Dynamic Light as a Transformational Tool in Computer-aided Design

Ellen Kathrine Hansen\textsuperscript{1}, Michael Finbarr Mullins\textsuperscript{2},
Georgios Triantafyllidis\textsuperscript{3}
\textsuperscript{1,2,3}Aalborg University
\textsuperscript{1,2,3}\{ekh|mullins|gt\}@create.aau.dk

New lighting technologies may fulfill a need for holistic design methods by offering opportunities for both architects and engineers to apply methods and knowledge from media technology that combine daylight and interactive light, in order to complement and deepen an understanding of context. The framework combines daylight and interactive light and includes human needs analysis, spatial understanding, qualitative analysis, qualitative tests and visual assessments. A transdisciplinary model termed the "Architectural Experiment" is applied in a specific case by combining serial, parallel and iterative processes which include contextual analysis, architectural design, simulation, C++ programming, implementation of the dynamic smart-film diffuser, programming of voltage ranges on Arduino boards, rapid prototype construction and lighting technology.

Keywords: Design Tools, CAAD Education, Design Concepts, Lighting Design

INTRODUCTION

New lighting technologies may fulfill a need for holistic design methods by offering opportunities for both architects and engineers to apply methods and knowledge from media technology that combine daylight and interactive light, in order to complement and deepen an understanding of context. The framework combines daylight and interactive light and includes human needs analysis, spatial understanding, qualitative analysis, qualitative tests, visual assessments.

Architecture and lighting technology has undergone a revolution in recent years, as new sensor technologies and computational skills enable 'intelligent materials', interactive control of light, energy-saving measures and new LED technology to be applied in the built environment, which can be applied to meet human biological, psychological and physiological needs. The implementation of these technologies transforms the functional split between engineers, technologists and architects into a complex transdisciplinary design process (Hansen 2014).

A criterion for success of this endeavor will be, as Nobel Prize laureate Herbert Simon wrote of complex systems, that a large numbers of parts interacting in a non-simple way are resolved so that the whole is more than the sum of its parts. Simon distinguished between two modes of apprehending structure: between the world "as sensed" (or description of state and the criteria for identifying objects) and the world "as acted upon" (the description of process and the means for producing or generating objects having...
the desired characteristics) (Simon 1962). The task then is to employ a sequence of processes and tools that support each other and lead to innovative design solutions based on a theoretical model of ‘state’. Simon’s theories may have relevance to complex systems encountered in architecture, however, where he expected complex systems to be hierarchies in a world in which complexity evolves from the interplay of single elements, the goal here is to achieve a resolved design of integrated simplicity, which evolves from an initial state of complex diversity.

Towards the end of testing this relevance, there is a need to develop mixed research and design methods, where computer aided design tools used in physical and virtual experiments assist the transdisciplinary design process. To study this in practice, it can be instructive to focus more narrowly on a single aspect of architectural intervention. This paper takes lighting as the specific focal aspect.

Toward describing and developing such methods, this paper focuses on the potential of lighting to act as a primary means of renovating and transforming architectural environments. In this regard, light as a transformational design tool is perhaps one of the most non-destructive, reversible and gentle ways to transform and redefine architecture and spaces (Magnusson et al. 2015). The case studied is a particular urban and architectural challenge represented by an urban church building, which had fallen into disuse. The building was acquired by a private buyer, who sought innovative ideas for its transformation.

The process to integrate digital tools and combine architecture, lighting engineering and media technology builds on a trans-disciplinary model previously developed in the context of 'smart homes' (Hansen 2013) and presented as the "Architectural Experiment" (Hansen 2014). This paper will document and analyse the application of this process from a graduate student group project, dealing with integrating computer-aided design and new technologies to transform an architectural context through light. The work was carried out at a lighting design programme at Aalborg University in Copenhagen, Denmark, which draws on knowledge and skills within architecture, lighting engineering and media technology, in teams of researchers, the lighting industry and graduate students of lighting design (see [1]).

The model is applied in a pedagogical curriculum, in the context of multi-level learning competencies.

**METHOD**

The initial statement of the "Architectural Experiment" is a theoretical proposition of how to design with light as a multi-dimensional design element, by integrating scientific, technical and creative approaches to light in 5 domains. It proposes that distinct qualitative and quantitative criteria and methods from different disciplinary traditions can be integrated successfully, despite disparate technical/scientific, social scientific and art/humanities backgrounds (see Figure 1).

The case study method is useful to investigate contextual conditions pertaining to the phenomenon of study, in this instance the processes employed in application of the transdisciplinary model. Based on this theoretical proposition, briefly described in the preceding sections, the method relies on multiple sources of evidence, drawn from a single case (Yin 1994).
The findings from the case study can then be compared to the initial proposition in order to refine the theory, for use in future applications.

