Sustainability through Light: A Contemporary Approach to Articulate Design and Technology

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Abstract
This paper describes the concept, design and development process of an interactive and immersive exhibition on state-of-the-art façade technologies for advanced daylighting control. Its aim is to propose an effective, informative and interactive experience that increases the awareness and understanding of designers and the general public about advanced daylighting strategies. This exhibition will focus on revealing their performance while emphasizing their key role in integrating sustainability in architecture. It will use tactic installations of these materials and assemblies to get architects to explore the fascinating spatial design opportunities enabled by their capabilities to control daylight and solar radiation. Visitors will interact with these technologies by walking through the space and getting to understand the basic principles of daylighting and the potential of these technologies through custom installations and case studies, using digital and analog media. The exhibition presents an opportunity to use a real space as a case study and a laboratory for new applications of these materials. The ultimate goal of this research project is to serve as an efficient didactic instrument to connect design, technology and industry at national and international levels.

Keywords: Daylighting Technologies, Energy Efficient Building Envelopes, Educating Sustainable Design

1. Introduction

Traditionally architects have been actively engaged in the development of building materials. Nevertheless, during the past two decades, such materials have started to rely ever more heavily on sophisticated technological advances, a tendency that led to a gradual distancing of designers from the materials' actual development process. As a result, two opposite perspectives have emerged when describing such systems. One is the technological perspective, where characteristics and performance are described through technical publications and numerical data. The other attempts to remain closer to a design-oriented perspective, recurring to minimal art formats, such as abstract images and other visual representations, exhibited in galleries and catalogs. Although the latter initially attracted the design community, its lack of reliable information about the systems' architectural feasibility has favored a fade-out of that first burst of enthusiasm.

This segregation between technology and design is of particular concern in the area of daylight control, since a decrease in electrical lighting usage and a better control of solar gains have become absolute priorities in contemporary energy-efficient architecture. Nowadays, buildings are responsible for 68% and 39% of the total electricity and energy consumption in the U.S., and almost of a quarter of the global annual energy needs of the planet [1]. Amongst the different end uses of this energy, lighting purposes causes particularly high costs in terms of energy, ecological impact and economics [2]. For these ecological reasons, the control of daylight and solar radiation through fenestration systems has received a growing attention in research and has led to the development of a large variety of innovative façade systems. Unfortunately, due to the lack of effective communication between the design and technological fields, a large portion of the contemporary showcase of daylighting systems remains largely unknown to the majority of designers [3], who at best envisage to incorporate these technologies a posteriori.

In order to support better-integrated systems and guarantee a harmonious association of sustainability with leading-edge design, it is fundamental to encourage the communication process at the earliest possible design stage, as illustrated in Figure 1. To achieve this, an effective collaboration between scientists and architects/designers is of paramount importance since the assessment of daylight systems' performance by engineers is critical for the industry. But, their effective implementation in buildings will ultimately depend on architects. Such a scenario presents an important challenge for academic environments, where interdisciplinary cooperation and didactics offer a privileged platform for promoting awareness of sustainable strategies in design and architecture.

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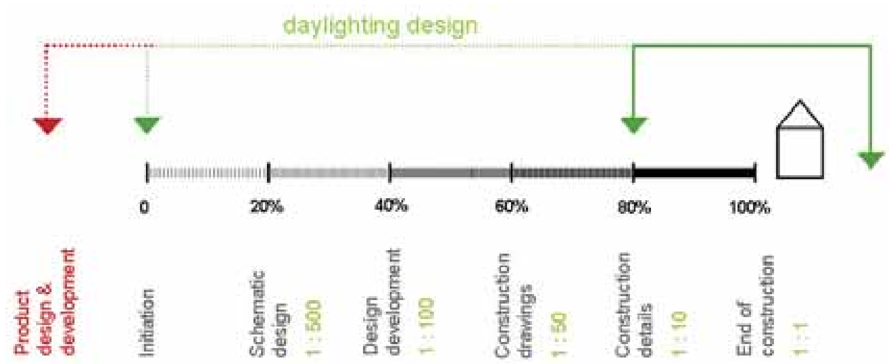

