Designing an Interactive Architectural Element for a Responsive House

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ABSTRACT
This paper presents the features and the reasoning followed in the process of designing a programmable architectural element for a prototype house – a interactive façade involving a matrix of programmable windows. The façade contributes to the precise adjustment of view, airflow, solar radiation, and heat, by allowing the automated modification of the chromatism, the angle and the light transmittance of each individual window.

KEYWORDS: Electroactive materials; autonomous control; interactive façade; performance; aesthetics.

Introduction

Objective of this research was the development of a responsive, energy efficient, home living environment. The method to address this challenge was to enforce sustainable operation through technological innovation, and the selected test-bed was to design and implement a full-scale prototype house in Trento, Italy. This paper presents the features and the reasoning followed in the process of designing a specific interactive element of the prototype, namely, a façade involving a 3 × 9 matrix of programmable windows. The façade adjusts view, airflow, solar radiation, and heat, by permitting the adaptation of the chromatism, the angle, and the light transmittance of each individual windowpane. Except from making the precise adjustment of the incoming air, sunlight and heat possible, varying the number and the distribution of the active windows on the façade affects the way the house is perceived from the public street. The class of the performatively acceptable façade configurations was approached as a visual language, and it was mapped through the conventions of a generative grammar. The novelty of this research is that combines the use of electroactive materials, light, heat, motion and humidity sensors, and the use of an autonomous control system, to associate in real time visual principles of 2-d pattern generation and levels of sunlight illuminance at the interior of the prototype. The dynamic façade operates complementarily to the other house systems, while the autonomous control system supplies real time performance evaluation using a model-based plan executive to optimize the long-term energy performance.

Background

Innovation in environmental engineering has far-reaching consequences in the design and operation of buildings. New environmental management methods are usually accompanied with delivery of new experiential qualities into the inhabited space. The impact is more significant as a whole when the advances in environmental control are available at domestic scale. For example, the environmental control advances of the industrial age, such as the electric lighting and the air conditioning have had strong stylistic, structural and functional implications in the architecture of the early 20th century. As Banham (1969) notes: "The tenuous curves, pale walls and luminous decorations of Art Nouveau, would be unthinkable without electric light".

Today the advancement of information/communication technologies and programmable materials reposition architecture into the late digital age. The ability to deliver computational power directly into the material components of buildings, to sensibly modify their attributes, greatly affects the environmental, aesthetic and social character of architecture and the ways we conceive and practice design. The flexible modes of use of the dynamic façade range from moderation of view and air, to privacy control, personalized daylight or shade, and ultimately personal communication and self-expression. A number of papers describe the state of the art in programmable materials, like electrochromic glass. Gugliermetti and Bisegna (2003) present a study on energy management with electrochromic technology, while Hausler et al (2003) present a technical comparison of electrochromic glass. The structural system of the prototype house is presented in Kotsopoulos et al (2012a). The rudiments of the autonomous control system of the prototype are presented in Kotsopoulos et al (2012b), and the generative grammar directing the states of the façade is presented in Kotsopoulos et al (2012c).

Configuring an interactive façade

The prototype house is a detached residential unit consisting of a loft space with an open-view curtain wall facing south. The interior is a free, open in layout space, differentiated functionally by built-in equipment for sleeping, eating, living, etc. The flowing interior space, the indoor and outdoor open areas, and the wide curtain wall, all typically demand considerable expense of thermal power and precise energy control. The interior atmosphere of the prototype is optimally serviced by its innovative environmental management systems. The plan and section of the prototype are adapted to these systems. Early typological studies mapped schematic building layouts and their ability to accommodate various energy production components, such as solar panels, wind turbines etc. Building layouts such as the single flank linear arrangement or the enclosed atrium arrangement, were examined to identify how particular geometries affect energy production (Figure 1, left). For example, a linear single flank arrangement that is appropriately oriented provides wide roof surface for the installation of solar collectors or wind generators, while a cubic arrangement with a central atrium offers a core area that can be used to produce energy and heat through a cogeneration plant. Of course, certain assumptions can always be revised, as new technologies can supply living environments with new, original features. The selected conceptual layout for the prototype was the single flank linear arrangement (Figure 1, right).