CASE: THE ABSALON CHURCH: COMPUTER-AIDED DESIGN OF DYNAMIC LIGHTING

Objectives and research questions

The intention of the project is to transform a city church building, situated in an older, dense, housing area close to the city centre of Copenhagen, from its traditional religious functions to a more dynamic, contemporary and multifunctional space, using light as the main design element. The initial question asked in this context is therefore 'how light can transform the interior space of the de-sanctified church to meet needs of the local community for new activities'. Drawing on knowledge and skills within architecture, lighting engineering and media technology, graduate students of lighting design teamed up to provide a design solution for a non-religious space, where focus is on an essentially neutral ceremonial volume. The needs for a non-religious ceremony were sought initially by proposing a dynamic, programmable visual spatial layering, adjustable from the start to the end of the ceremony.

By defining and combining the concepts of emotion/mood/atmosphere and light effects, three phases and illustrative light elements were defined: 1. light from pendants hanging from the ceiling, 2. highlights in the centre of the space and 3. polymer dispersed liquid crystal (PDLC) (Baetens 2010) sheathing placed in front of the windows and walls, thereby allowing dynamic diffusing of daylight and artificial light. Using these lighting elements, three phases of the ceremony, arriving, transition and departing, are illustrated (see Figure 2).

The diffuser was constructed of a middle layer of PDLC, surrounded on each side by a transparent conductive layer for the purpose of applying voltage, with an outer-most layer of non-conductive isolating material (see Figure 3). To slow the perceived transformation of the material, the diffuser was built up of independent triangular components, enabling a simultaneous variety of transparent to translucent to opaque.

The process of designing with dynamic lighting

The design process will be described using in terms used by the "Architectural Experiment" model.

Step 1: Transfer. Knowledge from different disciplines is collected, transferred, reviewed and coded into a common language to define a common problem statement for the design.

The very first step was to define a common imaginative research question starting by asking "Why is
Figure 3
The diffuser was constructed of a middle layer of PDLC, surrounded on each side by a transparent conductive layer for the purpose of applying voltage, with an outer-most layer of non-conductive isolating material (Source: Magnusson et al. 2015).

a church for sale?” Collecting knowledge on people’s need for a ceremonial space and not a religious space led to the imaginative research question: What if a now defunct church could be transformed into a neutral ceremonial space, satisfying new ceremonial needs in our society?

Knowledge on transformation and societal needs, religion, neutrality, similar projects, and stakeholders was collected to define the overall problem statement and the three success criteria. A reflection on transformation, heritage and light was made through literature survey. This knowledge was used to define the differences between the light in a typical church and a religion-neutral ceremonial space.

This led to the problem statement (see Figure 4): Can we transform a religious space into a religion-neutral ceremonial space, satisfying new ceremonial needs of our society, through the use of light?

1. Using light to achieve a new religiously unbiased identity.
2. Ensuring that the ceremonial contents and functions are supported and facilitated by the lighting design.
3. Ensuring that neutrality does not compromise the solemnity required of a ceremonial space.

Qualitative analysis was made based on architectural observations of the design space. It was noted that the large windows give the room unique features and allow much daylight to enter. The space presented an unique and solemn atmosphere.

Figure 4
Design elements for satisfying ceremonial needs of society, through the use of light (Source: Magnusson et al. 2015).
Quantitative analysis of the daylight in the building was done through illuminance measurements (see Figure 5).

Knowledge from different disciplines is collected, transferred, reviewed and coded into a common language.

Figure 5

Step 2: "Translate". The knowledge from the different fields is translated and investigated through experiments.

A literature survey of the meaning of ceremonial rituals referred to theory from sociologists, philosophers and psychologists and formed a fundamental design concept: Ceremonies are rituals that mark a change of state of being. This idea was combined with the question of how to satisfy the practical functional needs of the ceremony, as well as to add value to the ceremony. This led to the following assumption that became the core of the design concept, to be explored through a design proposal:

1. "If the ceremony is dynamic then the lighting could also be dynamic."

For example, if a funeral is charged with emotions, which evolve through the ceremony in phases, lighting could support these emotions by supporting the transition between phases and fulfilling the spatial and atmospheric needs attached to each phase.

For a better understanding of how different lighting attributes can support a transformation of religious space into a neutral one, an experiment was conducted.

Images of light attributes were replicated in a digital environment, defining a certain ceremony and placing 3D models of people in the space of the church building. An online survey was conducted to compare pre-defined variables.

From the results the following design guidelines were defined:

- A compromise between appropriateness and neutrality is a compromise between warm and white light: ideally between 4000-6000 Kelvin.
- Some level of contrast is needed to achieve solemnity and intimacy.
- A very neutral and preferred result seems possible with diffusion of daylight.
- Many small luminaries are preferred, but must avoid heavenly references to be neutral.

The visual hierarchy of the design is achieved using three different lighting elements that together constitute the design proposal:

- Pendant lights, floating over the benches in varying heights.
- A highlight of the floor in the ceremonial center.
- Dynamic diffuser panels that control and alter the intake of daylight.

The results of the attributes-test suggested that diffusion of daylight is a neutrally perceived element. The diffuser offered opportunities for the sought after dynamic element of lighting, by controlling how warm light of the pendants is perceived and amount of daylight present in the space.

