Radiation-active surface design: the use of photocatalytic concrete enabling buildings to be active environmental remediators

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Abstract

New research into photocatalytic architectural cement offers building professionals a renewed opportunity to contribute toward sustainable goals while improving value. A team comprised of a faculty from Architecture and Environmental Engineering has developed a computer algorithm that utilizes data from site conditions as a means of optimizing surface geometry for maximum photocatalytic activity. The paper reports on the collaborative work that incorporates environmentally-derived design and innovative photocatalytic concrete into the design of panelized concrete façade components.
Keywords: sustainability, environmental design, photocatalytic concrete, digital design and computation.

1 Introduction

Urban centers often have poor air quality due to high density industrialization, internal combustion vehicle traffic, and nearby power generation. This poor air quality can produce adverse consequences, such as photochemical smog, poor visibility, and a host of detrimental health effects. Volatile organic compounds (VOCs) and nitrogen dioxide are pollutants prevalent in cities, and are pre-cursors to photochemical smog. Photochemical smog is formed by a series of chemical reactions which require photons from sunlight, nitrogen dioxide, volatile organic compounds (VOCs), oxygen, and ozone. The effects of smog include eye and respiratory irritation, reduced visibility, ozone accumulation and exposure, as well

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as damage to forests and agricultural produce. Remediating the precursors to photochemical smog offers one way that buildings can play an active role in improving the environment.

An innovative technology that can help achieve this goal is photocatalytic cement - it uses daylight to react with and neutralize common air pollutants such as nitrogen and sulfur oxides, carbon monoxide, and VOCs; the reaction takes place on the surface of the concrete and the resulting inert nitrates can be washed off manually or by rain. On a bright and clear day the process can eliminate up to 90% of nitrogen oxides, aldehydes, benzenes and chlorinated aromatic compounds [1]. Research into the use of photocatalytic cements in building has been progressing for over ten years and this emerging technology is most commonly available in paving products.

2 Background of photocatalytic cements

Early work by Fujishima and Honda determined that titanium dioxide is a photocatalyst. As a photocatalyst, during exposure to UV-light TiO_2 forms oxidizing holes and photogenerated electrons, which create highly oxidative and reductive constituents. Included in these oxidative constituents are hydroxyl radicals (OH●). When VOCs are exposed to hydroxyl radicals from a photocatalyst, the VOCs can be completely destroyed. Additionally, as long as the photocatalyst is exposed to UV light, it will remain an active air pollution remediator as the UV-light/TiO_2 photochemical reaction continues to yield oxidative and reductive constituents in perpetuity. Titanium Dioxide is a non-toxic material widely used in personal care products and paints as a white pigment. When producing photocatalytic concrete, the conventional Portland cement, silica sand, crushed stone, and water are mixed – but the addition of titanium dioxide in levels reported between 3–5% gives the resulting concrete photocatalytic properties.

This paper reports on the research methods, designs and conclusions of a collaborative project that incorporates environmentally derived data and innovative photocatalytic concrete into the design of a panelized building façade surface. In resulting computer simulations the team was able to show a substantial increase in photo catalytic reaction. Consequently, physical photo catalytic panels were fabricated, tested for photocatalytic activity, and the results compared to initial computer simulations.

3 Approach

The developed method utilizes data from site conditions as a means of customizing each particular cladding panel variation to its location. Parameters like geographic coordinates, design test day, and a panel orientation from North are entered into a modified code ported into *vb.net* (Visual Basic .NET – an object-oriented programming language designed by Microsoft) and integrated into *Grasshopper*. (Grasshopper™ is a graphical algorithm editor integrated with Rhinoceros' 3-D modelling tools. Rhinoceros, also known as Rhino, is a 3-D modelling software.)

The coding algorithm enables us to analyze the daily incident solar radiation and determine the highest amount of radiation over a chosen day and selected location. (The algorithm is based on National Oceanic and Atmospheric Administration's Solar Position Calculator – see [2]). Figure 1 illustrates the generation of the panel surface.