Figure 1. Diagram showing the stages in which the daylighting design takes place, and the desirable displacement towards the initial stages of the building design process

In order to address this important issue, two approaches were considered. The first aims at comprehensively compiling and categorizing information about daylight-control technologies, but also at describing them in an appealing, useful and effective way to designers. Such an approach was materialized in the D-LITE project [4], a database of light-interacting technologies for architectural envelopes (freely accessible at www.d-lite.org). The second approach aims at the creation of a platform which promotes the collaboration between designers, scientists and manufacturers, relying on an exhibition format. In this paper, the concept and development stages of this exhibition are described. It is hoped to serve as an intense, physical, and effective instrument to actively assure the first contact with these innovative materials.

2. A case study, a mise-en-scene and a laboratory in one exhibition

Exhibitions strategically act as articulations where the production from a specific field, as well as the professionals involved and many different publics all intersect. Situated so critically, they function as the prime transmitters through which the updated production is brought into intense focus. With these characteristics, the design of this exhibition is a fundamental complement to the D-LITE database, as it explores applied research and creates a platform to grant an impacting contact with our targeted audience.

As referred in the introduction, we intend to adopt a didactical perspective within the exhibit's framework. In order to achieve such a goal, we identified three critical components that will benefit our enterprise: a) Availability of materials – an opportunity to gather and display samples of a representative selection of daylighting technologies, which allows visitors to have access to a tangible understanding of these materials (this is highly valuable since a range of them are of difficult access); b) Installation of materials - This is a key opportunity to explore the potential in integrating the design and construction aspects of these daylighting technologies in building envelopes, and to understand their flexibility and practical applications; c) Creation of scenarios - Through the planning of different 'mise-en-scene's with these systems, it is possible to understand not only their possibilities in the generation of the architectural envelope itself, but also to show the impact of the light performance projected on the space. Within this framework, our intention is to design an environment in which a selection of state-of-the-art daylighting technologies will allow visitors to experience the qualities of a space endowed with these materials' attributes, as the materials will be the protagonists of the exhibition themselves. Towards this end, the dynamic nature of sunlight will be incorporated in the way these systems are perceived, and the variety of ways in which these materials perform will be revealed, which will generate a tactic itinerary provoking a specific contrast of concepts.

The first exhibition venue will be the MIT Museum, wherein the installations will be distributed in the diaphanous interior space and the glazed south and southwest facades. These facades will host the different solar experimental technologies, to monitor and analyze the quantitative and qualitative performance of passive and active solar facades in real "in-situ" conditions. As a consequence, some of the materials will benefit from actual daylight conditions, while others will use a calculated lighting setup to precisely control specific stimuli and searched reactions/results over the studied space. Additionally, the exhibition will also include the display of graphical information about the basics of daylighting design and representative architectural case studies. This information will be transmitted by different means of representation, namely interactive digital media, physical models, and a printed catalogue.

3. Structure and layout of the exhibition

The exhibition is structured into five distinct physical areas that relate to five major subjects regarding the impact of daylight on the environment and on humans, illustrated through specific types of light-control technologies. These areas take the form of modules with similar construction conditions, to endow this configuration with the flexibility of being adaptable to different spaces and venues. The visitor's experience within each of these five modules can follow three different perspectives or itineraries that correspond to sensory, descriptive and conceptual narratives, respectively. While visiting the exhibition it is either possible to navigate through the modules within a single narrative perspective (itineraries A, B, C in Figure 2), or, to reinforce the didactic component of the exhibition by following the most complete itinerary from an educational standpoint, i.e. to visit each module in its three aspects (itinerary D in Figure 2). This structure tackles into the “what”, “how” and “why”, of daylighting systems throughout this exhibition. Through the first route (A), visitors will experiment the materials' performance in the space without ‘seeing’ the actual materials performing. The second itinerary (B) will get visitors to see the material protagonists working. This will allow them to identify specifically experienced environments and particular technical installations. This circuit will be particularly didactic, since it will include explanations and examples of how these technologies are installed, manufactured and used through different built case studies. The third itinerary (C) will be intermingled within the other two and in a way sews the exhibition as a whole. It will investigate which daylighting concepts underlie the visitor's experiences in each module. It will emphasize benefits and challenges in daylighting strategies, educating the visitor about why these concepts are important and why these technologies are useful.

