Designing With Knowledge Through Trans-Disciplinary Experiments

Ellen Kathrine Hansen* and Michael Mullins
ekh@create.aau.dk, mullins@create.aau.dk
Department of Architecture, Design and Media Technology, Aalborg University, Copenhagen, Denmark

Abstract: Taking its point of departure in a series of architectural experiments realized in the period from 2001-2011, this paper approaches the problem area of the development and application of new knowledge through design in a trans-disciplinary environment. This praxis grounded in innovation and design theory demonstrates that research from different traditions can be integrated in the design process using distinct criteria. It is thus possible, in the same process, to work with hypotheses that are tested in parallel on the basis of technical/scientific, social science and art/humanities traditions. It is also demonstrated how a procedural model derived from the trans-disciplinary experiments can be applied to the curriculum of a cross-disciplinary graduate university programme.

Keywords: Trans-disciplinary Design, Innovative Design Process, Design Research, Knowledge Based Design, Architectural Experiments.

Introduction

Designing is a process with many dimensions, where values from diverse fields of aesthetic, technical, theoretical and experienced knowledge must be synthesized in a creative practice. This process aims to create and combine products into buildings that meet the needs of both current and future generations, ideally without using more than it gives back to the environment.

The development of technological knowledge is generally founded on quantitative, measurable values and methods established through linear, evidence-based procedures. In contrast, design of space and atmosphere is primarily a qualitative, creative process that is guided by experience, intuition and open iterative approaches that are difficult or impossible to measure quantitatively. In the practice of architecture, these knowledge domains, cultures and practices are difficult to combine, and commonly lead to misunderstandings between the disciplines. The development of knowledge in technology and design therefore often takes place in isolated environments.

These issues are a central problem in a perspective, where building design is increasingly complex, where collaborations across disciplines and cultures are fundamental to reach national and international strategic targets, where new trans-disciplinary educations are being encouraged, where artistic educations are to be more research-based, and where science has to be related to design and innovation. Furthermore, there is a need to focus on user related aspects of design and holistic qualitative values, that is, in situations where scientific and technical knowledge are mixed with cultural awareness. These contemporary demands create the need to clarify how the domains can share their knowledge in trans-disciplinary processes. These difficulties raise some fundamental questions.

How it is possible to work across professional boundaries and in particular how to combine design and science?

This set of questions has been raised in the three architectural experiments realized by the first author in the period from 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. These experiments have been used as empirical material in the Ph.D. thesis by the first author "Architectural Experiments – designing with knowledge on light, a multidimensional design element" (Hansen 2013).

The thesis addresses the question of how the tacit knowledge inherent in different discipline domains can be integrated in the design process, how innovation is enhanced thereby and how knowledge gained in the project is made explicit. In a previously published paper (Hansen 2014) the authors developed the theoretical framework around the reflections on practice and employed the procedural model to demonstrate how research traditions can be integrated with explicit design criteria in trans-disciplinary experiments. Developing these themes further, this present paper will give an account of the research background and demonstrate how the procedural model can be employed in a pedagogical application for a graduate program of higher education which synthesises engineering and design.

Design through Practice and Research

"The deliberations of daily life concern in largest measure questions of what to make or to do. Every art and profession is faced with constantly recurring problems of this sort" (Dewey 1925).

The development of knowledge and explanatory theoretical principles, logic and practice in architecture and design are more often than not induced from experience and observed phenomena in the context of the built environment. Principles and tacit knowledge are logically inferred from observations of human patterns and reflections on the results of previous projects. This inductive process generally prevails among architects and designers over deductive experiments 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 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). More particularly, developing theoretical propositions for multi-disciplinary practice implies incorporating proficiencies and judgments acquired through experience, observations and reflection, with the best available external evidence from systematic research; in other words, the combination of the art and science of architecture.

Methods

The Three Experiments

"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 experiments, incorporating technical knowledge from a diversity of fields amongst engineering provide the empirical material from which a procedural model for interdisciplinary action is developed (figures 1 through 7). These will be briefly described and their principles defined in terms of theoretical models that underlie their procedures.

Experiment 1 (EX1) developed architectural parameters for future PEC cells (Photo Electrochemical solar Cells). Four workshops were held at the Aarhus School of Architecture and the School of Architecture in Copenhagen in close cooperation with PEC Group's Danish Technological Institute. Knowledge of the angular selective PEC solar cells, known as Grätzel Cells, and indoor air quality were integrated into creative exercises to develop future energy generation and climate responsive transparent facade.

