LIGHTING DESIGN

Toward a synthesis of science, media technology and architecture

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Light as a multi-dimensional design element has fundamental importance for a sustainable environment. The paper discusses the need for an integration of scientific, technical and creative approaches to light and presents theory, methods and applications toward fulfilling this need. A theory of design developed from three experiments show how distinct qualitative and quantitative criteria in different disciplinary traditions can be integrated successfully, despite disparate technical/scientific, social scientific and art/humanities backgrounds. The model is applied to a pedagogical curriculum in the context of multi-level learning competencies.

Keywords: *lighting design, collaborative design, trans disciplinary design, media technology, architectural experiments*

INTRODUCTION

"Light has always been recognized as one of the most powerful formgivers available to the designer, and great architects have always understood its importance as the principal medium which puts man in touch with his environment" (Lam, 1977).

There is substantial documented evidence for the life improving potential of light in architecture: differentiated daylight; awareness of architectural space; fresh air; reduction of glare; relation to site-specific surroundings through physical and visual access; and views to the surrounding landscape and cityscape are all factors which will be considered as essential to human life well into the future. Presently in Scandinavia however, the documented benefits of daylight in workplaces, institutions and dwellings are offset by quantifiable disadvantages in energy consumption when designing with extensive glazed areas (Hansen, 2013a). Building legislation has consequently imposed increasing restrictions which invariably lead to reduction in window sizes, less daylight and consequently increased design demands on the quality and effects of artificial lighting. Moreover, advances in new sources of artificial light such as OLED, QLED, 5G visible light communication, responsive media technologies, and intelligent and interactive lighting control are often driven by engineering and technological factors other than architectural design considerations.

In relation to designing with light, consideration of holistic solutions for aesthetic and technical design problems remains an essential ingredient in achieving overall project success; the challenge lies in integrating research-based science of light, and interactive media technology with a creative design thinking that focuses on both the qualitative and quantitative values inherent in architecture and lighting design.

The contemporary demand for trans-disciplinary (Meeth, 1978) teams has created the need to clarify how very different domains can input their knowledge in design processes. How can the design process work optimally across professional boundaries and in particular how it is possible to combine design and science when using light as a parametric, multidimensional design element? In order to answer these questions, explicit theories and methods to integrate science and creativity need to be developed.

This set of questions has been a common factor in three architectural experiments realized by the first author in the period 2001-2011. The experiments included projects and prototypes encompassing the environments of research, education, industry, technology and practice in the context of designing technical as well as qualitative environmental solutions.

Drawing from this empirical base, the paper develops a theoretical framework and presents a procedural model to demonstrate how research traditions can be integrated in trans-disciplinary practice. This model is implemented in a problem based pedagogical application for a graduate program in Lighting Design, synthesising lighting, media technology and architecture.

ARCHITECTURAL PRACTICE AND THEORY CONSTRUCTION

The development of knowledge and explanatory theoretical principles, logic and practice in architecture are more often than not induced from observed phenomena in the context of the built environment. Principles are logically inferred from observations, patterns and reflections on experience rather than deductive research applied and tested in a context-free environment, as practised in scientific, clinical and engineering experiments where little or no empirical evidence for a theoretical standpoint may exist. Where these latter methods have been attempted in architecture, such as in the evidence-based design methodology, they are often embedded in a knowledge base that lacks an explanatory theory which adequately predicts why some design solutions work and others do not (Stankos & Schwarz, 2007) This may be explained by the context-free single-variable nature of deductive hypothesis tests. The practice of architecture demands the resolution of a complex web of problems in arriving at contextually determined design decisions.

The development of a pragmatic theory derived from these conditions has been expressed as the "declarative proposition that such and such an act is the one best calculated to produce the desired issue under the factual conditions ascertained" (Dewey, 1925). Theory draws on the experience and skills of practitioners, teams of specialists, the values and preferences of the client, as well as a deliberate attempt to base design decisions on the best available research findings. More particularly, developing theoretical propositions for multi-disciplinary practice implies incorporating proficiencies and judgments, acquired through experience, observations and reflection, with the evidence from systematic research; in other words, the combination of the art and science of architecture.