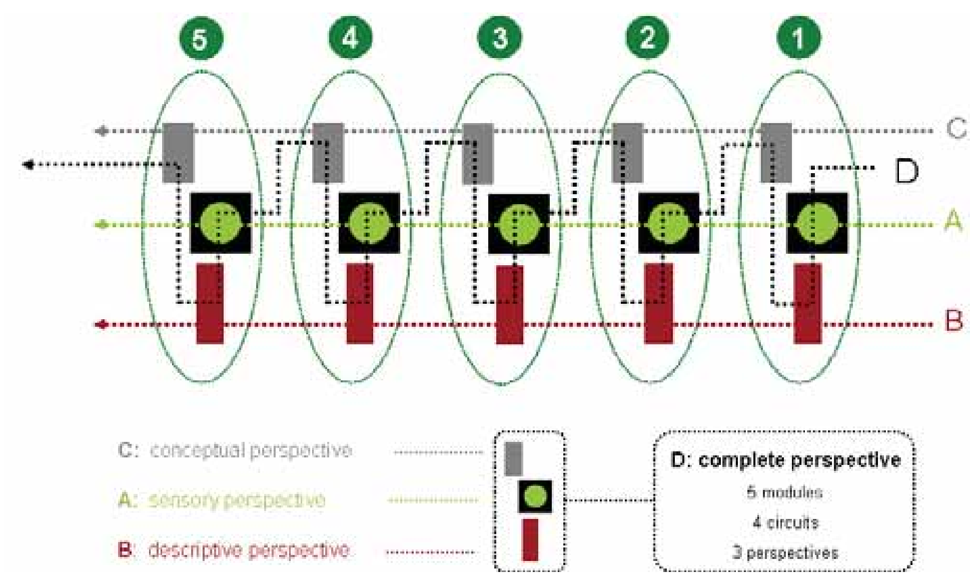

Figure 2. Diagram showing the modular organization of the exhibition, and the four designed routes to navigate the space.

The layout of the exhibition, shown in Figure 3, follows an arrangement with circles of different sizes, a geometry that favors the flow of people between the different areas. Each module is composed of circles to configure surfaces at different heights: one for the suspended ceiling, one for the treated floor and one to house cylindrical enclosed spaces for the environmentally controlled sensory areas. Albeit a selection of the daylight systems are set up to actively perform within the module's sensorial space, there are many others showcased that will configure a complex active screen installed in the MIT Museum's south façade, and will make up a special feature within the exhibition's installations.

