidence to a specific design context as well as the direct relevance of the evidence to design decisions.

Experimental Design Process

The first stage in designing a trans-disciplinary experiment of relevance to clients and designers involves defining topics that address real client issues and design challenges. Next, the literature surrounding those topics is consulted to assess the existing state of understanding about the topic and the methods used to explore it. Based on this literature, a hypothesis is formulated that suggests the relationship between the environmental condition and human outcomes. The experimental design used to test the hypothesis must then be matched to the location available for experimentation. Certain questions can be best investigated if tested in controlled laboratory conditions, whereas other questions can be addressed only in real world environments. After defining the topic, subject group, and location for experimentation, the methods for taking measurements can be defined precisely. If experiments are to be conducted on humans, ethics committee approval must be obtained and more rigorous standards adopted if children or patients are to be tested.

An iterative process is involved, where the existing literature defines topics and methods that could be studied. Appropriate locations and environmental conditions are defined, and then the literature is again explored at a deeper level to precisely design an experiment that can be performed in the agreed location, with agreed subjects, and with available techniques. Indeed, experiments should not be designed before specific information about the qualities of the setting, people, or techniques are defined, as many conditions must be taken into account to yield accurate, reliable, repeatable and, hence, valid findings.

Experimental Design

The Latrobe team adopted the general hypothesis that features of the built environment influence human responses and outcomes. The hypothesis further asserted that features of the built environment influence human *biological, psychological, and medical processes* that, in turn, influence measurable outcomes.

The Latrobe research team and the client representatives gathered during many meetings to define topics that address real client issues and design challenges. The team considered the influence of many built features on human responses and health outcomes that could be explored using experimental psycho-physiological techniques. The issue of color emerged as of particular importance to the client, who sought to understand if the many claims about the healing influence of color were borne out by an evidence-based approach that considered both the health and culture of the users.

An initial literature search on color and color preference was conducted (See Edelstein, Appendix: Color Perception & Preference), which demonstrated that numerous studies have explored a variety of factors related to color preference across cultures, societies, and individuals. Theoretical frameworks have categorized color preference in terms of nomenclature, linguistic and semantic evolution (Hardin et al., 1999, 2005). Many consider categorization to be a common property of human cognition and conclude that color categories help to facilitate recognition and influence perceptual judgment. However, analyses suggest that deviation from a uniform pattern of categorization may be explained by physiological evidence that certain people may actually perceive colors differently. Since Gladstone began this controversy 125 years ago, discussion persists whether the perception of hue differs by culture or biological diversity (Bornstein, 1975). Therefore, the Latrobe team decided that it would make sense to research physiological and behavioral responses to spectrum rather than focus on applied color. The following literature search on light and lighting confirmed that this was a promising research focus.

The Latrobe Experiments

Together, the Latrobe Natural Experiment and the Latrobe Laboratory Experiment hypothesized that light (independent variable) influences health outcomes (dependent variable). Based on initial literature reviews, the Latrobe Natural Experiment developed a process to evaluate the influence of compass orientation on outcomes as a means to test the influence of solar lighting on health. The Latrobe Laboratory Experiment, described below, tested the influence of specific lighting levels on defined health risk indicators and cognitive function. An advantage of this narrowly defined laboratory experiment was that the specific influence of the quality and quantity of light could be evaluated, and fewer experiments were needed to achieve high standards of repeatability, statistical significance, and validity.

The Latrobe Laboratory Experiment systematically altered only one environmental "independent variable" (light), in normal subjects in controlled laboratory conditions. The "dependent variable," health (the feature being influenced) was assessed by measuring cardiac responses known to be sensitive indicators of health and health risk (Thayer & Lane, 2007). In particular, heart rate variability was used as an accurate (sensitive and specific indicator of health risk), repeatable, and reliable metric. Brain wave electroencephalography (EEG) was used as a measure of cognitive activity. Given the sensitivity and specificity of such methods, statistical power analysis anticipated that a relatively small sample of subjects would have sufficient statistical power to yield significant results.

Both the natural and laboratory experiments used disciplined approaches to research, while maintaining a focus on creating evidence that would be useful in an architectural context. The laboratory experiment utilized physiological and psychological techniques within the framework of a scientific method in conjunction with techniques from the design process, including field studies and a design charrette, to test hypotheses about the influence of light on human physiology. The measurement systems used to test the light levels for experimental conditions were applied to test the actual light levels in real operational environments (post-occupied health care environments) and in pre-occupancy settings.

Together, these studies identify how environmental conditions can be measured and how human responses to those conditions are influenced. The findings and associated literature studies indicate how design of architectural and electrical lighting systems may be adapted to best serve human outcomes, including cognitive functions (alertness, working memory), physiological functions (heart rate variability), and ultimate outcomes (health status).

Literature Review: The Biological Response to Light

Eve A. Edelstein, Ph.D.

The Latrobe team decided that rather than focus on applied color, it would investigate the physiological and behavioral responses to light spectrum. The following literature search on light and lighting confirmed that this was a promising body of research based on biological and medical investigations of human responses to the color of light. The review revealed evidence of a pervasive influence of light on health and human function, and served as the basis for development of the hypothesis and design of the Latrobe Laboratory Experiment. The quality and quantity of light shown to influence human responses is markedly different to the commonly applied lighting standards designed for visual function (see LeSourd in Appendix; Rea et al., 2006).

Chronobiology

The influence of light on behavior, emotion, function, cognition, and health has been reported in a large body of research that uses either natural or electrical light to alter physiological and/or mental responses (Edelstein, 2006). The field of Chronobiology examines the cyclic, biological rhythms demonstrated by almost all living organisms. "Chrono" refers to time and "biology" to the study of life. In animals, many essential biological processes, including eating, sleeping, mating, and cellular regeneration, respond to diurnal and seasonal changes. Franz Halberg, commonly known as the “father of chronobiology,” is credited with first coining the terms “circadian” and “circannual rhythms” to describe biological responses to diurnal and nocturnal lighting. The term “circadian” comes from the Latin *circa* for "around" and *dies*, "day," meaning “around a day." “Circannual” means “around a year.”

Written record of the study of biological responses to light dates back at least to the 1800s, when Mairan and Linnaeus recorded plant movement in response to daily lighting changes. Charles Darwin’s work in the 1900s validated the biological response to light in animals. A myriad of behavioral, emotional, and physiological responses are now associated with exposure to electrical lighting, daylighting, and solar orientation. The field has progressed through multiple generations of study, including the investigation of endocrine changes related to electrical light exposures, such as the role of melatonin in sleep and wake cycles. Seasonal Affective Disorder is now an accepted consequence of seasonal lighting and climactic changes, and electrical light therapies are being actively investigated at major medical centers and by the National Aeronautics and Space Administration. Epidemiological studies at the University of California, San Diego, Harvard University, Brigham & Women's Hospital, and Harvard University Nursing Study have explored the relationship between disrupted light patterns and cancer risk.

Complex networks of physiological systems form the biological bases for these responses to light. Commonly known is the release of melatonin from centers in the brain that regulate sleep/activity cycles. Many other cycles and responses are affected, including vasoactive intestinal peptide (VIP), which affects blood pressure and growth hormone. Light also elicits release of serotonin, dopamine, and GABA in the brain, which are associated with motivation, muscle coordination, and focus. In addition, light is associated with increased levels of corticotropin releasing hormone (CRH), associated with stress, gastrin releasing peptide (GRP), related to hunger, and follicle stimulating hormone (FSH), related to reproduction. (For review, see Shanahan & Czeisler, 2000.)

Circadian Light

Circadian cycles can be modulated by a variety of external cues, but light is the primary variable that aligns (or entrains) humans to diurnal and nocturnal rhythms. Although decades of research have examined the influence of electrical lighting on circadian entrainment, it was not until 2001 that a new class of cells was discovered in the retina of the eye, thought to be "circadian" rather than visual receptors. This discovery renewed research that explored the spectrum, intensity, and duration of light that influences biological responses. Numerous studies have led to the development of "dose response curves" to electrical light, which reveal peak sensitivity in the blue wavelength (between 420-470nm) for modulations of melatonin suppression that regulates sleepiness. Bright white light has also been demonstrated to be effective in modulating mood, sleep, and activity cycles (Ancoli-Israel et al., 2003).

The range of spectra that influence the multiple circadian systems is yet to be explored fully. Although research has focused on short wavelengths in the blue range (420-470nm), a broader range of spectra is also associated with biological responses (Revell et al., 2006). Testing of red light has been uncommon, and many researchers have assumed that there is little to no effect of red light on the neuroendocrine or circadian systems. However, Hanifin and colleagues (2005) found that normal, healthy humans exposed to 630nm and 700 nm elicited small reductions of plasma melatonin levels. These findings are consistent with other studies that reveal the influence of a long wavelength light on cardiac responses (Schafter & Kratky, 2006).

Complexities also exist such that when a monochromatic light source with one primary spectrum is presented along with another spectrum, interaction effects occur leading to diminishedcircadian responses**.** Thus, Figueiro et al. (2005) demonstrated that melatonin suppression was influenced by polychromatic light even when the irradiance in the short wavelength (436nm) was equal to monochromatic light of the same wavelength. Veitch et al. (2006) noted that the claims made by those producing or selling "full-spectrum" lighting are largely unsubstantiated. It should be noted that "full spectrum florescent lighting" does not produce a continuous spectrum of wavelength power; instead it produces narrow spectral peaks across the range of light visible to the eye. Ongoing investigations are needed to more fully describe the range of spectra, intensities, and light durations most important to human circadian function.

The Pervasive Influence of Light on Health

Biological and medical literature reveals many biological functions, diseases, and disorders associated with lighting conditions. These are surveyed below. Several general categories of knowledge are evident. First, basic scientific research yielded evidence about physiological processes in animals that served as the basis for discovery about human biological responses to light. Recent discovery of a non-visual cell in the retina of the eye led to research that defined a "circadian" receptor that responds only to slowly changing light, and directly innervates the part of the brain that synchronizes circadian rhythms. Secondly, human studies evince the nature of circadian and circannual rhythms in normal subjects. These data reveal that cardiac rhythms, stress, endocrines, hormones, growth and aging, and developmental, cognitive, and emotional responses exhibit circadian patterns in normal individuals. Thirdly, the medical evidence base reveals diseases and disorders associated with disruption of circadian or circannual light conditions. For example, hypertension may be related to the disruption of normal diurnal conditions. Cancer risk may be associated with light induced disruption of melatonin production, which is implicated in the control of cancer growth. Emotional and behavioral disruption has been associated with seasonal lighting changes or climatic conditions where natural solar light is insufficient to maintain biological rhythms. Finally, therapeutic studies explore the use of electrical lighting to modulate circadian responses and ameliorate the consequences of circadian disruption.

A number of examples from human and medical literature are summarized in the text and in Table 4 below. It should be noted this table comprises a partial list. A search of a single database (PubMed MEDLINE) uncovered over 68,000 articles on chronobiology and over 37,000 papers specifically on humans. In order to apply these results using a scientific or evidence-based approach, critical analysis of these findings must include evaluation of the strength of evidence. The confounding influence of other environmental, individual, or methodological conditions must also be analyzed before global generalization or application of the findings.

Research Methodologies and Validity

A great number of the experiments reviewed were conducted in laboratories that carefully control conditions and systematically change only the light parameters. Such controlled study yields greater repeatability and reliability, and support greater understanding of the causal relationship between light and outcome (greater internal validity). For example, investigations that focused on suppression of sleepiness were conducted primarily at night, when the influence of light on melatonin is at its strongest. Although light is the principal circadian stimulus, other factors can influence rhythms, such as social sounds of traffic or people as they function within a typical work day, the smell of meals being prepared at typical meal times, and the change in temperature that occurs over the course of a day and night. Therefore, chronobiology laboratories are carefully constructed to exclude such variables.

However, if lighting solutions are to be useful in healthcare and other architectural environments, they must also have great “external validity.” That is, the performance characteristics of light that have been shown to be effective in a laboratory experiment must also be effective in real-world situations. The evidence base must also include research that defines the performance criteria of light that are effective both at day and during the night, looking beyond the influence of melatonin at night, to consider, in addition, many other hormones, biological, and functional systems that also respond to light. In summary, if research is to be broadly applicable, it must support lighting strategies that enable users to continue their work, routines, and schedules while obtaining appropriate light exposure.

TABLE 1:
The Pervasive Influence of Light on Health and Human Function

The categories below represent a partial list of human responses to light. Critical analysis of the research details provides the foundation for understanding the causal relationship between light and outcomes, and is required before the generalizations and applications are made.

- Stress, modulation of cortisol/ tress hormones
- Heart disease & hypertension

- Melatonin responses
- Sleep/activity/feeding cycles
- Cancer

- Basal metabolic rate, protein synthesis, and thyroid responses
- Growth
- Aging responses

- Hormone function
- Obstetric

- Neonatal responses
- Ophthalmic development and health
- Hyperbilirubinemia and kernicterus
- Long-term visual function in NICU graduates

- Gastro-intestinal conditions
- Diabetes

- Neural immune responses
- Inflammation and autoimmune disorders

- Brain development and function
- Ataxia, neuropathy

- Concentration
- Alertness
- Attention deficit disorder
- Working memory

- Psychological and psychiatric conditions
- Decreased memory, dementia
- Depression, emotional labiality
- Seasonal Affective Disorders

- Pain
- Perception and self-report of pain and pain management
- Medication rates relative to lighting dosage and length of stay

Survey of Evidence

Windows

Ulrich's seminal paper, which reported findings from a retrospective study of 46 patients recovering from abdominal surgery, revealed that patients with windows facing a view of trees had a shorter length of stay and better emotional well-being, and used less pain medication than patients with windows looking onto a brick wall. While this study was not designed to determine which parameters of daylight or view were of greater predictive value, several studies cited below suggest that access to light is important to health and well-being (Ulrich, 1984).

Circadian Rhythms and Health, Disease, and Disorders

Circadian cycles influence health and performance, including sensitivity to drugs and stimuli, hormone secretion, sleeping, feeding, and performance, suggesting that a change in circadian rhythm could mediate many clinical symptoms. The brain-pituitary-thyroid axis maintains a 24-hour thyroid functional cycle and is critical for basal metabolic rate, protein synthesis, brain development and function, sleep apnea, ataxia, neuropathy, insomnia, decreased memory, concentration, and neuropsychiatric syndromes (depression, attention deficit, emotional lability).

Pregnancy, Childbirth, and Lighting

The regulation of the immune system by estrogens is of particular importance during pregnancy, as it plays a role in suppression of maternal immune responses to prevent rejection of the fetus. Even transient hypothyroidism in pre-term infants is associated with an increased risk of cerebral palsy and impaired mental development, and the growth of newborns, infants, and adolescents is particularly responsive to the somatotropic system's control of metabolism and organ growth. Both GHRH and somatostatin are released in a 24-hour cycle and are strongly associated with slow-wave sleep (Squire, 2003, p. 1039).

Several clinical studies show an association between maternal stress and pre-term labor (Jansson & Holmdahl, 1998). The opportunity to reduce maternal stress or delay pre-term delivery by access to daylighting, or controlled electrical lighting that modifies circadian rhythms and associated hormonal fluctuations, warrants further investigation.

Mood and Seasonal Affective Disorders

A considerable number of studies have explored the use of lighting therapy to improve outcomes for patients with mental or seasonal affective disorders. A random controlled trail showed that bipolar patients in sunny rooms stayed an average of 3.67 days shorter than patients in dull rooms overlooking spaces in shadow (Benedetti et al., 2001). The absence of daylight in windowless hospital rooms is associated with negative effects on patient satisfaction and high rates of anxiety, depression, and delirium (Keep, 1997). Other studies support differential effects of morning versus evening light treatment and the effectiveness of electrical lighting parameters in treating patients with winter depression or Seasonal Affective Disorder (Glickman et al., 2006).

Pain

A randomized prospective study showed that perceived stress and pain were related to the intensity of sunlight in 89 patients undergoing elective cervical and lumbar spinal surgery. Post-operative exposure to sunlight in bright hospital rooms was 46% more intense (p=.005) than in dim rooms in the same hospital unit. Patients exposed to an increased intensity of sunlight experienced less perceived stress (p=.035), marginally less pain (p=.058), took 22% less analgesic medication per hour (p=.047), and had 21% less pain medication costs (p=.047) (Walch et al., 2005).

Circadian Regulation of Immune Responses

Autoimmune disorders, heart disease, and diabetes also have a circadian component, and disruption of circadian rhythms modulate growth, reproductive and endocrine systems, including those associated with aging and immune responses (Maestroni & Conti, 1996).

Cancer Risk

Of importance are studies indicating a relationship between nocturnal light, sleep duration, or night shift work and increased risks for cancer (Hansen, 2006). Stevens (2005) notes that the first speculation that light at night might increase risk of breast cancer in women was by Cohen et al. in 1987, and the relationship between shift work and increased risk was noted by Stevens et al. in 1992. Though causality remains elusive, empirical evidence increasingly supports the hypothesis that higher risk of breast cancer in industrialized countries is partly due to increased exposure to light at night. Continued, rigorous empirical inquiry into the clinical implications of lighting and health is highly warranted at this time (Jasser et al., 2006). Stevens and Rea (2001) suggest that electrical lighting standards, in comparison with sunlight, provide insufficient light quantity and quality during the day and too much lighting at night to replicate circadian stimuli. They suggest that electric lighting as currently employed contributes to "circadian disruption," and may be an important cause of "endocrine disruption," thereby contributing to health risks in industrialized societies.

The consequence of modern lighting conditions should also be considered in context with the lack of true darkness experienced in modern society. The circadian system is very sensitive to light at night, and in many settings or jobs some light may be present at all times (Figuerio et al., 2005). In addition, the level and spectrum of light experienced during the working day is unlikely to meet the physiological expectations of daylight conditions and may fail to entrain the body's responses. It could be said that industrial societies have been working under conditions of "inadequate" daylight in office spaces for over approximately 50 years, and have lit the night sky for at least the past 25 years.

Performance and Medical Error

Lighting levels have also been related to error rates and performance. A number of studies have examined the influence of environmental factors such as lighting, distractions, and interruptions on medical errors in dispensing medical prescriptions. A seasonal pattern of medication errors related to daylight and darkness hours was also reported in Alaska (Booker & Roseman, 1995). Results from the pharmacy study strongly suggest reduction of prescription-dispensing error rates with relatively high lighting levels. Medication dispensing error rates were significantly lower (2.6 percent) at an illumination level of 1,500 lux (highest level), compared to an error rate of 3.8 percent at 450 lux (Buchanan et al., 1999). The relationship between lighting and staff performance (Rajaratnam & Arendt, 2001), health, and satisfaction throughout hospital units should, therefore, be thoroughly investigated (McColl & Veitch, 2001).

EEG and Alertness

Light exerts acute alerting response as assessed by a reduction in the incidence of slow-eye movements, a reduction of electroencephalography (EEG) activity in the theta-alpha frequencies (power density in the 5-9 Hz range), as well as a reduction in self-reported sleepiness (Cajochen et al., 2000). Chapotot et al. (2000) demonstrated fronto-central EEG high frequency powers (22.5-44.5 Hz) decreased at the time of the midafternoon vigilance dip (14.00-17.00 h), along with slight concomitant increases in parietal alpha (7.5-13.5 Hz) and delta (1-3 Hz) powers. A slow ultradian rhythm with a 3-4 hour periodicity strongly modulated EEG power in all frequency bands between 1 and 44.5 Hz. The high frequency waking EEG may well reflect the activity of a brain arousal process underlying maintenance of the waking state, probably throughout the 24-hour cycle. Distinct circadian variations of EEG activity in the theta band and in the high-frequency alpha band may represent electrophysiological correlates of different aspects of the circadian rhythm in arousal.

Skene and Arendt (2006) and Revell et al. (2006) examined acute subjective alertness levels in response to three different short wavelength (blue) light pulses (420, 440 and 470 nm) and to 600 nm (red) light. Healthy male subjects (n=12) were exposed to a single 4-hour light pulse after 3 days in dim light. Subjective mood and alertness were assessed at 30-minute intervals during the light exposure, revealing a significant effect of duration of light exposure ($p<0.001$) on alertness, but no significant effect of subject. Compared to 470 nm light, alertness levels were significantly higher in 420 nm light and significantly lower in the 600 nm light ($p<0.05$). These data suggest that subjective alertness may be maximally sensitive to very short wavelength light (420 nm>470 nm>600 nm).

Cortisol, Alertness, and Light

Stress hormones, such as cortisol, also change rhythmically in a diurnal cycle, and have been shown to respond to light stimuli. Chapotot et al. (1998) describe a temporal coupling between cortisol release and central alertness, as reflected in the waking EEG beta activity. Bright white light presented in the early morning after enforced wakefulness induced an immediate elevation in cortisol and reduction in melatonin that was more effective than light presented in the afternoon.

The advent of independent component analysis of EEG responses, combined with recently developed, non-invasive measures of stress biomarkers, now offers a means to test the relationship of hypothalamo-pituitary-adrenal axis activity as it is related to the alertness level during wakefulness, and the inter-relationship with cognition and heath.

Cardiac Responses

It has been demonstrated that even brief exposure to changes in lighting influences heart function, a sensitive indicator of stress and health risk (Schafer & Kratky, 2006; Thayer et al., 2006). For example, Thayer and colleagues (2006) recently demonstrated that physical features of workplace environments, including electrical and day lighting changes, were associated with modulation of day/night differences in heart rate variability. Heart rate variability (HRV) is strongly associated with health and mortality (see Thayer & Lane, 2007). Interestingly, heart rate variability indicates flexibility in the brain's control of the heart, and broadly reflects cognitive and behavioral flexibility. For instance, individuals with certain psychiatric disorders also exhibit low HRV (Thayer & Lane, 2000). HRV is also associated with control of attention and self-regulation of behavior (Thayer & Friedman, 1998). Finally, several studies have indicated that HRV is significantly reduced during sustained attention or vigilance (Hansen et al., 2003, 2004). Schafer and Kratky (2006) demonstrated heart rate variability changes occurred within 10–15 minutes of colored fluorescent illumination in a light on /darkness protocol.

Lighting as an Environmental Stressor

Of particular interest is evidence that stress levels are responsive to light conditions. Stress is an important health risk indictor and of great importance to patients whose health is already compromised. The association between stress, cardiac, and healing (immune and inflammatory) responses is now well documented (Sternberg, 2003). Indeed, the influence of stress on health is also of great importance to all users of all architectural environments, including the medical team attending to patients and clergy ministering to those in crisis, as well as office, education, and factory workers. Residential and hospitality architects respond by striving to create stress-free environments.

The exact relationship between stress, attention, and lighting conditions remains to be explored, and forms the basis for the Latrobe experiment. Many studies show that stress responses change rhythmically with diurnal modulation, and yet our built environments provide constant, non-cycled light settings. The relationship between light and health outcomes is most important in healthcare environments, where the association between stress and healing is of vital concern.

Circadian Lighting

Based on some of the evidence cited above, it has been suggested that the introduction of brief "light showers" might provide a means to modulate circadian responses (Figuero et al., 2006). Such solutions will be particularly useful in built environments where the climate or architectural configuration limits access to adequate natural circadian lighting (e.g., compass orientation, interior spaces, etc.). A number of studies conducted in real-world situations show that brief exposure to individual lighting devices can assist in modulating sleep patterns and behavior (Ancoli-Israel et al., 2003).

The Latrobe Laboratory Experiment: Results

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Experimental Design

In keeping with the trans-disciplinary, evidence-based model outlined in the Latrobe Fellowship proposal, the Latrobe Laboratory Experiment was designed to be relevant to a broad range of architectural settings and users. Further, the study was designed to use rigorous scientific methods and physiological techniques that objectively measure human physiological and cognitive responses. A further goal was to provide original evidence that might assist in the development of lighting strategies within built settings.

To meet these goals, a laboratory experiment was designed, based on the literature, to test the hypothesis that brief "light showers" might influence stress, fatigue, and cognitive function. Electrical lighting solutions were investigated, given that adequate solar lighting is not accessible in all geographic locations or architectural sites, and, in any event. is not available for night staff. The outcome of this research is relevant to all people, in all architectural environments, whether they be patients, office workers, or other users or providers, since it addresses universal human needs to regulate biological and behavioral responses to light.

Multi-Site Study
A multi-center study was conducted, utilizing the unique expertise of each center to study the influence of light on mind and body. The specific objective of the study conducted at the Department of Psychology, Ohio State University, was to consider the influence of light on heart rate variability. Testing took place during the spring and during daylight hours. A parallel study was conducted at the Swartz Center for Computational Neuroscience, University of California, San Diego, to assess the influence on cognitive responses measured via electroencephalography (EEG) and independent component analysis of the brain waves (Makeig et al., 2007). Testing took place during spring and during night hours. Controlled laboratory conditions were used to minimize external light and sound. With the door closed and lights turned off, both rooms had light levels less than 15 lux during the day and night.

Light Stimuli

Both laboratories used two separate LED light sources (Lightbook), one emitting light with peak spectra at 600 nm ("red light") and the other emitting "bright white light" with a peak in the blue range. Light intensity was recorded by a spectral radiometer (Daysimeter, RPI, Troy, NY). Both red and bright light levels were well below damaging levels (i.e., outdoor sunlight reaches approximately 100,000 lux).

Light sources were positioned on a small table approximately 20 inches in front of the subject, and angled upward 45 degrees in the vertical plane and towards the subject's head at 45 degrees in the horizontal plane. The bright light was on the subject's left and the red light on the subject's right. Lights were turned on and off by the experimenter in an adjacent room. Subjects responded to tasks via keystrokes on a computer keyboard (Figure 1).

Figure 1. Physical Set-up of the Experiment

Legend: Separate portable LED light sources produced red with a wavelength and bright light ***[with?]*** *a wavelength, with a peak in the blue range*

Procedure

Four different lighting conditions were presented in a controlled laboratory test room: 1) florescent lighting, 2) darkness, 3) bright white light with a peak in the blue spectrum, and 4) red light. Recording began during a baseline period in florescent light of 5-15 minutes. Thereafter, 15 minutes in darkness allowed for dark adaptation, followed by the first light condition (bright or red) for 15 minutes. A second period of darkness (15 minutes) followed, and then the second light condition (red or bright) was presented. The total length of time was approximately 75 minutes. Psycho-physiological measures included a mood survey, a 2-back working memory task (OSU) or a driving simulation fatigue task (UCSD), and electrophysiological measurements of cardiac (OSU) or brain wave (UCSD) responses. Heart rate variability or EEG was recorded continuously throughout the experiment.

Subjects and Inclusion Criteria

Heart rate responses were studied in a group of students at Ohio State University, and electrophysiology was studied in a group of students from the NewSchool of Architecture & Design, San Diego, and testing took place at the University of California, San Diego. All volunteers who consented to study according to the institutional subjects were at least 18 years of age and reported no hearing dysfunction, color-blindness, low vision or cardiac dysfunction. Subjects were non-smokers and abstained from drugs, alcohol, and caffeine 24 hours prior to the experiment. These criteria are established because of the complicating effects nicotine, caffeine and alcohol have on cardiorespiratory physiology.

The Effects of Light on Heart Rate Responses

Objective

The experiments examined changes in cardiodynamics in response to two different light conditions: red and bright light. Heart rate variability was selected as a measure because it can be readily recorded in operational environments without interfering with people's activities or rest. As such, the experiment would provide a proof of principle that cardiac monitoring could become a useful addition to an architect's tool kit. Based on circadian literature, we predicted that the bright light would keep subjects in an aroused state and would be associated with an overall reduction in heart rate variability. More importantly, we looked for a change in heart rate and variability pattern that would indicate a *situationally-appropriate* response: that is, diminished variability and faster inter-beat-intervals when the subject was engaged during the memory task but not while sitting still. We looked for a difference in responses during the red light condition versus the bright light condition, again because of the arousal-inducing properties of the bright light.

Participants

Sixteen Ohio State University undergraduates (8 female, 8 male) participated in partial fulfillment of an option for course credit in an introductory course in psychology. All participants were non-smokers, were drug-free, and were asked to avoid both alcohol and caffeine in the 24 hours prior to participation.

Time Periods
After a 15-minute dark adaptation (ambient light less than 15 lux), either the red or bright light was turned on. The order of light conditions was counterbalanced across subjects: approximately half (*n*=7) received the bright light first, and the othersf (*n*=9) the red light first**.** After sitting quietly for 6 minutes with the light on, subjects performed a 4-minute cognitive task (auditory 2-back working memory task) that had been previously shown to reduce heart rate variability (Hansen et al., 2003, 2004). Having completing the task, subjects sat for 5 minutes in a recovery period. After another 15-minute period in the dark, the alternate light was turned on and the process repeated. The duration of the experiment was approximately 75 minutes.

Working Memory Task
During the auditory 2-back task subjects identified a "target" consonant if it was heard two constants previously. Subjects pressed one key on the computer for targets, and a different key for "non-targets."

Cardiography
Impedance cardiography provides especially sensitive indices of the activity of the heart in real time. The physiological recording technology is widely used in psychophysiology labs across the country. Electrodes were placed at seven sites on the torso. Data were analyzed using the suite of MindWare Technologies Signal Processing Applications.

Data Analysis
From each subject, seven time windows of data were analyzed: the "light on," "task," and "recovery" periods of both light conditions (red, bright), as well as the initial baseline in fluorescent light. HRV was analyzed in the frequency domain using a fast Fourier transform of the inter-beat interval series. The IBI series was subjected to a Hamming window for high frequency (HF) power. MindWare's automatic outlier-detection algorithm highlighted potential noise, which was manually removed and replaced as appropriate. Within each measure, a subject's baseline levels were then subtracted from the remaining values, creating reactivity scores to control for individual differences.

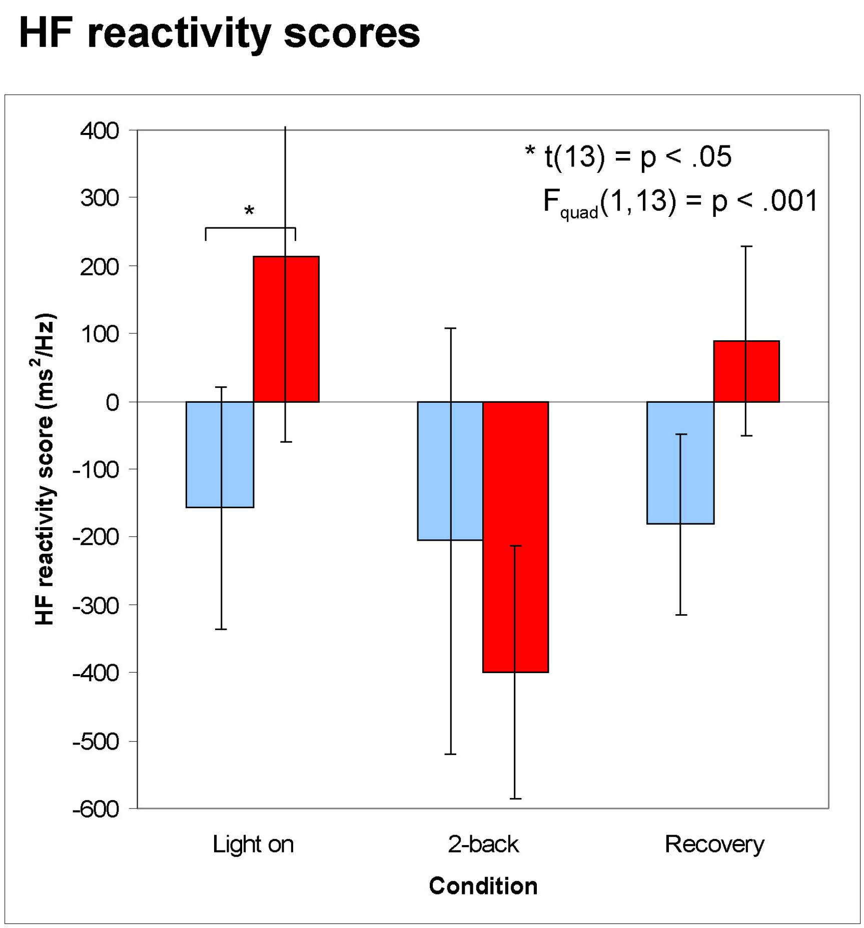
Statistical Analysis
Both high-frequency heart rate variability (HF-HRV) power and IBI change scores were analyzed using a (2×3) repeated-measures analysis of variance (ANOVA), with Light Condition (red, bright) and Period (Light on, Task, Recovery) as factors. The squared correlation ratio statistic (η^2) is reported, which is the proportion of variance uniquely explained by a specific effect (Keppel & Wickens, 2004). Because of this, η^2 values are more intuitively meaningful that F and p values, with the added benefit of providing a more "practical" indication of the importance of an effect.