Experiment 2 (EX2) developed strategies for valuing existing transparent solar cell components through a three-week workshop with 60 master students at the Aarhus School of Architecture in a series of 1:1 experiments. The components were studied in compositions with light using light-filtering solar cells as multi-functional components to contribute to indoor climate, quality of lighting and at the same time used to produce electricity.

Experiment 3 (EX3) was an experiment to design a smart-home of architectural quality: an energy producing single-family house with good daylight conditions, indoor air quality and high aesthetic value. Working closely with the construction industry (VELFAC and VELUX) and consultants (AART Architects and Esbensen Engineering) qualitative and quantitative criteria were defined, developed and tested across the various disciplines involved in the project.

Figure 1. Three Experiments: Solar Cell Technology; Transparent Solar Cell Components; Energy Producing Smart Home (Hansen 2013)

The three experiments represent scales and stages in the development of the interdisciplinary enquiry, spanning the development of future solar technology, the definition of architectural potential in commercial solar components to the design of an assembly of building components and technologies incorporated into a dwelling. A systematic account defined four main principles used to describe and compare the experiments:

- Vision: A shared vision for the project, which is based on the definition of three criteria.
- Criteria: Three criteria, which represent knowledge in different disciplines, functions and cultures. This knowledge is developed through exercises, models and concepts and compiled in a matrix.
- Construction: The criteria are synthesized through the design and construction of models and mock-ups.
- Evaluation: Designs are evaluated in terms of the applied criteria. (Hansen 2014)

Common to all three experiments is that in each case criteria were formulated which related to specific areas of knowledge. In EX1 these comprised ‘technology’ (solar cells), ‘function’ (indoor climate) and ‘aesthetics’ (transparency). In EX2 the criteria 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.

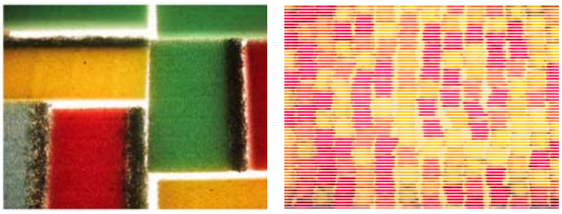

Figure 2. Exercises in EX1 exploring solar cell technology, transparency and light in space. Light is absorbed, transmitted or reflected in transparent solar cells. (Hansen 2013)

Figure 3. Exercises in EX2 exploring how light can create new communicating qualities in transparent solar cell components. (Hansen 2013)

Figure 4. Exercises in EX3, for an energy producing smart home, the cross disciplinary group defined personas and models, digital sketches and luminance animations. (Hansen 2013)

Figure 5. Constructions in EX 1, ice-cube bags and ornamentation imitating red colour pigment in PEC solar cell technology. Illustrates how solar cell technology can affect daylight in the façades and interiors. (Hansen 2013)

Figure 6. Construction exploring the potential of transparent solar cell panels, EX2. (Hansen 2013)

Figure 7. The construction of Energy-producing smart home, EX3. (Hansen 2013)

By comparing the three processes of the experiments, three models for integration and synthesis of knowledge were produced (Hansen, 2013).

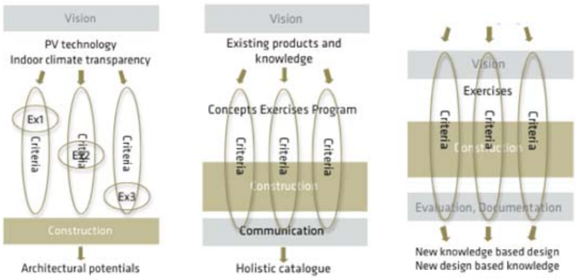

Figure 8. Three models, representing EX1, EX2 and EX3. (Hansen 2014)

The three process models illustrated in figure 8 show how the three criteria are incorporated in different ways. EX1 used the three criteria only in the early design phase, translating knowledge from discipline domains to design elements. Thus, knowledge of ‘solar technology’, ‘indoor air quality’ and ‘transparency’ was incorporated into the creative process of designing a solar cell integrated as an element of a transparent facade that evokes new architectural potentials, translating knowledge from various disciplines and integrating it into the design of future solar cell technology.

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 parties in the project. Participants collaborated across disciplines, but did not design together; in consequence knowledge is not transformed but only translated in the form of a matrix.

EX3 defined a vision 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. Specialists are part of a team where specific domain knowledge comes into play. This can be characterized as "hybrid design" in which technical, scientific and artistic disciplines linked together in a new way, defined by Meeth (1978) as “trans-disciplinary”, where knowledge is acquired from respective team members in pursuit of a common vision.