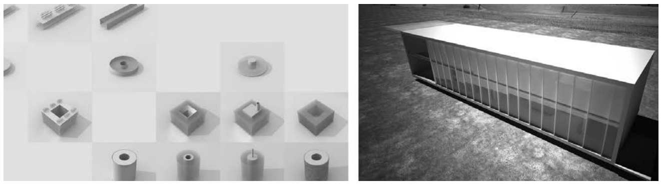

Figure 1

Two principles underpin the logic of the house design. First the house was conceived as a responsive living environment providing maximum interior comfort at minimum energy cost. Second it was envisioned as a custom-made sustainable building. Optimum energy performance was achieved through consideration of the local natural parameters, including statistical weather data and data produced via simulation. These are compiled by the control system of the house to yield real time performance evaluation in order to supply maximum comfort in response to the conditions, while retaining the long-term energy cost minimum. Customized sustainability required the consideration of the local cultural, social and economical parameters. Along these lines the prototype was placed within the context of Trento, Italy, where the traditional houses are made out of local wood and have patios and loggias functioning as intermediary spaces between interior and exterior. Louvered grilles, glass screens and light wooden structures are used to regulate the admittance of desirable elements from the external environment like sun light and heat, and to block cold air, rain and snow. Different degrees of privacy can be achieved thus making the interaction with the neighbors possible (Figure 2).

The consideration of the weather parameters of the region provided a basis to rethink how environmentally responsible design and information/communication technologies can radically improve building performance. Sun path data simulation plus illumination and temperature simulation provided quantitative information on how the sunlight affects

Figure 2

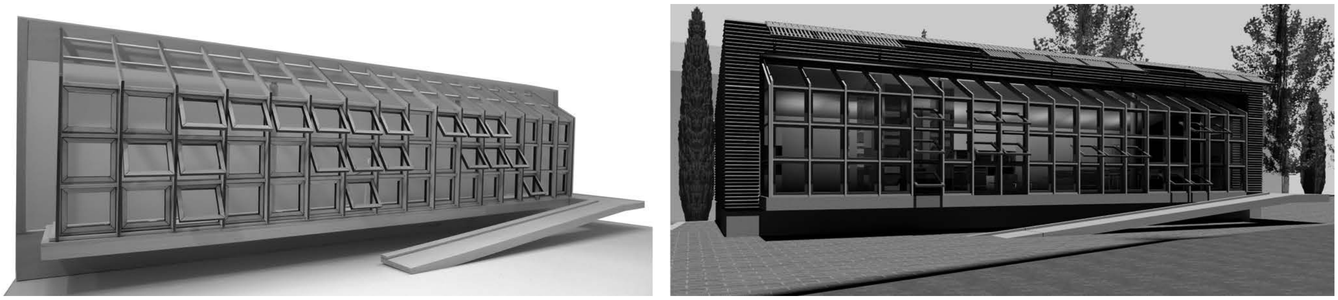

Figure 3

the interior illuminance and temperature during specific days of summer and winter. The south façade was designed to maximize the yearly solar gain. The simulations confirmed that higher energy efficiency could be achieved through combination of passive and active systems in a unique building envelope. Based on the projected yearly energy gains a high thermal mass wall was developed towards north to effectively insulate the house while preserving interior thermal conditions for as long as possible.

The consideration of the cultural, social and economical parameters of the region provided a basis to rethink how innovative, environmentally responsible architecture can be used to improve human interaction. The importance that windows and balconies obtain in Trentino culture provided a fertile context to experiment and test new technologies and to research on social sustainable design. For example, the windows of a typical residential building in Trento are operable and affect the thermal performance of the envelope but also the capacity for human interaction and the way the building is perceived from the public street. Wide-open windows welcome the new morning, signify the waking up of the inhabitants and communicate their availability to the neighbors. Semi-open windows signify a need for seclusion and privacy, while firmly closed windows signify absence. The tectonic vocabulary of the modern-style floor-to-ceiling curtain wall, on the other hand, derives from the architecture of the modern office building, were the use of artificial lighting, heating, ventilating and air-conditioning is constant, to secure an air-and-sound sealed interior environment. Apart from being energy intensive this solution is restraining and static. It confines user behavior strictly "inside" or "outside" of a building and prevents human interaction. Accordingly, the convention of the modern-style air-and-sound sealed interior was not followed in the Trento prototype and a more dynamic solution was proposed instead (Figure 3).