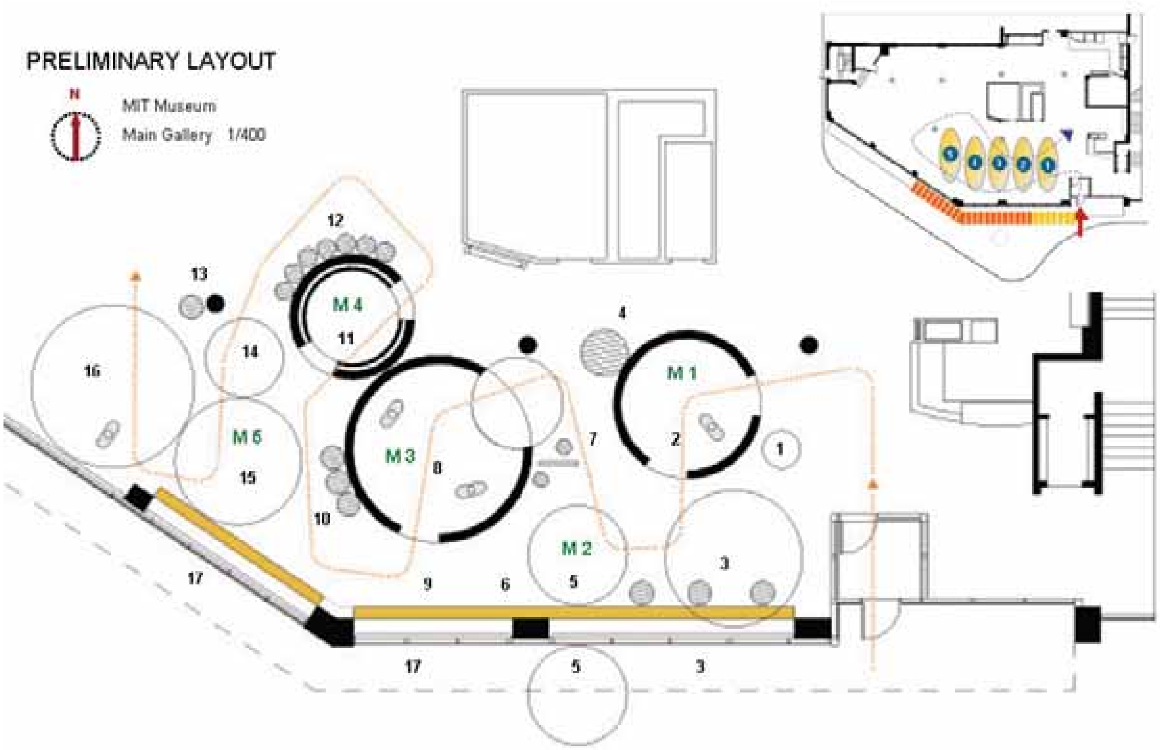

Figure 3. Preliminary layout for the exhibition at the MIT Museum building (exhibition program): M1 – Module 1; M2 – Module 2; M3 – Module 3; M4 – Module 4; M4 – Module 4; M5 – Module 5; 1 - Introductory point.; 2 - M1's Sensory space: Redirected light, 3 - M1's Descriptive area: Interior Student Work + Student Work on Glazing. 4 - M1's Conceptual area: Heliodon; 5 - M2's Sensory space: Transported light; 6 - M2's Descriptive area; 7 - M2's Conceptual area: Day-Night panel; 8 - M3's Sensory space: Colored light; 9 - M3's Descriptive area; 10 - M3's Conceptual area: peephole models; 11 – M4's Sensory space: Diffused light; 12 - M4's Descriptive area: envelope design models; 13 - M4's conceptual area; 14 - M5's Sensory space: Powered light; 15 - M5's Descriptive area: energy house; 16 - M5's Conceptual area: global energy context; 17 - Materials showcase on glazing.

3.1 Module 1: Daylight variability and sunlight dynamics with angularly-selective technologies

The first module addresses the sun course and how sunlight impacts on our built environments. Light-guiding technologies, with their sharp light pattern, clearly illustrate how natural light travels over the space (M1 in Fig. 3).