Results

Figure 2 plots high frequency heart rate variability in terms of power reactivity as a function of Light Condition and Time Period. The higher the HF power reactivity, the larger the parasympathetic influence on the heart. Figure 4 plots inter-beat-interval reactivity as a function of Light Condition and Time Period. The higher the IBI reactivity, the slower the heart rate, again indicating greater parasympathetic activity.

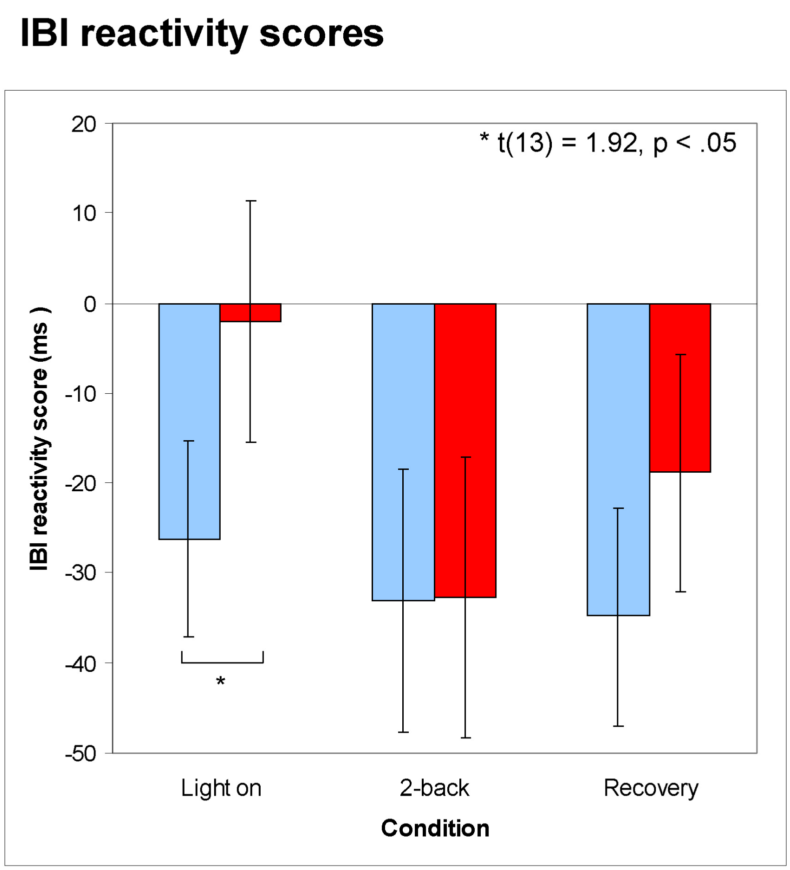
By visual inspection, differences between responses in red light during rest versus the working memory task are clear. During bright light, a constant level of heart rate and inter-beat-interval reactivity is observed. Using a planned comparison on each ANOVA, a significant quadratic trend was present in the Red Light condition in both the HF-HRV power reactivity and IBI reactivity. By contrast, quadratic trends were absent in the Bright Light condition in both measures. Effects for Period, Light Condition, and their interaction were not significant in the HF-HRV reactivity (ANOVA 3). While the latter two effects were significant in the IBI reactivity ANOVA, they still had had η^2s < .03 (Figure 3).

Figure 2. High Frequency Heart Rate Reactivity as a Function of Light Condition and Period.



Legend: Heart rate variability during red light exposure was situationally appropriate, showing significantly greater in baseline and recovery periods than during bright light, and during the working memory task. Bars indicate ±1 standard error of the mean.

Figure 3. Inter-beat Interval Reactivity as a Function of Light Condition and Period.



Legend: Inter-beat interval reactivity also revealed a significant difference between cardiac responses in red and bright light and displayed a similar pattern of situationally appropriate activation during working memory in red light. Bars indicate ±1 standard error of the mean.

The Effects of Light on Brain Wave Electroencephalography (EEG)

Participants
Six right-handed adults (3 female and 3 male students from the NewSchool of Architecture & Design) with normal or corrected normal vision provided informed consent to participate in this study. Two subjects completed a self-controlled study of EEG as well as fatigue responses. Subjects arrived in the late afternoon or evening, sat on an office chair with armrests in front of a 19-inch CRT monitor, and performed a computerized driving task that evaluates fatigue. Subjects reported variability in their fatigue levels before starting the experiment. All reported that they had avoided caffeine for 24 hours before testing.

Methods
Brainwaves were non-invasively recorded using 256 electrode electroencephalography (EEG) surface sensors in an elastic cap placed on the head. The lighting protocols and procedures were the same as noted above. Bright white light with a blue peak and red LED panels were installed on the left and right sides, respectively, in front of the subject (Fig. 4). Lighting conditions were altered every 15 minutes in the following order: Florescent → Dark → Red → Dark → Bright → Dark → Florescent. In one group, the order was reversed, with subjects receiving bright light before the red light.

During each light condition, subjects continuously performed an automated driving task that has been shown to effectively track drowsiness responses in terms of reaction time and brain wave response. Independent component analysis techniques, developed and validated at UCSD, were used to extract Theta and Alpha wave activity in the occipital (visual) and somatomotor (body movement) regions of the brain. Driving error was measured by absolute deviation from the previous cruising position, but not by the absolute distance from lane center. Single trials and their corresponding EEG epochs were then sorted by this error measure, which also correlated linearly with reaction time, the interval between deviation onset and response onset. Lower error or shorter reaction time generally indicated that the subject was alert, while higher error and longer reaction time indicated loss of vigilance or fatigue.

EEG Data Acquisition
256-channel EEG/EOG/EKG signals were recorded at 256 Hz using a BioSemi system from two subjects, 070404ZC and 070405EF. The subjects' responses and driving trajectory were also recorded in-sync with the EEG acquisition system. Maximally independent EEG processes and their dipole source locations were obtained using the EEGLAB toolbox. ICA finds an "unmixing" matrix, *W*, which decomposes or linearly unmixes the multichannel EEG data.

Independent Component Analysis (ICA)

Maximally independent EEG processes and their dipole source locations were obtained using the extended-infomax option of runica algorithm from the EEGLAB toolbox. ICA finds an "unmixing" matrix, *W*, which decomposes or linearly unmixes the multichannel EEG data, *x*, into a sum of maximally temporally independent and spatially fixed components *u*, where $u=Wx$. The rows of the output data matrix, *u*, are time courses of activations of the independent components. The ICA unmixing matrix was trained separately for each session and subject. Initial learning rate was 10^{-4}; training was stopped when learning rate fell below 10^{-7}. To speed up the training processes, the 232-channel dataset [070405EF] was reduced to 100 dimensions using principal component analysis (PCA) before the training of ICA unmixing matrix. 100 independent components were obtained, and some of them were identified as accounting for blinks, other eye movements, or muscle artifacts. Several non-artifact components showed event-related dynamics in various frequency bands that were time-locked to different phases of the drift events. Time-frequency analysis of brain dynamics for a visual component with equivalent dipole sources located in lateral occipital cortex and somatomotor cortex were analyzed under different lighting conditions.

Event-Related Spectral Perturbations (ERSPs)

Time series in each epoch *k* were transformed into time-frequency matrix $F_k(f,t)$ using a 1-s moving-window fast Fourier transforms (FFTs). Log power spectra were estimated at 100 linear-spaced frequencies from 0.5 Hz to 50 Hz, and then were normalized by subtracting the log mean power spectrum in the baseline (pre-deviation) periods for each group (lighting condition) of epochs. Event-related spectral perturbation (ERSP) images were obtained by averaging *n* time-frequency matrices of epochs under the same lighting condition, using:

$$ERSP(f,t) = \frac{1}{n}\sum_{k=1}^{n}\left|F_k(f,t)\right|^2 \qquad (1)$$

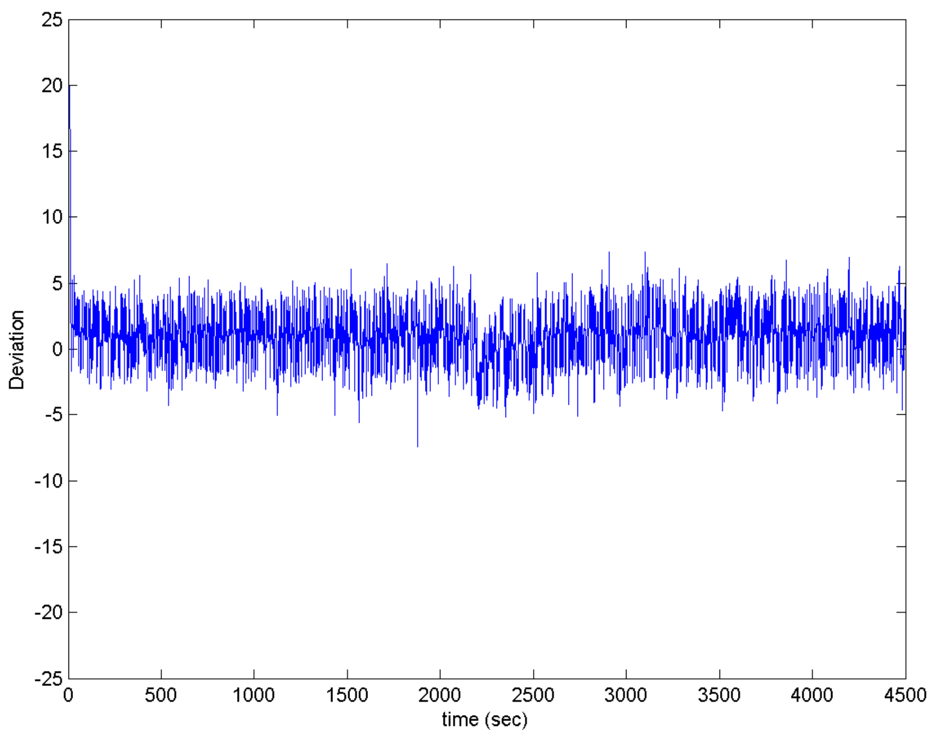
ERSP images were constructed to show potentially significant spectral perturbations (log power differences) from the mean power spectral baseline ($p < 0.01$, not corrected for multiple comparisons). Significance of deviations from power spectral baseline was assessed using a surrogate data permutation method. In the resulting ERSP images, non-significant time/frequency points were colored green.

Analysis of Performance

In total, five subjects maintained baseline levels of alertness. The subject who arrived reporting extreme fatigue did not maintain starting alertness levels.

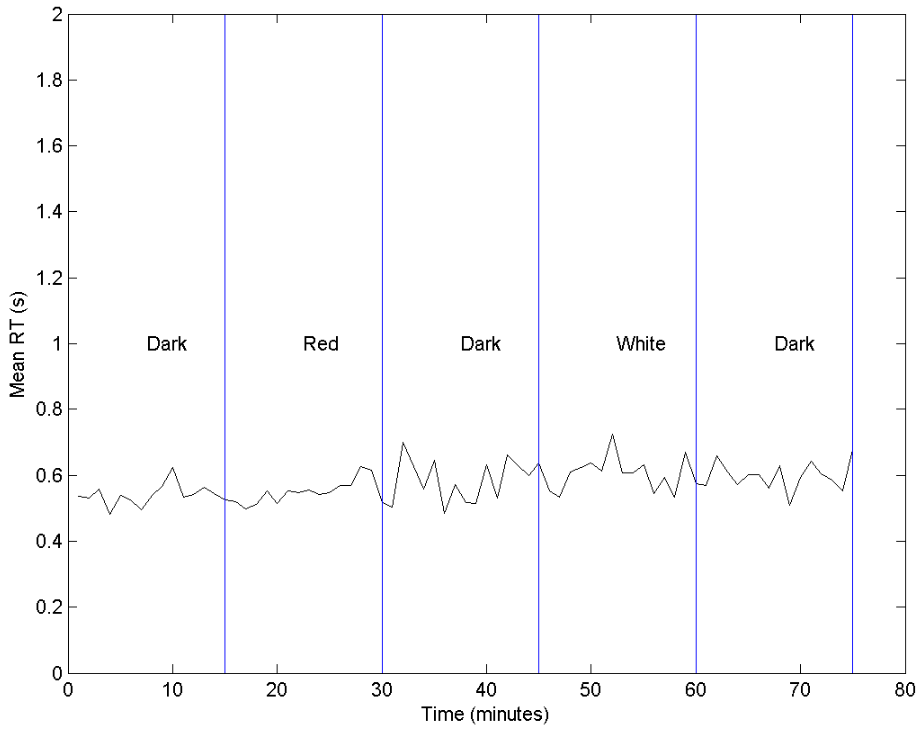
The figures below show little change in vehicle trajectory over the 75 minute session. This subject reported feeling alert at the beginning and at the end of the experiment. During a 75-minute session [Subject 070405EF], 1108 drifting events (trials) occurred (Figs. 4, 5). This subject was nearly alert during the entire session.

Figure 4. Maintenance of Alertness



Legend: Trajectory in a 75-min (4500 s) session [070405EF].

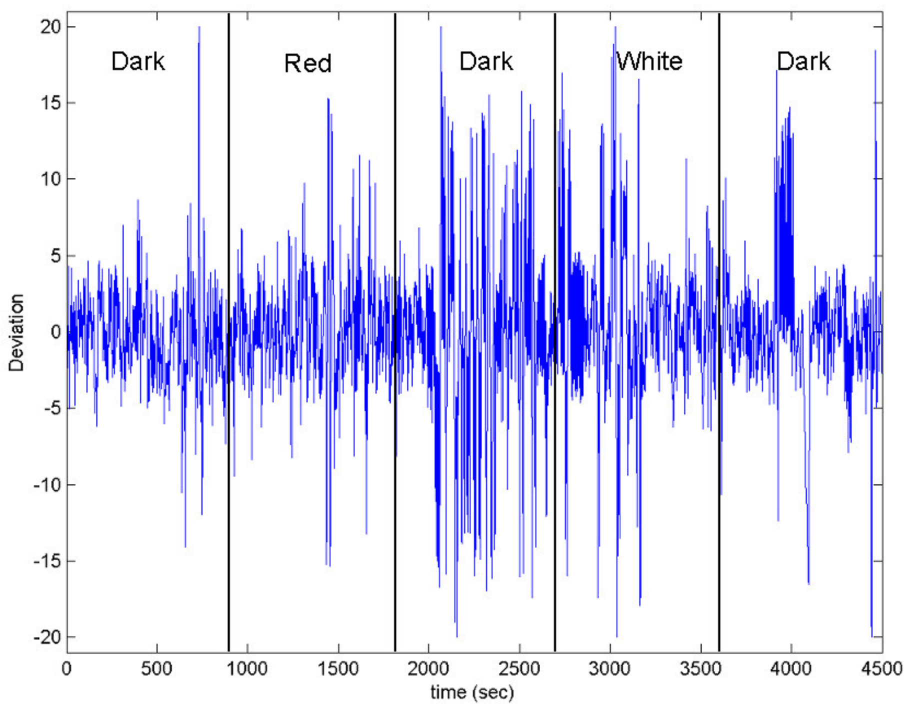
Figure 5. Mean Reaction Time (Per Minute) under Different Lighting Conditions



Legend: Reaction time remained roughly similar throughout the 75 minute session [070405EF].

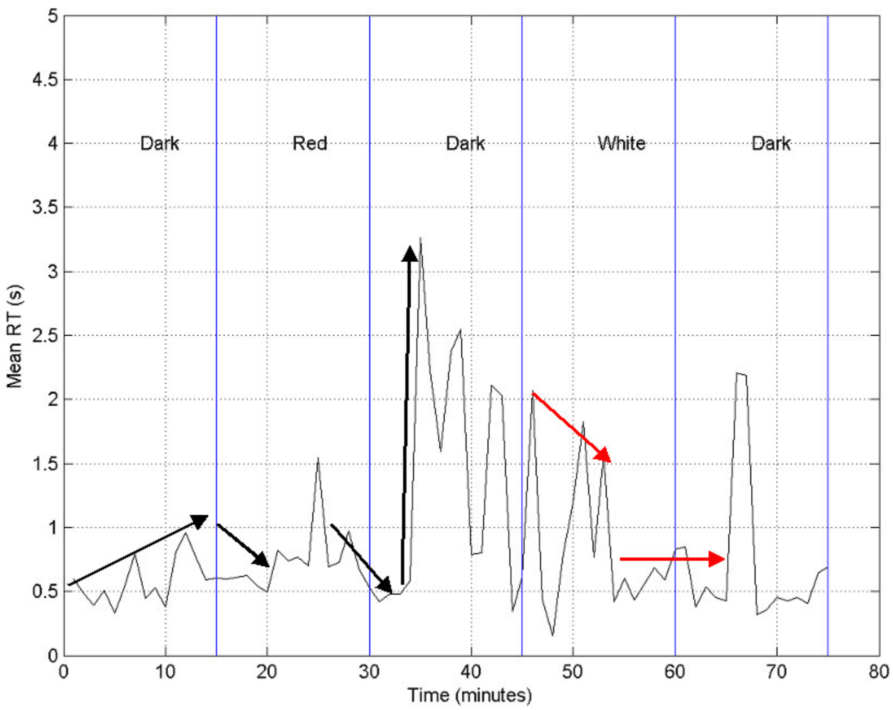
In another subject, [070417TT], 1009 drifting events (trials) occurred (Figs. 6, 7). The vehicle trajectory indicated that subject TT became drowsy and hit the curb or drove into the opposite lane several times. Fig. 6 shows that the performance changed in different lighting conditions. Errors increased intermittently during red light, but reached and maintained at high levels in the second dark condition. In the subsequent bright light condition, errors increased, and then decreased to baseline levels after brief exposure to bright light. Interestingly, in the final dark period that occurred after the bright light exposure, a brief period of increased error occurred but did not persist, even though it was the final episode in a lengthy experiment conducted at night after a full day of work.

Figure 6. Fatigue and Loss of Alertness



Legend: Trajectory in a 75-minute (4500 s) session [070417TT].

Figure 7. Time Course of Mean Reaction Time (per Minute) under Different Lighting Conditions



Legend: Changes in alertness during different lighting conditions [070417TT].

Analysis of EEG Responses

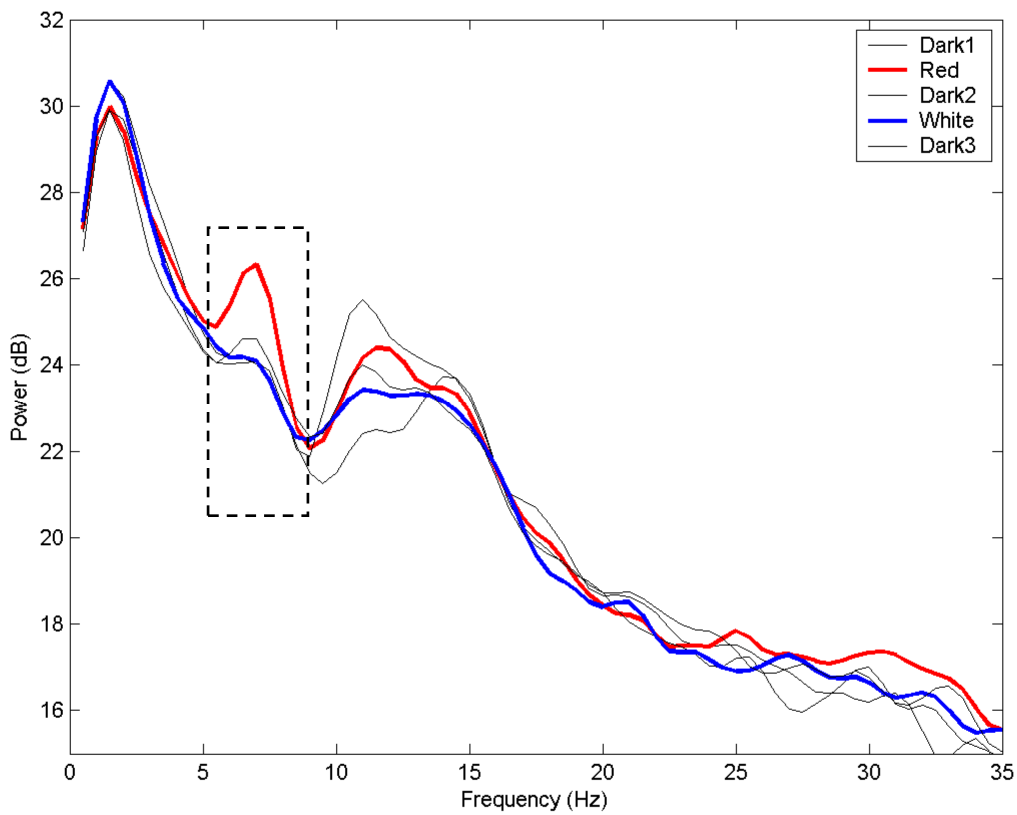
Baseline power spectra under different lighting conditions
In total, the representative training dataset [070405EF] contains 232 channels of 872 (out of 1108) by 6-s epochs of clean EEG data. Figs. 8 and 9 show averaged power spectra of epochs under different lighting conditions in a lateral occipital (visual) component and in a somatomotor (body movement) component, respectively.

Phasic Brain Dynamics
Brain dynamics at a small time scale (~1 s) were also observed. Alpha brainwave power was suppressed briefly after deviation onset, then increased strongly (~10 dB) just before the subject released the key. This transient (1.5-3 s) alpha rebound activity was consistently observed during all single events, regardless of lighting conditions.

The latency of alpha rebound was linearly correlated with reaction time (first response onset) in the first four groups. During high-error periods (80-100%), a prolonged suppression in alpha power was observed before response onset, followed by an alpha rebound that lasted for a few seconds (not shown).

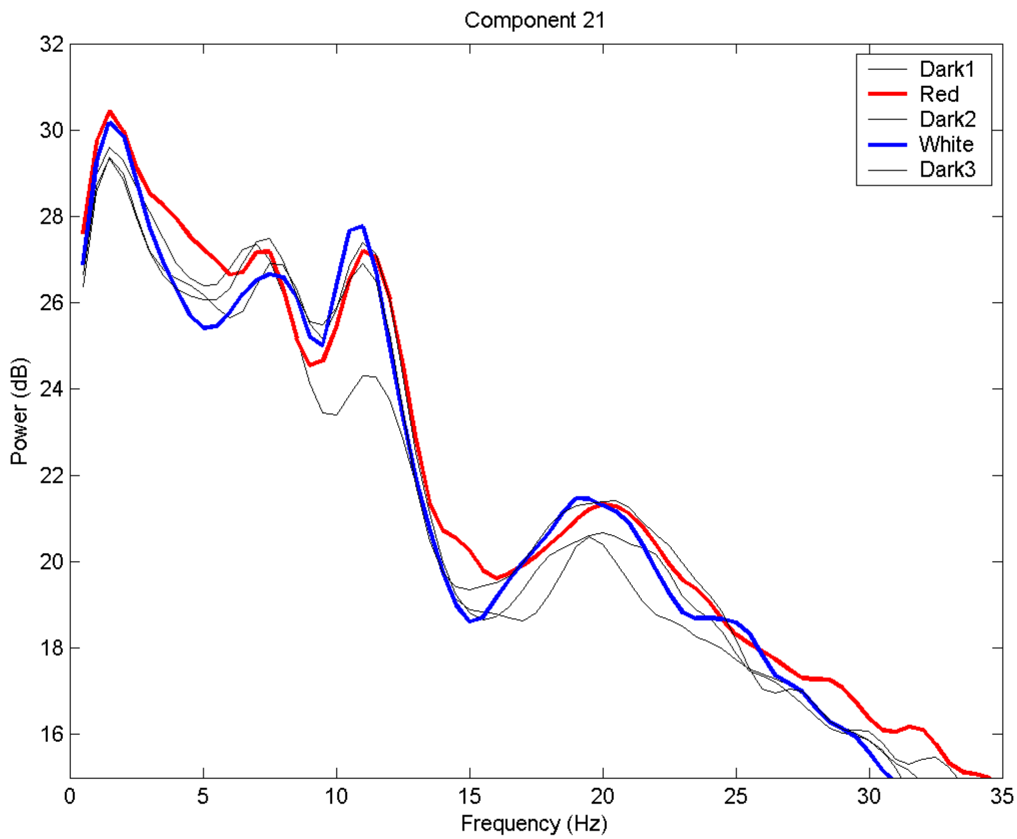
Subject EF [070405EF] did not show behavioral fluctuations in alertness levels under different lighting conditions. However, the power spectrum baseline showed increased theta brainwave activity in the lateral occipital component under “red-light” condition, relative to bright light and dark light conditions (Fig. 8). Figure 9 shows that theta and alpha waves vary little during different light conditions (red, bright, and darkness).

Figure 8. Power Spectrum Baselines of a Lateral Occipital Component under Different Lighting Conditions.



Legend: The dashed lines indicate theta band brain wave power. Theta power during red light (red line) was greater than during bright (blue line) or dark (gray lines) lighting conditions [070405EF].

Figure 9. Power Spectrum Baselines of a Left Somatomotor Component under Different Lighting Conditions



Legend: Alpha and theta brainwaves from the somatomotor component are similar during all light conditions (red, bright, and darkness [070405EF].

Interpretation of Results

Recently, Jung et al. (SFN Abstract, 2007) reported EEG dynamics during the transition from alertness to drowsiness during the same driving experiments, but in a realistic dynamic virtual-reality (VR) based driving environment that comprises a 360° VR highway scene and a driving simulator on a 6 degree-of-freedom motion platform. Fifteen healthy subjects (ages 18-28 years old) participated in comparable, 1-hour, lane-keeping driving tasks while their 33-channel EEG/EOG signals and driving behavior were simultaneously sampled and recorded at 256 Hz. EEG data, after artifact removal, were processed by independent component analysis (ICA) and time-frequency analysis to assess EEG correlates of cognitive-state changes. In their study, an independent component with equivalent dipole sources located bilaterally in lateral occipital cortex exhibited monotonic alpha-band (8-12 Hz) power increase during the transition from alertness to slight drowsiness, but monotonic decrease during the transition from slight to extreme drowsiness. On the other hand, the theta-band (4-7 Hz) power of the component increased monotonically during the transition from alertness to slight and extreme drowsiness.

Makeig and Jung (1995) observed pre-stimulus increase in theta-band EEG prior to lapses in an auditor target detection task. Their study confirmed and further quantified early reports (e.g., Davis et al., 1937), most notably a 1962 study by Williams et al. in which this phenomenon was seen in EEG tracings of some subjects after 30 hours of sleep deprivation. Beatty et al. (1974) also reported "detection efficiency of human observers deteriorates rapidly in monotonous monitoring tasks; this effect (the vigilance decrement) has been associated with increased theta band activity in the electroencephalogram."

Conclusions

Based on the analyses of heart rate reactivity, we can state that even brief exposure to light can modulate typically observed patterns of physiological change. The response pattern in red light is consistent with flexibility in adapting to challenges and changes in the environment, and with an ability to conserve energy resources. In red light, higher heart rate reactivity scores during the "light on" and "recovery" periods reflect relaxation, while reduced reactivity during the memory "task" is considered "situationally-appropriate" activation. This is consistent with literature that shows decreased parasympathetic nervous system (PNS) activity when attention and working memory are engaged, and increased PNS activity once the task is complete and subjects are free to relax.

In contrast to red light conditions, the constant levels of reactivity observed in the bright white conditions reflect constant attentional changes. This suggests that activation or arousal are maintained during the brief bright light exposure, with no drop in parasympathetic nervous activity during the memory task.

An interesting response was observed in the subject who completed a self-control study during dark, red, and bright light conditions. This subject (EF) did not display any signs of drowsiness in reaction time analysis in any of the light conditions. However, in red light he produced greater power in the theta band of brain waves. In contrast, he did not expend greater power in the theta band in order to maintain his reaction time during bright light or in darkness. In all light conditions, darkness, red and bright light, alpha waves were of roughly similar power. Additional experiments must be conducted in order to confirm or interpret these findings.

Klimesch (1999) found that "after sustained wakefulness and during the transition from waking to sleeping when the ability to respond to external stimuli ceases, upper alpha power decreases, whereas theta increases." In our results, we did not find any significant difference in task performance under different lighting conditions. However, the theta power was considerably higher when the subject was exposed to the red light. It remains to be seen if the increased theta activity was caused by drowsiness. We suggest increasing the difficulty or complexity level of our sustained-attention task to better understand the nature of the observed theta power increase.

Discussion

The Latrobe Laboratory Experiment tested light through the extremes of the visible range: short wavelength blue light with bright light known to stimulate melatonin pathways, and long wavelength red light that was demonstrated to influence cardiac responses. Whereas melatonin and other endocrine systems were not measured in these experiments, it is interesting to speculate that different physiological pathways might come into play in dark conditions versus bright conditions, and at the extremes of the visible spectrum relative to cardiac or melatonin responses. Further study will reveal such associations.

Evidence-Based Design Implications

While great complexity exists in the relationship between light and outcomes that is yet to be completely described, a strong evidence base exists suggesting that design solutions can be developed that are likely to yield significant outcomes. By using an evidence-based design approach similar to that described by the evidence-based medicine movement, careful selection of the strongest and most compelling evidence can focus design efforts on the most reliable data.

In general, it can be stated that, to date, strong, valid evidence demonstrates the influence of light on sleep/activity. Compelling evidence suggests a relationship between the lack of light/dark cycles and health risk in night shift workers. A substantial amount of evidence suggests daylight has a positive influence on health and behavior. Indeed, diurnal light changes are the natural state for all humans. By identifying the exact qualities of light associated with such changes, we predict that designs replicating those qualities will have significant influence on outcomes.

The original findings from the Latrobe Laboratory Experiment and other studies demonstrate that even brief exposure to light during the day is associated with heart rate changes that are sensitive to health risk. In addition to increased and maintained alertness levels with bright light, appropriate reactive levels were observed in heart responses during red light. This evidence has important implications for the choice of lighting in architectural design and healthcare facilities, where levels of illumination are implicated as stressors related to increased health risk and implicated in functional levels associated with performance error.

Principles

While research continues that will confirm and enhance our understanding of the influence of light, generalizations from the preponderance of literature can be summarized as design concepts below.

Exterior Conditions
Scientific data reveals that the built exposure to exterior conditions or climates may not provide enough light for circadian stimulation, or may provide more light than is needed to drive circadian rhythms. If an external site does not provide sufficient natural light, window design alone cannot be used to specify the amount of light that will enter a space.

Interior Conditions
Since interior materials and furnishings interact with incoming light, a complex relationship exists between window dimension, orientation, distance from the eye, and the spectrum and intensity of light exposure.

Individual Exposure
Since many facilities continue operations at night, electrical sources for circadian stimulation should be considered for those working night shifts. The latter point highlights an important consideration in circadian lighting design. In the past, lighting has been measured at the level of the lamp emitting light or the desktop. Such static measures are relevant only if a person sits at the same location all day and does not receive solar light from the exterior.

Temporal Pattern
An individual's exposure to light in a building is determined by the time spent in each place. The use of mobile light measurement devices is now able to reveal the actual light patterns of our industrial lifestyle, which has heretofore been rarely considered in architectural design. Epidemiological evidence and laboratory research suggest that the pattern of light/dark exposure over days is very important to biological, behavioral, and health responses.