THE ARCHITECTURAL EXPERIMENT

"Any deliberate action undertaken with an end in mind is, in this sense, an experiment...the move is confirmed when it produces what is intended for it and is negated when it does not." (Schön, 1987)

Three architectural experiments, incorporating knowledge from a diversity of fields including architecture, engineering, anthropology, and media technology provide the empirical material from which a theory and model for interdisciplinary action is developed.

The three experiments represent scales and stages in the development of the interdisciplinary enquiry, spanning from the first experiment (EX1; see Figure 1) in the development of future Photo Electrical Cemical (PEC) solar technology, to the second

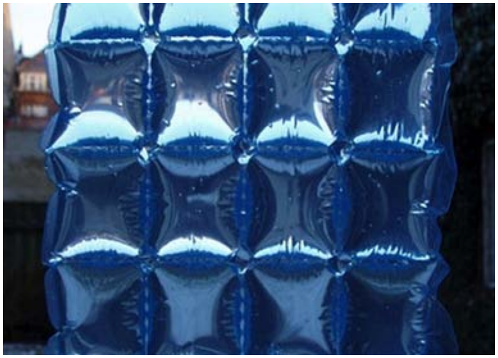


Figure 1
Exercises in EX1 exploring solar cell technology, transparency and light in space. Light is absorbed, transmitted or reflected in transparent solar cells in the project illustrated through ice cube bags.

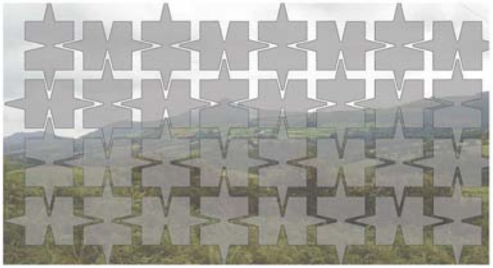


Figure 2
Exercises in EX 2 exploring how light can create new qualities in transparent solar cell components, in this project through ornamentation of the PEC solar cell.

Figure 3
Exercises in EX 3, for an energy producing smart home, the cross disciplinary group defined personas and models, digital sketches and luminance animations to optimize indoor climate, passive energy and daylight conditions.

(EX2; see Figure 2) in the definition of architectural potential in commercial transparent solar components and to the third experiment (EX3; see Figure 3) in the design of an assembly of building components and technologies incorporated into an 'active-house' or energy producing dwelling. A systematic account defines four principles used to describe and compare the experiments. (Hansen, 2013b)

- Vision: A shared vision for the project
- Criteria: Based on the shared vision, design criteria for the different disciplines is explicitly stated, developed through exercises and conceptual discussions
- Construction: The design criteria are materialized through sketches, computer models and mock-ups or those means most suitable to the independent disciplines (see Figures 4, 5, 6)
- Evaluation: The results are evaluated in terms of the applied criteria.

Light as a multi-dimensional design element was common to the vision in each of the three experiments. Moreover, in each of the experiments, criteria were formulated which related to light within specific areas of disciplinary knowledge. In EX1 these comprised 'technology' (solar cells), 'function' (indoor climate) and 'aesthetics' (transparency). In EX2 the parameters were 'regulating', 'communicating', and 'producing'. In EX3 the criteria were 'energy', 'indoor climate' and 'aesthetics'. In all cases, the criteria suggest solution-oriented approaches commonly employed in different professional domains, with the intention to integrate these qualitative and quantitative aspects of knowledge into creative and innovative designs.

Comparing the three processes of the experiments, three models for integration and synthesizing of knowledge can be produced. The three process models illustrated in Figure 7 show how the criteria are incorporated. EX1 used three criteria only in the early design phase, translating knowledge from discipline domains to design elements. Thus, various aspects of knowledge of 'solar technology', 'indoor air quality' and 'transparency' were incorporated into designing a solar cell integrated as an element of a transparent façade.