In the enclosed sensory area (numbered 2 in Fig.3), the space is conceived to be perceived as 'dynamized' by sunlight: light beams move all over the surrounding surfaces showing long well defined trajectories. A conceptual sketch about this effect is shown in Figure 4a. The installation consists of an enclosure that contains a square window on the top through which the space is lighted. That window houses a rotational wheel with one sample of standard clear glass (to be used as a reference) and five samples of light-deflecting materials (holographic glass, prismatic structures, laser cut panel, retrotechnology blinds and Lumitop panels) to provide a diversity of the space's lighting patterns for the same incident light conditions (the daylighting systems and technologies mentioned throughout this article are described in [4]). The space is illuminated, in sequence, through these five materials as well as without any sample, and each of these six situations configurations will undergo one cycle of four different angles of incidence. During each cycle, a 'print' – or trail - of the transmitted light's trajectory is revealed, that shows the area of space that was lit. This trail will be physically marked with lines of flashing LEDs and will display relevant quantitative data at reference points: illuminance (lux) registered at that location, distance and height of light penetration and sun's angle of incidence. Every cycle will project its own print over the previous ones, making it easier to compare the materials' performances in this context. At the end of the complete sequence only the set of prints remains as well as their corresponding quantitative indicators.

The descriptive area of this module consists of digital and analog graphical information describing these materials and their manufacturing processes, as well as prototypes and physical models related to representative architectural case studies in which they have been applied. This area is starred by an installation developed by students (numbered 3 in Fig.3), consisting of a light-redirecting blind that occupies a highly visible portion of the MIT Museum's south-facing facade. The students' blind is complemented by a ceiling-hung chandelier that will also design and whose purpose is to receive and spread the redirected light in the gallery.

A custom-designed heliodon (numbered 4 in Fig.3) will hold the leading role in the conceptual area, meant to educate and illustrate about the importance and evaluation of sunlight conditions in architecture. The device will consist of a horizontal platform with a motorized rotating center; three rotating arcs, applicable to two latitude settings (20º and 50º), that are all moving; three motorized torch lamps (one per arc, with flipping translucent flaps to (conceptually) represent diffuse light (overcast skies); and a model with various openings and architectural light-control components (such as light-shelves, clerestory windows, etc). A digital camera equipped with a fisheye lens, connected to a digital screen, will show interior images of the lighting situations in real-time.

3.2 Module 2: Designing with daylight under the spotlight of light transporting technologies

This module (M2 in Fig.3) addresses the quantitative implications of daylight in relation to human physiological impact (health), psychological impact (productivity and satisfaction), and emotional impact (perceived 'quality' of a space). The technologies presented in this module (whose descriptive area is numbered 6 in Fig.3) are capable of remotely transporting daylight; they thus represent a valuable mean to contribute with a solution with daylight benefits to those interior spaces where opening windows is very limited or impossible.

In this module, the sensory area has an interior display in connection with the solar façade installation, by means of two systems for the transport of light. One of them is confined and exhibits the Parans system in its three modes: sun-tracking collecting panels installed on the façade, optical cables transporting light over several meters towards the interior gallery, and luminaries to release natural light deep inside the room. The second system is open and is based on reflection through heliostats and mirrors. These are installed so as to form a vertical light 'band' along the façade (from the top cornice to the upper edge of the ground floor) that ultimately gets redirected to penetrate inside the main gallery space. Part of the outside vertical light performance creates a small play of light on the sidewalk, which catches the passers-by's attention, and part of it is redirected to the inside through a trajectory of controlled light manipulation with reflective pieces strategically set (sketched in Figure 4b). The interior light performance indicator (numbered 5 in Fig.3) will display the distance and amount of light that reaches a given point.

In the conceptual area (numbered 7 in Fig.3), a two-sided panel (one side to represent "day" – brightly and harshly lit - and the other "night", illuminated by dim and soft light), will discuss the effects and benefits of (day)light on the health and well-being of occupants, with a particular focus on the effects of light spectrum, intensity, timing, duration and contrast.

3.3 Module 3: Human response to daylight illustrated with colored light and switchable spectrally-selective technologies

This module (M3 in Fig.3) addresses the qualitative effects of daylight on humans at two levels: physiological response at the eye (visual versus circadian), and psychological response (individual preferences such as visual interest, pleasantness and space quality). The technologies installed to illustrate this module, that will be described in the area numbered 9 in Fig.3, are those that have spectrally-selective properties, given that every range of the solar radiation's spectrum has specific direct effects on human beings, e.g. UV radiation, thermal radiation or colors .