Circadian Responses
While there is a significant body of evidence that demonstrates that electrical light sources can be used to drive many circadian responses, it cannot be said that a single electrical light condition can replace solar light as a means to stimulate all circadian effects. Many human systems respond to circadian and seasonal lighting changes. Only a few aspects are well understood, and more research is clearly required. Nonetheless, we can form some general design hypotheses based on current findings that are expressed below.

Benefits
It is expected that human function, performance, biological, medical, and mood responses will change subject to lighting conditions. This is not to say that the simple response of creating more light or more windows will suffice. Architectural and electrical lighting must be designed for users, their function, and their environment over time.

Estimating and Measuring Light
Several computer rendering programs are available to model the lighting distribution that an architectural opening might provide. Such analysis can take into account the latitude, longitude, and compass orientation of windows, and demonstrate the differential

influence of a building's position on a site. The climactic and seasonal external light levels can be accessed via national databases. However, the interior light will be determined by local site conditions and adjacencies.

In addition, actual light levels may vary from such estimates due to window location, obstructions, shades, or materials. The spectrum of light will change as a function of the material through which it passes and the finishes that absorb and reflect light. Furnishing may provide interior obstructions to light, and light levels will diminish with distance from the light source or opening. Radiometers and photometers that measure actual light levels should examine light distribution at each site occupied, and at the level of the eye (seated, standing, in a patient bed). Mobile loggers can be used to track light exposure over time for individual movement and exposure patterns. The collection date from existing conditions and post-occupancy conditions will provide user-specific information about the influence of environmental features and materials in specific functional environments.

Table 2
Circadian Lighting Design Principles

1. Daylight is the primary environmental feature that modulates circadian responses that influence health and function.

2. Light/dark patterns (diurnal/nocturnal lighting) are important for establishing and maintaining circadian rhythms.

3. Site, climate, architectural and interior features determine if adequate circadian light will reach each user. The presence or dimensions of windows alone do not guarantee adequacy of circadian lighting.

4. The users and functions within buildings determine circadian lighting needs. The time spent by an individual in a space is the greatest determinant of circadian lighting needs. (Total time an individual spends in a space, and time of day in that space.)

5. Electrical light with specific quantities and qualities modulates specific circadian responses. Different spectral qualities have different effective levels. Different circadian rhythms respond differentially to spectrum and intensity.

6. The "circadian" effectiveness of light is related to the combination of its spectrum, intensity, distribution, duration, pattern (on-off), and time of day.

7. The quality and quantity of light arriving at the eye is the key measure for calculating circadian stimulation, and can differ significantly in spectrum and intensity from measures of light emitted from lamps or incident on horizontal (desktop) or vertical (wall) surfaces.

8. The ultimate quality and quantity of light arriving at the eye results from the interaction of all light sources and all materials that may alter light's reflection, refraction, absorption, and distribution.

9. Typical photometers minimize calculations of light intensity in the short and long wavelengths known to be effective in modulating circadian responses.

10. Many climates do not provide adequate daylight across all seasons for circadian stimulation. The compass orientation of architectural openings will influence the amount of diurnal light entering the building. Exterior site conditions or built structures may significantly influence access to diurnal light. Exterior lighting may be sufficient to disrupt nocturnal darkness needs.

Table 3
Summary of Circadian Lighting Qualities

1. Daylight provides a broad spectrum of light, with roughly equal power across the visible range. The power and spectra change rapidly throughout the day with climactic changes induced by clouds, dust, precipitation, and interaction with environmental features, such as large bodies of water and expanses of natural or built landscape.

2. Short wavelength blue light (420-470nm) is highly effective at modulating melatonin levels associated with sleep and activity/arousal responses, and appears to require lower intensities and less time to modulate melatonin than broader light spectra (e.g., 30 lux).

3. The influence on melatonin saturates, or reaches a maximum, so that increased light intensity beyond a certain level is not associated with greater melatonin modulation. Melatonin suppression by light is effective at night, and depends on the subject's history of exposure to a light/dark cycle.

4. Bright white light is effective at modulating melatonin and sleep, activity and behavior. Bright white light treatment in the morning or the evening has been used to shift sleep and activity patterns. In general, greater intensity of bright white light is required than blue light to be equally effective.

5. The Latrobe Laboratory Experiment study demonstrated that brief exposure over 15 minutes to bright white light with a peak in the short blue wavelength was associated with constant heart rate activation (reduced reactivity). These findings suggest that light exposure, even during the day, may influence cardiac responses. Brief and moderate changes in heart reactivity are not necessarily problematic. Further studies are required to determine if these short-term effects persist over longer exposures, or are associated with chronic cardiac stress.

6. Red light over a brief, 15-minute exposure was shown in the Latrobe Laboratory Experiment to influence heart rate in a situationally appropriate manner, enabling a relaxed state (increased reactivity) during baseline and resting conditions and an activated state (decreased reactivity) during working memory. Further studies are required to observe user responses to this lighting condition in operational environments.

7. Typical "full spectrum florescent" lights produce multiple spectral peaks at higher intensities across the visible spectrum, superimposed on a lower intensity broad spectral band. Several studies suggest that the claims supporting the therapeutic value of full spectrum lighting require further study to substantiate.

8. Multi-spectral lights
   Research suggests that interaction effects occur when multiple spectra are presented. This "spectral opponency" may influence the effectiveness of a known spectrum if it is presented with another spectrum. Therefore, careful studies are underway to determine the influence of a variety of light sources that might yield improved circadian function while maintaining accurate visual acuity and color rending perception. Examples include high Kelvin florescent lighting.

Design Options

The design of a physical environment that supports health, mood, and performance is likely to incorporate the principles that guide circadian lighting, visual function and ambient effects. Competing lighting requirements can be balanced by using a variety of systems, materials, and methods. As an example of evidence-based design, the following describes how the general principles and specific parameters of circadian light might be applied to a patient room within a hospital. It should also be noted that many of the options described below could be equally well applied to multiple building types, including office spaces, laboratories, etc.

Objectives
The objective for circadian, visual, safety, and ambient lighting is to provide controlled, appropriate light levels. Each function has different maxima and minima in terms of light spectrum, exposure time, and intensity. Efforts to maximize light exposure may exceed effective circadian levels, create extreme glare or brightness that minimizes visual acuity, and be uncomfortable. Therefore, the goal is not one of simply increasing the area of glass or window walls. Along with light level and spectrum, control of glare, temperature changes, equipment veiling, brightness, and contrast must be controlled to minimize discomfort and dysfunction.

Site conditions and building orientation
Building orientation relative to solar access, compass and site conditions can significantly influence the amount of light entering a building or opening. Virtual animations are routinely available and can be used to simulate the light pattern entering a building at a specific geographic location. However, adjacent buildings and geographic or natural structures, as well as interior materials, also dramatically influence light, and should be built into the calculations.

Architectural solutions

Building footprint and the perimeter to interior ratio
- Thinner building footprints, or an increased perimeter to interior ratio that provides a 20 foot distance to architectural openings, enable solar light to penetrate deeper into the building interior.

Windows and architectural openings
- Architectural openings and windows as required by code and guidelines for patients and egress provide access to solar light, but do not guarantee adequate levels of circadian lighting.

- Climactic and site conditions, building orientation and built adjacencies, window design, and interior obstructions, materials and finishes determine the intensity and spectrum of light entering the building and reaching the level of the eye.

Therefore, the dimensions or design of a window alone is not sufficient to determine if adequate light levels will be provided.

Access to exterior spaces

- Accessible paths and views to exterior spaces with direct, reflected, or shaded solar access provide opportunities for natural "light showers" if climactic and site conditions allow.

Building geometries and the control of light

- The design of the building's geometries and orientation modify the entry of light from the exterior and the distribution of light within.

- Several architectural systems, such as light shelves, clerestories, solar tubes, and specular materials, can be used to carefully distribute light entering from the exterior or from electrical light sources.

- Areas requiring controlled light or dark conditions should be specified in the programming phase, and may be placed away from the perimeter/architectural openings.

Materials or mechanisms that limit light distribution while maintaining sight lines

- The architectural and finishing materials used have direct influence on the quantity and quality of light arriving at the eye.

- Careful use of transparent and translucent materials facilitate light distribution, but also change the spectral quality and intensity of light. Transparent glass that becomes opaque with electrical charge is more useful in healthcare environments, where a loss of power would yield the screen transparent without requiring use of internally generated electricity.

- Careful use of specular or reflective materials can assist in the distribution of light, but must be controlled to reduce glare and the veiling of electronic equipment.

- Privacy concerns must also be balanced if transparent materials are used, and this is of importance in health care environments.

- Sight lines must be maintained so that patients and staff can see each other, and so that staff can see other staff.

- Darkness and privacy are important requirements in patient areas, certain clinical procedure areas, and in staff rest and respite rooms because of the circadian need for a light/dark cycle. Currently, typical privacy screens in hospitals do little to control distribution of light.

Electrical lighting

- Electrical lighting with automated controllers should be set to vary the total light intensity in a room or zone, incorporating the sunlight entering in space as well as the light emitted from nearby electric lamps.

- Electrical lighting should run parallel to the window wall with individual controls so that lights closest to the window can be turned off if sunlight levels allow.

- Multiple lighting solutions should be used to reflect the geometries and materials of the space, and the user, their function or condition, needs and desires.

- Complex tasks, such as those that occur in healthcare environments, laboratories, factories, etc., demand a variety of light intensities. A single lighting source and intensity are unlikely to meet these changing functional needs.

- Procedural lighting, visual acuity lighting, healthy lighting for circadian function, therapeutic lighting, and lighting for communication and amenity all have different optimal lighting ranges.

- The individual and special needs of building users can best be served by incorporating flexible and individual lighting areas.

Circadian lighting

- A user's length of stay in a particular space can be used as a criterion that assists in the designation of program and room function based on the solar levels reaching interior.

- Spaces for long-term users (e.g., staff respite rooms, long-term inpatient rooms) should be given greater priority for greater access to solar lighting than short-term spaces (entry areas).

- Patients rooms are required to have windows. However, the actual level of light exposure received per day is subject to many variables beyond the dimensions or design of the window (see below).

- Field studies of actual light levels reveal that use of sun shades and adjacent electrical lighting have a great influence on the amount of light the patient and distributed nursing staff receive.

- Staff work areas should be provided circadian lighting as well as views. In those areas where procedures require dim lighting, priority should be given to nearby respite or work areas that provide adequate circadian lighting conditions.

- Field studies reveal that borrowed light from patient rooms may be insufficient for circadian lighting of staff areas.

- Areas that provide brief electric “light showers” or desktop lighting devices might provide lighting exposure to regulate circadian needs.

- Access to exterior areas provide circadian lighting if climate or time of day allows.

- Dynamic lighting systems that use florescent overhead lights or LEDs that wash walls with light may provide circadian stimulation for a room or area. However, the effects and influence on users relative to the light level chosen is yet to be fully studied and verified.

- Red light that enables adequate vision for surveillance may provide a useful lighting condition for surveillance of patients at night. It has a lesser influence than bright white or blue light on melatonin and sleep suppression. Broad spectrum (white) task lighting should be provided for task lighting and visual acuity. Staff function and preference for this lighting condition should be explored

Differing circadian needs according to user role, function, and time of day

- Patients, day shift, evening, and night shift have different lighting needs over a 24-hour period.

- Individuals within each user type are also likely to have different needs as their shift and personal lighting exposure change.

- Patient circadian needs vary greatly with their length of stay, medical condition, procedures undertaken, and level of acuity. Light distributed from other functional areas should be minimized to reduce patient circadian disruption.

- For both patients and staff, individual circadian rhythms differ, and each user has a different light history that may influence his/her response to light. Therefore, the provision of lighting overrides, and individual circadian lighting should be considered.

- Individual circadian (handheld or desktop light devices) are likely to be most useful as they can be timed to address individual schedules. Light intensity and spectra should be designed to minimize light distribution to other staff or patients.

Lighting for medical condition

- Programming and design could take into account evidence that shows a relationship between medical condition and light stimulation.

- For example, long-term care units may be given the highest priority access to morning and evening daylight (e.g., seasonal depressive and bipolar inpatients, long-term obstetric inpatients). Oncology treatment areas might be positioned in areas where greater control of daylight access is provided, so that patients' circadian wake cycles can be timed to coincide with medical treatment schedule.

- Remote mechanisms that control patient window shades and privacy screens will be of benefit in 1) minimizing patient falls as they get out of bed to open shades; 2) reduce workload on staff to open and close shades; 3) encourage patients to obtain more access to daylight, as they are unlikely to ask staff for help.

Functional lighting

- In a patient room, several user zones are often described, including the patient, or bed zone, visitor or family zones, service, and clinical zones. Within each zone, lighting needs can change dramatically over a short period.

- Basic requirements for the patient and clinical zones include safety, walking paths, medical procedures, visual tasks, surveillance, communication (lip-reading and facial recognition), health, circadian and therapeutic lighting, rest, reading, and amenity. Lighting needs in the patient zone include sleep and privacy considerations. Circadian lighting must be controlled so that it is sensitive to the medical condition, state of acuity, and need for rest and privacy.

- Lighting for medical procedures should conform to guidelines and should be shielded so that light is not distributed beyond the surgical field. Lighting for medical procedures must be immediately accessible at the patient's bedside, along with an override switch available to obtain required light levels with a single switch.

- A single lamp placed overhead will not serve these multiple needs. Rather than having such a light source turned on for up to 24 hours per day, economic balance might be met by automatic controllers mixing solar and electric light during the day (with remote shade control), minimizing use of electrical power and cooling during the day. Individual lights could be used at bedside, in the visitor's area, and for clinical procedures only as needed, again reducing electricity consumption. Circadian stimulation could be provided by individual light sources at bedside that would not be distributed to nearby patients or staff.

Distribution of lighting

- Architectural design has a direct influence on the distribution of light from one zone to another, and should be taken into account early in the design process.

- During decision making, the investment in lighting must be balanced relative to the distribution of nursing stations and the transmission of light from centralized work areas, as well as from safety lights in hallways.

- Adjacent communal areas should be carefully placed so that they do not disturb patient lighting conditions. For example, conference areas, waiting areas, and centralized nursing or administrative stations that require full visual acuity lighting throughout the light should be distant from or screened from patient room openings.

Safety, security and surveillance lighting

- Safety and security guidelines for lighting must be addressed in keeping with codes and guidelines. However, multiple methods might be explored to meet these needs, including pathway lighting and the use of lights with different spectral and distribution parameters.

Innovative temporal lighting solutions

- Local or regional temporal lighting systems that dynamically change wall or room light levels across the course of a day are being developed, but have not yet been evaluated in terms of their influence on satisfaction, mood, biological, or circadian responses.

- Staff might benefit from the introduction of automated dynamic lighting that entrains the staff to their work shift. This could be provided by either dynamic area lighting or by brief light showers. Night-time light systems must be controlled to minimize light distribution to patient areas. However, control and distribution of light are primary concerns so that patients and people on other circadian cycles are not disturbed.

Innovative spectral lighting solutions

- Different spectral lighting solutions are associated with different behavioral and biological responses. Evidence-based lighting design that utilizes existing knowledge could provide a selection of light profiles demonstrated to serve differing functions.

Hierarchy of Needs: Balancing Conflicting Requirements

Design features significantly alter the light arriving at the eye. Multiple needs for safety, visual, circadian and ambient lighting are likely to be served by varied light sources. The presence of a single environmental or architectural variable, such as a window, is not guaranteed to provide adequate circadian or visual lighting. While the climatic conditions and compass orientation impact the amount of light entering a window, the light reaching the eye inside of a building is determined by the dimension, geometry, and distance from the window, as well as the materials, objects, and finishes that reflect, absorb, and otherwise interact with that incoming light. Using evidence from research and post-occupancy evaluations, a human decision hierarchy can be applied to prioritize design options (Edelstein & Marks, 2007). Cost analysis of materials, installation, maintenance, and energy use can be factored along with health, satisfaction, and performance measures to assign value to each design option.

Human efficiencies

- Value assessment should also consider the potential cost to human health, performance, error, and satisfaction ratings. Here, further research is warranted to demonstrate the influence of different conditions in real, operational settings. The advent of lightweight, wearable technologies enables measurement of actual environmental levels of light exposure over 24-hour periods (versus calculated/hypothetical levels).

Material costs and energy efficiencies

- Assessment of the cost/benefit of using multiple lighting systems should include: energy consumption calculations, operational and replacement costs, and first time purchase costs.

Room layout: Inboard or outboard toilets, single-handed rooms, view versus light

- The selection of design options might differ, dependent on the solar orientation of the patient room (south and west facing rooms without exterior shields may choose smaller windows and outboard toilets). Patient rooms in northern or inclement locations might select inboard toilets and beds, turned to maximize both the view and the area available for windows.

Single versus multiple patient rooms

- In those sites where multiple patients are housed together, the type and location of privacy screens and window proximities should be designed to control light distribution and control. New materials and moveable systems could be developed and explored.

Unit layout: Distributed nursing stations, travel distance, footprint and perimeter

- The choice of distributed versus centralized clinical stations should not be based on lighting needs alone. However, they should be factored into decisions about room layout, station proximity, door openings, and the choice of materials that might control the distribution of light. The timing and type of functions occurring in adjacent or nearby spaces should also be taken into account in the design of adjacent rooms and units.

Staff areas: Work, respite, rest

- The descriptions above could be rephrased to consider multiple "users" instead of just patients, and multiple building types.

- Room layout must balance access to diurnal light, nocturnal darkness and, most importantly, the control of light intensity, spectra, and timing.

- Rooms with multiple users should build in mechanisms and materials that control light distribution and provide for individual circadian entrainment.

- The facility layout and program should provide access to diurnal and nocturnal awareness, and carefully control light transmission by material as well as functional adjacencies.

Charrette

Following are the results of design charrettes and other collaborative interactions among the team members. In some cases, they substantiate concepts that healthcare architects are already pursuing. In other cases, they challenge the typical approaches to lighting in hospital environments.

Evidence: Circadian Systems Need Darkness as Well as Light

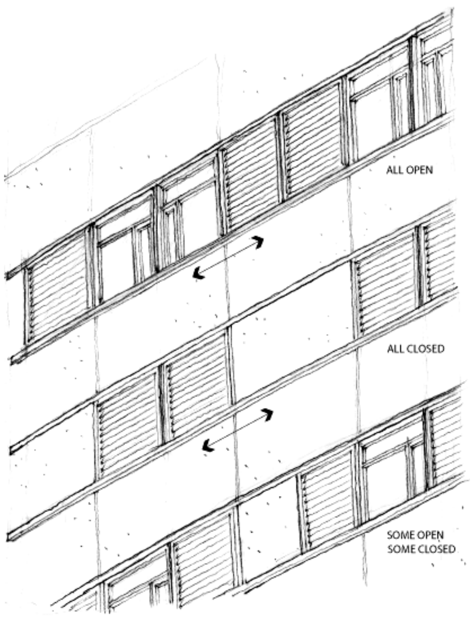
The need for light is well known and discussed, but circadian systems also require periods of darkness. In many current hospitals, light intrusion into patient rooms from outside the building, as well as from corridors and other proximate interior spaces, is often at levels sufficient to disrupt the patient's circadian rhythms.

Design Interpretation:

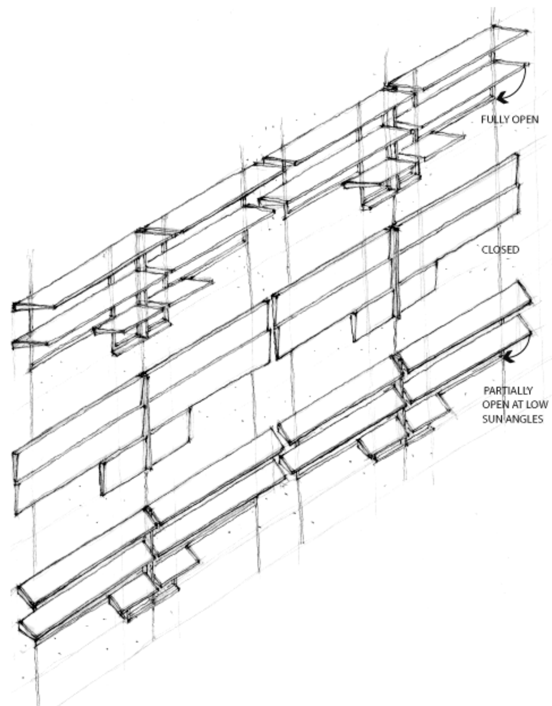
- Patient rooms must have the ability to be darkened. This includes ability to control light intrusion from both outside and inside the building.

- Accessible controls should provide patients with the ability to adjust light for their individual needs. A single-touch, programmable control for medical staff to immediately establish optimal lighting for assessment and procedures should be provided at bedside and/or at clinical stations.

- Achieving optimal light level starts outside the building with external shading and shielding devices. A kinetic skin that adapts to seasonal and diurnal light changes (but has manual overrides) may help balance needs for circadian light and darkness, view and glare control.



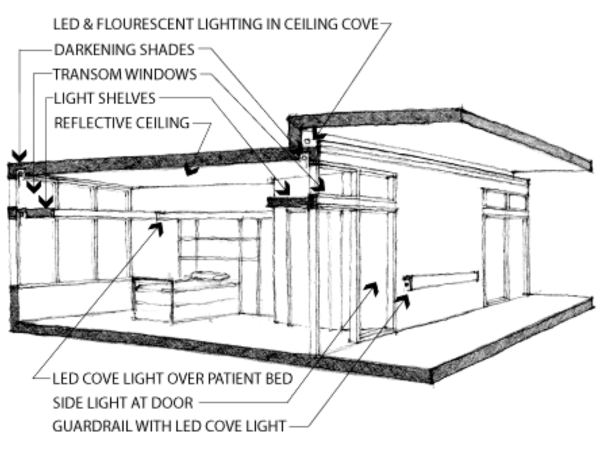
KINETIC SKIN: SLIDING EXTERIOR SHUTTERS



KINETIC SKIN: ROTATING EXTERIOR LOUVERS

Motor operated remote controls can be pre-set to adjust for daylight and night-time conditions, with a manual override for patient control. Two possibilities are shown here.

- Shades should be installed to effectively seal out light around the window perimeter.
- Low intensity lighting on the corridor side of the patient room walls may reinforce pathways for safety while limiting light pollution into patient rooms.



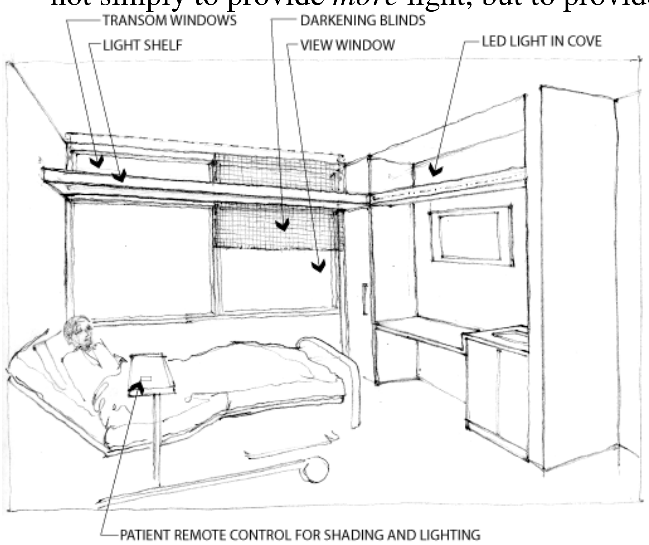
SECTION AT PATIENT ROOM & CORRIDOR

Evidence: Circadian Systems Need Varied Light Conditions

Natural daylight can be considered the "gold standard." Different frequencies, intensities, and dynamic patterns of light exposure are related to measurable differences in biological responses. Constant exposure to a single frequency and level of light is not ideal for normal circadian patterns. Daylight and electrical lighting that emulates natural diurnal, nocturnal, and seasonal cycles is most likely to support circadian needs and health.

Design Interpretation:

- Brightness and frequency of light should vary throughout the day. The objective is not simply to provide *more* light, but to provide the appropriate range of spectra.



PATIENT ROOM WITH LIGHT SHELF

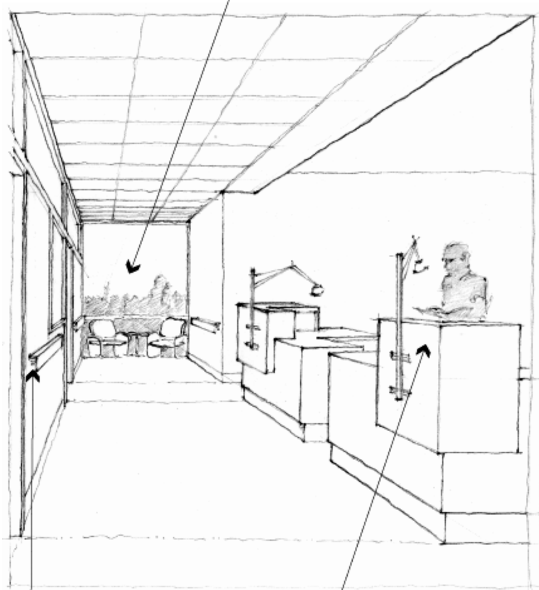
The lighting of the room can be programmed so that the internal darkening shades come down at the end of the day to keep external light out of the room. The LED light in the alcove can be programmed to provide different spectra and intensities of light at different times of day to augment circadian rhythms.

- Building footprint should allow for controlled daylight penetration to the nursing stations or team work areas.

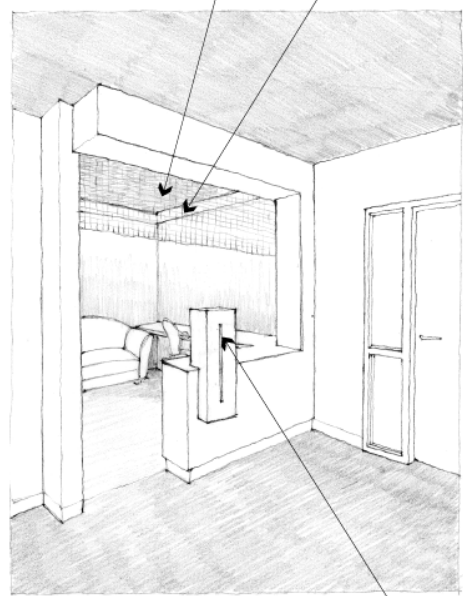
- Atria and light wells might, but do not necessarily, provide sufficient circadian light to interior areas. Orientation, floor level, and atrium proportions should be modeled for light frequency as well as intensity.

- Light shelves may be used to introduce daylight to spaces where "borrowed light" may be blocked by doors, window coverings, or bed drapes.

- Staff should have access to spaces for both darkness and light. There could be a break room with daylight or electrical circadian lighting for night shift that does not interfere with patient needs. A separate dark room to serve those with circadian rhythms off cycle with diurnal patterns.



CORRIDOR WITH WINDOW SEATING



LIGHT SHOWER NICHE

An informal break room can be provided by a window at the end of the corridor with comfortable chairs and programmable light. This also brings daylight into the central nursing stations. A separate break area with controlled light distribution may be needed for night workers. Programmable LED lights could provide different spectra and intensities.

A niche could provide a place where staff could retreat for "light showers." The LED cove lights would be programmed to provide light stimulation while minimizing the distribution of light to patient or other staff on different work shifts.

Electrical Lighting Options:

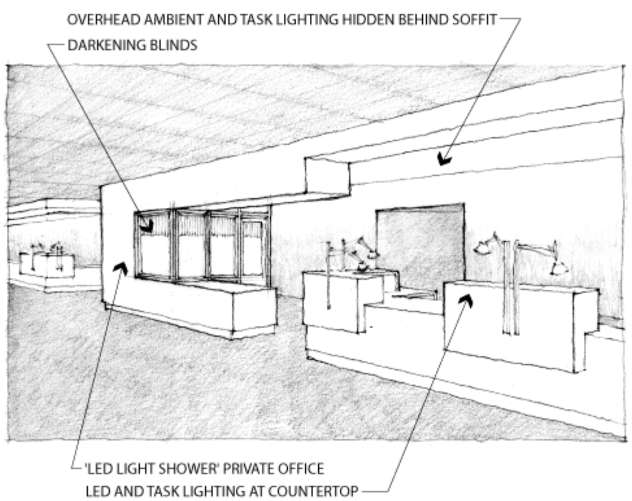
For areas where daylight is not feasible or practical (such as imaging rooms, procedure rooms, operating rooms), controlled electrical lighting that can be varied according to user, function, frequency, intensity, and distribution may provide useful circadian stimulation and might enhance visual function. The lighting concepts outlined below reflect ideas that require further testing in both real operational and laboratory settings to determine user satisfaction, function, and physiological responses. Care must be applied to ensure that light is not so bright as to cause visual discomfort or harm, and not so dark as to limit visual acuity and accuracy or the ability to safely monitor occupants or egress.

- For areas where daylight is not feasible or practical (such as imaging rooms), controlled electrical lighting that can be varied according to user, function, frequency, intensity, and distribution may provide useful circadian stimulation.

- For night shift workers, daytime patterns of light frequency variation should be recreated to the extent feasible while still supporting patient needs for darkness and staff needs for visual acuity, safety, and security.

- The use of white and blue frequency light augmented by task and safety lighting may support staff circadian sleep / wake patterns. Red light in corridors could be explored as a means to support night- time monitoring while minimizing circadian sleep/wake patterns in patients. White lighting at clinical stations would provide for task- related visual acuity. Individual controls are essential at staff stations. Green lighting might assist in visualization of computer images while supporting greater visual acuity in generally dark conditions.

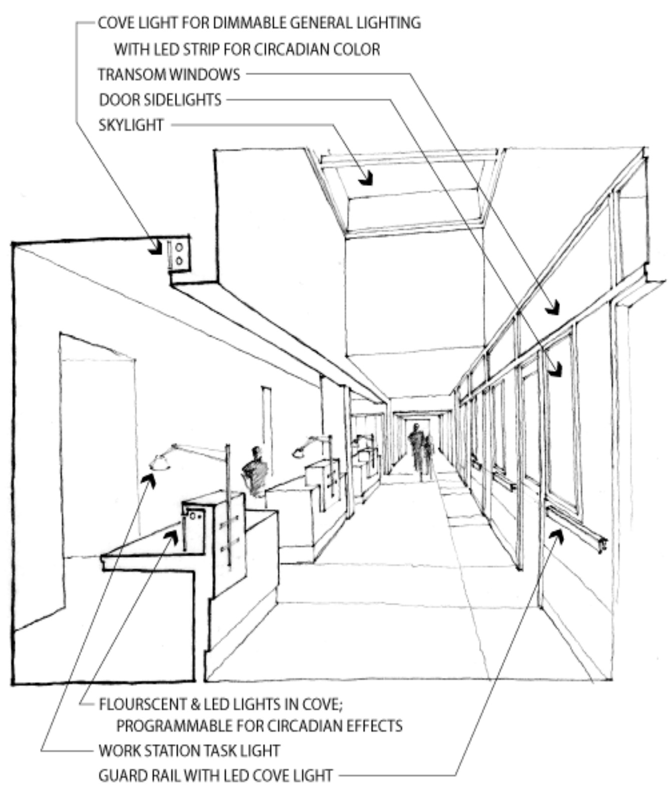
- Localized "light showers" (brief exposure to light that stimulates the melatonin systems) at distributed desks may provide for needed circadian activation.



CORRIDOR WITH 'LIGHT SHOWER' OFFICE

A niche at the side of the staff room or along the corridor with the nurse stations may provide controlled lighting opportunities.

The combination of LED and fluorescent lights in the work station returns could be programmed to provide a range of light spectra red, blue or white-blue lighting that would help reset the circadian rhythms of evening and shift workers. The LED lights under along the corridor guardrails could be programmed red to provide adequate lighting for walking and egress, while minimizing minimal corridor lighting without disrupting disruption to patients' need for darkness at night



SECTION & PERSPECTIVE OF NURSING STATIONS AT CORRIDOR

- Low level ambient light should be complemented by task lighting at work centers for visual acuity. Bright light should be screened as to not penetrate into the patient rooms.