In EX2 the criteria were maintained throughout the process. The exercises in the early design phase were concentrated into a single criterion as the purpose of the experiment was to evoke architectural potentials of components already available on the market. The focus was thus on defining qualitative values and integrating these with quantitative values defined by other professional disciplines in the project. Participants collaborated across disciplines, but did not design together; in consequence knowledge was translated in a form understandable to all team members.

EX3 defined a vision which was then expressed as a common element within each of the three criteria. The vision was experienced as a source of motivation and commitment from the different parties. Communication across the three criteria had a large degree of influence on the design process, making it possible to evaluate ideas on energy and climate perspectives at all levels of the process. This can be characterized as form of hybrid design, defined by Meeth (1978) as "trans-disciplinary" design in which technical, scientific and artistic disciplines are transformed by linking together in new ways, and where knowledge is acquired from respective team members in pursuit of a common vision.

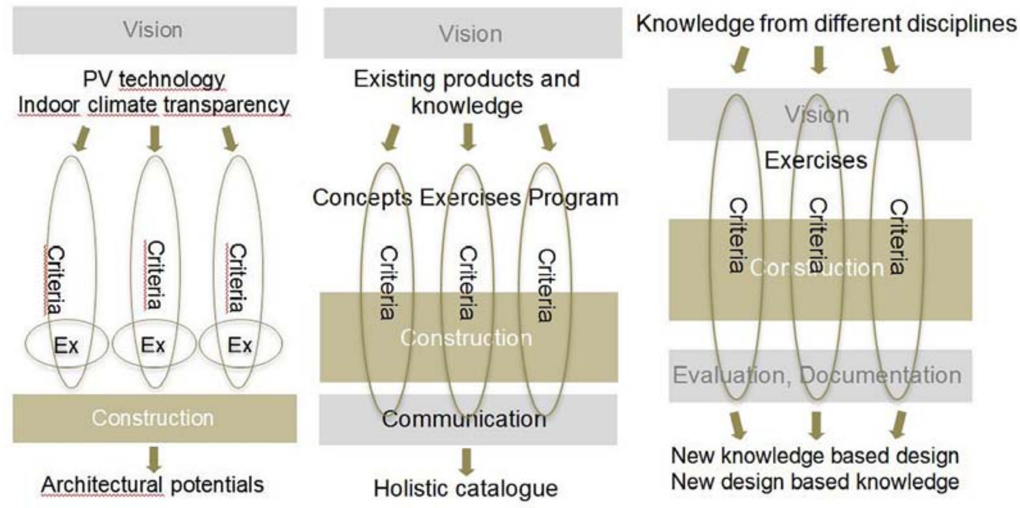
The three experiments illustrate differences in that knowledge in EX1 is tacit (or silent), in EX2 it is both tacit and explicit and in EX3 it is largely explicit. This difference is determined by how the criteria are maintained and whether evaluation criteria, hypotheses or research questions can be evaluated. In EX1 knowledge is communicated through the design, the construction can be seen and discussed and images are created which demonstrate how transparent solar cells can influence form and space. With reference to Schön's (1987) description of three types of experiments, EX1 can be described as "explorative"; while

Figure 4
Constructions in EX 1, Ornamentation in glass facade imitating red color pigment and electrical conduits in PEC solar cells to illustrate how solar cell technology can effect daylight in the façades and interiors.

Figure 5
Construction exploring the potential of light and transparent solar cell panels, EX2.

Figure 6
The construction and test of living in a home designed with light to be energy producing and apply a good indoor climate and architectural qualities EX3.

Figure 7
Three models, representing the process in EX1, EX2 and EX3.



EX2 where all three criteria representing the discipline domains were applied throughout is "move - testing" and disseminated in the form of a matrix. In both EX1 and EX2 evaluation takes place in the form of discussions on the basis of presentation and observations of the designed models. However, no research question, hypothesis or a program can be evaluated. In consequence, most of the knowledge developed remains tacit and cannot be generalized.

EX3 can be described in terms of Schön's definitions as "hypothesis testing", where knowledge was disseminated and evaluated within the three criteria and the building was actually constructed for occupation and use as a dwelling. However, the hypotheses generated are not limited, as Schön describes them, in terms of hypothetico-deductive methods, but derive from several research traditions and can thus be evaluated through the qualitative and quantitative methods preferred by those traditions. The model of Experiment 3 is therefore strongest in its combination of creative potential as well as in its knowledge generating logic.