A second experiment was conducted to test how people perceive light with different fading phases of the dynamic diffuser, viz.: 60, 30, 10, 5, 2 and 1 seconds.

A predominant consensus was achieved from this experiment, and a 30 second fading time for each triangle was chosen as a basis for the dynamic diffuser.
Rapid prototype simulations of daylight and the smart-film diffuser were essential to study the design potentials of the double interior skin, appropriate to the three phases in the ceremonial space.

**Step 3: Transform.** The findings from the above experiments were transformed into a design solution using 3D models, scale models and simulations. The effects of the dynamic diffuser together with the other lighting elements were rendered in 3D models, renderings and photometric simulations (3DSMax, Rhino, V-ray, IES files) to examine the quantitative relationship between daylight intensity, translucency of the interactive interior wall, as well as time-lapses in relation to the ceremony.

In accordance with the design concept, daylight entering the ceremony space was to be filtered in dynamically to support emotions present in the course of the funeral ceremony. The solution to these specifications was a setup comprised of a PDLC smart-film material, an Arduino controller using open frameworks and customised electronic architecture. To perform experiments with each of these technologies and to test the final functionality and compatibility, a down-scaled prototype was developed.

The 12 individually controlled PWM outputs situated on the Arduino Mega offered individual output voltage levels in the range between 0 and 5 volt direct current (VDC). To meet the higher voltage requirements of the PDLC material, additional electronics were needed between the Arduino outputs and PDLC composite. Observations of the quality of the light transmitted through the diffuse and transparent panels were made and measurements of the values of the transmittance and reflectance of light in the different stages of the material were measured.

In order to test different lamp sources with different luminous power and lighting distribution a system was needed, which would provide a flexible approach for access to the space and the different light sources. Dialux software was used for this process.

**Step 4: Test.** 3D physical models and digital simulations were used for qualitative testing in this case (see Figure 6). A user focus-group was questioned on different scenarios and moods of the changing scenarios and their reaction to different solutions was observed.

**Step 5: Share and learn.** Video, renderings, animated materials were prepared to communicate the design idea under different lighting conditions (see Figures 7-9). The time aspect was essential in this context and the video was therefore an important tool.

**DISCUSSION**

The transdisciplinary model for the "Architectural Experiment" is applied to the case study, which combines serial, parallel and iterative processes and which included contextual analysis, architectural design, simulation, C++ programming, implementation of the dynamic smart-film diffuser, programming of voltage ranges on Arduino boards, rapid prototype construction and lighting technology.

The case demonstrates the potentials of combining digital, engineering and architectural design tools and methods to transform the meaning of spaces, by coding intelligent materials and dynamic light to meet the changing needs of the urban architectural environment.
The case focuses on the creation of a neutral ceremonial volume, using a complex system of resources. It attempts to create, through lighting, an influence upon the sensed or perceived world. The case study is used to examine the process it employs to achieve this aim.

Following the "Architectural Experiment" model, the process and tools can be grouped in the following five domains:

1. **Transfer.** Knowledge from different disciplines is collected, transferred, reviewed and coded into a common language.

2. **Translate.** The knowledge from the different fields is translated and investigated through experiments. Rapid prototype simulations of daylight and the smart-film diffuser were essential to study the design potentials of the double interior skin, appropriate to the three phases in the ceremonial space.

3. **Transform.** The findings from the experiments are transformed into a design solution using 3D models and simulations. The effects of the dynamic diffuser together with the other lighting elements were rendered in 3D models, renderings and photometric simulations (3DSMax, Rhino, V-ray, IES files) to examine the quantitative relationship between daylight intensity, translucency of the interactive interior wall, as well as time-lapses in relation to the ceremony.

4. **Test:** The 3D model and simulations were used for qualitative testing in this case. A user group was questioned on different scenarios and moods of the changing scenarios and their reaction to different solutions is observed.

5. **Share and learn:** Video, renderings, animated materials, communicating the design idea with different light settings. The time aspect was essential in this context, and the video therefore an important tool.

While luminance levels can be predicted and measured relatively easily, several of the success criteria for the project revolved around achieving a dynamic architectural atmosphere of neutrality suitable to a ceremonial space where perception and time is subject to the inherent ambiguity of visual perception, subjective feeling, emotional response and personal preferences. An attempt was made to approach this question both analytically and with a qualitative approach and established results that indicate that lighting attributes can have an important role in affecting whether a space is perceived as religious or not.

The process of combining complex combina-
tions of daylight and electrical light, by employing the initial model has confirmed for the authors its usefulness in integrating many disciplines and computer-aided technologies in a design studio setting. The method of moving from an analytical phase centered on research and testing, into creative design-proposal phase, followed by a series of smaller experiments to develop implementation and detailing was successful in incorporating the three academic fields of lighting engineering, architecture and media technology and in achieving a resolved design of integrated simplicity, evolved from an initial state of complex diversity.

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