- Building footprint should allow for controlled daylight penetration to the nursing stations or team work areas.

Atria and light wells might, but do not necessarily, provide sufficient circadian light to interior areas. Orientation, floor level, and atrium proportions should be modeled for circadian light frequency as well as intensity.

Evidence: Individuals Have Different Light Needs

Lighting needs vary by individual medical condition, visual acuity, preference, and culture. , An individual's history of light exposure (over several hours, days, weeks) influences his or her need for circadian light. Swing and especially night shift workers may suffer from stress responses due to misalignment of their sleep/ wake cycles and natural daylight and darkness.

Design Interpretation:
Lighting controls are as important as lighting. Patient and family are often most likely to make preferred adjustments, but they mightmay not know what light is healthiest.

- Individual control of lighting systems should provide for multiple needs. Ideal system wcould combine computerized control to provide desirable circadian light, over-rides for required procedure or safety lighting, (that the patient or staff might not choose) and over-rides to adapt be adaptable for to individual preferences. Short term users have lesser need for diurnal lighting patterns than long term patients.

- Patient controls must be accessible and easy to use,; and should allow control of electric light as well as window coverings. Follow-up studies could be conducted to determine if bed-side controls are associated with reduced falls.

- Special lighting needs should be considered when setting such levels available. In healthcare environments, the need for sleep and rest during the day should be accommodated. For example, elder patients are more likely to need greater light levels, but may be more disturbed by glare and reflection.

- Cultural and individual preferences may have a great influence on color choices. Patient control of color through LED lighting may provide a sense of control and ability to adapt the environment easily as occupant needs and preferences change.

Conclusions

A scientific process was applied to the Latrobe Laboratory Experiment. The experimental hypothesis asserted that lighting influences health. By understanding the reason *why* light is associated with health outcomes, that is, the mechanisms by which it influences health, one is better able to specify the range of light qualities and quantities that yield positive outcomes and the range of what might be harmful or yield negative outcomes. Given such measures, designers can more readily create performance guidelines and develop a myriad of ways to design access to light that serves outcomes. Indeed, architects can apply a great number of techniques to achieve similar lighting conditions, including site decisions, architectural openings, and reflective materials to distribute daylight. In addition, the evidence base suggests that electrical light can be designed to provide similar benefits.

In terms of its circadian lighting (versus visual function), the light arriving at the eye (not on the desktop or wall) must be defined in terms of its intensity, spectrum, distribution, duration, and temporal pattern. The interaction of these parameters yields different results and responses. Therefore, one must carefully assess the evidence and apply specific findings to specific environments, and then measure the lighting once the building and light sources are installed to ensure that the design parameters are met.

Given these general observations, a number of architectural solutions can be applied to provide lighting for vision and biological function. Some of the solutions listed make use of existing methods and materials. Others will rely on design innovation, material development, and new concepts yet to be explored. Clearly, decisions must be balanced in terms of programmatic needs, their cost, benefit, and perceived value to the users.

Discussion

Although further research is required, biological and medical evidence reveal a pervasive influence of light on many human functions. As such, the evidence base supports the value of architectural and electrical lighting strategies for both visual and circadian needs. As all humans display circadian responses, the influence of architectural light on health is relevant to all environments where architects play a role, but has most impact in healthcare environments where patients, visitors, and staff present the broadest range of conditions and needs.

Wearable technologies now provide the means to measure the actual level of architectural light provided and to study the influence of a variety of design solutions in functioning environments without impeding the provision of services. The addition of rigorous findings from both laboratory and on-site studies will enhance the range of evidence to be considered in a decision hierarchy that balances safety, security, health, performance, emotional, social, and economic needs. The ultimate goal of the evidence-based approach that includes literature reviews, epidemiological studies, and laboratory experiments is to assist in developing design strategies that support health, performance, and the emotional and social needs of all users.

Appendices

APPENDIX I.

Literature Search Criteria

A literature search yielded thousands of citations about influence of lighting on human performance, behavior, and psychological and physiological responses.

Inclusion criteria:

- Published in English
    - Occasional search with all languages
- Limited to Humans
    - Occasional search for animal studies directly supporting human findings
- Publication date to MEDLINE limit
    - Date limit varies with MeSH category
    - Focus on most recent or most relevant
- All gender, age, interventions, variables, indicators, measures, outcomes
    - (Specific searches on key terms and measures below)

Process:

- Primary search for lighting and health in PubMed (see key words below)
    - Specific search in Avery, PsychINFO, Avery, Web of Science

- Limited searches
    - Cochrane Library, Center for Health Design,
    - Robert Wood Johnson Foundation, Institute of Medicine, Informedesign,
    - Coalition of Health Environments Research, American Medical Association, Society for Neuroscience

- Focus on daylight and electrical lighting influences on:
    - patient health
    - staff performance and health
    - satisfaction
    - physiological responses to light
    - entrainment of circadian responses to light

APPENDIX II

Color Preference

Eve A. Edelstein, M.Arch., Ph.D. (Neuro)

Color preference has been studied for several decades and across many cultures. The following reviews a small subset of this work in order to demonstrate the complexity that must be accounted for in designing color experiments, and for the interpretation of the results.

Cultural Effects

Abel's study (2005) of 90 undergraduate students from 5 different cultures expressed color preference in mosaic design. Researchers found that Japanese students preferred green and Mexicans blue, and that Iranian students chose fewer colors. Choungourian (1968) found definite cultural and some gender differences in color preference of paired comparisons among 160 American, Iranian, and Kuwaiti university males and females. Saito (1996) studied 490 university students (Japanese, Chinese, Indonesian), who selected the most liked color from a color chart. People from each country showed tendencies for unique color preferences, with significant differences in frequency of colors and hues. A high preference for white was common, along with a preference for some colors. Images based on environmental and cultural aspects may be important influences. However, in order to make direct cultural comparisons, one must also consider the influence of changing preferences that occur over time, and that such changes differ across country and culture even within the same location. A rigorous analysis is required for comparisons across references in order to discern rigid or fixed preferences that will stand the test of time and location.

Gender differences have been considered in studies on color preference and affect. Gender difference was observed in children's toy preference for object features, color, form, in children with pre-natal exposure to atypical levels of androgens (Alexander, 2003). Henry et al. (1978) found that 20 female and 20 male students ranked the Luscher Color Tests (LCT) differently by gender in terms of mean sexual and preference ranks, apart from for yellow and green. There were no gender differences in preference ranks, and only one color was ranked differently on gender dimension by males and females. Seefeldt (1979) demonstrated gender differences in color preference using the color test ranking of yellow and green (yellow ranked more highly in females).

Preference in Children

Shaoying et al. (2004), using paired comparison methods, examined color preference in children from the ages of 4–6 years old. There was remarkable gender difference, with the sequence of colors as: red, yellow, orange, blue, purple, green. It has been published that white preference is a general quality in all humans. May et al. (1979) studied 160 infants and young children (6 months to 4.5 yrs), where pairs of white or black toys were presented. Results did not support a white preference under these conditions. A study by

Duckitt et al. (1999) of South African children (3–5 years old) was consistent with a cultural socialization approach, implying that color bias in early childhood is acquired through verbal learning of human color symbolism. While 360 Filipino children (matched for gender, socioeconomic status, and age) responded to Luscher Color Tests in a manner consistent with Flehinghaus (1961), their preference changed with age (Gustilo-Villasor, 1986). Adolescents ranging from 6 to 16 years old who ranked 7 colors showed considerable agreement among males but not females, with significant difference between gender (Sinha et al., 1970). Nelson et al. (1971) had Canadian children choose from 6 color crayons during drawing. Their results suggest that color "appears to imply less about cultural membership and affective characteristics of the material being communicated than the degree to which individual expression is directed by society." They conclude that both clinical and cultural hypotheses have serious limitations, and that color preference involves both perceptual and sensory phenomena.

Preference for form over color has been reported to occur with increasing age (Serpell, 1969). Studies with small samples reveal that boys prefer form over color, and that lively boys respond more than quiet ones to color. Schuman (1966) investigated whether the age relationship between color and form preference typical in Euro-American societies is also found in non-Euro-Americans undergoing different educational experiences. Three color versus form preference nonverbal tasks revealed that in children aged 3-15 there is no developmental transition from color to form preference at any age. Of 357 color form tests, 24 showed a form preference.

Performance and Mood

Kwallek et al. (1996) studied the effects of 9 monochromatic office interior colors on clerical tasks and worker mood. Pre/post studies of 9 treatment groups examined proofreading performance, 6 mood states, and color preference in high/low saturation, dark/light value, and warm /cool colors, in 341 male and 334 female subjects (16–37 years). Significantly more errors were made in the white room than in blue and red, with females performing significantly better than males. Saturation of color was the most salient predictor of difference between male and females, with females indicating more depression, confusion, and anger in low saturation colors (white, gray, beige), and males in high saturation colors (green, blue, purple, red, yellow, and orange). Subjects revealed that they would prefer to work in beige and white offices over orange and purple offices.

Ishihar (1995) found that 50 male prisoners with normal color vision responded similarly to normal subjects. Color preference was assessed using the color pyramid test in normal subjects (green, blue, red, and yellow in descending order). Kuznetsov et al. (1990) used color selection from the LCT as an indication of emotional status in pilots post training. Categorizing color-emotion pairs, 14 British and 17 Chinese students assessed 20 colors and 10 color-emotion scales. There were no significant differences between males and females, but three scales were identified: color-activity, color-weight, and color-heat.

Physiological Influence on Color Perception and Preference:

Of course, in considering the physiologic bases affecting color perception, one must control for different color vision and deficiencies in individuals of different genders, age and health status (Buckalew et al., 1989; Levinthal, 1983). In particular, natural aging of the lens alters not only the optics, but also color through which the environment is perceived (Hardy et al., 2005). Also, medical conditions beyond visual disorders have both expected and unexpected impact on color perception and preference, such that deaf children tend to show greater preference for color over form, and adult schizophrenics show a high degree of color preference relative to other groups (Serpell, 1979).

Therapeutic Effects of Color

Tofel et al. (2003), having reviewed 3000 citations, found "no direct linkages between color and health outcomes," with insufficient evidence in the literature to imply the following causal relationships. They concluded that "color's influence on emotional states or mental and behavioral activities is unsubstantiated by proven results." They found that "color-mood associations exist, but that there is no evidence to suggest a one to one relationship between color and emotion. Certain colors do not contain inherent emotional triggers." Rather, "emotional responses are caused by culturally learned associations and by the physiological *and* the psychological makeup of people." They suggest that oversimplification of the psychological responses to color pervades popular culture and that the direct applicability to architecture and interior design of healthcare settings seems "oddly inconclusive and nonspecific." They assert, "The attempt to formulate universal guidelines for appropriate colors in healthcare settings is ill advised." They note that the perception of spaciousness is attributed to brightness and less by hue, and is highly influenced by contrast effects, particularly between objects and background.

Methodological Inconsistencies

The inconsistencies revealed in the initial literature search likely reflect the different study methods used by the authors. Color literature dates over many decades, and some of the earlier reports from the pre-World War II period are clearly skewed according to societal biases and preconceptions. While their study methods might be sound, their conclusions are tainted with the biases of their time. Further, cultural and societal attitudes to color change over time, none more so than after the cultural changes accepted or imposed in post-war societies. Comparing reports over many decades must acknowledge such changes.

Throughout the body of literature that explores color preference and effect, numerous different methods were applied, making it very difficult to compare findings across multiple studies. In some studies, small color chips were used, while in other studies whole rooms were painted. Different types of experimental tasks were applied, ranging from statement of abstract preference to behavioral responses or questions about sexual symbology. One of the classical methods, the Luscher Color Test, was found by Braun et al. (1979) to have inadequate (33%) test-retest reliability (21 days later n=88) in 125 Canadian students, and the authors recommended alternate test methods.

Summary

Two consistent principles are noted: 1) cultural background is related to color preference, and 2) brightness and contrast are more strongly related to color perception than hue itself (Tofel, 2003). Re-examination of the findings about color in terms of brightness and contrast would be more consistent with understanding color from the biological perspective, and has the potential to lead to further understanding about color perception and preferences among cultures. The above literature search focused primarily on psychological and behavioral literature. By focusing on physiological and biological responses to spectrum, a different evidence base was accessed, which formed the basis for the Latrobe experiments.

APPENDIX III

Visual Perception of Light

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NewSchool of Architecture & Design, San Diego

Within the United States the Illuminating Engineering Society of North America (IESNA) is the organization that develops standards for illumination, and sets target illuminance levels for various types of activities.

Lighting designers have traditionally relied upon their experience, judgment, and historical precedent to select interior lighting. Such historical precedent has its roots in the use of fenestration, including windows, clerestories, glazed doors, roof monitors and skylights, to modulate, diffuse and direct natural light so that the entire building, both interior and envelope, can act as a kind of luminaire.

From a thoughtful analysis of daylighting, a mathematical understanding of optical performance has evolved that has served the designers of luminaries for electric lighting sources. It has provided a language and methodology for quantifying lighting effects in terms of how they are experienced by the human body. Primary among these effects was illuminance, and for a long time this was thought to be the only one that really mattered, so it was provided for in abundance.

For many years, through eight editions of the *Lighting Handbook*, the IESNA published illuminance standards which established the basis of practice for architects and electrical engineers. The standards matched a space or building type to a recommended level of light intensity, as expressed in footcandles (lux in the metric system). The intensity of illumination suggested for each space was related to the type of activity expected to be performed there. A specifier of lighting systems need only determine the type of space to be lit and select the appropriate lighting level from the list. The recommended level was, and still is, largely based upon the collective professional experience of the authors. Over time, however, a body of scientifically rigorous data has been accumulating that has not only provided a sound basis for the standards, but has also had the effect of revising the recommended levels of illumination (downward, in most cases), and of adding a greater degree of nuance and specificity to the guidelines.

Even as they were producing the IESNA illuminance standards, the authors were acutely aware that the much larger body of knowledge contained in the *Handbook's* other chapters was not being appreciated and applied as fully as it might be. It was decided to try a new approach. In the 9th Edition of the *IESNA Lighting Handbook*, Chapter 10 gives a different method for lighting design that considers *both* light quantity and light quality. A matrix is provided with suggested illuminance levels for a wide variety of building spaces, and a set of Design Criteria that must also be considered to produce an optimal lighting design. These criteria are often specific to a given task and are discussed in detail in other chapters of the *Handbook*. Taken together, the Design Criteria modify the suggested illuminance levels as well as other factors, to arrive at an optimal lighting design.

The Design Criteria seek to address a variety of issues that affect lighting quality, rather than just quantity. These include glare, contrast, color temperature, color rendering, the modeling of faces and surfaces, and the overall evenness of light distribution. These factors can sometimes be quite subtle. Brightness may depend upon the surface to be illuminated. A small amount of light on a white paper, for instance, may be as effective as a large amount on a darker surface.

The human eye does not see brightness as an absolute value, but rather as being relative to an adjacent area of brightness. This difference in brightness between a detail and its immediate background is called contrast. Greater contrast improves visual acuity and task performance. Increasing brightness does not improve visual acuity nearly as much as increasing contrast, and it is much more costly to accomplish. Illumination of one footcandle (equivalent to bright moonlight) is sufficient to read an Exit sign, for example, with high contrast while over 100 footcandles is required to read the sign under conditions of low contrast.

The eye perceives color differently under differing levels of illumination. Within the retina, the cones are active at higher light levels and are sensitive to color (the “photopic” range). The rods are not sensitive to color, seeing the world in shades of gray, but they are very sensitive to contrast in low light (the “scotopic” range called “night vision”). Both rods and cones are functioning at dusk, in bright moonlight, and under most forms of outdoor lighting (the “mesopic” range).

The color temperature of a light source will affect the accuracy with which it renders colors, as well. This is measured using the Color Rendering Index, with sunlight equal to a CRI of 100. Since our eyes have evolved to respond to the distribution of wavelengths found in sunlight, most artificial light sources score below 100 and appear to do an imperfect job of rendering color.

Visual acuity improves when the surrounding light is of a high color temperature (blue-ish rather than red-ish). If the color temperature of the ambient lighting is changed from low (incandescent) to high (a cool fluorescent), it is possible to achieve the same level of visual clarity while using a quarter of the light and electric power. For these reasons medical facilities and offices, as well as daylighting designs that seek to match natural and artificial light sources, will typically use a fluorescent lighting system with a higher color temperature.

Color contrast also affects perceived lighting quality, especially when the eye must adapt to differently colored light in the same space. When one color predominates, the dominant color receptors become saturated and the others become more sensitive, compensating so as to maintain a constant brightness ratio among them. However, the eye cannot adapt to two very differently colored light sources of equal intensity at the same time, and the clash of colors will cause fatigue, eyestrain and stress headaches.

Likewise, the eye cannot adapt to two very different brightness levels at the same time, whether colored or black and white. Excessive contrast between brightness levels, known as glare, can become uncomfortable and annoying at the periphery of our view, and can be completely debilitating when it occurs near the center of vision, where the eye is most sensitive. Substantial losses in contrast, and hence in visibility, can result from specular surfaces or bright sources with high contrast to their surrounding environment. Control of these brightness ratios, maintaining a difference of 3:1 between the surfaces of a book and the desktop, or 5:1 between the book and a surrounding partition, 10:1 between the book and a distant wall, and 20:1 between the book and a bright window, will reduce eyestrain and stress.

Although uniformity of illumination is often desirable, for example, in the performance of an office task, comfortable lighting should also include shadows or changes in light levels to relax the eyes. Small pockets of bright contrast, called sparkle, can liven up a uniformly lit workspace.

Lighting quality will also depend on the nature of the task to be performed, and the amount of time one has to focus on that task. Larger size lettering and higher contrast is required to read a road sign flashing by at sixty miles an hour in the dark, as compared to a book resting motionless on a table. A small increase in lettering size can increase visual acuity as much as a large increase in illumination, which is the reason why Grandpa always appreciates the "large print" books in the library.

Lighting quality is experienced differently by different people performing the same task, varying markedly with age. We lose approximately 10% of our vision by the time we reach age 40, and 10% more every decade, making it ever more difficult to pick out fine details as we grow older. For this reason, grade-school lighting levels can be half the brightness required in nursing homes for the same reading task.

To account for all these variables in lighting design, the new standards put forward in the *IESNA Lighting Handbook, 9th Edition* evaluate each architectural space within a matrix where the Design Criteria are ranked as being "Very Important," "Important," "Somewhat Important," "Not Important" or "Not Applicable." For example, a hospital examining room flags as "Very Important" such design values as Color Rendering, Glare Control, Control of Flicker (from light bulbs that oscillate at a noticeable rate), Uniform Light Distribution, and Modeling of Faces. Other "Important" considerations include the Appearance of Luminaries, Distribution of Light on Surfaces, and Luminance (light reflected off surfaces). "Somewhat Important" is the Source/Task/Eye Geometry.

The suggested illuminance categories are then presented for each type of space, giving a letter rank for both vertical and horizontal illuminance levels. Letters A, B, and C are for spaces where visual performance is unimportant, and the lighting is intended only to provide orientation or to illuminate simple visual tasks. For these letters the *Handbook* suggests a baseline illuminance of 3, 5, and 10 footcandles (30, 50, and 100 lux). Letters D, E, and F are for spaces where visual performance is important, and the recommended baseline lighting levels are 30, 50, and 100 footcandles (300, 500, 1000 lux), according to the size and contrast of the tasks. For the hospital examination room given in the example above, the recommended illumination levels are "E" (50 f.c.) for horizontal surfaces, and "C" (10 f.c.) for vertical surfaces. Finally, the letter G represents lighting for tasks performed near the limit of human visual ability, and the *Handbook* recommends a baseline figure of 300 to 1000 footcandles (3000 to 10,000 lux). Each of these suggested illuminances must then be evaluated by the designer in terms of the Design Criteria, weighted in the matrix as described above, and the baseline number is then adjusted up or down accordingly.

The method described in the *Handbook* is representative of the current thinking in lighting design. The emphasis on designing for lighting quality requires that an architect apply not only past experience, judgment, and historical precedent, but also an understanding of how the human eye and brain will respond to a variety of environmental factors, and at different times in the cycle of life. This is a subject to which the translational design approach employed by the Academy of Neuroscience for Architecture can make a meaningful contribution.

REFERENCES

Abel, Theodora M. (1981) Color preferences in the Lowenfeld mosaic designs of university students in five cultures. Academic Psychology Bulletin. Vol 3(2), pp. 173-176

Alexander, Gerianne M. (2003) An evolutionary perspective of sex-typed toy preferences: Pink, blue the brain. Archives of Sexual Behavior. Vol 32(1), pp. 7-14

Beatty J, Arana Greenberg A, Deibler W, and O'Hanlon J. (1974) Operant Control of Occipital Theta rhythm affects performance in a radar monitoring task, Science (183):871-3.

Beauchemin KM, Hays P. (1996) Sunny hospital rooms expedite recovery from severe and refractory depressions. J Affect Disord;40(1-2):49-51.

Benedetti F, Colombo C, Barbini B, Campori E, Smeraldi E. (2001) Morning sunlight reduces length of hospitalization in bipolar depression. J Affect Disord ;62(3):221-3.

Bornstein, Marc H. (1975) The Influence of Visual Perception on Culture. American Anthropologist, 77, 4, Dec, 774-798

Braün, Claude M; Bonta, James L. (1979) Cross-cultural validity, reliability, and stimulus characteristics of the Lüscher Color Test. Journal of Personality Assessment. Vol 43(5), pp. 459-460.

Buchanan TL, Barker KN, Gibson JT, Jiang BC, Pearson RE. (1991) Illumination and errors in dispensing. Am J Hosp Pharm ;48(10):2137-45.

Choungourian, A. (1968) Color Preferences And Cultural Variation. Perceptual And Motor Skills. 26(3, Pt. 2), Pp. 1203-1206.

Cohen M, Lippman M, Chabner B. (1978) Role of pineal gland in aetiology and treatment of breast cancer. Lancet ;2:814–6.

Conti, A and Maestroni GJ (1998) Melatonin Rhythms in Mice: Role in Autoimmune and Lymphoproliferative Diseases. Ann. NY Acad. Sci 840:395-410.

Davis, H., Davis, P.A., Loomis, A.L., Harvey, E.N., and Hobart, G., (1937) Human brain potentials during the onset of sleep. J. Neurophysiol., 2:24-37.

Davis S, Mirick DK. (2006) Circadian disruption, shift work and the risk of cancer: a summary of the evidence and studies in Seattle. Cancer Causes Control.;17(4):539-45.

Duckitt, John; Wall, Carolyn; Pokroy, Barry. Color bias and racial preference in White South African preschool children. Journal of Genetic Psychology. Vol 160(2), Jun 1999, pp. 143-154.

Edelstein, E. A. (2006) Excerpts from: Translational Design: The Intersection of Neuroscience & Architecture. Master of Architecture Thesis. NewSchool of Architecture & Design, San Diego.

Figueiro MG, Bullough JD, Parsons RH, Rea MS.(2005) Preliminary evidence for a change in spectral sensitivity of the circadian system at night J Circadian Rhythms. 2005 Dec 11;3(1):14.

Foster RG (2002) Keeping an eye on the time: The Cogan Lecture. Invest. Opthalmol. Vis. Sci. 43:2386 – 1296.

Glickman G, Byrne B, Pineda C, Hauck WW, Brainard GC. Light therapy for seasonal affective disorder with blue narrow-band light-emitting diodes (LEDs). Biol Psychiatry. 2006 Mar 5;59(6):502-7. Epub 2005 Sep 13.

Gustilo-Villasor, M Theresa. Color as an index of the Filipino child's developing personality. Philippine Journal of Psychology. Special Issue: The Filipino family. Vol 19, 1986, pp. 41-49.

Hardin, Clyde L. Explaining basic color categories. Cross-cultural research, vol. 39 no. 1, pp. 72-87, Feb 2005.

Haus E, Smolensky M. Biological clocks and shift work: circadian dysregulation and potential long-term effects. Cancer Causes Control. 2006 May;17(4):489-500.

Henry, Dennis L; Jacobs, Keith W. Color eroticism and color preference. Perceptual and Motor Skills. Vol 47(1), Aug 1978, pp. 106.

Heschong Mahone Group (2001) Re-Analysis Report, Daylighting in Schools, for the California Energy Commission, published by New Buildings Institute, www.newbuildings.org.

Ishihara, Keiko. Responses of criminal offenders to the Color Pyramid Test/Hanzaisha \no "Color Pyramid Test" hanno Japanese Journal of Criminal Psychology. Vol 33(1), 1995, pp. 41-49.

James FO, Walker CD, Boivin DB. Controlled exposure to light and darkness realigns the salivary cortisol rhythm in night shift workers. Chronobiol Int. 2004;21(6):961-72.

Jansson L, Holmdahl R (1998). Estrogen-mediated immunosuppression in autoimmune diseases. Inflamm. Res. 47: 290 – 301.

Jasser SA, Blask DE, Brainard GC. (2006) Light during darkness and cancer: relationships in circadian photoreception and tumor biology.Cancer Causes Control. 2006 May;17(4):515-23.

Keep PJ. Stimulus deprivation in windowless rooms. Anaesthesia 1977;32(7):598-602.

Keeping patients safe: Institute of Medicine looks at transforming nurses' work environment. Qual Lett Healthc Lead 2004;16(1):9-11.

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev 29:169–95.

Kuznetsov, O N; Egorov, V A; Frantzen, B S. Colour selection in the Luscher Test as an indication of a typical emotional status of the flying personnel. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina. Vol 24(2), Mar-Apr 1990, pp. 15-18.

Kwallek, N; Lewis, C M; Lin-Hsiao, J W D; Woodson, H. Effects of nine monochromatic office interior colors on clerical tasks and worker mood

Lewy AJ, Bauer VK, Cutler NL, Sack RL, Ahmed S, Thomas KH, Blood ML, Jackson JM. Morning vs evening light treatment of patients with winter depression. Arch Gen Psychiatry. 1998 Oct;55(10):890-6.

Lubkin V, Beizai, P, and Sadun, AA (2002) The Eye as Metronome of the Body. Survey of Opthalmology. 47(11):17-26.

Maestroni GJ and Conti A (1996) Melatonin and the Immune-hematopoietic System Therapeutic and Adverse Pharmacological Correlates. Neuroimmunomodulation. 3:325-332.

Marques-Deak A, Cizza G, Eskandari F, Torvik S, Christie IC, Sternberg, EM, Phillips TM. (2006) Measurement of cytokines in sweat patches and plasma in healthy women: Validation in a controlled study. Journal of Immunological Methods. Article in press.

Marques-Deak A, Cizza, G and Sternberg EM. Brain-immune interactions and disease susceptibility. Molecular Psychiatry, 2005, 10 (3), 239-250.

May, Jo W; May, J Gaylord. Color preference for black and white by infants and young children. Perceptual and Motor Skills. Vol 49(1), Aug 1979, pp. 143-148.

McColl SL, Veitch JA. Full-spectrum fluorescent lighting: a review of its effects on physiology and health.

Nelson, T M; Allan, D K; Nelson, J. Cultural differences in the use of colour in northwest Canada. International Journal of Psychology. Vol 6(4), 1971. pp. 283-292.

Rajaratnam SM, Arendt J. Health in a 24-h society. Lancet. 2001 Sep 22;358(9286):999-1005. Review.

Rea, Mark S., Ed. IESNA Lighting Handbook, 9th Edition (Illuminating Engineering Society of North America, New York, N.Y., 2000)

Revell, V. L., Arendt, J., Fogg, L. F., Skene, D. J. (2006) Alerting effects of light are sensitive to very short wavelengths. Neuroscience Letters. 399 (1-2), 96-100.

Rozlog LA, Kiecolt-Glazer JK, Marucha PT, Sheridan JF, Glaser R. (1999) Stress and immunity: implications for viral disease and wound healing. J. Periodontol. 70: 786-792.

Saito, Miho. A comparative study of color preferences in Japan, China and Indonesia, with emphasis on the preference for white. Perceptual and Motor Skills. Vol 83(1), Aug 1996, pp. 115-128.

Seefeldt, F Michael. The Luscher Color Test: Sex differences in color preference. Perceptual and Motor Skills. Vol 48(3, Pt 1), Jun 1979, pp. 896-898.

Serpell, Robert. The influence of language, education and culture on attentional preference between colour and form. International Journal of Psychology. Vol. 4(3), 1969, pp. 183-194.

Shaoying, Liu; Liezhong, Ge; Yao, Zhu. A Research of Color Pereference of Children Aged 4 to 6. Psychological Science (China). Vol 27(3), May 2004, pp. 669-670.

Shoyama, Shigeko; Tochihara, Yutaka; Kim, Jungsook. Japanese and Korean Ideas About Clothing Colors for Elderly People: Intercountry and Intergenerational Differences. Color Research and Application. Vol 28(2), Apr 2003, pp. 139-150.

Squire, L. (2003) Fundamental Neuroscience. Opp. Cit. pp 1039 .

Sternberg EM. Neuroendocrine and neural factors in autoimmune, inflammatory, infectious, and allergic disease: a summary of the conference. Ann N Y Acad Sci. 2003 May;992:xi-xii.

Sternberg EM (2001) The Balance Within: The Science Connecting Health and Emotions. WH Freeman, NY.

Sternberg EM, and Gold PW (2002) The Mind-Body Interaction in Disease. Scientific American. In Special Issues. The Mysteries of the Mind. P 82-89.

Stevens RG (2005) Letter: Epidemiology of Urinary Melatonin in Women and Its Relation to Other Hormones and Night Work . Cancer Epidemiology Biomarkers & Prevention Vol. 14, 551, February 2005.

Stevens RG, Davis S, Thomas DB, Anderson LE, Wilson BW. Electric power, pineal function, and the risk of breast cancer. FASEB J 1992;6:853–60.

Stevens RG, Rea MS. Light in the built environment: potential role of circadian disruption in endocrine disruption and breast cancer. Cancer Causes Control. 2001 Apr;12(3):279-87. Review.

Terman JS, Terman M, Lo ES, Cooper TB. Circadian time of morning light administration and therapeutic response in winter depression. Arch Gen Psychiatry 2001;58(1):69-75.

Tofel RB, Schwarz B, Yoon S-Y, Max-Royale A (2003) Color in Healthcare Environments: A Critical Review of the Research Literature. CHER. www.cheresearch.org. [Accessed May 1, 2006].

Ulrich R. S. (1984) View through a window may influence recovery from surgery. Science. 1984 Apr 27;224(4647):420-1.

Walch JM, Rabin BS, Day R, Williams JN, Choi K, Kang JD. (2005) The effect of sunlight on postoperative analgesic medication use: a prospective study of patients undergoing spinal surgery. Psychosom Med. Jan-Feb;67(1):156-63.

Wallace-Guy GM, Kripke DF, Jean-Louis G, Langer RD, Elliott JA, Tuunainen A. Evening light exposure: implications for sleep and depression. J Am Geriatr Soc 2002;50(4):738-9.

Webster JI, Tonelli L, Sternberg EM. Neuroendocrine Regulation of Immunity. Annual Review of Immunology. 2002. 20:125-163.

Williams, H.A., Granda, A., Jones, R., Lubin, A., and Armington, J., (1962) EEG frequency and finger pulse volume as predictors of reaction time during sleep loss. Electroencephalog. clin. Neurophysiolog., 14:64-70.

Veitch JA, McColl SL. A critical examination of perceptual and cognitive effects attributed to full-spectrum fluorescent lighting. Ergonomics. 2001 Feb 20;44(3):255-79. Review. Erratum in: Ergonomics 2001 Mar 15;44(4):473.

CHAPTER 3 – THE INTEGRATED DATA MODEL

THE INTEGRATED DATA MODEL (IDM)

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The Kaiser Permanente Integrated Data Model: A first integration of medical, physical, and social data for architects and environmental designers

Introduction and Overview

This chapter describes the primary research strategy the team at Kaiser Permanente used to create a tool, the Integrated Data Model, that can be used to answer important, current questions about the impact of design elements on patient well-being in hospitals. This tool integrates three classes of data never before connected—physical design features, patient experience, and patient medical outcomes. Broadly speaking, this original coordination allows planners and architects to understand the effect of architecture on health. The tool is especially powerful because of the enormous size of the sample, which allows fine discrimination between the effects of one variable versus another.