The sensory space (numbered 8 in Fig.3) will focus on how the materials' surfaces can interact with light and project light within the surrounding space. Switchable materials (such as colored liquid crystal, electrochromic glass, suspended particle devices, photochromic glass and switchable mirrors) will be set to generate a performance according to a predefined sequence, in which their appearance rhythmically mutates between two extreme states: from clear to translucent, from clear to dark colored or from clear to mirror. The installation consists of a set of round frames, each of them holding one of these materials, suspended from the ceiling and forming a strategic geometrical arrangement, as illustrated conceptually in Figure 4c. This set up will be lit by a set of lamps making up a cycle in which light beams can cross the discs (clear states), be filtered (colored states) or be reflected (mirrored states), which will result in a play of light beams with changes in color and direction, filling the space.

The conceptual area of this module (numbered 10 in Fig.3) will be distributed over three pieces: one to explain the human eye's response to daylight, the second to illustrate the eye and brain's adaptations to different environments, and the third one to manifest the subjectivity of environmental comfort. The first piece is a dynamic lighted panel that will illustrate and compare the eye's visual and non-visual systems and discuss the benefits of daylight from both perspectives. The second piece, which will be placed in front of that panel, will consist of a peephole set-up containing three interior models with three lighting environments, that will differ by their color temperature and will demonstrate the eye's and brain's adaptation capabilities: greenish environment ('bright' for vision), bluish environment ('bright' for circadian system) and white environment (daylight). The third piece will be an interactive touchscreen showing interior views of rooms where the perceived comfort or pleasantness of the space will be evaluated by the visitor as a function of critical factors such as view interest and overall brightness contrast due to sunlight penetration for example.

3.4 Module 4: Human impact of daylight (and "night" light) using diffused light

This module (M4 in Fig.3) addresses how daylighting performance and envelope design relate to each other and illustrates this with uniform illuminating conditions and a changing building enclosure. Light-diffusing systems, such as insulating glass units with nanogel, were thus chosen as the technology of choice to generate these effects.

In the sensory area (numbered 11 in Fig.3 and sketched out in Fig. 4d), the change of illumination in the space is accomplished by a dynamic, multifold envelope that enables different types of openings covering a range of areas, shapes, positions, orientations and optical properties. The core layer of this changing enclosure will be a rigid surface that houses all the windows with the light-diffusing material installed. An interior, concertina-like movable layer installed in front of the middle layer will be responsible for uncovering and covering the different openings. A set of lamps will be distributed behind the windows, between the central and outer layer: their function is to conceal the technical equipment and finish the wrapping. This immersive experience addresses concepts such as transparency, translucency, brightness, glare, light density and uniform distribution of light in a space.

The descriptive area (numbered 12 in Fig.3) will include a display of seven physical models to relate envelope design considerations to daylighting performance metrics (Daylight Factor and Daylight Autonomy). A touchscreen will accompany the installation with pre-computed animated scenarios, related to four subjects: climate-based modeling, dynamics of daylight over time, and support for design through simulation methods. An ongoing research project, called Lightsolve and led by one of the authors (M. Andersen), addresses these concepts and will be demonstrated too [5].

The theme studied in the conceptual area (numbered 13 in Fig.3) deals with a key question: what is good daylighting? The idea is to increase awareness of how challenging it is to find a balance between all the (conflicting) daylighting goals: illumination, view, glare, heat, seasonal needs, non-visual light and quality-space. The installation will contain a desk panel with a digital screen and a static text embedded in it. The digital screen will display continuous animations and offer a pre-computed didactic sequence that can be activated on demand. The static text will be printed on an interactive LED-lit panel that will evidence how challenging it is to evaluate daylight through a sequence of overhead and LED dimming scenarios that will illustrate glare and visual comfort issues.