THE PROCEDURAL MODEL

Drawing from the work briefly outlined in the preceding section, a theoretical framework has been developed for how research traditions can be integrated in trans-disciplinary practice, illustrated in a model for architectural experiments (see Figure 8). Building on Carlile's (2004) theory of innovative processes and the work in design research by Koskinen et. al. (2011) the model attempts to resolve the question first formulated of how the knowledge of different disciplines can be thoroughly integrated into the design process, create innovative solutions and generate new explicit knowledge.
The model comprises five steps:

- Step 1 IMAGINE & ASK ('transfer')

Knowledge from different disciplines can be included in the early design phase, "the entrance level", where a common vision meaningful to all parties is created. This step cuts across knowledge boundaries and its output is 'the imaginative research question', which expresses a common commitment to create value through the experiment.

- Step 2 EXPLORE & PROPOSE ('translate')

The unfolding of the research question defines three criteria that represent knowledge in different practice cultures, disciplines and research traditions. These criteria are explored and translated from a common language of parametric and fysicak models, sketches, photographs, diagrams, concepts and matrices. The output is a formulation of an explicit statement or hypothesis within each criterion, and which attempts to answer the 'imaginative research question'.

- Step 3 LINK & CONSTRUCT ('transform')

The three criteria are each resolved into preliminary design solutions and scale models representing the input from discipline domains and linking knowledge across criteria.

- Step 4 TEST & EXPLAIN ('evaluate')

Designs are tested in terms of the statements or hypotheses within each of the criteria which generated it by methods specific to the diverse research traditions. The results of the hypotheses tests are combined and assessed in terms of how criteria individually and collectively answer the "imaginative research question".

- Step 5 SHARE & LEARN ('communicate')

Knowledge is shared by communicating within the individual criteria as well as across the three criteria with the intention of gaining a holistic perspective of the issues at hand. This knowledge is iterated in the form of explicit knowledge, spread into the specialized networks behind the project partners, and communicated externally to users, practitioners and academics.

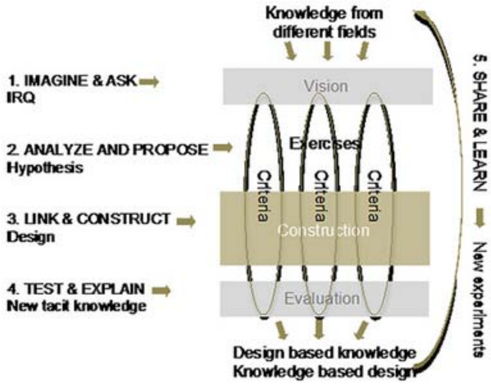


Figure 8
Model illustrating the process of the architectural experiment, synthesizing the three criteria in five steps

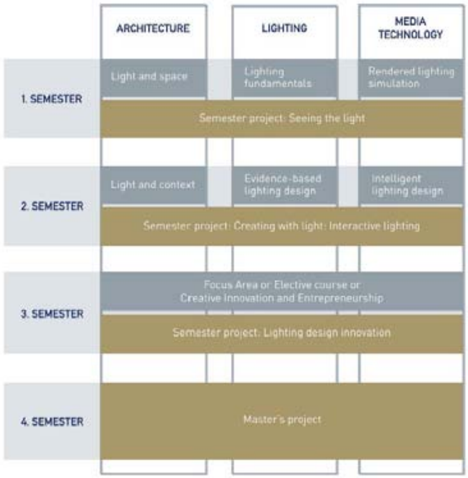


Figure 9
Model illustrating the curriculum structure of the MSc in Lighting Design, synthesising the three academic fields (vertical) in the horizontal problem based project work.