The three experiments illustrate a difference in that knowledge in EX1 is tacit, 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 that the transparent solar cells can influence form and space. With reference to Schön (1987) description of three types of experiments, EX1 can be described as “explorative”; EX2 as “move–testing” where all three criteria representing the discipline domains were applied throughout and disseminated in the form of a matrix; and EX3 as “hypothesis-testing”. 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, is difficult to transfer 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 use as a dwelling. However, the hypotheses generated are not limited, as Schön (1978) describes them, in terms of science but derive from several research traditions and can thus be evaluated through a variety of qualitative and quantitative methods. The model of Experiment 3 is therefore strongest in its combination of creative and knowledge generating logic and will in the following section be related to the theory of innovative processes and design research in order to test and improve the process of creating explicit knowledge in design.

Innovation and Design Research

Innovation theories developed by authors such as Carlile (2004) emphasize the importance of the people who are the generative source of new knowledge. This human factor is emphasized by applying verbal descriptors to the four steps of the model: ‘transfer’ (here applied to the transfer of knowledge from several disciplines), ‘translate’ (here translated as knowledge through exercises) and ‘transform’ (here transformed as knowledge through construction). Another essential element of innovation theory is the notion of iteration, illustrated in the model by an arrow to indicate the transport of explicit knowledge back to the domains behind the process.

Koskinen *et al.* (2011) illustrate how traditions with different methodological approaches encompassed by design research can be represented by "the lab, the field and the showroom." These three methods are related respectively to technical-scientific, social-scientific and artistic-humanistic research traditions. Koskinen’s purpose is to illustrate how the design practice must understand and accept the differences between these traditions and how they can be combined in the course of a broader research perspective. By relating Koskinen’s methods to the criteria described in the model of EX3, support is provided for the potential of a simultaneous interdisciplinary design process in which different criteria can be evaluated by different research methods.

The observations of the three architectural experiments indicate that there is a potential to improve design methods by making knowledge more explicit. In order to achieve this, it is necessary to reflect on how elements of the scientific tradition, such as the research question, hypothesis testing and analysis can be integrated in the model. Bang *et al.* (2012) discuss this issue and present the concept of the "entrance level". This can be described as the initial stage of design where there is space for conjecture, ideas and assumptions based on past experience, and where the opportunity for creation of new combinations of existing knowledge is greatest. The entrance level concept is used by the model, through work with introductory exercises that develop an overall and shared vision between the disciplines. While research questions and hypotheses as such were not described in the three experiments, the vision described in the model can beneficially be defined as an 'entrance level'.

Pallasmaa quotes Immanuel Kant as saying: "In knowledge imagination serves the understanding whereas in art understanding serves the imagination" (Pallasmaa 2011). To resolve these very different ways of approaching design problems, the initial research question can rather be defined as "an imaginative research question", that is it begins with the question: "What if we imagine that ...?" This supports the intent of the initial exercises to develop the criteria of the model and can be used to clarify tacit assumptions within each discipline's criterion. It is then possible to formulate hypotheses or predictive statements within each of the various criteria, all of which are derived from a common vision. These statements can subsequently be tested independently by methods of the different research domains and the findings gained can be expressed as explicit and transferable knowledge.

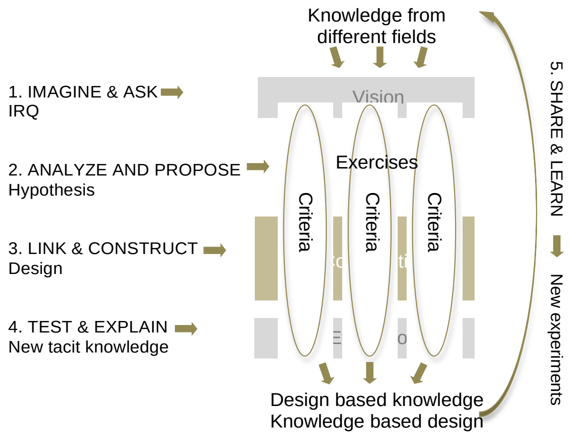

Figure 9. Model for the Trans-Disciplinary Experiment (Hansen 2014)

Analyses

The procedural model for the trans-disciplinary experiment (figure 9) summarizes the observations made from empirical data gained from three separate experiments of an interdisciplinary nature. Building on theories of innovation and design, the model attempts to resolve the question first formulated of how knowledge of different disciplines can be thoroughly integrated in the design process, create innovative solutions and generate new explicit knowledge.

The model comprises five steps where different criteria or discipline-related goals are transferred, translated, transformed, tested and shared as researched-based knowledge. The respective steps and approaches associated with the different discipline domains are defined as exemplified here in the context of team-based projects for lighting design in the built environment.