3.5 Module 5 : Energy conscious living and daylight facts within examples of hybrid technologies to harvest and control sun energy

The last module of the itinerary (M5 in Fig.3) will depict the critical role of daylighting within the global understanding of sustainable architecture. After the advent of fluorescent electric lighting and air-conditioning, the development of daylighting as a discipline was revived by the necessity to design more energy efficient buildings. In today's environmental context, it is very natural to see that a lot of emphasis is placed on daylighting's ecological benefits, which usually puts this argument first in the list of benefits associated with daylighting. In this exhibition, the order is deliberately inverted as an educational mechanism that goes from the individual to the collective experience of daylighting significance. By interiorizing direct feelings related to comfort, aesthetics and health, we believe it will be easier to understand a second level of not so directly sensed implications, such as how the judicious use of daylight affects the global energy balance of buildings, which in turn, influences the global sustainability of the planet. .

The sensory area (numbered 14 in Fig.3) exhibits the still emergent hybrid solar technologies that are able to produce power as well as contribute with daylight-control. The installation shows how the new solar cells are able to create a specific lighted environment. The set-up will place four samples of different patterns of colored solar cells forming a square. Below each of these, one lamp will be placed that turns on and off alternately to have one sample lighted at a time. The light will thus be coming from below, will travel across the sample and be projected on the ceiling. There, a mirrored surface will spread it around. The floor will also mirrored be underneath that area, so that the colored light forms a solid volume.

A selection of these hybrid materials will actually be installed on the façade, and form part of the descriptive area. It will make up an intuitive interactive installation, which aims at engaging visitors by making it easier to grasp the energy aspects of daylighting. The set-up will be a 3-D representation of a family-house, where a diagram with the house's set of needs will be depicted and where corresponding energy usage will be shown. These will include electricity inputs (solar cells from the facade) and outputs (consumption from domestic appliances), but also the energy variables due to daylighting considerations in relation to heating and cooling (number 15 in Fig.3). All these parameters can generate different energy uses and energy savings, depending on the way they are combined. Through our energy-house scenario, an electronic circuit will be prepared that will get these components to interact with each other. The visitor can thus see different cycles showing different ways to use the house resources, making it more, or less, sustainable. The aim of this setup is to assess all the factors that contribute to achieving a sustainable house, and how new proposals take advantage of different perspectives to get better results, by mixing solar energy and daylighting research.