This chapter describes who created this model, its component parts, and when, where, why, and how it can be applied. Our initial research focus is on design elements related to natural lighting. Previously published research findings about the relationship between light and health are reviewed as a way to demonstrate how the Integrated Data Model can be applied to resolve questions, confirm suggestive findings, and expand the ability of architects to make informed trade-offs in their decision-making.

The Integrated Data Model

<u>Who thought of the IDM?</u>

The Latrobe planning team asked Kaiser Permanente about the possibility of using patient data to improve hospital design. This question stimulated Kaiser Permanente to think about finding a way to tie together its extensive data about patients with another large body of information about physical facilities. Kaiser Permanente already had initiatives underway to integrate two departments—Service Quality Research (about patients) and National Facilities Services (about buildings). The two departments started to work together to find ways to make their extensive data sets available to one another. In order to connect information about hospital rooms and other physical features, on the one hand, with patient well-being and satisfaction, on the other, they created an integrated database.

Healthcare organizations routinely collect and store large amounts of data detailing aspects of the patient's history, but these data are not always stored in ways that are easy to connect. For example, much of the information is stored on patients' written charts, or in isolated computer databases that are not designed to communicate each other. In recent years there has been a large movement to "automate" these medical records. Kaiser Permanente has undertaken one of the largest efforts of these kinds, which is called HealthConnect.

Digitally connecting these vast stores of data has at least two major benefits. First, the immediate quality of patient treatment increases as providers have instant and accurate access to all relevant patient records. Duplicate tests are reduced or eliminated, complications from drug interactions will be reduced, and doctors will, in general, have a fuller picture of a patient's medical history at their fingertips.

Second, and most relevant to our project here, the large integrated databases provide a rich resource of information for conducting clinical research projects. Having the various, coded sources of data organized similarly makes it practical and economical to conduct studies of large populations over time. The standard data contained in a patient's record provide information regarding what was done to a patient, what health outcome was achieved, and important personal characteristics about the patient.

In order for these databases to facilitate design research, additional data are needed beyond the patient record. Specifically, we need to have data that allow researchers to know attributes of the patient environment that were present during the care of the patient. We need information about the overall hospital itself (where is it built, how large is it, how many floors does it contain), about a nursing unit design (is it decentralized or centralized), about a patient room (how large is it, how many beds does it have, what is the view of the room, which direction does it face). These design attributes are equivalent to the experimental interventions.

This sort of data is not routinely tracked in patient medical records. Some of it may be available elsewhere, but identifying these design data sources and connecting them to existing patient data are key logistical challenges in doing large scale research on the impact of facility design on health outcomes. Further, for many types of research questions, new types of design data may need to be identified, codified, and then inserted into the databases.

To illustrate strategies for creating useful, large-scale data sets, we discuss in some depth the process we underwent in our Latrobe project. We hope this discussion will help others to understand the goals and objectives of the IDM project and provide some insights for other research projects.

One of our first decisions concerned whether to focus on design attributes at the hospital, nurse unit, or room level. There are important design questions at each of these levels, but we decided to focus on room level, for two key reasons: (1) room level issues are particularly important to the patient's direct experience of the physical environment since patients generally spend most of their time in their rooms; (2) room level data provided the richest data source from a statistical power perspective. This second reason can be further explained as follows.

The 32 plus[1] hospitals owned by Kaiser Permanente make KP a relatively large hospital system, but from a statistical perspective 32 hospitals would be a relatively small sample size for conducting research. Each hospital has many patients coming through it each year, and we can get information on these patients, but if our research questions were aimed at the design in the overall hospital, then 32 is the sample size. For example, if we were interested in how the age of the overall hospital impacted overall hospital satisfaction, we have only 32 different hospital ages with which to work.

The number of nursing units varies by hospital, but 10 is a good average number for this discussion. If we were to focus our analysis on aspects of the nursing unit, we have more statistical power than at the hospital level. We have 32 (hospitals) x 10 units per hospital, or roughly 320 units. Statistically speaking, 320 is a lot better than 32, but we have even more statistical power if we focus our research at the room level. The total number of licensed beds in KP is about 4300, quite large statistically speaking, and, as discussed in more detail below, there are ways to vary the conditions experienced by each patient in the room, which would allow us to take advantage of the larger number of patients who occupy each room over time.

To illustrate the magnitude of these differences, we list here the confidence intervals for each number of units for the measure “length of stay,” which is one of the key outcome measures we consider in the model. Length of stay (LOS) in the hospital in an important measure, since it indicates how long it takes the patient to heal from his or her ailment. LOS is commonly used to measure the efficacy of different treatments in the hospital. For our illustration, consider an average length of stay of 3 days. If we have a sample size of 32, the 95% confidence interval around the mean is about 1 day; for sample size of 300 nursing units; the confidence interval is about .4 days; for 4300 units about .05 days, and for 100000 about .02 days. So, for us to find an impact of a treatment using a sample size of 32, we would need to have a very large impact on length of stay—more than half a day. With the larger sample size of 4000, we would only need an impact greater than .05 days.

Though we obviously want to identify those features that have a large impact on outcomes, many factors impact health outcomes in the hospital setting. We have a much greater chance of identifying impacts of design elements if we can pick up smaller differences in performance. A half-day or quarter-day difference on average, for all patients, could still represent millions of dollars in healthcare costs over time, and could also indicate substantially better health outcomes and lower risks to the patient. In addition to greater precision in measuring design impacts, a larger sample size allows us to consider multiple design elements and contextual issues simultaneously.

[1]Note that Kaiser Permanente is continuing to open hospitals. Thus, the number 32 represents the total owned at the time databases were created.

For most statistical methods, the more data available, the more factors can be considered simultaneously. This form of statistical "power" is most important for "natural" or "retrospective" experiments, where existing data can be used to test for relationships in actual settings, rather than designing a randomized experiment ahead of time. In such natural experiments, one must be able to control for as many related factors as possible; a larger sample size allows for this. For example, one might want to test the impact of drinking various amounts of alcohol over time. For ethical and logistical reasons, it would be challenging to develop a random experiment to examine the impact of such drinking, i.e., assigning people into groups drinking nothing, one drink a day, three drinks a day, etc. So one would instead need to look retrospectively at the impact of drinking. Since people who chose to drink different levels may have other differences, the researcher would want to control for all those differences that might also be linked to health status. Younger people may drink more and are generally healthier, so one would control for age. People who are in chronic pain may drink more, so one would control for health status. For each control added, there would have to be an increasingly large sample size to perform the appropriate analysis. We illustrate these issues later on for those less familiar with these processes, though most people are likely to understand intuitively the high value of large experimental samples.

As we continue to explain the decision to build the large IDM database and why we think that its large size is an important aspect of its value, we first mention explicitly that scientific rigor is not determined by the size of data sets. One can design highly rigorous, or "high quality," scientific studies with very small data sets, and low quality studies using very large data sets. Likewise, there are many approaches to generating scientific knowledge and, though opinions vary about relative value, we do not take a position that one method is better than another. Each method type is generally geared to answering different types of questions. Some methods may lead to more immediately actionable data, some to data that is more widely generalizable, but we do not take any opinion on one best way of conducting science. Lab experiments, clinical trials, econometric analyses, individual case studies—all have their place in generating scientific knowledge. Often scientists are limited in their efforts by resource constraints, and they may use smaller samples than they would ideally prefer. These smaller samples may yield results that offer less certainty and less precision. Lack of certainty and precision do not reflect on the quality of the experimental design, and replication of the studies can expand and further confirm results. Replication of a study can enhance sample size effectively through a separate experiment.

Nevertheless, sometimes a large study that has either a large cross-sectional sample size and/or data over time is necessary from the beginning. To illustrate, consider the impact of smoking on health. It is well established that smoking has severe health consequences. However, if one examined the impact of smoking on health over a period of two weeks across a couple hundred people, one would not likely see any convincing evidence about its negative health consequences, as these take many years to develop. One might even notice a "positive health" impact of nicotine, in terms of its calming effects. Replicating this study time and again would likely yield the same results, which would lead to the erroneous conclusion that smoking is not bad for one's health. When considering the impact of design features on health outcomes, we argue that many of the features to test may require large data sets in order to recognize important but subtle impacts. The layout of rooms, access to natural light, and related issues may have health impacts that are important but not measurable in short-term or small sample size studies.

We may find that some design elements, when examined in a large dataset over time, do not have substantial impacts on health. Results showing that certain design elements do not have meaningful impacts are equally important. As readers of this know better than the authors, the more criteria a designer must consider in creating a building, the more constraints he or she faces and, potentially, the higher the cost of the building. If designers try to accommodate goals mistakenly thought to have an impact, they are then less able to focus on issues that do matter. If we find that certain design features are not important, we must test this with a large, well designed study to assure that we did not miss small impacts over time.[2]

To accomplish our goal to create a large database to support evidence-based design programs, we needed to find a way to link data about room design to other data in KP's systems. The key patient identifier in Kaiser Permanente, the Medical Record Number (MRN), is unique to each current Kaiser member and can thus link data about specific patients—their office visits, hospital stays, medical records, etc. For some patient survey programs the MRN is also recorded with survey responses.[3]

MRN, then, links two types of information—a patient's health records and survey responses. In order to add room information to this mix, we needed to determine if the room in which a patient stayed was routinely recorded in his or her medical record. When we started the Latrobe project, we were not sure that this room record existed; fortunately, it was, indeed, noted in the patient's record. However, room numbers that appeared in the health records database did not consistently match those noted in the facilities records database. We discovered that different naming conventions had been used after we started merging data files, and that less than 50 percent of the records merged. Since 50 percent success would still give us a large sample size, we continued to build and test the database while also correcting room naming issues.

Because the mismatching of room numbers was not likely to have been random, matching all rooms would help to ensure that we were not building a bias into our data source. To correct the mismatches, the team first looked through the data to find logical matches—i.e., did the letter R precede all room numbers in one database but not in another? These corrections were easy to make without further investigation. But the

[2]Note that from a philosophy of science perspective, because a large study that does not find anything may owe its lack of findings to missing the appropriate measures or experimental design, one must be careful in drawing conclusions from these studies as well.

[3]Please note that there are strict guidelines for how any of these data can be used as well as high penalties for inappropriate use. The MRN and the data they tie into are available for use in research so long as the use is approved by the Institutional Review Board (IRB), the body that oversees research activities to ensure compliance with confidentiality rules and general ethical research regulations.

remainder of unmatched records required that the team search for original plan drawings or make site visits to look for secondary room signage (the number that was actually on the door) that would give enough information to link rooms with patient stays. Another field was added to the Rooms Table in order to capture permanently the Health Connect alias (additional room number variable). Out of a total of 4,269 patient rooms, 92% have currently been matched, and the team is working towards 100 percent.[4]

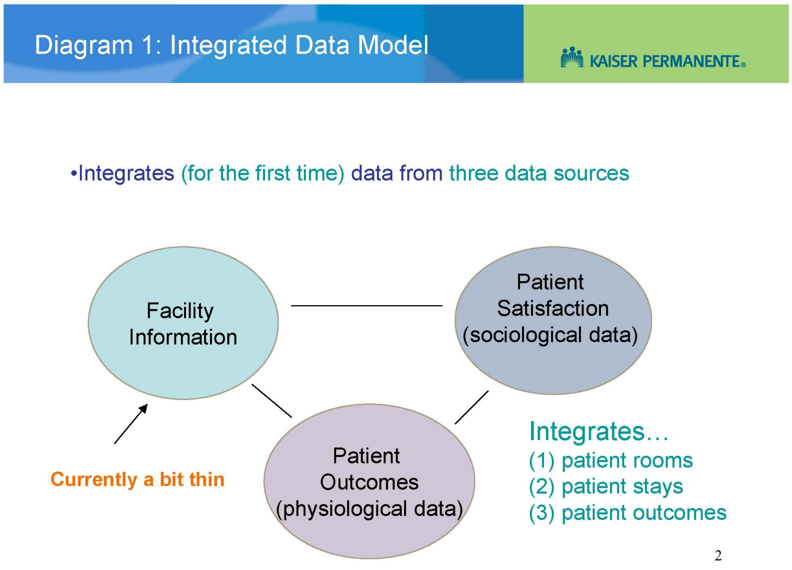
Matching room data creates the potential to link huge arrays of existing patient-level data with room data. We should note that, although we invested great effort to drill all the way down to the room level, a side benefit of the endeavor is that we also know which nursing unit the patient was in and, of course, which facility. Since we have information on individual patients, we will also conduct research at the "patient-level," factoring in issues like the patient's gender and cultural background. We are still focusing on the design elements in the 4,269 rooms, but for some research questions, our sample expands from 4,269 rooms to tens or hundreds of thousands of patients and patient-stays in the hospitals.

Access to natural light was the design feature of primary interest in this research project. Accordingly, we needed to create and codify information about light condition in order to have a "test" variable—the equivalent of a "drug" in pharmaceutical research. Typically, healthcare databases do not have information about the light quality in a room, the size and number of windows, window treatments, etc.

To begin our research, we focused on design elements of hospitals that have been thought to shape the light conditions experienced by patients. Room orientation is one important variable, since prior research has shown an impact on patients. Whether a room faces east, west, north, or south impacts how much light a room gets, and whether it is morning or afternoon light. Prior research shows that room orientation affects such health indicators as length of stay in the hospital and survival rate. We decided to look also at floor level because higher floors are likely, on average, to have less light blocked by adjacent buildings, and prior research suggests that rooms facing blocked light have worse outcomes.[5] The floor level was already captured in our data, but we had to construct a measure for compass orientation. Below we describe how all these variables are used in the analysis.

[4]Sacramento was scheduled to be completed by July 13, 2007, and Walnut Creek and Vallejo by the end of the same month, when the Diablo Service Area was scheduled for its annual space review. Mike Mannina, Kaiser Permanente, e-mail communication July 11, 2007.

[5]Note that we review the literature on light's impact in more detail further below in the document.



What is IDM?

Kaiser Permanente brought together for the first time three different sets of data to create the IDM. Now information about the patient's experience, health conditions, and health outcomes can be correlated with information about the physical environment of the hospital room. Consequently, scientific hypotheses and architectural questions about possible effects of design on patient well-being and satisfaction can be tested on a very large sample of patients over many years in 30 different hospitals.[6]

The first data source, information about physical facilities, comes from the Kaiser Permanente National Facilities Services division, which has a Computer Aided Facilities Management (CAFM) database. CAFM is a system that manages all key facility data for owned and leased real estate assets throughout the United States, which amounts to over 60 million square feet. The information in CAFM is a combination of graphical Computer Aided Drafting (CAD) floor plans and discreet data elements that relate to the building. It includes specific information about the physical environment at three different scales: rooms, buildings, and location.

Information about rooms includes a unique room identifier (room number); the department in which the room resides; the room net area (room square footage as measured to the inside face of the walls); and the room gross area (net square footage plus a prorated percentage of wall space).

[6]The entire system includes 32 hospitals, but 30 were mapped, and two others, in Hawaii and the Northwest, were not. Since the latter two currently have different data systems, mapping will be done at a later stage. California has been opening up more hospitals, so the number in California exceeds 30.

Information about buildings includes a unique building identifier; site identifier; building name; building address; city, state, county, and zip code in which the building is located; building type (hospital, medical office building, or regional building); the name of the Kaiser Permanente business entity that owns the building; whether the building is owned or leased; the number of floors in the building; the exterior gross building square footage; the site acreage; and the building's age.

Information about the location includes the Kaiser Permanente region in which the building is located; the (customer) service area; a unique facility identifier; a location identifier; and the building location type, name, and state.

Since our research goal was to measure the impact of room orientation on health outcomes, we needed to add an orientation variable to the database. Since the orientation had never been recorded on a room-by-room basis, it was necessary to catalog the room directional mappings. To do so, a facilities team took the plans for all of the California hospitals and validated the directions on the plans by checking the direction of north against Google maps. Then a large compass rose was superimposed over the entire plan for each floor. This allowed the team to identify into which of eight directional sectors each room fell.[7] This information became a new field within the Room Table of the database. Once these data were linked to the room database, given that the room database then linked to other patient databases, the room orientation variable could be used for any desired future analysis.

The second major source of data concerns patient experience derived from patient satisfaction surveys. The Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) collects this survey information, but it had never before been correlated with other kinds of data about design. The HCAHPS "program is a public-private initiative to develop standardized surveys of patients' experiences with ambulatory and facility-level care."[8] This database includes demographic and patient subjective experience of the hospital and its services. The demographic information includes age, gender, ethnicity, self-reported health status, education, and language spoken. The HCAHPS survey asks patients to rate a hospital relative to the overall patient experience of both the physical and social environment. The instrument includes additional patient assessments of areas of care, such as communication with nurses, responsiveness of staff, clean and quiet environment, pain control, communication with doctors, communication about medications, and discharge information.

[7]Each researcher used his or her knowledge of the facilities and best judgment regarding which direction was the closest match to the orientation of each room. Mike Mannina, e-mail communication, July 12, 2007.

[8]The program is sponsored by the Center for Medicare and Medicaid Services (CMS). The development of the survey instrument itself is guided by the Agency for Healthcare Research and Quality, which works closely with a consortium of private and public organizations.

The third important kind of data, physiological data about patient outcomes, is generated by inpatient medical records from the KP HealthConnect System. Thus, the IDM includes a variety of objective outcome variables, beyond merely patient perceptions, that will allow researchers to measure the impact of design initiatives on the actual well-being of patients. These improvements in the quality of the data collected increase the significance of the findings.

Kaiser Permanente spent significant funds to institute the use of a common software system for all of their regions and facilities. Implementation started in 2003 (http://ckp.kp.org/kpindepth/archive/indepth_faq_all.html, 2007). The Kaiser Permanente website explains, "The HealthConnect System is important in that it integrates of all of a patient's information in a single system." As of mid-2005, every region of Kaiser Permanente had implemented some part of KP HealthConnect, and deployment was substantially complete by 2007.

How would these different sets of data be brought together to answer questions and test hypotheses about the design of light? Specific diagnoses or diseases were coded in the system using standard governmental codes (DRG's), which can be used to analyze how physical environmental qualities (e.g., south facing light) might affect the outcomes of different diseases. If differences we observed, that is, if one patient did well and another not, then this could mean that an ideal environment for one diagnosis, like stroke, might not be the same for another diagnosis. We could check to see if stroke patients did as well in south facing rooms as patients would with heart conditions or other diseases.

With this tool we were also able to investigate whether or not such possible outcomes vary by different social groups. For example, we would be able to test if these effects of light on disease outcome are different for men and women, children, adults or the frail elderly, or for cultures from southern versus northern latitudes.

The architectural implications of being able to understand the effects of light for different kinds of patients suggest complexity and variation. Accordingly, an ideal hospital does not necessarily have to have, for example, all southeast rooms. The architectural guideline will not be so simple as "it's just better to have more light."

When, where, and how will IDM be used?

Specifically and immediately, Kaiser Permanente will use the tool to guide the design of its hospitals and to provide operational guidance for using and modifying existing structures.

- A step-by-step guide to using the new IDM model

1. Create a research question relative to a specific building design and/or design attribute.

This research question can be developed into a hypothesis based on a literature review, evidence created through focus groups, analyzing key business drivers, or operational necessity, etc. For example, a research question might be, "Do natural light variations make a difference to patient outcomes?" The general hypothesis is that natural light affects patient outcomes; a specific hypothesis might be that southeast light shortens patient stay (Benedetti et al., 2001).

2. With this general hypothesis in mind, take advantage of the power of IDM by utilizing the data generated by patient stays at 30 plus Kaiser Permanente hospitals. Patient rooms, located in different units facing different directions, were coded for their compass orientation.

3. Run IDM to uncover possible relationships between room orientation and different dependent variables, such as length of stay, patient assessment of the room, and amount of medication.

4. Check for intervening variables, such as the nature of the disease, gender, age, and psychological state.

5. The second phase in the research would be to build some well-considered interventions in order to test research findings in practice. Both the natural experiment and others' published research that have established compelling hypotheses could lead to clinical and architectural experiments. In either case, a hypothesis from any source would have to be well substantiated before committing resources to test it.

Since Kaiser Permanente will be building new hospitals, these ideas can be put to test experimentally and evaluated in real life situations. For example, if southeast light is confirmed to be the best healer for some diseases, decision-makers may wish to maximize southeast exposure for them and locate others elsewhere. A hospital so designed, built, and occupied would then be evaluated to see how it worked in comparison with other hospitals. Likewise, efforts to mimic certain types of natural light through the use of different types of artificial light and fixtures could be tried in a randomized, experimental fashion.

6. Perform direct measurements at these sites as required to capture any new features that will need to be evaluated post-occupancy or post-intervention.

7. Use the pre-intervention data as a baseline to measure the effects of the intervention.

8. Collect the post-intervention data.

9. Compare pre- and post-intervention data to determine the impact and outcome of the intervention.

10. Apply an econometric model to the cost of the intervention to determine its impact on the organization and, hence, its worth. Create calculations for "return on investment" initiatives, assuming and ensuring that equal or better health outcomes are achieved.

Why will it be used?

- Large sample size

The Kaiser Permanente Integrated Data Model will be used widely throughout KP's facility planning, fundamentally because it offers a solution to a common problem—namely, not having large enough samples to yield reliable results. Architects, whether in academia or in business, typically have not invested in constructing samples of adequate size and complexity to capture all the variation within a population. The architectural profession has never invested in large, well-constructed samples regarding building type or recurrent architectural issues.[1] By contrast, professionals who are required to predict responses in advance do fund large, carefully constructed samples. For example, opinion pollsters and their clients, who want to predict elections outcomes, construct representative, stratified samples that come extremely close to forecasting who will win and by what margin. Similarly, market researchers who want to anticipate or create demand for a product invest in scientifically constructed samples large enough to predict who will buy what.

In the U.S. today, an important next step for establishing the practice of evidence-based design in architecture is to determine how to conduct research with samples large enough to cancel out the accidental effects of idiosyncratic extremes. Such samples would increase the reliability of research findings. Further, sufficient data would make it possible to test a variety of design features while controlling for a variety of conditions. Instead of samples of 40 or even 100, we need large samples, orders of magnitude larger but not prohibitively large. Samples in the thousands or hundreds of thousands would have sufficient statistical power to research many important questions and, if chosen correctly, could still be representative of a larger portion of the population. For example, the U.S. Census is able to construct a sample of several thousand to capture accurately the experience of the entire population. Actually, this sample is remarkably small in relation to the 300 million population, but, because it is carefully selected to represent known variations, it is representative and reliable.

One goal in creating the Integrated Data Model is to provide a tool that will facilitate the production of straightforward and compelling evidence. We are creating a very large sample size in order to improve chances of generating believable and precise results.

- Contribution to the evidence-based design movement

Another reason for the usefulness of the IDM pertains to the evidence-based design movement. Evidence-based design, like earlier research-based approaches, is "applicable to many types of building projects, but is currently being used in the healthcare industry to help convince decision-makers to invest the time and money to build better buildings - and realize strategic business advantages as a result" (Wikipedia, 2005).

In the world of design, evaluation ideally provides evidence for the next round of new buildings. Without evaluation of buildings no one can accumulate a record of established cause and effect relationships between design features and human experience. "Post occupancy evaluation" informs the architect, client, and user whether the new design improved an organization's "clinical outcomes, economic performance, productivity, consumer satisfaction, [or] cultural measures" (Wikipedia, 2005). Academic researchers, for example, the architects, planners, psychologists and other social scientists in the Environmental Design Research Association, have been conducting such post-occupancy evaluations for the last 40 years, but practicing architects have not been using them as often as their authors might like. The "evidence-based design" movement may give new impetus to the project of bringing architecture into the culture of science, with its continuous cycles of induction and deduction, i.e., formulating a hypothesis, testing it empirically, and readjusting it for its next test in a new empirical setting.

> This cycle of hypothesis formulation, testing, and re-hypothesizing has remarkable parallels to architecture, since a building can be seen as a set of hypotheses about what will serve its purposes, and these hypotheses can be tested to determine if they were realized in practice. Evaluations of what worked and what did not can inform all stakeholders—architect, client, and agencies—the next time a building of that type is planned. Architectural researchers and social scientists have encouraged architecture professionals to base their designs and plans on evidence, and then, after buildings are constructed and occupied, to collect evidence about their use.

- Natural experiment offers safe, reliable, and valid data

A classical laboratory experiment compares two identical groups in identical settings with only the dimension of interest being varied. This kind of study design, respected for the precise control that it establishes, is also known to be limited in scope, sample size, and realism. In a natural experiment, by contrast, variation can be studied to see if it affects anything important in real settings. This is like the difference between studying biological processes in test tubes versus in bodies. Test tubes offer precise control regarding a specific relationship, while the living body offers an opportunity to see how that interaction occurs in the context of other biological processes. Both approaches are useful, and we were able to pursue both in the Latrobe project.

Buildings offer the opportunity to investigate potential effects of such built-in ("natural") differences, for example, regarding the orientation of rooms. We know from some previously published research that both the solar orientation and the view from the room have had effects on health outcomes. Kaiser Permanente, having accumulated information about 30 of its hospitals, is in a position to analyze an enormous architectural experiment that has been occurring naturally for decades.

One can tap the information in a naturally occurring experiment only if one has a way to take measurements and a method for correlating those measurements. The buildings themselves already existed; all that was needed was a way to map the data about the rooms, buildings, and locations so that these data could be correlated with patient outcomes.

Thus, before measuring the effects of a specific design intervention—which can be disruptive to patients and staff—the team committed to finding out, first, what had happened over the course of this long, natural experiment about the relationship between hospital design and healthcare outcomes. After that, narrower, more specific experiments could be conducted.

The experiment can itself be conducted using the Integrated Data Model, which has particular advantages for the experimental process. To illustrate, consider the gold standard of clinical pharmaceutical studies, the randomized, double blind study. Study subjects are randomly assigned to intervention or control groups. Each group gets a pill, but one gets a pill contains the drug and the other is administered a sugar pill or other "placebo." The subjects are "blind" to the assignment. They do not know whether they are receiving sugar (the placebo) or the drug. The other "blind" party is the experimenter, who is in contact with the patient but is not told which pill is which. In this way, the experimenter's knowledge can neither impact the subject patient through subtle cues nor bias the experimenter's observations and analyses. The double blind procedure is important because research shows that the placebo effect is strong and that experimenters' own biases can impact the situation substantially.

In such drug studies, achieving this blindness is relatively easy because the intervention is a little pill, and an identical placebo is easy to create. In the design world, achieving blindness or any other forms of pure equality between control and experimental group is far more difficult, because by definition the intervention—a building—is observable by the experimental subjects. It is also more difficult in the design world to achieve true randomness, especially in a real clinical setting. Even in experiments that "randomly" assign people to different rooms, experimenters cannot know how many factors other than the intended intervention are really different. For example, consider a study of people who were randomly assigned to either east or west facing rooms. Though the variable of interest was positioning relative to the sun, it is impossible in this form of study to control for all other important factors. Did views from each side of the building face the same way? Were noise conditions identical? Were these rooms assigned the same set of nurses and other professionals, since nurse units are often assigned geographically?

A strength of the IDM approach is that it is a data set that contains many hospital buildings. Thus, issues that might be challenging or distorting in one hospital will be canceled out by all the other hospitals; false effects can be "randomized out of the experiment." For example, if we are comparing east and west facing rooms across all of the hospitals, we dramatically reduce the chance of a consistent bias in terms of view, staff, noise, etc. We are randomizing at the level of the hospital. This randomization is not totally foolproof. For example, we must make sure that patients are randomly assigned to each compass direction, rather than assigning labor and delivery, for example, to preferred south facing rooms. But this type of randomization addresses most issues and leaves fewer matters to be controlled through other statistical means.

- Ultimate outcome measures

The large size of our data and the metrics available allow us to measure the impact of design elements on ultimate outcome, not merely intermediate processes, even if the impacts are not strong at an individual patient level. This specific advantage relates to some issues discussed above pertaining to the value of large data sets, but it is, in itself, one of the most important features of the IDM.[9] It will enable us to measure the impact of factors like hospital orientation on the ultimate well-being of patients, even though many other factors (quality of doctors, nurses, etc.) also strongly affect patient well-being. Measuring ultimate impact is important for evidence-based design in healthcare, because ultimately we measure success and make choices based on positive impact on people in hospitals—patients and employees.

Patient well-being is one of the most important ultimate outcomes. Some design features do have non-linear impacts on patient well-being. For example, Ulrich, Zimring, Quan, and Choudhary (2004), in reviewing the literature on the impact of sound on well-being, explain that too little noise in a hospital can be problematic, just as cam too much noise. People need some stimulation. Similarly, light can have positive impact on mood, and bright light can at times increase risk of suicide. This non-linearity is a common feature in human well-being. We can have too little or too much of many things—food, sun, exercise, alcohol, etc. The correct amount is likely to be dependent on one's context: e.g., recovering in a hospital vs. resting on the beach. Accordingly, we need to know which levels of environmental variables have the best impact on people in the hospital. We can learn this by examining the impact of design elements on ultimate outcomes.

[9]To illustrate what we are attempting to do regarding ultimate outcomes, we briefly describe a research project conducted by one of the authors that informed the analytic approach underlying our Integrated Data Model (Konrad & Mangel, 2000). This examined the impact of work/life programs on firm productivity. Programs to help workers balance life and work pressures had been gaining in popularity, but little or no research demonstrated whether they had a net positive impact on organizational performance. One reason for the paucity of such research is that many factors contribute to the success of organizations, all of which together create "noise" when trying to determine the specific impact of work-life programs on the ultimate outcomes. This measurement noise can be overcome by having sufficiently large samples with enough analytical power to detect the impacts of work-family initiatives as directly as possible. With enough statistical power and the proper analytical framework, one can examine the impact of individual initiatives on ultimate performance, even in situations when there may be many intervening or competing initiatives. Konrad and Mangel's work-life study looked across hundreds of organizations and found that work-life programs can positively impact workforce productivity, especially when there are high percentages of female workers and professionals.

Consider also recent healthcare studies covered in the popular press that have shown how generally well-understood treatments lead to unintended consequences.[10] Given the complexity of cause-effect relationships in the real world, measuring the impact of initiatives on ultimate outcomes is extremely important. Again, this is not to say that research that illuminates intermediary mechanisms is not useful—it is highly useful in moving scientific inquiry forward. But we do insist that one needs direct evidence of ultimate outcomes to be confident about the impact of one's decisions. The amount of data contained in the IDM, and the measures included in it, allow researchers to compare the effects of different policies and arrangements on ultimate outcomes. This stands out as a major value of the IDM tool.

All research carries with it some risks of different sorts, and there are limits to using the IDM, both practical and financial. To begin, some things will still be easier to test than others. For example, measuring serotonin levels in individual brains would be expensive. Moreover, finding differences by personality or individual physiological response to light will not be possible unless survey instruments are adjusted to include items that will measure that difference. The natural experiment lends itself to easier measures. Kaiser Permanente will necessarily consider cost, impact, and ease of each new variable added to the database. Light, for example, is easier to measure than color because color is more multi-dimensional that light per se.

Another limit of this research is that it takes time. Once in place, it can potentially answer many questions posed by medical practitioners, hospital managers, and architects. However, the political will necessary to establish this comprehensive database may not come easily in other organizations, in part because it takes time to set it up. Corporate culture demands quarterly results, and this kind of research enterprise requires a longer term and different perspective.

Other risks might entail spending too much money for inconclusive results, the harm caused to those in the experimental group exposed to a new drug, or to the control group by withholding a potential cure. But analyzing the effects of light on various measures of disease over decades of a naturally occurring experiment at a large scale is relatively risk-free.