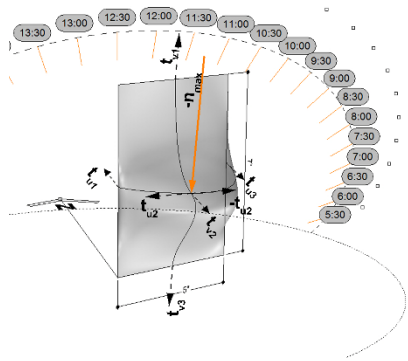

Figure 1: Panel generation – the surface is constrained by face normal angles, modeled in Rhinoceros®.

4 Design data

For the purposes of testing our design approach we have selected a medium density suburban location at latitude 40°39'50"N (40.66°), longitude 75°22'0"W (-75.37°), and altitude 116m (380'). The climate during the hot summer months form mid-June until mid-August is classified as warm humid and the weather station is less than a mile away, which makes the available weather data highly pertinent. The values are gathered from weather data available from the U.S. Department of Energy [3] and formatted in *Weather Tool 2011* (Weather Tool™ 2011, ©2010 Autodesk, Inc.).

5 Catalytic activity

A master panel was 3d-printed and a silicone mold was prepared. The design panel, Panel A, and a control panel, Panel B, of identical dimensions were fabricated and tested for photolysis according to Chen *et al.* [4] (Figure 2). Rhodamine B is a degradable tracer dye that can be used to evaluate the color change following exposure to sunlight. Measurement of the change in color intensity with respect to panel geometry was used as an indicator of the efficiency of the photocatalytic panel.

The design panel (A) and the flat panel (B) were located on a rooftop of the lab, shielded by possible glare and reflection from the ground or adjacent structures by a gray photographic muslin drop cloth, in full and direct exposure to the sun, and oriented according to the predetermined angle from North.

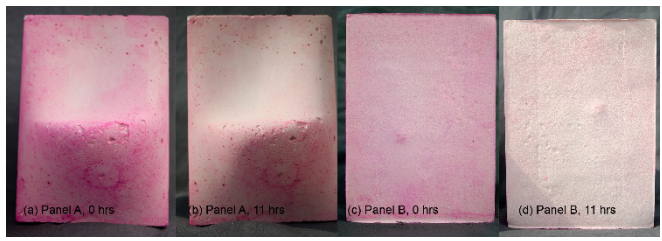

Figure 2: The color variation of Rhodamine B coated TiO_2 specimens: (a) flat panel before test; (b) flat panel after 11 h irradiation; (c) design panel before test; (d) design panel after 11 h of irradiation.

During the time of exposure to light radiation, from sunrise to sunset on the test date, images at 30 min intervals were taken with a Cannon D5900 equipped with a variable neutral density filter. (A neutral density filter reduces the wavelength, or color, of all light equally. It is used to reduce glare and hot spots in photographed objects without changing the hue of the color rendition. The images were taken with locked exposure and F-stop and in high resolution RAW format.) The color changes of the Rhodamine B dye applied on the two specimens were expressed in CIE LAB colorimetric coordinates. (In 1976, the Commission Internationale d'Eclairage (CIE) established the CIE Lab color system capable of displaying every color perceived by the human eye. Unlike RGB colors that are screen-dependent and CMYK colors that vary with printer, ink and paper characteristics, CIE Lab colors are device-independent and remain consistent on monitors, printers and scanners. The CIE Lab color mode has a lightness component (L) that can range from 0 to 100, an a component (green–red axis), and a b component (blue–yellow axis) can range from +127 to –128.) Similar to Chen *et al*. [4], measurements are taken from 9 fixed sampling points on the surface of each specimen at 30 min intervals from start of irradiation. The nine measurements at a specified time were averaged for subsequent calculations. The color variation (ΔE) was calculated as follows: $\Delta E = [(\Delta a)^2 + (\Delta b)^2 + (\Delta L)^2]^{1/2}$, where Δa, Δb, ΔL were the differences of coordinates a, b, and L before irradiation and at the specific time of irradiation.

The panel with the greatest dye degradation would indicate the panel with the greatest photocatalytic capacity for air pollution removal. The color variation (ΔE) of the Rhodamine B dye applied on the TiO_2 panels are illustrated in Figure 3.