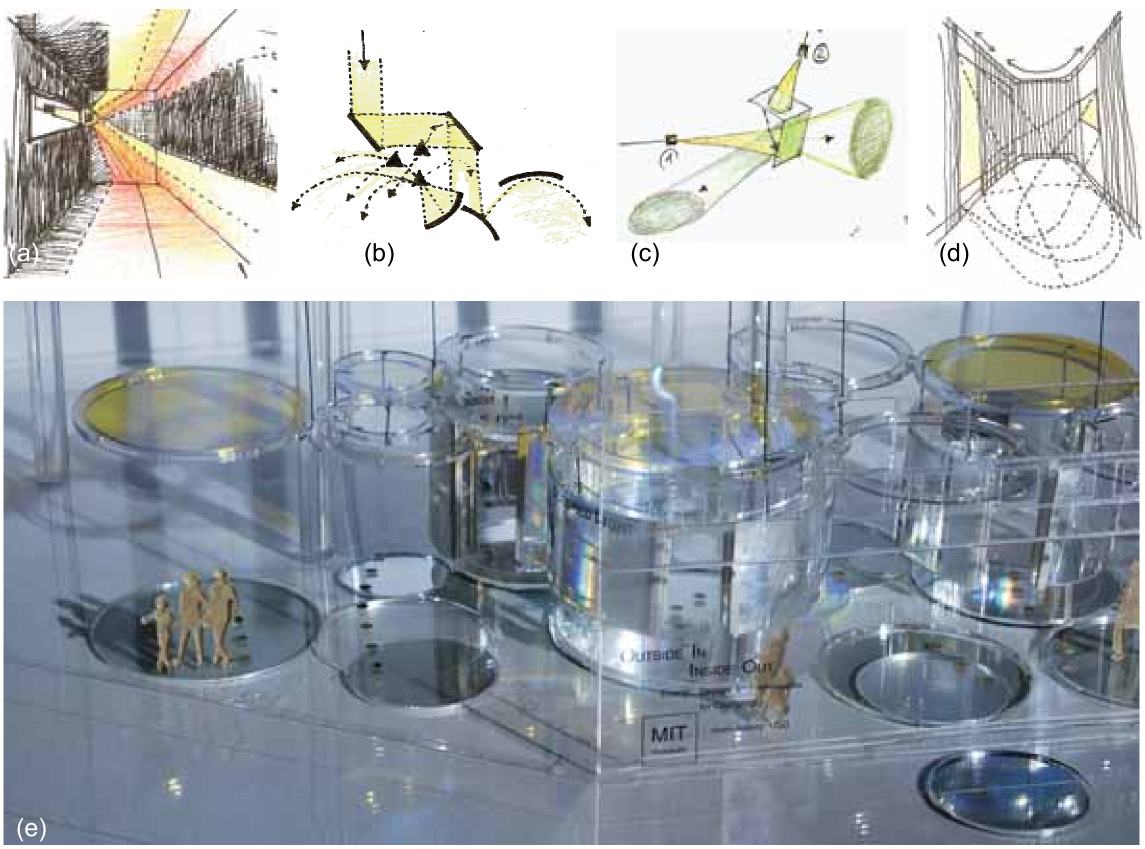

Figure 4. Conceptual sketches for exhibition's modules 1-4 (a-d) and preliminary 3D model of its installation in the MIT museum (e).

4. Conclusions

This paper describes an exhibition on light-interacting technologies for architectural envelopes, whose first installation is currently being designed for the MIT Museum façade and main gallery. The exhibition establishes a compelling means to transmit knowledge about daylighting benefits, strategies, technology and applications, and was developed as a phenomenological storefront to a parallel effort led by the authors of generating an interactive online database of light-interacting materials (D-LITE)[4].

The installation of the exhibition materials, as a simulation of a possible reality, proposes a new kind of laboratory in which one can physically interact with these technologies and better understand how advanced daylight and solar control can be applied in concordance with architectural requirements. We are living a vibrant moment in which architecture is experimenting an evolution defined by sustainable concepts. At the same time, it is crucial to revise how sustainability will shape future spaces. As a consequence, we witness a shift in society values, which include a refreshing openness towards leading-edge technology therefore making the timing of this project optimal. Indeed, there is now a wide range of technological alternatives and metrics available, while market and public perception are still permeable enough to new concepts in merging energy-efficiency, aesthetics and comfort in contemporary architecture.

The didactic focus is reinforced by the inclusion of students work, resulting from a daylighting class taught the semester preceding the exhibition. Students will be asked to design and build unconventional ways to express the dynamics of daylight and its interaction with advanced façades, with specific format constraints. We plan to create a strategic itinerary for this kinetic showroom to be displayed in schools of design and architectural centers of reference, to engage the participation of students and designers in different countries.

This project optimally satisfies a confluence of interests, offering a challenging opportunity to link the technological and design perspectives into an immersive and enriching experience. This project can thus be seen as a unique opportunity to become an active meeting point for designers, scientists and manufacturers. The show is not only educational but a unique occasion to explore how design-based approaches to research can actively complement science-based work.

5. Acknowledgements

Rosa Urbano was jointly supported by the Fundación Caja Madrid and the MIT Energy Initiative. Marilyne Andersen was supported by the Massachusetts Institute of Technology. The authors would like to thank the MIT Museum, and particularly John Durant, Gary Van Zante and Laura Knott, for their support to this project and their contribution in terms of project ideas and development. They also want to acknowledge the MIT architecture student Gerhard van der Linde for his help making the physical model of the exhibition.

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