PEDAGOGICAL APPLICATION

The model, drawn from empirical material gathered by the experiments and theoretical explorations described above, is applied in a new pedagogical curriculum for lighting design (see Figure 9). The graduate program is designed to fulfill a need documented by the Danish Center for Light in 2012 for trans-disciplinary lighting designers in Denmark. The training comprises a full-time interdisciplinary, research-based program that combines natural and artificial lighting within the established disciplines of media technology, engineering and architecture. In addition to aesthetic values, the aim is to produce graduates with academic, technical as well as process-related skills in virtual and physical light. The students are given an understanding of the interaction between light, its context of the built environment, light technologies, digital media, human factors and design methods. The educational program is structured such that the students develop their skills in synthesizing knowledge from the program's three disciplines through immersion in team-based problem solving within the context of real-world project experiments, and which have tangible results.

These intentions give rise to diversity among the backgrounds of students as well as among academic researchers, teachers and representatives from the lighting industry associated with the program. Undergraduates who have been accepted for admission to the graduate program come from previous studies such as architecture, industrial design, media technology, architectural engineering, natural science, electronic engineering and civil engineering, among others. This situation of multi-level competencies and widely disparate knowledge domains leads to some students for example having strong design knowledge but weak technical skills, vice-versa, and many other combinations. The challenge for educators is to integrate divergent threads from these knowledge spaces into a coherent whole (Carlile, 2004). Various process models (Hiim & Hippe, 1998; Inglar, 1999) describe how phases in a project or the design process can be organized from idea to outcome, from visions to details. But these models do not explore how knowledge from different disciplines may be integrated.

One of the stated goals in the competence profile of the programme formulated in the curriculum for the master's programme in lighting design is to "be able to understand and synthesize knowledge of light from different subject areas: design, architecture, media technology and engineering on highest international level." To achieve this tri-disciplinary approach, the disciplines of lighting science, media technology and architecture are layered as three disciplines and the curriculum is built around these three 'academic pillars'. Knowledge within each domain is learned in parallel through three courses of 5ECTS each, comprising lectures, discipline-based exercises, literature and demonstrations of how these disciplines relate to practice.

Knowledge acquired in courses is synthesised in the 15 ECTS semester projects based on the "Problem Based Learning" (PBL) method. PBL defines a learning process in terms of idea generation, problem analysis, problem solving, design, and implementing solutions (Kolmos, Du, Holgaard, & Jensen, 2008). The projects are accomplished in groups of 4 to 5 students with different academic backgrounds, a situation which can ordinarily be difficult to deal with by both students and supervisors. Towards easing this problem the students are lead through a contact phase, a contract phase, preparation phase, implementation phase, evaluation phase and a final phase where the students discuss what has been learnt (Hiim & Hippe, 1998; Inglar, 1999).

These stages of PBL pedagogy can be integrated in the procedural model of the architectural experiment, which specifically indicates the synthesis of knowledge from different disciplines. Idea generation (contact and contract phase) relates to Step 1 in the Model, "imagine & ask" and definition of the IRQ (imaginative research question), which in scientific disciplines refers to an initial problem statement. Problem analysis (preparation phase) relates to Step 2, the translation "analyse & propose" of hypotheses through exercises. Problem solving (Implementation phase) relates to Step 3, transformation, "link & construct"; and finally Implementation relates to Step 4 of "test & explain", here the results can be tested in relation to the hypothesis defined within each discipline and therefore using research with technical/scientific, social scientific as well as art/humanities backgrounds.

An essential point in innovation (Carlile, 2004) is to return new knowledge gained in the experimental projects back to the different discipline domains. This is what occurs in Step 5, where knowledge is shared among the disciplines and can feed into future projects. That is to say, knowledge learned through coursework is transformed by the students in the experimental trans-disciplinary projects and generates explicit, shared knowledge within the different disciplines.

The model has therefore shown how multi-level entry competencies may co-exist within one curriculum through the combination and transformation of knowledge from three different disciplines based on technical/scientific, social scientific and art/humanities backgrounds . Problem-based, project-oriented learning is combined with the trans-disciplinary process indicated by the procedural model. The methods described may be applied by combining multiple criteria from the three disciplines of architecture, media technology and lighting science toward achieving a synthesis of trans-disciplinary design solutions.

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