Since this is basic research about the primary elements of environment, patient, and medicine that has potentially profound significance, why has it not been done before? Perhaps the project of mapping the human genome provides some insight into why basic research can take as long as it sometimes does. That project did not require the invention of new measurement techniques; rather, it required a commitment to assemble

[10]New research suggests that being moderately overweight leads to longer life overall (Kolata, 2007). Although being overweight increases the risk of heart disease, other diseases are less prevalent. Likewise, a class of cholesterol lowering drugs has been shown recently not to have positively impacted heart health. Interestingly, the connection between obesity and heart disease has long been known, but when looking at overall survival, the picture is less clear. Likewise, drugs such as statins, which lower cholesterol, have been shown to decrease heart disease, but apparently not all cholesterol lowering drugs do so, and overall survival for those not showing severe heart disease is not increased (Parker-Pope, 2008).

information all together in one place. So, too, our first exploration of how the basic components of a healing environment come together can be followed by specific interventions under more controlled circumstances, as needed, to clarify questions that will inevitably emerge from the research process and its findings.

- Health relevance

We have noted that IDM integrates heretofore disconnected data sets, which have to be connected in order to answer questions about the relationship between the designed environment and healing. Also, it does this for extremely large samples. With IDM a designer-researcher can utilize readily available data on samples as large as 100,000 patient-stays. As noted earlier, epidemiologists prefer large samples, to ensure that variation in variables other than the one under study average out. This powerful integration allows us to answer many questions about the relationship between architecture and health precisely.

Moreover, while we can test specific hypotheses, we can also pursue exploratory investigations. For example, some literature has described the effects of operable windows in schools, but no research about operable versus fixed windows in hospitals has been found by those who have conducted systematic reviews (Boyce et al., 2003). This powerful new tool makes it possible to add this to the KP data sets as an independent variable. There would be a cost to add a new independent variable, but because all of the dependent variables are already in place, such a study in the context of this larger integrated data set will cost much less than starting from scratch.

How IDM Can Be Used to Test Hypotheses about Healing Environments and Light

Now that the IDM has been described in terms of who created it, what it is, and when, where, why, and how it will be applied, we can turn to a review of previous scientific findings about light and human health in order to demonstrate why this model offers the means to make significant scientific advancements. With this powerful model, research questions can be formulated to address unexplored issues, resolve inconclusive findings, and test promising findings in need of further substantiation.

The entire team chose to focus on the empirical investigation of the role of light in the design of the hospital environment, for many reasons. First, architects in particular and people in general feel that light is important. Second, researchers have already conducted sufficient empirical studies to confirm that light has effects on human health. Third, this background of prior research has produced a series of hypotheses, some competing and contradictory, others complementary, which we can test, and, thereby, make a significant contribution.

This review demonstrates that prior research on light has raised as many questions as it has solved (or, to put it more positively, has yielded many hypotheses that merit further testing before designs are changed). Importantly, our large integrated data sets can be used to clarify some of current and competing claims about the role of light in the design of healing environments. Conventionally, a review of the literature comes at the beginning of a scientific paper, followed by discussion of method. Here, however, the order is reversed: the literature review demonstrates both actual and potential applications of the IDM. We turn now to some of what has already been published about the effects of light on healthcare.

- Natural light

One major review of 600 articles on healthcare design (Ulrich, Zimring, Joseph, Quan & Choudhary, 2004) concluded that more research on the role of light would be helpful, noting in particular that relatively few studies have examined the effect of light and other environmental factors on preventing medication errors. Based on research to date, one of the researchers' primary recommendations is to improve lighting in hospitals, "especially access to natural lighting and full-spectrum lighting" (p. 27) because of its beneficial effects on mood and recovery rates. T his hypothesis can now be tested on Kaiser Permanente's extremely large sample.

> Another basic hypothesis is that using daylight rather than artificial light saves energy. However, we do not yet know if the cost of long and thin versus large and "fat" floor plates offers financial return on investment. While making this evaluation on the basis of health and healing must be part of the calculus, first, how much do we know about the effect of light on health and healing? One study found that rooms with direct, bright daylight reduced stay significantly in comparison with rooms with no direct, dull light (Beauchemin & Hayes, 1996). The same authors (1998) reported that people die at a higher rate in north-facing rooms than in others. These two important findings merit further testing before investing in the long, thin floor plan, which is more expensive than the large, "fat" plan.
>
> Other research on environments that are lit by daylight rather than by artificial light suggests that south and east daylight is superior to north light in regard to healing, but this hypothesis has yet to be tested on extremely large samples. Another study found that when east light was blocked by a tall building, patients in rooms on the west side recovered faster than those on the east (Walch, Rabin, Day, Williams, Choi & Kang, 2005). These findings give weight to the hypothesis that daylight has a significant effect on health outcomes, and suggests a refinement of this hypothesis, namely, that the different qualities of daylight have different effects on health.

Some ideas about the role of light in hospitals invite further testing because they have significant design implications. For example, an architect or planner would want to know if the *view out* on a window is even more important, or at least important in very different ways, than the *light that comes in through* a window (Boyce, Hunter, & Howlett, 2003). Objectively speaking, windows are merely a means for delivering light, which can also be delivered through electricity. However, windows are preferred because they also provide a view out. Ulrich (1984) studied the effects of views out of windows on 46 patients recovering from surgery in rooms with two different types of views. Those with a view of nature (versus a view of a brick wall) "had shorter postoperative hospital stays, had fewer negative evaluative comments from nurses, took fewer moderate and strong analgesic doses, and had slightly lower scores for minor postsurgical complications" (Ulrich, 1984, p. 421, as cited in Delvin & Arneill, 680). Ulrich's later research (in 1990 and 1991) found that scenes of nature influence faster recuperation than urban scenes (as cited in Delvin & Arneill, 681). This confirmed earlier research by Kaplan, Kaplan and Wendt (1972) that, in general, people prefer scenes of nature to cityscape. Designers would benefit from further research on views and the specific properties of light—amount, hue, cyclical variability—that make it a health benefit, so that they can make appropriate compensations as required for unusual sites and circumstances. Light per se, whether artificial or natural. can be a source of stress (for example, glare) as well as benefit, so learning more about how different qualities of light specifically affect health is one goal of this research. Delivery of light, whether through windows, artificial means, or some combination, has tremendous architectural significance. Decision-makers must be aware of the importance of architecture in this regard. If appropriate kinds of architectural arrangements can reduce length of stay or have some other measurable benefit, architecture becomes both a medical and financial tool.

> A provocative hypothesis has emerged from experts' well-documented observations—that, in addition to any practical consequences, people simply prefer daylight to artificial light. In one comprehensive review article on the benefits of daylight, the authors (Boyce et al., 2003) call for a test of what has come to be known as the biophilia hypothesis, the intrinsic love of and benefits from contact with other living things, including views of them. The research model we have developed during the fellowship period will allow us to test this hypothesis as well. If the Kaiser Permanente Integrated Data Model does, in fact, supporting the biophilia hypothesis, it would have important architectural consequences, and might even imply that access to natural light should be a legal requirement, as it is in some European countries (Boyce et al., 2003).

- Light and Circadian Rhythms

Collectively, researchers have learned some things about light and circadian rhythms in relation to numerous health outcomes, including medication, especially pain medication, length of hospital stay, patient satisfaction, provider satisfaction, various measures of well-being, mental status, anxiety and depression, pain self-rating, sleep, hospital-acquired infection rates, stress behaviors, weight and weight gain (especially in newborns), patient comfort (self-rating), and physiologic indicators like heart rates, blood pressure, and respirations. More empirical studies have been conducted regarding light in relation to mood, depression, and Seasonal Affective Disorder (SAD). The findings indicate that effects can be different for each disease category. They also underscore the need for additional research because of differences and ambiguities in the studies. No one has established which is more important, duration of daylight, direction or timing of light, brightness of daylight, or even artificial light. Here, too, Kaiser Permanente's IDM can help clarify the relative influence of different aspects of light on health.

Moline, Mellerup, Bolwig, Scheike, and Dam (1996) studied the influence of climate on the development of winter depression in Copenhagen. Neither cloud cover nor rainfall, nor atmospheric pressure, correlated with scores on the Beck Depression Inventory (BDI), but minutes of sunshine, global radiation, length of daylight, and temperature did. This confirms the general theory that lack of light contributes to Seasonal Affective Disorder. Further, Lewy, Bauer, Cutler, Sack, Ahmed, Thomas, Blood and Latham Jackson (1998) discovered in northern countries (45° latitude) that morning light is at least twice as effective as an antidepressant as evening light in the treatment of SAD. This would suggest that east light or southeast light might have more significant effects on health outcomes than light from other directions. However, other research suggests that the *timing or direction of light* is not as important as *duration*.

In particular, Lambert et al. (2002) studied the effect of sunlight and season on serotonin turnover in the brains of healthy men aged 18 to 79, because serotonin is thought to regulate mood and low levels are linked to depression. It is lowest in winter and directly related to the *duration* of bright sunlight. Similarly, when Knight, Thompson, Raboud, and Hoffman (2005) studied the relationship between light, exercise, and melatonin production in women (because of the possibility that melatonin protects against cancer), they learned that season and *length of day* effected melatonin production, but light brightness did not.[11] Similarly, Wallace-Guy, Kripke, Jean-Louis, Langer, Elliott, and Tuunainen (2002) studied the effect of evening light exposure on sleep and depression in postmenopausal women, who often report problems with depression and waking up too early or too often in the night. The amount of light during the 4 hours prior to bedtime had no effect, but the *total amount of light* during the day did. The greater the amount of light, the less the depression and the less the sleep disturbance. The authors suggest that the total amount of light, rather than the timing of the light, may be what is critical, and they call for further research to clarify this finding.

Artificial light may be able to compensate for some of the benefits of daylight. Eagles (1994) found a close association of mood with hours of sunlight, both "today" and "yesterday," for bipolar patients. But when artificial light replaced sunlight, the correlation disappeared. In other words, when artificial lighting was used, it did not matter if the day had many or few hours of sunlight. However, in windowless, intensive treatment rooms, patients experienced more delirium, hallucinations, and delusions than in rooms with windows and daylight (Keep, 1977; Keep & Inman, 1980). These subtle differences in findings call for testing hypotheses about comparative effects of the direction of light, its brightness, and duration as an important next step. A very large sample will be needed to tease apart these effects.

Additional research may also help resolve an apparent paradox discovered by Papadopoulos, Frangakis, Skalkidou, Petridou, Stevens, and Trichopoulos (2005), who

[11]They speculate that this could be because of the difficulties of measuring light brightness and the light spectrum.

studied Greek suicide data for ten years (1992-2001). They learned that suicide risk is significantly associated with solar radiance (brightness) the day before the suicide especially, and also for the previous four days. Males needed longer sunshine exposure than females to trigger suicide. In general, light seems to affect humans differently by gender. What is more surprising even than gender differences is the possibility that sunshine appears to trigger suicide and to lift depression.

- Gender, mood, and light

The effects of light on mood fade over time. Mood is less stable than personality structure (for example, optimist vs. pessimist). Both mood and psychological predilections have been studied in relation to light. In a study of depression, Benedetti, Colombo, Barbini, Campori, and Smeraldi (2001) found that morning eastern sunlight, in contrast to western windows, reduced length of hospitalization in bipolar depression. Bipolar depressed inpatients in eastern rooms (exposed to direct sunlight in the morning) had a mean 3.67-day shorter hospital stay than patients in western rooms, but no effect was found in unipolar depressed inpatients (the average stay was 23.45 days; the improvement was about 11 %). Will such differences hold up when a test of the hypothesis about this effect of eastern light is replicated in the sample of 30 hospitals and thousands of patients now offered by the Kaiser Permanente Integrated Data Model?

What about reported male-female differences in response to light? In their study of depression, Beauchemin and Hays (1996) found that sunny hospital beds facing due east reduced length of stay for recovery from depressions for both sexes, compared to those beds that receive no direct sunshine. But the effect was stronger for males. Those in sunny rooms had an average stay of 16.9 days, compared to 19.5 days for those in less well-lit rooms.[12] This difference, consistent over the seasons, appeared more marked in males—bright rooms, 15.3 days, darker rooms 22.1 days—as compared with females—bright rooms, 17.9 days, darker rooms, 18.6 days.[13]

Knez (1995) and Knez and Kers (2000), studying differences between cool white and warm white light in relation to mood, also discovered differences for males and females. Males' mood is best around 3000K, whereas females' is best around 4000K. They also found that females think 4000K is warmer than 3000K. In general, they found that females have more emotional feelings about light than males. If these differences hold up in Kaiser Permanente's large sample, designing ways to adjust lighting level and color in each room (whether through external shading devices or interior light fixtures) has medical, psychiatric significance depending on whether the occupant is male or female. If architects, and those who hold the purse strings, know that paying for adjustable shading devices improves mood and, thereby, possibly increases patient satisfaction and reduces length of stay, they will have a way to justify this expense, or at least weigh it against other expenses. In any case, this finding suggests that light may affect not only

[12]A difference of 2.6 days (15%): $P < 0.05$.

[13]However, a subsequent analysis of variance to discover interaction effects of group and gender was non-significant. thus, females may still be the more affected by light, as the Knez studies suggest.

mood, but also more stable psychological conditions, like general outlook on life. This question about differential effects on mood and psychological structure is one that has been identified in the research literature and may merit further investigation using the IDM.

- Age

Light may have different significance at different stages in the life cycle.[14] Infants respond differently than elderly. Because premature infants have trouble sleeping and gaining weight, researchers (Mann, 1986; Miller, 1995; Blackburn & Patterson, 1991) have experimented with variation in light to recreate a normal night and day cycle. In all three studies infants who experienced a day and night cycle repeated both physical and behavioral developmental benefits— including more sleep and weight gain—in contrast with those in nurseries with constant light and noise levels. From such studies we hypothesize that variation in the amount of light might be more important than any particular amount of light, a hypothesis that can be tested using the IDM.

Light per se cannot help resolve every problem. For example, 16 percent of premature infants suffer retinopathy, inadequate development of the blood vessels of the retina. Several researchers who conducted experiments to test the role of light in this disorder (Ackerman, et al., 1989; Kirchner, 1998; Reynolds, 1998) decreased light levels for an experimental group in different ways, but observed no differences in the incidence of retinopathy compared with control groups. This could be because the light levels were still not sufficiently reduced. however, because the incidence and severity of the disorder decreases the longer the infant is in utero (Retinopathy, n.d.), developmental factors other than light are more likely responsible for the failure of blood vessels to have developed properly in premature babies.

- Ethnicity

What is the effect of ethnicity on one's relation to light? Are the effects cultural or individual? Euro-Americans, Hispanic Americans, African Americans, and Asian Americans have different responses to some issues of interest to hospital and health care providers—e.g., family pride, substance abuse, parent smoking, self-esteem, depression, suicide attempts, perception of high rates of peer substance abuse, perception of peer approval for substance abuse, and delinquent behavior—but none of these are directly relevant to light. Without a clear theoretical expectation for different responses to light or consistent observations leading to such a hypothesis, no research has been published on cultural differences in response to different qualities of light in any setting, including hospitals.

Color has been associated with culture. For example, white symbolizes purity in Anglo-Saxon culture, and death in Chinese culture. Orange symbolizes good health in East

[14] The adolescent patient wants a TV, music, telephone, and a place for his or her stuff; the elderly are more sensitive about being disturbed by sound in a hospital than media- and communication-oriented adolescents. This suggests a management policy regarding assignments to double rooms.

Asian Indian culture, but is less popular in Euro-American culture, symbolizing caution for roadwork. These anecdotal reports that ethnic groups have different reactions to different colors have not been substantiated through published empirical studies. This observation could form the basis for testing some hypotheses in this new area of research using IDM, which contains data on ethnic identification.

Even if a connection exists between color and culture, does it matter? That is, are there health consequences to being in the "wrong color" room? Since California especially, and the rest of the United States in general, is becoming more culturally heterogeneous, being able to consider possible effects on the cultural perception of light and color is another valuable exploration made possible by the Kaiser Permanente Integrated Data Model.

This review of the literature points to unexplored research questions, contradictory research findings, and important hypotheses that need further testing in regard to light and health. It implies the specific ways in which the Integrated Data Model will be useful in health care design research. More can be said about the value and use of IDM when we turn to a consideration of healthcare decision-making in architecture.

Use of the IDM in Healthcare Decision-making and Cost in Architecture

In healthcare, decision-making is a not based solely on financial considerations. Saving lives and healing people are goods in and of themselves. Nonetheless, quantification is useful in that it helps us compare alternatives. Moreover, it is possible to quantify both health outcomes—lives saved, pace of healing—and financial outcomes.

In terms of health outcomes, the chief dependent variable would be the number of days in hospital, or length of stay (LOS). Methodologically, reducing LOS would be a proxy for healing. From a public-health point of view, it indicates a faster pace of healing and less exposure to risks posed by hospitals (e.g., infections). From a personal perspective, leaving the hospital usually means going home to greater personal comfort. From a planning perspective, if one arrangement reduces LOS and another does not, there is a serious basis for choosing the first.

Similarly, number of lives saved can be quantified. For example, imagine that bringing natural daylight into the center of each building required long, thin buildings, only 30 feet wide, and that doing so would save .2% lives per years. One could calculate the number of lives saved over the life of the building. Imagine also that some other aspect of medical care, for example, speed of nurses' responses to patient calls, saved lives at the rate of .5% per year. One could also calculate number of lives saved over the life of the building. If the two features were complementary, one could consider investing in both, but if they would require a trade-off (if longer buildings increased nurses response time), then decision-makers would have evidence on the basis of which to choose one solution over another. Thus, quantifying financial return on health outcomes will help decision-makers decide which features are the best investments.

Sometimes quantification is financial. More efficient and effective care is sometimes less costly care, but, even so, knowing what the extra investments are buying is important. Are they buying the most effective possible care? Research using the IDM is intended to be cost neutral—that is, to describe trade-offs to decision-makers.

One important example of the need to quantify financial return on investment relates to windows. Neither the health nor financial returns on different features of windows have been measured (Boyce et al., 2003). For example, if windows of a certain size are more important than operable windows relative to lives saved or LOS, then it would be easy to justify investing in windows of that size rather than in the hardware to make them operable. However, the estimated cost of heat loss for every additional square foot of window would also have to be figured into this equation.[15] Kaiser Permanente's use of the Integrated Data Model can contribute substantially to the goal of quantifying both the medical and financial value of windows.

Preliminary findings and analysis illustration

In order to further illustrate the potential uses of the IDM model and how it can be used, we discuss here some initial, preliminary findings of the model. We cannot emphasize strongly enough that these findings are preliminary and that we have not tested them enough to believe that they represent true results. As we refine our models with appropriate additional variables, the results will change in substantial ways. Once we have completed building the statistical models, at minimum we will need to take some organized measurements of environmental conditions in a sample of rooms in order to feel confident that we have results that can be published. Since we are dealing with research in the healthcare realm, we must be prudent, i.e., we must not put forth unready findings that would then be looked to for possible changes in care protocols.

Despite these reservations, we share the information at this point since it provides, we hope, a clear way to illustrate the specifics of how research of this sort can be conducted, as well as insight into the steps taken in our initial research efforts. We begin by looking at key variables chosen for our analysis.

The IDM has the potential to use many different measures of health outcomes: patients' perception of their care, need for pain medication, readmission rates, survival, and length of stay, among others. As mentioned above, we decided to start our analysis using length of stay (LOS). To reiterate why, LOS has already been used as an indicator in examining

[15] In this regard, Keep (1977, p. 600) has remarked, "Window size is a compromise between the need to afford a satisfying view and the need to conserve energy and afford privacy. When window size is reduced, the shape and position of windows can be altered to optimize the view." This researcher offers the hypothesis that views that include three "layers"— ground, middle, and sky—are best, and that the middle layer is best when it is natural rather than man-made. Further, people prefer wider windows (3.1 m) for near objects than for distant objects (2.4 m). Finally, Keep reports that people like windows to occupy 20-30% of the wal1.

the impact of light conditions on outcomes. It is a commonly used measure of treatment efficacy in healthcare research. It is generally objective, easily quantifiable, and, perhaps most importantly, a measure of ultimate outcome rather than intermediate processes. While both process and outcome measures are useful, our main research goal was to see if design attributes and care environments have an impact on ultimate outcomes.

In addition to LOS, we used the patient's "overall rating of the hospital during their stay" as an outcome variable. This rating appears as one question at the end of the government's standard survey. Although the patient's perception of his or her care is not the same as a clinical outcome, overall perception is in and of itself an important outcome.

With LOS as the initial dependent or outcome variable, we then needed to choose the primary independent variable(s), i.e., variables that represent the design elements we wished to test. As we discussed above, the data set already included an indication of floor level set, and we added by hand a variable to indicate which direction the room faced (east, north, etc.).

We begin our analysis with the floor level variable, since compass orientation had not been fully mapped. Our initial analysis showed surprisingly strong support for the hypotheses that rooms higher up had shorter lengths of stay, with the assumed mechanism being greater access to light. The word "assumed" is quite important. We needed to do further analysis to determine if light access was, indeed, the key factor or if there were other explanations. For example, Ulrich (1984) has shown that the view from the window can impact outcomes. It is possible, then, that higher floors have better views and, thus, the view leads to the outcomes. Indeed! We would most likely have needed to measure the view to separate these mechanisms fully. Before we got that far, though, we noticed other telling relationships in the data.

In examining the results for each individual hospital, we found that the longest lengths of stay were on the first floor for most hospitals, but on the fourth floor for one. This was unexpected. After a bit of investigating, we determined that the Intensive Care Units (ICUs) were located on the first floors of most hospitals, but on the fourth floor of one. Thus, our analysis had successfully located the ICU units! More seriously, this situation illustrates a common process used for natural experiment research. One starts with a simple model and works to make sure that all variables needing to be "controlled" are included in the analyses.

Though we could still find ways to measure the impact of floor level on LOS, while controlling for ICU location, the initial results did not indicate a strong impact. Therefore, we turned our direction to room orientation, since some evidence in previous literature has shown orientation to have an impact. Our research team had mapped sixteen potential compass points—North, NorthNorthEast, NorthEast, EastNorthEast, etc. Our first step was to calculate the average LOS for each compass point (a process made "simple" only after our extended team manually remapped the 4000 plus room numbers and assigned a compass direction to each room by hand).

We next needed to take steps to make sure that we controlled for any variables that would lead to a spurious effect. The key issues we needed to look for were variables that would be related both to our dependent or outcome variable, LOS, and the independent (or test) variable, compass orientation. For example, different nursing units may have different types of window treatments than others, and these can impact the quality of light that enters the room. If light quality impacts recovery, as some hypothesize, it would potentially impact our dependent variable. We would have to control for this formally in our models, though, only if there were some systematic relationship between window treatments and compass orientation,[16] the independent variable. If the variation is not systematic, these differences become unbiased measurement error and are washed out by the large numbers of our sample. In contrast, consider the issue of different types of hospital patients. If there is a realistic chance that certain types of patients are directed to one compass orientation more than others, we would need to control for that. Maternity patients are one key population that comes to mind. Conceivably, some hospital planners decided where to place maternity units based on sun exposure—either wanting the brighter light of a southern exposure, the more peaceful lighting of northern exposure, the good morning light of eastern exposure, etc. Since maternity stays are generally short—about two days—if all maternity patients were directed to southern exposure, we would see a shorter length of stay in south units based solely on this assignment. Even if we do not know that hospitals are intentionally structured this way, we need to control for such reasonable possibilities.

Below, we list some key control variables that we have been using in the model, along with an explanation of why we think they are important. We also mention others we are considering adding and why. Our statistical approaches include different types of multivariate analysis—OLS regression, logistic regression, etc.—which allow one to consider simultaneously the impact of independent variables (compass orientation) against our dependent variable (LOS) while controlling for many contextual factors that can impact this relationship. (We will not get into all the details of why we are using specific methods here, but just want to mention that certain types of data require certain types of analytic methods and that we are using various methods to explore relationships in more detail.)

Patient Type: Along with maternity patients, we are controlling for the key services of surgery and medicine. These are key patient types that may be related to placement in the hospital.

Diagnostic Related Group (DRG): DRG's, standard government codes that indicate specific diagnoses of the patients, represent a much more finely-grained specification than patient type. For example, there are approximately 25,000 separate DRG designations. To work with these in a meaningful way, we will group them into

[16]We did control for facility, as we mention later on, which would control for differences among the facilities in areas such as window treatments. For example, if a certain set of facilities have the same type of window treatment throughout the facility, controlling at the facility level could help control for this pattern.

categories. We can use the DRG designations as a further check to make sure that differences in compass orientation are not due to certain types of patients being directed systematically to certain sides of the hospital. We can also use them to see if light/compass orientations impact different types of ailments (because previous research has demonstrated that certain conditions are more affected by light than others).

Season: Time of year impacts the quality of light and the direction of the sun's movement. The impact of orientation on LOS may thus be substantially different, even directionally different, at certain times of year. It may also have a stronger or weaker impact at different times of year.

Facility: Since some facilities may have different lengths of stay and face different directions, or both, we will need to control for facility.

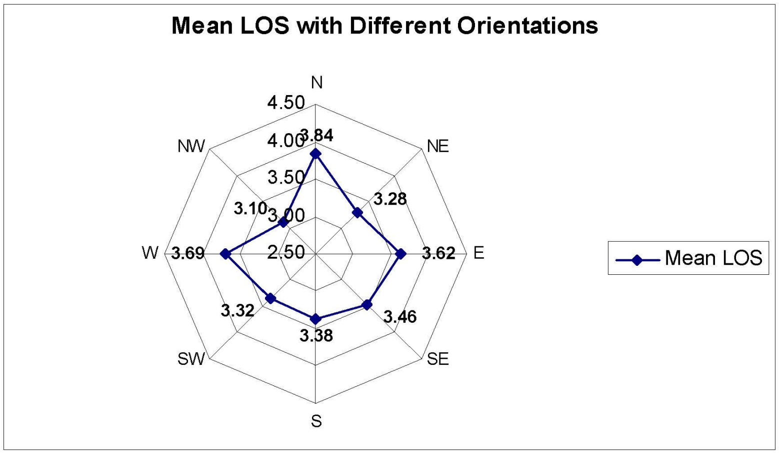
Region: Distinct climates inherent in different California regions may impact the orientation or length of stay.

Patient demographics: Gender, ethnicity, health status are all variables that can be controlled to help ensure we are comparing apples to apples. We can also use information about patients to see if design elements impact different groups of people in different ways.

Survival: Previously mentioned research has suggested that orientation can even impact whether a person survives the hospital stay (Beauchemin & Hays, 1998). We assume that such extreme effects are not common and, like all research, needs to be further replicated. Nevertheless, we will need to control for survivability, since a shorter hospital stay could mean either that a patient recovered more quickly or did not recover at all.

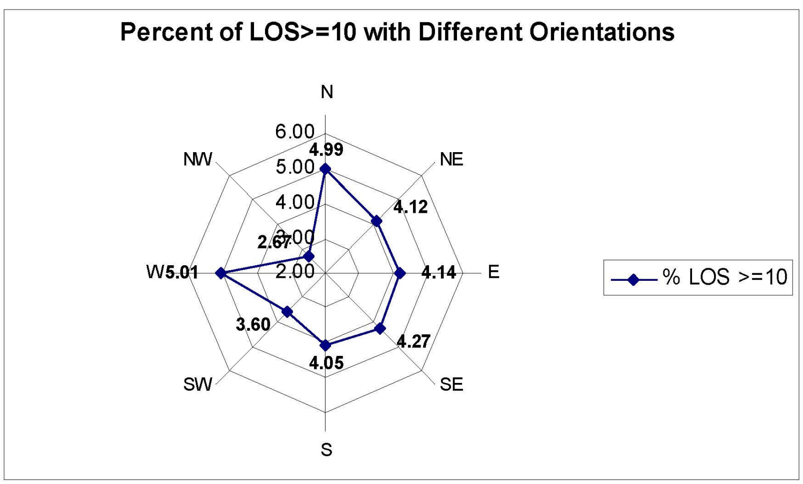
Graph 1: LOS and Orientations

KAISER PERMANENTE®



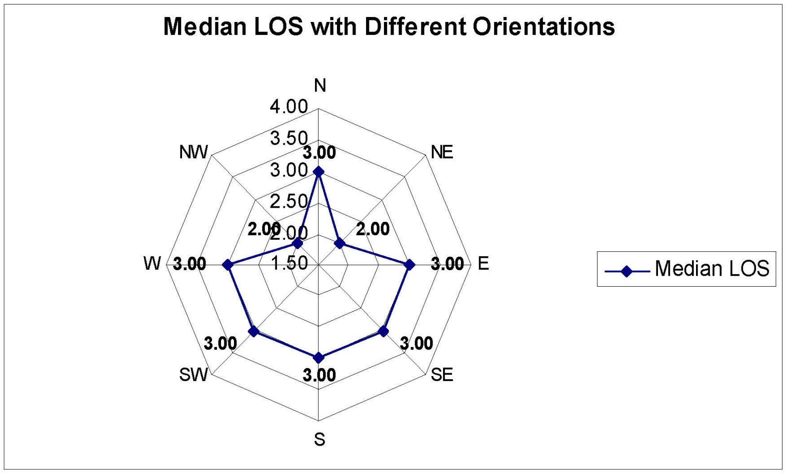
Graph 2: LOS and Orientations

KAISER PERMANENTE®



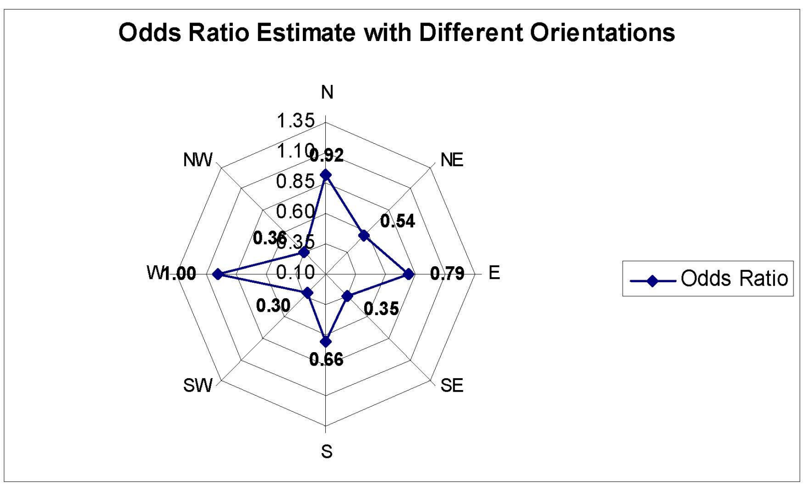
Graph 3: LOS and Orientations

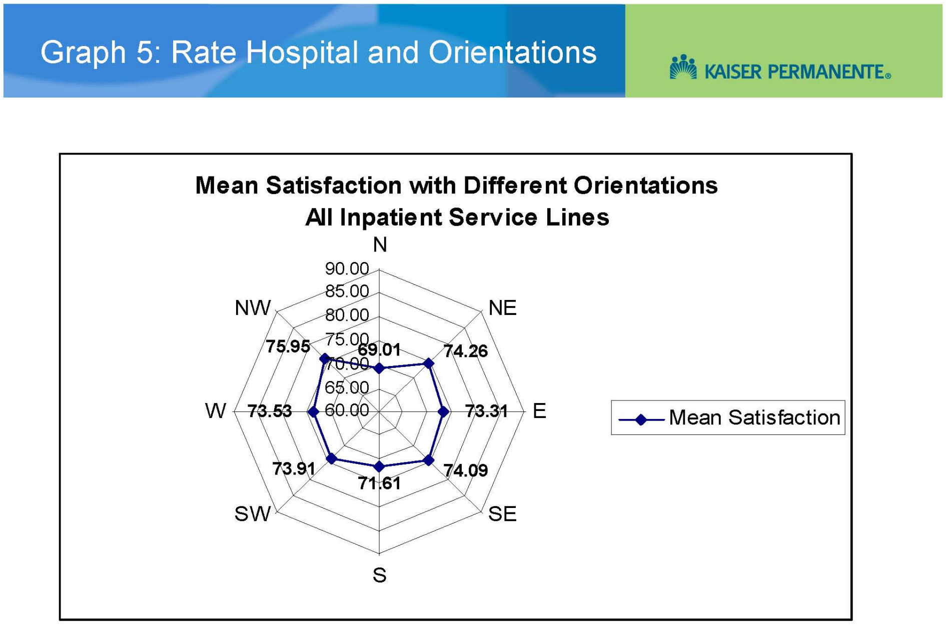
KAISER PERMANENTE®

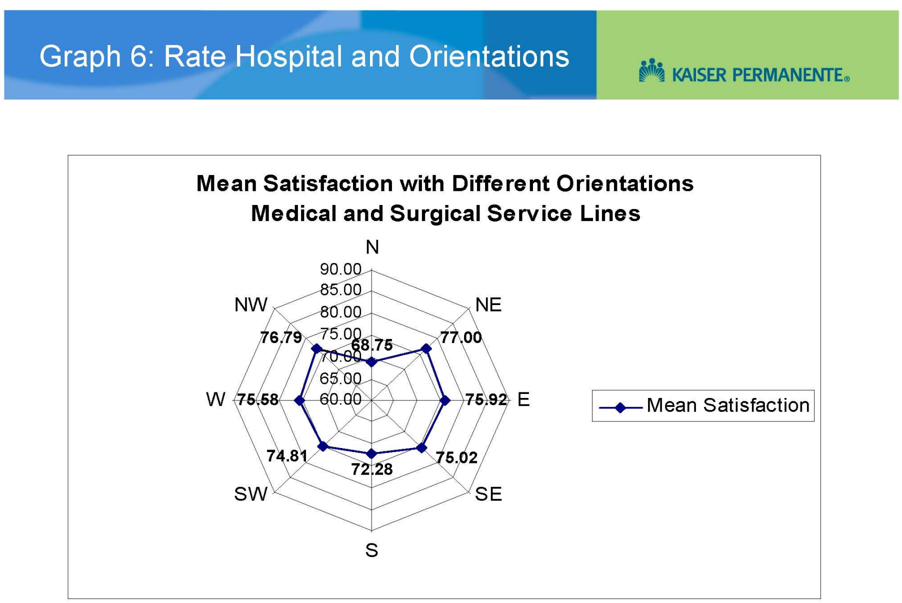


Graph 4: Odds Ratio Estimate on LOS>=10

KAISER PERMANENTE®







Our initial draft results are presented in Graphs 1-6. These "spider" graphs plot the results in a form analogous to compass orientation so that one can visualize the pattern of the results as they map to the compass. In order to perform the type of multivariate analysis we thought appropriate for data of this sort—a logistic regression—we dichotomized LOS into less or more than 10 days. The sample size is over 24,000 patient stays. This draft analysis uses data only from southern California, since, for logistical reasons, that data set was ready first. The northern data, which has the rooms matched, will ready for analysis shortly. We offer views of the relationships with several different variables: Graphs 1-3 show the relationship of orientation to LOS, with LOS measured as an average, a median, and the percentage of cases with a LOS greater than 10 days. Graph 4 shows the "odds ratio" (a common measure used for interpreting a logistic regression) of the length of stay being greater than 10 days. The higher the ratio, the higher the odds of the LOS being greater than 10 days. Each of these analyses included the following control variables: Facility, Visit Type (Medicine, Surgery, Childbirth), and Season. (DRG will be added when fully categorized.) Graphs 5 and 6 show the relationship between patient satisfaction and compass orientation for all types of patients and for all types except maternity.