6 Results

It was observed that for the flat Panel B, most of the color change happened in the first hour 1.5 hours of exposure to sunlight, after which the increase of rate of color change was minimal. In contrast, the color change in the design panel Type A kept increasing during the first 3.5 hours of exposure, and at a higher rate than that of the flat panel B. Not only was the rate of color change higher and longer lasting, but the design panel Type A degraded 44.6% more dye than the plat panel, indicating that Panel A photocatalysed the Rodamine-B dye better than Panel B.

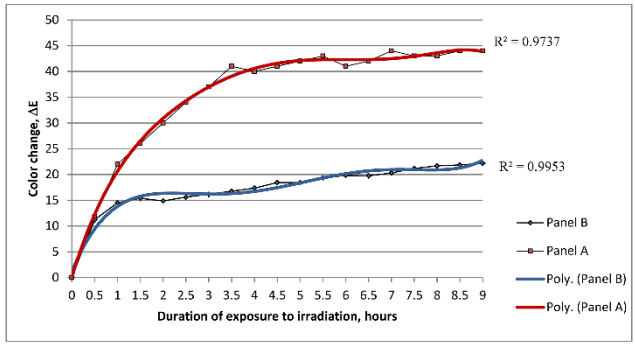

Figure 3: The color variation (ΔE) of the Rhodamine B dye applied on the TiO_2 panels type A and B.

7 Conclusions

An interesting observation can be made that the panel's performance is not related to its size. Comparisons of a number of different scales produce density patterns with varying aesthetic readings and fabrication implications but, importantly, all of them result in identical total areas of surface available for photocatalysis and identical amount of surface area with higher exposure to radiation than that of a flat panel. Therefore, the size of the panel can respond to aesthetic considerations or be derived from typical construction modules but for the purposes of testing for photocatalytic activity the panel size is not significant.

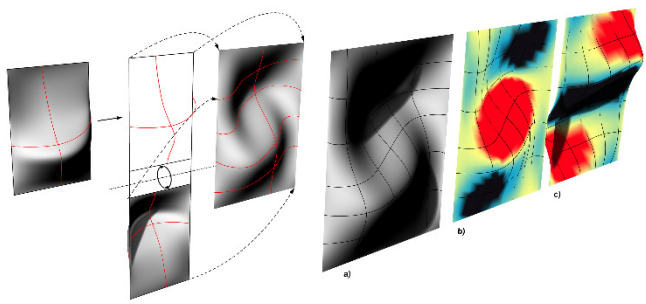

Figure 4: Derivative surface generation, showing areas exposed to 90% of irradiation, in red, and 10% of daily irradiation, in black.

Using the previously established panel as a prototypical model a derivative surface is developed that is topologically equivalent in both short and long axes – this allows it to perform identically on each side in terms of photocatalysis (Figure 4). A ¼-scaled physical mock-up of the panelized concrete façade was produced (Figure 5). It served as a test for the tectonic and aesthetic implications of applying the panel system at the scale of an 8' privacy wall (Figure 6).

Figure 5: Panelized concrete façade mock-up, concrete, 3”=1’-0” scale.

Figure 6: Privacy wall concept.

The work herein served as a foundation for the team’s research into the use of photocatalytic cements in building façade design and their potential role in remediating urban air pollution.

References

[1] “TioCem® – High Tech Cement for the reduction of air pollutants.” Accessed January 18, 2013. http://www.heidelbergcement.com/de/de/country/zement/lieferprogramm/spezialzemente/tiocem_en.htm
[2] National Oceanic and Atmospheric Administration’s Solar Position Calculator. http://www.srrb.noaa.gov /highlights/sunrise/azel.html
[3] http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm
[4] Jun Chen, Shi-cong Kou, Chi-sun Poon, Photocatalytic cement-based materials: Comparison of nitrogen oxides and toluene removal potentials and evaluation of self-cleaning performance, Building and Environment, Volume 46, Issue 9, September 2011, pp. 1827–1833.