- Step 1 IMAGINE AND 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 AND PROPOSE ('translate')
  The unfolding of the research question is defined by criteria that represent knowledge in the domains of the participating teams. The output is a formulation of an explicit statement or hypothesis within each criterion particular to a discipline domain, and which attempts to pose a solution or answer to the 'imaginative research question'.
- Step 3 LINK AND CONSTRUCT ('transform')
  The three criteria are resolved into preliminary design solutions, each representing the input from discipline domains. The criteria are explored and translated in a common language of models, sketches, photographs, diagrams, concepts and matrices.
- Step 4 TEST AND EXPLAIN ('evaluate')
  Preliminary designs are tested in terms of the statements or hypotheses within each of the criteria which generated it, through 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 AND LEARN ('communicate')
  Knowledge is shared and iterated with the intention of obtaining a holistic solution to the issues at hand. Explicit knowledge is spread into the specialized networks behind the project partners, and communicated externally to users, practitioners and academics. (Hansen 2014)

Pedagogical Application

The models drawn from empirical material gathered by the experiments and theoretical explorations described in this paper provide a framework for a new pedagogical curriculum for lighting design (figure 10). The graduate program is designed to fulfil a documented need in society for trans-disciplinary lighting designers (*Behov for lysuddannelse i Danmark* 2012). The training comprises a full-time interdisciplinary, research-based program that combines natural and artificial lighting knowledge within the subjects 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.

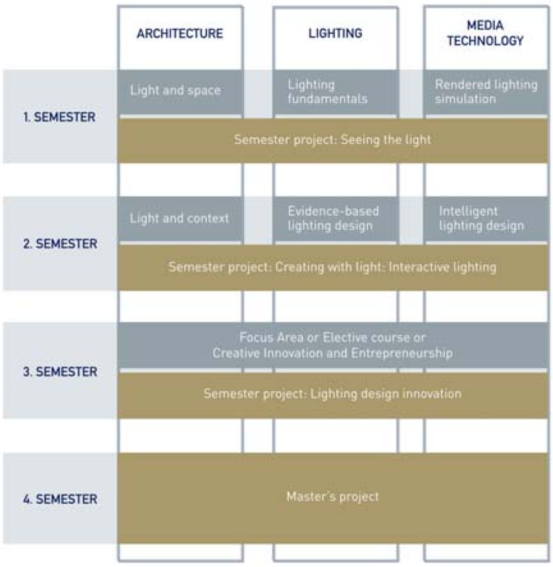

Figure 10. The curriculum of the MSc in Lighting Design, synthesising the three academic disciplines, light, architecture and media technology in the problem based project work. (Hansen 2014)

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, architectural engineering, natural science, electronic engineering and civil engineering, among others. This situation of widely disparate knowledge domains can be termed multi-level learning competencies, where for some students design knowledge may be strong and technical skills weak and vice-versa. The challenge for educators is to integrate divergent threads from these knowledge spaces into a coherent whole – the lighting designer.

This tri-disciplinary approach is layered with the three criteria developed by the model through architectural experimentation. The curriculum is then built around three 'academic pillars'. Knowledge within each subject is taught through various courses by the professional disciplines themselves, while this knowledge is synthesised in the process of semester projects based on "Problem based learning": idea generation, problem analysis, problem solving, design, and implementing solutions.

Idea generation relates to Step 1 in the Model, "Imagine and ask" and definition of the IRQ. The Problem analysis relates to Step 2, the translation "Explore and propose" of hypotheses through analysis exercises. Problem solving relates to Step 3, transformation, "Link and construct"; Implementation relates to Step 4 of "test and explain". An essential point in innovation is to return this new knowledge to the different discipline areas. This is what occurs in Step 5, where the knowledge is shared among the disciplines and thereby can feed into new experiments. This step can create a new understanding of how the knowledge achieved through the courses is transformed by the students in the experiment and generates new explicit knowledge. The model demonstrates how this new knowledge can feed back, in this case, into the three academic "pillars" at the university, architecture, light and media technology.

Learning needs and multi-level entry competencies may thereby co-exist within one curriculum and focus on the transformation of knowledge across boundaries in an innovative design process.

Problem-based, project-oriented learning is thus combined with the trans-disciplinary process represented by the procedural model for the trans-disciplinary experiment.

Conclusion

The paper discusses the need for an integration of scientific, technical and creative approaches in trans-disciplinary design and presents empirical experiments, theory, methods and applications toward fulfilling this need.

A procedural model developed on this foundation shows 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 may be applied as a pedagogical application in the context of multi-level learning competencies as when designing at engineering educations.

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