In looking at the results, we see some subtle patterns, but nothing dramatic. This is not surprising since one would not expect orientation to have a dramatic impact on LOS. Given our large sample size, most or all of these differences are statistically significant, meaning they are not due to random luck tied to our sample of patients. However, the question remains whether the differences are truly tied to room orientation or some other, unidentified factor. Since these are preliminary results, we discuss only those issues related to our key relationships here. We do not go into full detail regarding statistical specifications since these models are not complete and such in-depth discussion will distract from our larger points in this report. Likewise, we have not stated formal hypotheses. The literature review above leads to some obvious ones regarding the benefits of east facing windows and the downsides of north facing, and we discuss these briefly below; detailed hypotheses will be developed later when chains of cause and effect are more clearly specified.

The results show that rooms facing north and west tend to have longer lengths of stay and lowest levels of patient satisfaction. Previous research has suggested that north facing rooms may lead to lower survival rates among cardiac patients (Beauchemin & Hayes, 1998); our study may be picking up on a similar dynamic. Yet we cannot assume that we have a definitive finding at this point, for several reasons. First, as we added controls to the statistical analyses, the results have changed such that sometimes other orientations perform worse than north. (Therefore, we must be especially careful to include appropriate control variables.) Second, the observed pattern across neighboring compass points is difficult to interpret. The results would be easier to understand if we saw clear patterns, e.g., that all of the compass points to the north (NE, N, NW) have a similar impact, and all south (S, SW, SE) have a similar impact as a group. However, the NW and NE orientations have shorter LOS and higher patient satisfaction. Why might this be true? Perhaps the dullness of full northern exposure is bad for patients, but the indirect lighting of NW and NE presents the correct balance of light variation without getting the intense, direct sun of East or West. The shading of the partial northern exposure may be especially useful in the hot climate of southern California. These explanations sound plausible but at this point are still speculation.

An important issue that has emerged from our initial analysis is that the distribution of room orientations is not even across the 16 compass points we mapped because most of our hospitals are four-sided, i.e., not round. To deal with the uneven distribution, we reduced the original 16 points into 8, as these graphs currently show. This helped to even out the distribution.

Distribution is a potential issue, because if we have only a few buildings facing a certain direction, the shorter length of stay in that direction could be coincidental, due to the type of care provided in those buildings rather than the directions they face. We can control for the impact of individual buildings, but, given the potentially large impact of this issue, we need to build the statistical model carefully to deal with this reality.

Likewise, the existing literature does not articulate any relative advantages of closely related compass points, e.g., NNE versus NE. For the most part, existing studies contrast eastern directions (with morning sun) to western directions (afternoon sun), or the relative lack of sun of northern exposure to the brighter southern exposure. Therefore, a next step in our analysis will be to combine current orientation variables into a set of contrasts—all northern points versus all southern, all eastern versus all western. By combining these categories, our tests will be more in line with existing theory that expects east to be better than west and north to be worse than south.

Finally, we are using orientation as a proxy for light. Later, if we take actual, organized measurements of light and other environmental conditions in the rooms, this would increase confidence in our findings about the impact of orientation on LOS. With our room linking process, we can add these measurements directly to the database and conduct analyses to explore the relationships. Because these measurements would take substantial time, we would not do them for every room, but such a sample would be extremely helpful.

<u>Future research projects</u>:

The IDM already includes other variables that would allow relatively quick analyses to be conducted on other design related topics. These are beyond the content focus of the Latrobe study, but we mention them here to give a further sense of the potential of the tool. For example, since we have information on the number of beds included in a room, we could measure the impact of number of beds on LOS, on patient satisfaction, and on hospital-acquired infections (we have these DRGs). We have information about the size of the rooms and could add data about how far the rooms are from the nursing station. Once this measurement is added, we already have the data in place to look at its impact on LOS, survivability, patient satisfaction, etc. Once the infrastructure is set up, the logistics and cost of conducting large-scale research are greatly reduced. We do not want to give the impression that one will merely be pushing a few buttons. On the contrary, the structure of the research will require careful consideration, especially if additional measures need to be created. But the length of a research project will be reduced from a matter of years to a matter of months, and the cost reduced by many zeros.

Summary: Why KP's IDM will be useful and influential

This study has the capacity to make many contributions to the project of defining and designing healing environments. If the IDM model is used in a systematic way to create evidence in a healthcare setting, in time it will be possible to articulate what creates a healthy environment. Once all of the components are known, architects and policy makers can successfully create healthy environments in hospitals.

The importance of light, and circadian rhythm in particular, to both patients and staff has been established by numerous studies, but these hypotheses are tentative and have not been tested on extremely large samples. For the first time researchers will be able to test these hypotheses on samples as large as 100,000 cases, and researchers can test them across multiple facilities, simultaneously.

Healthcare decision-making will benefit from this project. The econometric model will provide designers and owners with a tool to evaluate the cost-benefit of different design options. This will omit the aggravation for design professionals in having to persuade owners to pay for design solutions that have demonstrated financial benefit. Theoretically, this might even decrease the need to build more buildings if better management policies emerge. For example, if certain diagnoses respond better than others to daylight , the total savings in patient days that might accrue simply by assigning the right patients to the right rooms could conceivably reduce the overall demand for rooms.

The possibility of different outcomes for different disease categories would have important management implications in concert with physical design implications. For example, assigning people to the sunny sides of a building might be especially important for those who have diseases that respond well to natural light. Similarly, the sunny rooms might be saved for those who have long (8-10 day) stays rather than short (2-day) stays.

Architectural practice will benefit, starting with those architects who specialize in healthcare design. For various reasons, architectural practice is often not based on systematic evidence. The IDM model now offers an effective way to include research data in practice because it creates a large body of scientific evidence that is directly relevant to healthcare design decision-making anywhere in the nation.

Ultimately, the IDM will be used because it will improve hospital design, which, in turn, will benefit so many different groups—patients, hospital staff, architectural firms that specialize in the design of healthcare facilities, and all architects interested in evidence-based design.

Reference List

Ackerman, B., Sherwonit, E., & Williams, J. (1989). Reduced incidental light exposure: effect on the development of retinopathy of prematurity in low birth weight infants. *Pediatrics,* 83 (6), 958-962.

Beauchemin, K. M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. *Journal of Affective Disorders,* 40, 49-51.

Beauchemin, K. M., & Hays, P. (1998). Dying in the dark: Sunshine, gender and outcomes in myocardial infarction. *Journal of the Royal Society of Medicine,* 91, 352-354.

Benedetti, F., Colombo, C., Barbini, B., Campori, E., & Smeraldi, E. (2001). Morning sunlight reduces length of hospitalization in bipolar depression. *Journal of Affective Disorders,* 62, 221–223.

Leonard L. Berry et al. (2004). The business case for better buildings. *Frontiers of Health Services Management,* 1(1), 6.

Blackburn and Patterson. (1991). Effects of cycled light on activity state and cardio respiratory function in preterm infants. *Journal of Perinatology and Neonatal Nursing,* 4(4), 47-54.

Boyce, P., Hunter, C., & Howlett, O. (2003*). The Benefits of Daylight through Windows.* Rensselaer Polytechnic Institute, New York: Lighting Research Center. 83pp.

Devlin, A. S., & Arneill, A. B. (2003). Health care environments and patient outcomes: a review of the literature. *Environment and Behavior*, 35 (5), 665-694.
Duffy, F. (July 6, 2007). E-mail communication.

Eagles, J. M. (1994). The relationship between mood and daily hours of sunlight in rapid cycling bipolar illness. *Journal of Biological Psychiatry*, 36, 422-424.

Evidence based design. (n.d.). Retrieved June, 2007 from Http://en.wikipedia.org/wiki/Evidence--based _ design, 10/10/2005.

Ferraro, F., Pfeffer, J., & Sutton, R. I. (2005). Prescriptions are not enough. *Academy of Management Review*, 30(1), 32–35.

Gibbons, M., Limoges, C., & Trow, M. (2004). *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Sage Publications.

Heerwagen, J. H. (1990). Affective functioning, 'light hunger,' and room brightness preferences. *Environment and Behavior,* 22; 5, 608-635.

Kaiser Permanente Hospitals. HealthConnect System described by Kaiser Permanente. Retrieved June, 2007 from on the World Wide Web: http://ckp.kp.org/kpindepth/archive/indepth_faq_all.html

Kecske´sa, I., Rihmera, Z., Kissa, K., Varghab, A., Szilia, I., & Rihmer, A. (2003). Possible effect of gender and season on the length of hospitalization in unipolar major depressives. *Journal of Affective Disorders,* 73, 279–282.

Keep, P.J. (1977). Stimulus deprivation and windowless rooms. *Anesthesia,* 32, 598-600.
Keep, P., James, J., & Inman, M. (1980). Windows in the intensive therapy unit. *Anaesthesia,* 35**,** 257-262.

Knight, J. A., Thompson, S., Raboud, J. M. & Hoffman, B. R. (2005). Light and exercise and melatonin production in women. *American Journal of Epidemiology*, 162(11), 1114-1122.

Kolata, Gina. (November 7, 2007). Causes of Death Are Linked to a Person's Weight. *New York Times*.

Konrad, A. M., Mangel, R. (2000). The impact of work-life programs on firm productivity. *Strategic Management Journal*, 21(12),1225-1237.

Kouletsis, J. (July 13, 2007). E-mail communication.

Lambert, G.W., Reid, C., Kaye, D.M., Jennings, G.L., Esler, M.D., (2002). Effect of sunlight and season on serotonin turnover in the brain. *Lancet*, 360, 1840– 1842.

Lewy, A. J., Bauer, V. K., Cutler, N. L., Sack, R. L., Ahmed, S., Thomas, K. H., Blood, M. L., & Latham Jackson, J. M. (1998). Morning vs. evening light treatment of patients with winter depression. *Arch. General Psychiatry*, 55, 890-896.

Mannina, M. (July 12, 2007). E-mail communication.

Mann, N.P., Haddow, R., Stokes, L., Goodley, S., & Rutter, N. (1986). Effect of night and day on preterm infants in a newborn nursery: Randomized trial. *British Medical Journal,* 293, 1265 -1267.

Marcus, C. C. (July 12, 2007). E-mail communication.

Miller, C.L., White, R., Whitman, T. L., O'Callaghan, M. F., & Maxwell, S. E. (1995). The effects of cycled versus noncycled lighting on growth and development in preterm infants. *Infant Behavior and Development,* 18, 87-95.

Moline, J., Mellerup, E., Bolwig, T., Scheike, T., & Dam, H. (1996). The influence of climate on development of winter depression. *Journal of Affective Disorders,* 37, 151-155.

Papadopoulos, F. C., Frangakis, C.E., Skalkidou, A., Petridou, E., Stevens, R.G., & Trichopoulos, D. (2005). Exploring lag and duration effect of sunshine in triggering suicide. *Journal of Affective Disorders*, 88, 287–297.

Parker-Pope, Tara, January 29, 2008, WELL; Great Drug, but Does It Prolong Life?

Pfeffer, J. & Sutton, R. I. (2006). Evidence Based Management. *Harvard Business Review*, 1-13.

Retinopathy. (n.d.) Retrieved June, 2007, from **http://www.nei.nih.gov/health/rop/index.asp**

Reynolds, A. D., Hardy, R. J., Kennedy, K. A., Spencer, R., Van Heuven, W. A. J. & Fielder, A. R. (1998). Lack of efficacy of light reduction in preventing retinopathy of prematurity. *The New England Journal of Medicine,* 1572-1576.

Ruga, W. (1989). Designing for the six senses. *Journal of Health Care Interior Design*, 1, 29-34.

Sachs, A. (2007). *Research for Architecture: Building a Discipline and Modernizing the Profession.* University of California at Berkeley: unpublished Ph.D. manuscript.

Salamone, L. M., Dallal, G. E., Zantos, D., Makrauer, F., & Dawson-Hughes, B. (1993). Contributions of vitamin D intake and seasonal sunlight exposure to plasma 25-hydroxyvitamin D concentration in elderly women. *Am J Clin Nutr,* 58: 80-6.

Schweitzer, M., Gilpin, L., & Frampton, S. (2004) Healing spaces: Elements of environmental design that make an impact on health. *Journal of Alternative and Complementary Medicine*, 10, (supplement 1), pp. S-71-S-83.

Stern, A. L., MacRae, S., Gerteis, M., Harrison, T., Fowler, E., Edgman-Levitan, S., Walker, J., & Ruga, W. (2003). Understanding the Consumer Perspective to Improve Design Quality. *Journal of Architecture and Planning Research,* 20 (1), 13 pp.

Stevens, R. G. & Rea, M. S. (2001). Light in the built environment: Potential role of circadian disruption in endocrine disruption and breast cancer. *Cancer Causes & Control*, 12 (3), pp. 279-287.

Takasu, N. N., Hashimoto, S., Yamanaka, Y., Tanahashi, Y., Yamazaki, A., Honma, S. & Honma, K. (2006). Repeated exposures to daytime bright light increase nocturnal melatonin rise and maintain circadian phase in young subjects under fixed sleep schedule. *Am J Physiol Regulatory Integrative Comp Physiol,* 291:1799-1807.

Ulrich, R. S. (1981). Natural versus urban scenes: Some psychophysiological effects. *Environment and Behavior*, *13*, 523-556. Cited in Devlin & Arneill Devlin, A. S., &

Arneill, A. B. (2003). Health Care Environments and Patient Outcomes: A Review of the Literature. *Environment and Behavior*, 35 (5), 665-694.

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*, 420-421.

Ulrich, R. S. (1991). Effects of interior design on wellness: Theory and recent scientific research. *Journal of Health Care Interior Design*, *3*, 97-109.

Ulrich, R. S. (1992). How design impacts wellness. *Healthcare Forum Journal*, *35*, 20-25.

Ulrich, R. S. (1995). Effects of healthcare interior design on wellness: Theory and recent scientific research. In S. O. Marberry (Ed.), *Innovations in healthcare design: Selected presentations from the first five symposia on healthcare design* (pp. 88-104). New York: Van Nostrand Reinhold.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A.,& Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*, 201-230.

Ulrich, R., Zimring, C., Joseph, A., Quan, X., & Choudhary, R. (2004) The role of the physical environment in the hospital of the 21st century: A once-in-a-lifetime opportunity. *Report to The Center for Health Design for the Designing the 21st Century Hospital Project.* 69 pp. [Electronic version.] Retrieved July 2007, from http://www.healthdesign.org/research/reports/physical_environ.php

Verderber, Steven, "Person-Window transactions," *Environment and Behavior,* 18, 4, July 1986, 450-466.

Verderber, S., & Refuerzo, B. (1994). Empowerment on main street: Implementing research based design. In R. M. Feldman, G. Hardie, & D. G. Saile (Eds.), *Power by Design. Proceedings of the 24th annual conference of the Environmental Design Research Association.* (pp. 281-283). Oklahoma City, OK: EDRA.

Verderber, S., & Refuerzo, B. J. (1999). On the construction of research-based design: A community health center. *Journal of Architectural and Planning Research*, *16*, 225-241.

Walch, J. M., Rabin, B. S., Day, R., Williams, J. N., Choi, K. & Kang, J. D. (2005). The effect of sunlight on postoperative analgesic medication use: A prospective study of patients undergoing spinal surgery. *Psychosomatic Medicine,* 67:156–163.

Wallace-Guy, G. M., Kripke, D. F., Jean-Louis, G., Langer, R. D., Elliott, J. A., & Tuunainen, A. (2002). Evening light exposure: Implications for sleep and depression. *Journal of American Geriatrics Society,* 50, 4, 738-739.

Wirz-Justice, A., Graw, P., Kauchi, K., Sarrafzadeh, A., English, J., Arendt, J., & Sand, L. (1996). 'Natural' light treatment of seasonal affective disorder. *Journal of Affective Disorders,* 37, 1O9-120.

Zimring, C., & Welch, P. (1988). POE: Building on 20-20 hindsight. *Progressive Architecture*, *7*, 55-60.

CHAPTER 4 – THE MODEL

THE MODEL

W. Mike Martin, Ph.D.

The Model: Its Grounding and Derivation

The conceptual model that informed the process undertaking in the Latrobe Project took its framework from recent research associated with what is referred to as Mode 2 Research (M2R). At the core of this model is the agenda of knowledge production connected to a context of addressing everyday challenges in people's lives, business, education, etc. It is a model whose intent is making research more accountable to the people it serves.

As noted earlier in the introduction to this report, Gibbons et al. identify M2R knowledge production as having five characteristics, all of which to some degree were considered in the design of the Latrobe Project research approach.

- It is generated in the "context of application." This does not imply certainty about results, nor is it independently conceived and generated Mode 1 research later applied to a real setting. It arises from "the very work of problem resolution."
- It is "trans-disciplinary." A range of methods is used that come together often in novel forms to solve a specific problem.
- It is produced "across knowledge organizations and in a variety of settings."
- It is "reflexive" in that there is conversation between the researchers and the subjects. The problem-resolution environment influences the topic, the research design, and the end uses. Consequences are intrinsic to the research process.
- It must "accommodate multiple definitions of quality" because there are many players and a lack of strict disciplinary criteria with which scientific peers can evaluate.

The specific research question addressed in the Latrobe Project (LP) was: "Credible, applicable 'evidence' of relationships between design and client organizational performance will result from 1) a collaborative approach that unites the perspectives, skills, and resources of an architectural firm, a university research community, and a client; and 2) the use of both scientific research methods and inductive reasoning." This research hypothesis is formulated in a context of architectural practice, where an emphasis is now being placed on decision-making, in which evidence about the impacts of the physical environment on human response and organizational performance is explored as a means to advance the practice of evidence-based design.

As a starting point, the Latrobe Project Team (LPT) agreed that cultural practices, procedures, language, and other mores exist that divide the way practicing architects, academic researchers, and clients approach knowledge production and management. These differences in approach were summarized in Chapter 1 of this report, but are repeated here to help frame the context of the research process reported in this chapter:

- Architects have valuable experience, technical knowledge, and creative skills. However, in the realm of human response to environment, architects too often turn to intuition, personal experience, precedent and anecdote, rather than methodologically rigorous research. They thereby perpetuate conventional wisdom and fail to provide their clients with the information they need to make the design decisions that would best support their end users.

- Expert in research methodology and focused on qualification through scholarly peer review, university research communities possess a critical understanding of scientific protocols that enriches the body of knowledge available for design application. However, university researchers also often discount research done outside academia and work within their discipline in isolation from both architects and their clients—the people who need to utilize the research results. Consequently, many researchers pursue topics of scholarly interest but limited potential value in actual design application.

- Some people with responsibilities for in-house facilities, real estate, and capital planning within client organizations believe that design has the power to enhance their core businesses, but they lack access to the "evidence" they would need to make credible business cases to that effect. Not finding the compelling data they require, interpreted in terms of relevant econometric and other performance measures, some client organizations are conducting their own research. This varies greatly in quality, depending on the skills of the individual.

The Latrobe Project proposed that despite these differences, the three stakeholders—practicing architects (Chong [now Stantec]), the clients they serve (KP), and university research communities (UC Berkeley)—together had the perspectives, skills, and resources to enrich the understanding of ways that design outcomes influence human response and organization performance. The goal was to create and make accessible "evidence" that is useful, valid, and reliable for informing decision-making in architectural practice. Architects, informed by empirical data, not conjecture, need to know what to build and to be able to support their assertions about design impacts in order to garner client approval to implement the most effective design strategies and innovations.

A Summary of the Research Model Approach

The Latrobe Project framed its research model around three characteristics:

1. Utilizing scientific methods and research techniques from the behavioral sciences, bio-medical and neurosciences, as well as inductive reasoning from architectural practice processes, as the informants and tools for collecting data;

2. Applying the organizational sciences, applied economics, psychological, sociological, and physiological metrics to measure human responses and organizational performance to various design conditions; and

3. A collaborative process composed of a practicing architectural firm, a university research community, and a leading healthcare provider to seek the best ways to utilize the skills and knowledge of all three in a trans-disciplinary framework.

There were two concurrent focal points to the research:

1. In a disciplined manner, observe, assess, refine and document the approaches used to create the research in order to allow the architectural profession to learn from it and apply the outcome in future architectural practice settings (The Model).

2. Conduct a pilot study in a healthcare context to yield immediately applicable data and to construct and test the model (The Pilot).

The specific research plan, presented in Chapter 1, sets the stage for the specific research efforts of the Latrobe Project and its team members, both individually and collectively. As an overview, the research plan can be understood as comprising four major phases, each with sub-components:

1. Problem Definition and Research Plan
    - Team building/ Establishing goals
    - Engaging stakeholders and experts
    - Preliminary literature search
    - Lighting and health
    - Color and health
    - Evidence-based practice
    - Healthcare design
    - Mode 2 knowledge production
    - Refining pilot study topic(s)
    - Research plan development

2. The Natural Experiment: Eventually this became titled the KP Integrated Data Model. The concept was to take advantage of the wealth of existing data residing within KP's medical data routinely collected of all patients, which could provide physiological measures in great numbers without intrusion. Design interventions could be conducted to modify environmental characteristics and assess resulting medical responses and patient perceptions; or analyses could be conducted of existing room attributes to determine correlations with medical or satisfaction measures. The Principal Investigator for this work was Robert Mangel, Ph.D.

3. The Laboratory Experiment: This approach was based on using rigorously controlled conditions and multiple measures to enhance the strength of evidence. Physiological and cognitive responses to specific light qualities were analyzed and interpreted in the context of an extensive literature base. This Mode 1 research was complemented by field measurements and design charrettes relating it to Mode 2 applications. Scientists from Ohio State University, UC San Diego, Rensselaer Polytechnic Institute, and the National Institute of Mental Health provided advice, technical expertise, and resources. The Principal Investigator for this work was Eve Edelstein, Ph.D. (see Chapter 2).

4. The Model: A primary goal was to learn about the benefits of the research approach. Observation of the model as it was actually applied to define and carry out the research plan, therefore, was treated as its own research track. W. Mike Martin, Ph.D. was the Principal Investigator for this work.

A brief chronicle of the specific tasks and activities of the Latrobe Project team illustrates the struggle to operate effectively in this trans-disciplinary, multi-organizational structure. The team first looked internally to identify goals and measures of success. This was followed by engaging Chong Partners Architecture (subsequently Stantec) designers and KP representatives to identify research inquiries that would be useful in real application on healthcare projects. The team identified a number of potential topics for pilot studies and, concurrently, debated the merits of various disciplines and methodologies to determine how to ensure an appropriate level of rigor and guarantors of success in terms of evidence that would meet the requirements of the users in the applied context.

At the same time, interests of the team members, the need for additional disciplinary expertise, and available resources were explored to bring the process of refining the topic and approach of the pilot study to closure and agreement. Ultimately, two parallel tracks, noted above, were defined that would enable exploration of different sets of specific research questions and methodological approaches, with the potential of bringing the outcomes together at the end to inform the development of a model for research in practice, as well as to provide specific evidence to inform evidence-based design practice.

Tracking the Process

In an effort to track the process components of these two parallel research projects, careful minutes were kept of each formal team meeting. A total of 14 such meetings were recorded. In addition, each team member was asked to keep a logbook of special meetings and activities of the research effort to be reflected in the final report of the specific research track.

Each team member was also asked to respond to a set of process questions that would provide insight into the specific engagements, research applications and methods, protocols for analysis, outcomes and conclusions of the experiment, and statements about the implications of the outcomes for designing each of the parallel tracks. They were also asked to reflect specifically on the process of conducting the research track in the context of the Latrobe Project agenda and note the challenges, successes, failures, and things they would change.

The following is a synthesis of this process tracking data, as reflected by each major question category. Included are example responses by team members to the specific questions, as well as extractions from meeting notes and the formal reports. The purpose of this section is to establish the flavor and operating values embedded in each of the projects and the team as a whole. (Note that specific track comments are identified as follows: NE—Natural Experiment, LE—Laboratory Experiment)

1. **<u>In terms of outcomes, what form and substance will the evidence take?</u>**

    - NE—The Natural Experiment, the "Integrated Data Model" (IDM) created a large database structure and established variables around facility orientation related to natural light. This is a starting point for a large scale, ambitious research process that will continue within KP to contribute usable evidence to inform future facility planning and design projects in KP. We chose to set up a large scale, long-term project, to be integrated with other projects at KP, rather than to have a smaller scale initiative that would be more likely to have near term results.

    - NE—The Natural Experiment will not yield "evidence" in the time frame of the Latrobe Project, but the IDM, as a tool, will exist in a functional form and it will produce "evidence" when applied in future research efforts. The idea of integrating medical records data that are real, active, and continually building with design attributes through an equally "active" CAFM system is a very powerful condition for future research.

    - NE—The IDM has the potential to be very substantial by virtue of its unprecedented size and ability to correlate medical data with design attributes. However, it will only be as useful to designers as the design attributes that are added to it. One immediate limitation is the paucity of meaningful design attributes that have been added to the database, e.g., those that a designer might be able to apply and that would be innovative.

- NE—The potential survey data for the Natural Experiment of the Latrobe Project are notable, given the sheer size of the sampling. Despite the fact that the survey was not written specifically to answer questions that inform design, numerical trends may lead, in the future, to definitions of design hypotheses that can be studied in a laboratory or other setting, through simulation or in field environmental correlations.

- NE—With the addition of light measurements and compass orientation, empirical tests of current hypotheses about the effects of light on patient well-being using the KP IDM allows for tapping a natural experiment that has been occurring for years through a normal data collection process.

- LE—The Laboratory Experiment provides evidence in the form of physiological data (heart rate variability and EEG brain waves) that are accepted by the scientific community as sensitive indicators of health risk, health status, and cognitive function. These data included:

    - Evidence literature reviews from a broad range of disciplines: biological, medical, psychological, engineering, architectural.

    - Evidence from literature reviews of the social sciences and humanities (architectural, sociological, psychological, the arts), which provide a continuum from qualitative to quantitative and descriptive statistical findings that offer information and insights into personal, cultural, and social behavioral responses.

    - Evidence from original laboratory research using quantitative studies conforming to best practice for empirical research utilizing scientific methodologies for designing, measuring, and analyzing results.

    - Statistical analyses of such data provide measures of significance.

    - Case studies of occupied and built (unoccupied) sites using new, lightweight, mobile methods to make measurements within architectural environments.

- LE—The Laboratory Experiment has yielded data using valid, physiological measures. In that sense, it will advance the pursuit of connections between design and highly predictive human responses.

- LE—One concern about the Laboratory Experiment is that it did not test directly the influence on design applications. If there are alternative means of providing the lighting profile that achieve the same benefits, will redesigned rooms or reconfigured floor plates be pursued in the context of the larger arena of healthcare facility planning? The answer to this is "possibly," if the studies consider multiple design attributes that included patients, family, and staff well being.

2. **<u>How will the findings be illustrated so that they inform design and designers?</u>**

- NE—The teams that will be conducting the future research utilizing the IDM will be multi-disciplinary, with architects and designers as integral members. With these design professionals in place, it will be illustrated in a way that it will inform design and designers.

- NE-LE—Design principles, charrettes, field studies, and illustrations exemplify how the findings may inform design. However, more time is needed to test design interventions based on the findings, as well as their physical implications.

- LE—The Latrobe's decision to include physiological measures and health indicators (stress as evidenced through heart rate variability) was served by experiments in a controlled environment. The process was thus repeatable and controlled, allowing for greater statistical power from a limited sample of subjects.

- NE—The data resulting from future use of the IDM can be illustrated in correlation figures and tables that will be the first demonstrations of these relationships on a large scale, and then literal illustrations might be drawn in order to demonstrate the physical significance of these relationships.

- LE—The application of our experimental findings are described as:

  - "Design hypotheses"

  - "Design principles" that reflect the scope of application of the new original data and related results from existing literature.

  - Case studies of built and occupied facilities that demonstrate how to test the hypotheses in real environments.

- A charrette that brought together representatives from the disciplines to consider how the scientific findings relate to qualitative and intuitive observations in the design of healthcare spaces. Design concepts were discussed and derived based on the charrette format.

- LE—Translation of the research outcomes across disciplines is still required. Participants with expertise in design, architecture, the humanities and sciences must participate to provide this insight and to test resultant outcomes in real, operational environments.

3. **<u>What are the "best practices" associated with domain of research that have informed your strategy for undertaking the specific research agenda?</u>**

- NE—Econometric techniques have been used recently to analyze issues from baseball to wine tasting; we are applying this body of methodological approaches to evidence-based design.

- LE—The scientific method is the "best practice" approach associated with empirical research and applied in the design of the research agenda.

- LE—The Scientific Method includes controlled research design, an empirical research approach, and statistical analysis of results to substantiate the repeatability, reliability, and validity of results.

- LE—The lab experiment made good use of previous research from the literature and also engaged the involvement of experts with relevant research protocols. This increased the likelihood of valid results and expanded the strength of evidence well beyond the small sample studied in this project.