The proposed interactive façade is an attempt to re-establish the functional and expressive attributes of a traditional residential building façade in the late digital age. The final façade of the Trento prototype is a 3 × 9 matrix of independently switchable windows, functioning as a programmable filter between exterior

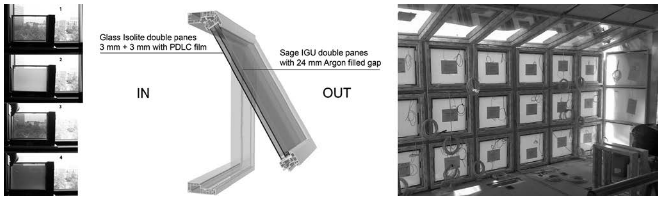

Figure 4

and interior. A structural grid of galvanized steel holds the individual window frames, made out of Fiberglass, and completes the structure of the prototype towards south (Figure 4, right). The dimension of each frame is 70 cm × 70 cm while the dimension of the main section of the uprights is 50 mm × 150 mm × 4 mm. A beam of laminated wood is used in the upper structural element accommodating a bar of post-tension, in its lower part (Kotsopoulos et al 2012a). The façade regulates airflow, adjusts the percentage of sun and heat penetrating the house, modifies the interior daylight illuminance, and supports the interaction between interior and exterior. Direct interaction and air regulation is achieved by making each window frame operable at precise angles via a system of electronic chain actuators (C20 by TOPP). The permeability to airflow is accurately adjustable, and cross ventilation is achieved when windows facing north and south are simultaneously open. Furthermore, the windowpanes admit or exclude sunlight, heat and view as desired. Each windowpane is an overlay of two electroactive materials with varying response times and different optical, thermal and power consumption characteristics (Figure 4, center). First an electrochromic coating applied on the external glazing provides the desirable degree of sunlight penetration. Electrochromic technology functions as a screening system, permitting light and heat transmittance (τ) to vary from 60-75%, for idle glass, to 3-8% for active obscured glass. Second a polymer dispersed liquid crystal film (PDLC) applied on the internal glazing, provides the desirable degree of visibility. The slow dimming response of 8 minutes of the electrochromic glass is appropriate for sunlight and heat adjustment, while the immediate transition of the PDLC film is used for the instantaneous control of shade and privacy. The electroactive layers work in combination to supply the desired façade state (Figure 4, left).

The efficient functioning of the façade rests on the capacity to monitor and modify the state of each individual window in real time. At a global level, the façade is managed by the central control system of the house (Kotsopoulos et al 2012b). A system of sensors collects data enabling the façade to become increasingly interactive. The control compiles climatic data, ambient data and sensory feedback to supply real time building performance evaluation and to modify the state of the façade as needed. This becomes possible through the rules of a generative grammar without storing façade patterns in the system's memory. The grammar links visual principles of 2-d pattern generation to levels of interior daylight illuminance (Kotsopoulos et al 2012c). At a local level, each window has its independent low-level intelligence, software and custom electronics enabling its activation. It is equipped with a system of electronic chain actuators that allow precise operability, a photocell that calculates the level of light illuminance that it is exposed to, an IR sensor that detects the presence of the residents, and also sensors measuring airflow, temperature, and humidity.

Contributions

The house systems operate in a concerted manner to attain complementary objectives as the autonomous control proactively adjusts the parameters affecting the interior environment. The flexible use modes of the façade contribute greatly to this objective. The reprogramming of the windows allows autonomous, responsive and reactive behaviors to emerge while acknowledging performance but also social, cultural and aesthetic aspects. The use modes of the façade range from moderation of view and air, to privacy control, personalized daylight or shade, and ultimately communication and self-expression. At a performative level, the electroactive leayers of each windowpane are managed to supply comfort and to exploit the thermal capacity of the building envelope. During the summer, to protect the interior from direct sun exposure, the control sets the electrochromic material to its minimum solar transmittance, and during the winter, to expose the interior to the sun, the control sets the electrochromic material to its maximum solar transmittance, thus making the storage of heat in the high thermal capacity building envelope possible. Beyond its contribution as a climate regulator, the façade operates as a mediator between the private and the public sphere. Direct interaction between "inside" and "outside" is achieved by making each window operable. The kinetic effect caused by the repositioning of windows and the real time readjustment of façade patterns, animate in pleasant way the south elevation. A variety of visual distinct façade configurations can be achieved to always renew how the house is perceived from the public street.

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Figure 5