- NE—A review of the literature, and especially several articles that review and evaluate the quality of research done regarding the nature of light and wellness outcomes.

4. **<u>What are the markers of quality that are the guarantors for the expected outcome evidence?</u>**

- NE—Well argued hypotheses, tested empirically, and requiring statistical levels of significance.

- NE—Medical data, volume.

- NE—Research does not guarantee results, but we will be following well-defined markers and applied economics protocols. For example, we will work to present the information at peer-reviewed conferences and in peer reviewed journals.

- LE—Statistical analyses demonstrate the quality of the findings, namely, a highly significant difference between responses under different light conditions. Markers of quality include measures of statistical significance, the research design, the use of objective measurement systems, and a validated methodology based on and compared to established standards (gold-standards).

5. **<u>How will this evidence inform evidence-based practice methods?</u>**

- NE—By following approaches that have as clear as possible linkages between design specifications and performance outcomes, for example, the well-being of patients.

- NE—The significant result is the database as a means to both test specific new interventions on site and to mine for effects of pre-existing conditions. It will be continually refreshed and benefit from scale.

- NE—By discussing the design implications in print, in different kinds of publications, some architectural, some hospital administration: Kaiser Permanente's influence on other hospitals around the United States and the world.

- LE—The laboratory experiment is an important link between bio-medical research, architectural and electrical lighting design, and health outcomes. It continues the efforts to connect design and neuroscience.

- LE—The results demonstrate that literature reviews and laboratory research in the biomedical disciplines provide information on direct relevance to design.

- LE—Biomedical findings provide specific information relevant to design. The original data and literature demonstrate a pervasive influence of light on health outcomes, and indicate the range of light parameters that influence biological responses.

- LE—Technological advances enable on-site measures of the architectural environment. A new measurement system used in field studies demonstrated that architectural elements, lighting systems, and furnishings had significant influence on the amount of light reaching different functional zones within the building.

6. What are the theoretical and methodological foundations of the research agenda?

- NE—Person-environment theory that environment plays a role in human social life, personal well being; methodological foundations are empirical correlations between objective physical conditions and objective patient outcomes, not just reported patient experience.

- NE—Drawing on appropriate bodies of literature from architecture, organizational science, applied economics, and the healthcare field.

- LE—The scientific method and theoretical foundations from the biological, medical and neurosciences provide the basis for this work.

- LE—Sensory system research defines the means to study human responses to environmental variables such as light, color, sound, and touch.

- LE—Chronobiology and circadian research defines the means to study the human response to light.

- LE—Psycho-physiological research defines the means to study the emotional, functional, and cognitive response to environmental variables and relates cognitive and neurological responses to biological and behavioral outcomes.

- LE—Methodological foundations are derived from empirical sciences for exploring physiological and psychological bases of human responses.

- NE-LE—Irrespective of the methodology, rigor, or author, each research approach used to build evidence that informs design has its limitations. Evidence is perhaps better understood if looked at: 1) from various and multiple perspectives (opinion surveys, observation of behavioral performance, laboratory experiments, or in field measuring of environmental conditions); and 2) subject to various measures (organizational, economic, psychological, social, and physiological).

- NE-LE—Evidence gained through research is "additive" rather than private mentorship, experience, or intuition, providing multiple means of informing design. The importance of how much of each type of evidence is dependent on the circumstance, skill, and comfort level of the researcher/designer, and the strength of the method used to collect the evidence.

- LE—The foundations of this research effort started with fundamental scientific method, controlled research design protocols, empirical research procedures, and statistical analysis.

- LE—The experiment must be designed so that it is repeatable, reliable, and statistically significant.

- LE—Methodological foundations derived from empirical scientific methodology for exploring physiological and psychological bases of human responses.

7. **<u>Where in the context of research in the domain of this type of research does your specific agenda fit?</u>**

   - NE—Fits into the general domain of interest about the relation between the design of the physical environment and human performance; more specifically, this research fits into the substantial amount of research on hospital design and patient well-being, and the research on hospital design and staff well-being. Even more specifically, it fits into the substantial research on the role of light on human well-being.

   - NE—The current agenda is quite broad since we are just laying a methodological foundation (a tool) for future research.

   - LE—Chronobiology, psychology, physiology and their relationship to evidence-based design. Research about user responses in healthcare facilities is generally relevant to all architectural types, in that it can be generalized to the humans who occupy such spaces.

8. **<u>How will the research project contribute to the domain and to design practice?</u>**

   - NE—The tool resulting from IDM will be able to investigate specific hypotheses from this domain, resolve some of the competing or ambiguous effects, and help architects design the large number of new hospitals that will be created over the next 25 years.

   - LE—The research provided new findings for psycho-physiological and chronobiological research.

   - LE—The research also provided new suggestions for the use of different light methods in architectural environments. In order to achieve the lighting goals described, architectural design may include changes to master planning, programming, site decisions, exterior architectural openings, shields and shades, as well as choices for interior materials, finishes, and electrical lighting systems.

- LE—The case studies demonstrated the use of new technologies in the measurement of actual architectural environments, and suggest differential influence of architectural features in addition to the influence of user function.

9. **<u>What was the specific research question(s)?</u>**

- NE—The creation of a tool (IDM) in order for other teams to create many research questions in the future.

- NE—Does solar orientation of the room have an effect on length of stay, controlled for disease type? This is the major opening research question, and several other hypotheses will be tested in the future.

- LE—How does brief exposure to electrical lighting influence stress responses known to be important indicators of health risk, mortality, and morbidity?

- LE—How does brief exposure to lighting influence cognitive, mood, and performance responses?

- LE—Does brief light exposure during the day influence responses?

10. **<u>What were the specific theoretical informants of the research question(s)?</u>**

- NE—The role of circadian rhythms, light, and solar orientation on human biological functioning.

- LE—The body of chronobiological research. This research demonstrates the pervasive influence of light on biological and behavioral responses. It defined the parameters of light to be applied in the experimental design.

11. **<u>What were the specific methodological frameworks that guided the research questions?</u>**

- LE—Methods derived from standardized psycho-physiological tests using empirical scientific methodologies.

- LE—The scientific method provides the framework for designing the research question.

- NE—Methods imported from the organizational sciences and applied econometrics.

- NE—Ulrich's research is particularly important because he used objective measures of patient welfare rather than relying on subjective reports in his research on the effect of light and length of stay in hospital.

12. **<u>What are the critical components, activities, tools, etc. that would help define the model of research in your specific research agenda?</u>**

- NE—Empirical and objective measure, and very large data sets—the latter distinguishes this research from all prior research. The IDM tool integrates three classes of data never connected before—physical design features, patient experience, and patient medical outcomes.

- LE—Gold-standard methods for objective measurement as defined in peer reviewed literature.

- LE—Repeated testing using standardized and controlled conditions.

- LE—Measurement systems and location of testing selected to answer the specific question asked.

13. **<u>How could this specific research agenda be translated to design practice research?</u>**

- LE—The methods used in laboratory studies are now ready to be applied by creating design interventions that include the lighting parameters described in scientific studies, and measuring responses to such changes in occupied architectural settings.

- NE—The IDM could be used as a methodology to create evidence-based post-occupancy evaluations.

- NE—Through the facility planning unit at Kaiser Permanente, through publication, and special workshops for hospital designers.

- NE-LE—Given the realization that there need to be multiple approaches to developing evidence, it is probably most important to develop a firm culture that is comfortable with various approaches to doing research as another resource to informing design.

- NE-LE—Unlike research into building performance, which deals with the building, the focus of our efforts is human response: the occupants and the value brought by the building; the building as "means rather than end."

14. <u>What were the major challenges in establishing the research agenda, its implementation, analysis, evaluation, and reporting mechanisms?</u>

- NE—The enormity of the data sets from over 30 hospitals as well as thousands of patient records and surveys required time and extra coding.

- NE-LE—The major challenge for the overall Latrobe team in developing the research agenda was competing desires/ideas/needs on what the that research agenda should be. It should be noted that the Latrobe research proposal committed to the inclusion of a physiological approach in addition to other objectives. The diverse groups—an architectural firm, a university, and a client—had different and competing needs for the research topic. For example, KP wanted to study a topic that included "action research" and that was within the context of its large building program, and others wanted to research a topic that could guarantee some method of physiological measurement. This is not to say that one group was right and another wrong, only that there were competing desires and no foreseeable way to reach a conclusion that worked for all. Also, the overall teams' goals were too ambitious, and in order to complete the work, they needed to concentrate and go in their own directions to complete the concurrent projects.

- LE—Narrowing the research agenda to specific questions that *<u>can be</u>* answered by rigorous methods. This approach is different than that commonly used in the humanities and in design, yet can provide information of direct and practical relevance.

- LE—A primary issue in trans-disciplinary teams is carefully to define a set of issues to be investigated in a way that yields valuable results. The problem that is to be addressed and the context of the chose study site dictate the type of research tools that may be used, the design of the study, and the methods for implementation, analysis, and evaluation. A trans-disciplinary agenda uses several methods in parallel, such as observations, surveys, and laboratory experiments. This is commonly applied in clinical studies, and is the closest model for evidence-based design. It was a challenge to the team to incorporate all of these goals in a single study.

- LE—A truly trans-disciplinary approach would go beyond parallel disciplinary research streams, merging some of the methods and analyses and perhaps develop new approaches. However, a difficulty arises here, as individual disciplinary approaches determine the value of data according to their historical guidelines. In the early phases of such research, these disciplinary barriers may be breached by conducting research in the medium of each and all disciplines included, along with their traditional approaches.

  This will add meaning and acceptance to a broad audience that crosses disciplinary boundaries. In this way, an analysis of the findings will be more powerful, demonstrating where methods and results are consistent, and validating new means to collect and apply information.

15. <u>How does this specific research agenda interact with the concept of evidence-based practice (design)?</u>

- LE—The psycho-physiological experiment uses all aspects of evidence-based design, in that the research question is based on the opinions, desires, and intuition of designers and users; the methods are based on a broad number of psychological and physiological measures. The results are considered in the context of design needs, economics, and desires.

- LE—The research demonstrated the use of rigorous, scientific data as part of the continuum of information that creates an evidence base for application in practice. It also demonstrated the value of literature review in guiding the specific research design. Although our original concept was to explore the influence of color, findings from previous studies demonstrated that our resources were not ideal to pursue this question. It was the strength of evidence available in the biomedical literature that suggested a focus on the "color" of light and the influence of circadian lighting on health, rather than the influence of pigmented color on walls.

- NE—IDM will create useful evidence and findings that will be applied to KP's knowledge base and large building program. The evidence and findings created by IDM will inform the KP Standards Program.

- NE—The IDM tool will provide the opportunity to show that design decisions and trade-offs can be made on the basis of measurable benefits to diverse stakeholders.

16. What would you change if you were to start the process again?

- Devote more explicit attention to the culture of science and the culture design, so that each side understands what is considered valuable to the other.

- This project/process has provided an incredible learning experience for us, and I wish I could start this project/process with the knowledge and information that I have gained to date.

- If I could start the process again, I would:

  - Create a solid team infrastructure, including signed agreements.

  - Create "rules of the road" for the team.

  - Discuss the "rules" and requirements of each organization (such as IRB, confidentiality, etc.) that cannot be changed, and discuss how the project must fit into that framework.

  - Set expectations much more clearly upfront.

  - Interests/passions must be aligned more closely.

  - Appropriate compensation must be available for all.

  - Establish specific goals, objectives, and methods during the grant writing phase.

  - Take advantage of each team member's unique expertise in designing research objectives.

  - The expertise, ideas, and desires of each team member should be fully utilized. This can be taken into account by setting up forums at the initial stages to share concepts, backgrounds, and resources.

  - Follow-by tours of each other's facilities to generate ideas for study design on each other's sites, and understand the limits thereof.

  - Thereafter, craft a study that utilizes the collective knowledge, experience, and facility.

  - Write and submit IRBs within the first three months.

- Use a more horizontal operational hierarchy. When gathering a group of individuals from a broad range of disciplines, each with deep expertise, it is common to use a horizontal hierarchy, with one head decision maker, and all else at the table with equal authority and opportunity to express their knowledge. Models from NASA would be relevant.

- When relying on broad and deep knowledge and expertise, and in pursuit of an evidence-based model, it is important to give equal opportunity to consider the full range and depth of knowledge.

- Make design collaboration and innovation a major part of the project by having an evidence-based design charrette and concept development at multiple stages throughout the process.

- Create and test the response to design interventions that derive from research, literature reviews, and charrettes.

o Commitment to research topic and research team: The Fellowship proposal contained a clearly defined topic of research that was developed by a core team represented by each group representing the alliance. It is usual in scientific and other research efforts to adhere to the topic defined in the proposal. We discovered the value of this requirement—as much time was spent in the initial phases of our efforts to reconsider and redefine the research topic and approach. Time and resources would have been utilized more effectively had we been guided more strongly by our initial proposal. This includes commitment to the proposal topic and a research team and resources that specifically addressed the topic. In the same way that architects select their design team based on specific knowledge and experience (such as healthcare designers selected for hospitals, and acousticians selected for concert halls), the research team should be selected according to their knowledge and experience related specifically to the topic being investigated.

o Funding: We should also recognize that, like the design of a building of lasting value, research takes time and money to create a work of lasting value. Although our study relied greatly on the good will and contributions of many unpaid or underpaid scientists and staff, we should no more expect a research team to work below market rate than we would expect a construction crew to do the same. Further, I am often asked what research findings I might produce in less time. The answer is similar to that of an architect if asked what building might be produced in less time, with less material, and lower cost. Both research and building are likely to be of less lasting value.

- Authorship: Agreements about authorship and attribution are best agreed at the outset and even before grant submission.

- Communication Structure: In scientific circles, a flat hierarchy is used for the exchange of information. Each team member brings unique and deep expertise that cannot be readily conveyed through a vertical information structure. Open exchange of ideas and opinions are integral to a process that yields novel concepts, insights and solutions that reflect the deep and broad knowledge of the team to address the complexity of research.

- Practitioners are interested in "actionable" results, while researchers are worried about how results will be used, attributed, and interpreted. This was a value that is always present in this collaboration of architects, clients, and research. Is this about language, or is it inherent in the way we work?

Connecting Knowledge Production and Evidence to Evidence-based Practice

The connection between knowledge production, evidence, and evidence-based practice has been central to this project. One of the guiding values of the team has been the goal of connecting these three components of the Latrobe Project. In this effort to collaborate, the project did not escape the voices of different disciplines, worldviews, and individual passions.

Evidence-based practice has been well established in medicine. It is also becoming a major concern for the disciplines of education, forecasting/statistics, environmental management, information technology, social work, and just about any field where service is central to the mission. In all cases the intent of its application is to address concerns of practice that are unsystematic, reliant on intuition, and prone to political/legal influences. The primary objectives of evidence-based practice is to provide practitioners the tools and skill to access, assess, and adapt existing evidence for use in a specific context and to formulate context-specific evidence when existing evidence fails to meet existing standards of practice.

The definition of what is "evidence" also tends to be context specific, with various disciplines making interpretations of what appropriate evidence constitutes. For some disciplines it represents tangible, testimonial, acceptable facts. For others it must be grounded in rigorous, systematic, and objective methods. In all cases, however, there is agreement that evidence has both qualitative and quantitative dimensions along with a range of guarantors.

For the Latrobe Project, it was agreed early on that knowledge production was the armature of the creation of evidence. It was this dimension, creating knowledge in context, that specifically connected the issues of evidence to evidence-based practice in architecture—the application of established, guaranteed knowledge as evidence to inform specific architectural practice activities on a specific or set of client driven projects. As in medicine, it was also recognized that this evidence could come from various sources, ranging from past experience—intuition and experience to rigorous, systematic research—as undertaken in the two concurrent tracks of the Latrobe Project.

Conclusions, Implications, and Connections

Research by its very nature is riddled with risk. Connect research to architecture and the level of risk is even more so increased. The purpose of research in general is to pose questions with uncertain outcomes. As such, sometimes the outcomes match the expectation or predisposed intensions, and sometimes they do not. When research is conducted in the format of Mode 2m the outcomes become even more dynamic. The Latrobe Project outcomes are a good example of this phenomenon.

The two research reports as presented in Chapter 2 and 3 of this report document the specific findings and implications of those findings. Each stands on its own, illustrating the nature of the research question, positioning the work in a larger body of work, setting forth a methodology of exploration, and reporting the outcomes. Each of these research tracks was highly influenced by the process interactions of the Latrobe team members, the organizational conditions of the context in which the research was conducted, and the larger expectation that it be a thread of connection in the work.

When this project began, it was assumed that there would be a single project, possibly with multiple dimensions, but not two separate research tracks, that there would be overlapping, disciplinary engagements that would establish trans-disciplinary outcomes. In addition, it was assumed at least by some that the measures of quality of the outcome would be socially constructed by the team and the larger sets of communities, i.e., healthcare, architecture, and research disciplinary standards, giving merit to a whole that was larger than the some of its parts. Each of the separate tracks to some degree accomplished these conditions, but not in the manner expected. It is important to keep in mind that these outcomes do not represent failure, but reflect the nature of the struggle to undertake meaningful and important research.

In an effort to illustrate the underpinning issues and values that focused the team's efforts and to demonstrate the nature of that struggle, the following is a set of observations about the process of the Latrobe Team interactions. In looking to the future, it is these conditions that will allow the framing of new research efforts in practice to gain from the process experience of the Latrobe Project.

These observations are grounded in the materials previously documented above that reflect outcomes from meetings, presentations, research reports, and the process questionnaire. Each of the items listed represents a significant aspect of the research experience. The intent is to provide an overview of the work setting of the process over time.

- **Navigating disciplinary boundaries.** The question of was this work trans-disciplinary, and what that might mean in our context, is still an open question. All of the principal investigators share the basic scientific model of research (whether social, organizational, or biological), making communication fairly straightforward and about rigor and quality. What makes this work interdisciplinary is that the independent variable is design and the outcome variables are physical, social, and organizational.

- **New ways of knowing.** This project created "new" knowledge and may have created knowledge in a "new" way.

- **Agreements are central to progress.** This was an iterative process. Whatever agreements made along the way certainly positioned challenges and introduced change at every step of the process.

- **Implicit vs. explicit knowledge.** As practitioners, both our education and practice center on "problem resolution"; as such knowledge tends to be "problem specific" and thus not seen as directly applicable to the next problem because of its dependency on context of application. This suggests that it is only after many years of practice that a body of knowledge is developed experientially. Additionally, the process of developing knowledge is redundant for the individual and difficult to transfer to others within or outside the profession. It is this culture and practice that research for the purpose of creating multiple forms of evidence and, more specifically, evidence-based design are challenging.

- **Language is central to understanding.** The search was for trans- or interdisciplinary (scientific) processes that provided insight into how one acquires knowledge that can be additive to a practitioner's typical problem resolution process (context of specific application) and that enhances predictive performance outcomes. Thus far, lack of a common language, processes, and protocols makes this process slow and difficult. This project marks a starting point for the generation of a new body of expertise that speaks both the language of science and the language of design.

- **Knowledge always in context.** Knowledge produced in context is not new, but it is how context is defined that creates the challenge. The assumption here is that if the knowledge is to be accepted, the parties with vested interest—architects, clients and researchers—must socially construct it.

- **Tension between agendas of players.** There was tension between research opportunities that have the greatest potential and the specific issues that are of greatest interest and concern to the stakeholders—clients, researchers, designers, regulators, etc.

- **Outcomes to serve the majority.** "Clinical research" is in many ways the healthcare equivalent of "research in context." It must address the many complex factors that define each individual patient's conditions and his other unique needs and values, while investigating specific questions directed at creating applications that serve to improve outcomes for the majority of people and circumstances.

- **Vocabulary and differences.** The vocabulary and cultures of the members of a trans-disciplinary team vary widely. However, the process of research had great similarities across the social, organizational, and scientific fields that comprise the Latrobe team.

- **Horizontal consensus building.** The team process initially presented its members with a highly uncertain task, and the meetings and interactions were organized to reduce that uncertainty, that is, to define the research question, to mobilize resources, to develop a structure and set of operating processes to facilitate tasks based on a horizontal organizational structure. The challenge in the process was to reach agreement through consensus. The two concurrent tracks represent a resolution of the process of consensus decision-making and the practical realities of conducting research in the most stringent of environments, healthcare settings.

- **Survival in uncertainty.** Mode 2 research, as noted, guarantees high uncertainty. The ability of a group of people to survive this ambiguity was challenged often in the process. The determination of the quality of the outcomes of this experience of working together will be in the acceptance of the evidence presented in this report by the appropriate peer groups.

- **Commitments unquestionable.** The commitment of this team to the project was unquestionable. As noted, the struggles were about language, definitions, roles, outcomes, and resources. Research in context, with diverse disciplinary representation and a lack of a tradition, made the day-to-day actions and activities seem fuzzy, but in the big picture significant progress was made toward achieving the goals.

Great care was given to monitoring the process of the Latrobe Project. As such the natural question to ask is: is there a model inherent in this process that is transportable to other research settings? Yes, but not as a new model, rather as one grounded in the concepts and principles of Mode 2 research adapted as a framework for conducting research in practice. A way of framing this model is to look at each of the major components of Mode 2 research and evaluate match and mismatch of these conditions with the Latrobe Project.

- **Outcomes generated in the context of application**

  Conditions
  The armature of the original proposal for the Latrobe Project was born out of the concern for providing a framework for producing knowledge in practice. As such the three-party partnership was the mechanism for establishing an operational model that represented the stakeholders of knowledge and its application—the architect; the client; the researcher.

  Implications
  For parties to take ownership of the research outcomes it is critical that they be a part of the conceptualization and implementation of the research effort. By doing so each party has a vested interest in framing the research questions, determining the acceptable measures of quality, and testing the applicability of the outcomes in real settings.

- **Trans-disciplinary with a range of methods, procedures, and standards**

  Conditions
  A range of methods is used that come together often in novel forms to resolve a specific problem. This was another of the primary considerations in the original proposal. The partnership was committed to representing a diverse set of disciplines within the original team structure and expressed the willingness to bring additional disciplinary expertise when needed. The original team was composed of architects, organizational scientists, applied economists, healthcare administrators, sociologists, and neuroscientists. Others—additional psycho-physiological and neuroscience researchers, healthcare administrators and facility planners, and designers—were brought to bear as needed along the way.

  Implications
  If research is to be conducted utilizing the M2R structure, it is critical that all of the possible stakeholders with a vested interested in the nature of the research question be represented within the team. It is also important to recognize that it may be necessary to add new members and that that some original members may need to leave. However, this model is not consistent with biological or medical research programs, where the research team is developed based on its match to the topic being investigated. In joining the team, and accepting any grant monies, members contract a commitment to completing the project and reporting on the research outcomes.

  It is also important to understand that these transitions will also impact the nature of leadership and communication structure embedded in the project. As such, however, it is necessary to have an executive leader for the project who takes responsibility for directing the ongoing work and process of the project and for monitoring the process of conflict resolution when conflicts arise. This was not done in this project. Flat organizations still require a leader, who may change over time, but there must always be someone with executive authority for the project.

- **Outcomes produced across knowledge organizations and in multiple settings**

Conditions
As noted in each of the research track reports, multiple knowledge organizations and multiple settings were an integral part of this project. The research was moved to the appropriate expertise and setting during the various phases of the project. Multiple divisions of KP participated at each phase of the Natural Experiment, and the project was taken to multiple sites as necessary. In terms of the LE, numerous researchers from the University of California, San Diego and Ohio State University, as well as staff from KP and Chong Partners Architecture were integral to the project. Because of the mismatch between funding and scope of the research projects, it was necessary to acquire in-kind services from disciplinary experts to provide the knowledge and skill to carry forward certain specific tasks within the project. In both of the concurrent projects their staffing and location were dynamic, adjusting to the needs of work required by incorporating additional people and new settings. In addition, ethics committee standards required that procedures complied with federal standards, limiting the scope and context of study.

Implications
When knowledge production is carried out in practice, it is critical to have access to expertise from various disciplinary individuals and groups. This requires that the organizational structure and funding mechanisms be nimble and transportable, both in terms of mission and location. This was clearly true in our case with KP, as they were most generous in providing additional funding and people to allow for the development and completion of the Natural Experiment. In terms of the Laboratory Experiment, the challenge was the funding mechanism, requiring revisions to the sub-contract process as well as limiting the scope of the effort, primarily sample size and number of measurement conditions. Similarly, the laboratories and scientists contributed their expertise, staff, and equipment to complete the research on time.

- **Reflexive with conversations and dialogue between researchers and subjects**

Conditions
Research in context requires that there be open communication lines within and across the boundaries of the researchers, clients, and service provider, in our case Chong Architecture, UC Berkeley, and KP. This may have been our weakest link, both in terms of creating an organizational structure that was horizontal and at the same time providing appropriate mechanisms for being reflexive. This also at times challenged the leadership structure of the team when boundaries between the partners became fuzzy or the partners became non-responsive. The issue of language of exchange was also a challenge, partially because of the disciplinary breadth of the team members, but also because opportunities were not provided for time to listen and learn from the experience of others.

Implications
It is extremely important to create an organizational structure and leadership format that are flexible and porous, given opportunities to interact in settings where action is expected, but also time to communicate and share the work so it is carefully studied through listening and not judging. Partnering skills are central to this process and, if they are not possessed, get them early in the project.

- **Accommodation of multiple definitions of "quality"**

Conditions
This was a project conducted under the guidance of three independent and diverse organizations, each with long-standing cultures of operational environments, work patterns, processes and procedures, and organizational norms and values. Making this aspect transparent and navigable was a challenge. The project team was challenged by this condition, mainly when it came to connecting the research and its resulting evidence to its implications and application to practice in an evidence-based process.

Because of the nature of the resulting two tracks, neither of which got to the stage of direct application in a design setting, all that can be provided here is what each of the reports provides as suggested implications and applications for the outcome. This is not, however, unusual to the process of transporting finds from discovery to application of new knowledge production. This should not in any way suggest that the outcomes of this research are not important. On the contrary, the findings are significant; they represent major knowledge contributions now and provide a framework for additional important research in connecting research outcomes to design practice.

As noted early in the report, "practitioners are interested in 'actionable' results while researchers are worried about how results will be used, attributed and interpreted." This is an important component of checks and balances on defining quality in a manner such that research outcomes become meaningful design informants.

Implications
Knowledge production in an M2R model with the four previous conditions must also have a structure that allows that measures of quality be socially constructed, not only by team members, but also by positioning the research effort in the larger body of work in the domain that it addresses. This allows the work to be evaluated by peers not directly related to the project and to judge its quality by standards of the domain in terms of reliability and validity. This will also allow others to build on the work by repeating or extending the specific research question. It is also the arena where acknowledgement of the work is achieved both formally, by the standards of the associated research community, and also internally to the work team responsible for the research project.

It is also the arena where these dilemmas of actionable outcomes versus how the outcomes will be used, attributed, and interpreted find understanding. If the organizational structure of the Mode 2 research endeavor is handled appropriately, it is through the social construction of measures of quality that agreements and understanding of the limits of action and use can be articulated and established in a transparent manner, allowing the practitioner the opportunity use outcomes as evidence, but at the same time to appreciate and honor the limits on use and how to attribute that use.

Summary of Findings and Outcomes

The Latrobe Project has provided the opportunity to explore an aspect of the future of architectural practice that is critical to formalizing the format and intentions of the mission of the profession for the future. It is clear that the future of the profession is grounded in knowledge management: what do we know; how do we know it; and how do we renew that knowledge in the fast changing world of practice.

As noted earlier, the Latrobe Project was structured around two commitments to the College of Fellows of the American Institute of Architects—first, in a disciplined manner, to observe, assess, refine and document the approaches used to create the research in order to allow the architectural profession to learn from it and apply the outcome in future architectural practice settings (The Model) and, second, to conduct a pilot study in a healthcare context to yield immediately applicable data and to construct and test the model (The Pilot).

In an effort to accomplish these goals the team structured two independent pilot projects, The Natural Experiment and the Laboratory Experiment. As noted, the working process of the team was documented from the beginning, where the research question(s) were formed, to the completion of the formal reports included here. The preceding pages of this chapter document the evidence that illustrates this process.

In its simplest form the two pilot projects were conducted in a traditional form Mode 1 Research (M1R) of the application of the scientific method but modified to reflect three primary differences. First, the nature of the research question(s) was defined in the context of application by the three partners of the Latrobe Project. In addition, it was agreed that, where possible, additional disciplinary representation would be brought to the project when needed and, finally, that the measure of the quality of the outcomes, in addition to the disciplinary standards, and the outcomes would be judged by their capacity to represent empirical evidence that could inform an evidence-based practice process.

The outcomes of each of the two pilot projects resulted in evidence for future application and a framework for conducting future research in search of evidence. The Integrated Database Model (IDM) provides a major framework for future research, using the IDM to inform specific research questions at a sample scale unprecedented in either healthcare or architectural settings. The Laboratory Experiment, composed of two sub-studies, (1) The

Effects of Light on Heart Rate Responses, and (2) The Effects of Light on Brain Wave Electroencephalography (EEG), provides significant empirical evidence that, when physiological measures, heart rate and brain waves are used under diverse lighting conditions, various human response and performance are observed. In both cases there is evidence presented, a model for future use, and human performance outcomes for exploration in real design settings. The design charrette undertaken as a part of this study illustrates the capacity of this effort not only to directly inform design, but to set the stage for further applications in a designed setting.

In both cases, the Latrobe research outcomes of the two tracks represent significant advances in the understanding of how to create evidence from practice settings and understanding the knowledge required to inform design decisions in practice. The outcomes of both tracks taken together make a strong case for the capacity to create empirical evidence to inform evidence-based practice.

The next steps must be grounded in the identifying metrics for establishing a set of physical attributes of architectural spaces that house human services so that human performance can be or is measured. The IDM and LE argument made suggests that it is possible to establish a robust field of empirical evidence that can inform the outcomes of architectural practice, specifically focused on healthcare environments. It also suggests that the processes and methods used here are transportable to other environmental facility types and settings.

In terms of the model, it can be said that the concept of collaborative research is a critical form of inquiry that needs to be pursued in the discipline and profession of architecture. Did the Latrobe Project deliver “a model”? Maybe not, but it did apply the structure and conditions of Mode 2 research that did provide an important framework for structuring the Latrobe Project outcomes. It is safe to recommend that the framework of the four defining elements of M2R are important to collaborative research, i.e., research generated in a context of application, trans-disciplinary, socially constructed measures of quality, conducted across knowledge organizations and sites, reflexive, and concurrent with the need in architectural practice to merge the outcomes of research with actionable design results and with a degree of trust in the empirical evidence by the larger community of practitioners and researchers.

It is well understood that our future in architectural practice will be highly influenced by evidence-based practice. It is important to recognize that evidence comes in many forms, from personal experience (intuition), to best practices, to rigorous scientifically established findings. As such, evidence for use in architectural practice does not need to be all in one form or another, but. as in medicine, practice must use the evidence from as many sources as possible to predict the nature of the outcome of specific actions. The critical issue here is not the evidence itself, but the transparency of the evidence, so that others can judge and understand the impacts and influences of specific forms of evidence on performance.

The Latrobe Project has contributed to this dialogue concerning knowledge production (evidence) and its management (evidence-based practice). The outcomes have resulted in a multi-disciplinary, physiological lab experiment that was intended to be a pilot, but that, in fact, is a valid study in its own right which makes significant contributions to the domain of light and lighting knowledge for designers. It has inspired a major client, Kaiser Permanente, to develop and implement an evidence-based analysis methodology for application within its organization. The partnership and resulting collaboration have created a foundation for future design interventions based on new knowledge and a framework for validating the outcomes to apply the IDM analysis to determine the implications of decisions on a wide set of important issues and economic, medical, and human satisfaction measures. The IDM and LE provide fertile arenas for future research and the model for conducting research in practice. Yes, there is still work to be done, but these studies have made significant contributions, and a direction has been established that, if pursued, will continue to produce significant outcomes.