Combining Old and New Tools for Visualizing Environmental Factors

Most of what architecture students do in studio is design and not all of the research they do in support of making an architectural design is original. However, some of it can be. The unstated aims of the two courses that prompted this paper are to stimulate student curiosity about design research and to accord value to the research they do through limited publication.

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Students in the University of Texas at Arlington School of Architecture have indicated by their actions that they prefer to learn visually and adopt new technologies early. These preferences have guided the instructional development of the two courses reported upon in this paper. One course is a required fourth year architectural design studio and the other is an elective special topics course. In both courses traditional technology like a heliodon, a machine that simulates the interactions of sun with buildings and elements in the landscape, has been augmented by new technologies like digital cameras or other technologies like ultra-violet Light Emitting Diodes (LED), Laser Induced Fluorescence (LIF) and Planar Laser Induced Fluorescence (PLIF). These technologies are used in conjunction with open channel water flumes to enhance students' ability to visualize and understand the interactions of wind with buildings and in landscapes. These solar and wind interactions are documented digitally and shared with classmates, faculty, and the architecture librarian using cloud based drop box technology.

PEDAGOGY

Teaching in these courses emphasizes the notion that simulation is an active learning technique and not an end in and of itself. Observations of simulated conditions, student visualizations, are treated as phenomena until they are able to link them with some probable underlying cause and confirm the link through experiment. It is assumed that students know the probable cause or causes of observed phenomena from prerequisite course work in natural science and history but cannot easily identify or name it when they see it. Identifying a probable cause or causes is a challenge for most of the students.

In the studio course students use both a heliodon to simulate seasonal sun penetration and shadow patterns and an open channel water flume to simulate air movement patterns. Their observations are the basis for the development of criteria they expect to use to select a site and guide their design for a prototypical mid-rise urban housing block for Fort Worth, Texas. In the special topics course LIF and PLIF techniques are used to make the usually invisible patterns air makes as it moves about, in and through buildings and landscapes visible. The following sections illustrate how some of the sun and wind simulations are effectively used in the studio setting.

SUN

The heliodon is one of the oldest apparatus for simulating daylight and its shadows for any place on the planet from sunrise to sunset for any day of any year. Its contemporary incarnation has been combined with digital camera technology to record simulated sun and shadow patterns made by an incandescent light source on models of buildings and in the spaces adjoining them in two and three dimensions. In addition to digital still and full motion recorded images, simulated daily and seasonal solar patterns have been recorded using web cams, digital cell phone cameras, single lens reflex (SLR) cameras, and a digital stereo camera. When these recordings are played back at different frame rates, students have opportunities to study the qualities of simulated daylight and shadow on and in the forms, spaces and the surfaces of models of buildings and landscapes as either a continuous moving image or as a series of still images. While slow motion playback provides opportunities to visualize the effects of simulated daylight over time, printed hard copies of freeze frame outtakes are more easily compared. Visual data about maximum, median and minimum daily and seasonal sun penetration and the physical extent shadow patterns produced by it for a given date and time-of-day may be organized, reorganized and reviewed on comparative timelines.

WIND

In conceptual drawings moving air is typically depicted by linear, smooth and parallel sinuous lines and / or arrows. These depictions often convey notions of continuity and breezy comfort. I.M Pei's design for the curtain wall of Boston's John Hancock Tower aside (LeMessurier, 68-75), anyone who has ever been to the windy city, Chicago, in winter or, who may more recently have read about Richard Meier's encounter with San Francisco's wind ordinance (Barrionuevo, "In San Francisco Life Without 'Starchitects'.") knows better.

Wind tunnels are designed to allow scientists to simulate and visualize aeronautical conditions like lift and drag in laminar, smooth, transitional and turbulent air flows. All flows are typically expressed in terms of a dimensionless Reynolds number. (The Engineering ToolBox, "Reynolds Number.") To approximate Reynolds numbers for our simulations, we use a stopwatch and homemade float.

Open and closed water flumes have been used to study flowing water (aqueous flows) in open and closed channels for at least as long as modern wind tunnels have existed. In this context, science defines air is as a fluid. (School of Physics and Astronomy, "Physics Force") For a number of practical reasons, paramount among them safety, followed by security, space requirements, cost and noise, a simple water flume was adopted as the preferred apparatus for teaching architecture and landscape architecture students about visualizing the flow patterns of simulated moving air.

We call our flume a water table (pun intended), because we are architects. Students made two small demonstration water tables to help them visualize simulated air flows. One water table, a shallow tank, is used to study turbulent flows. It is equipped with a variable velocity recirculating pump and a self-contained water source. It is used to conduct two dimensional studies of simulated air flowing about building footprints in site plans and in cross-section. Vegetable dyes (food coloring) are injected into flowing water using a pressurized syringe or a hand held injector syringe.

The other water table, a fifteen gallon tank, is deeper than the shallow self-contained tank. Fluorescing fluids are introduced into still water as plumes via a vertical gravity feed tube. These plumes are sometimes induced to move directionally at extremely low velocities by convection. This deeper tank is used to investigate simulated flow patterns about urban and building forms and landscape designs in three-dimensions. Students also use three smaller ten gallon water tanks for their investigations. All of the student tanks and the fifteen gallon tank are off-the-shelf purchases. They were selected on the basis of cost and availability.

FLUORESCING FLUIDS

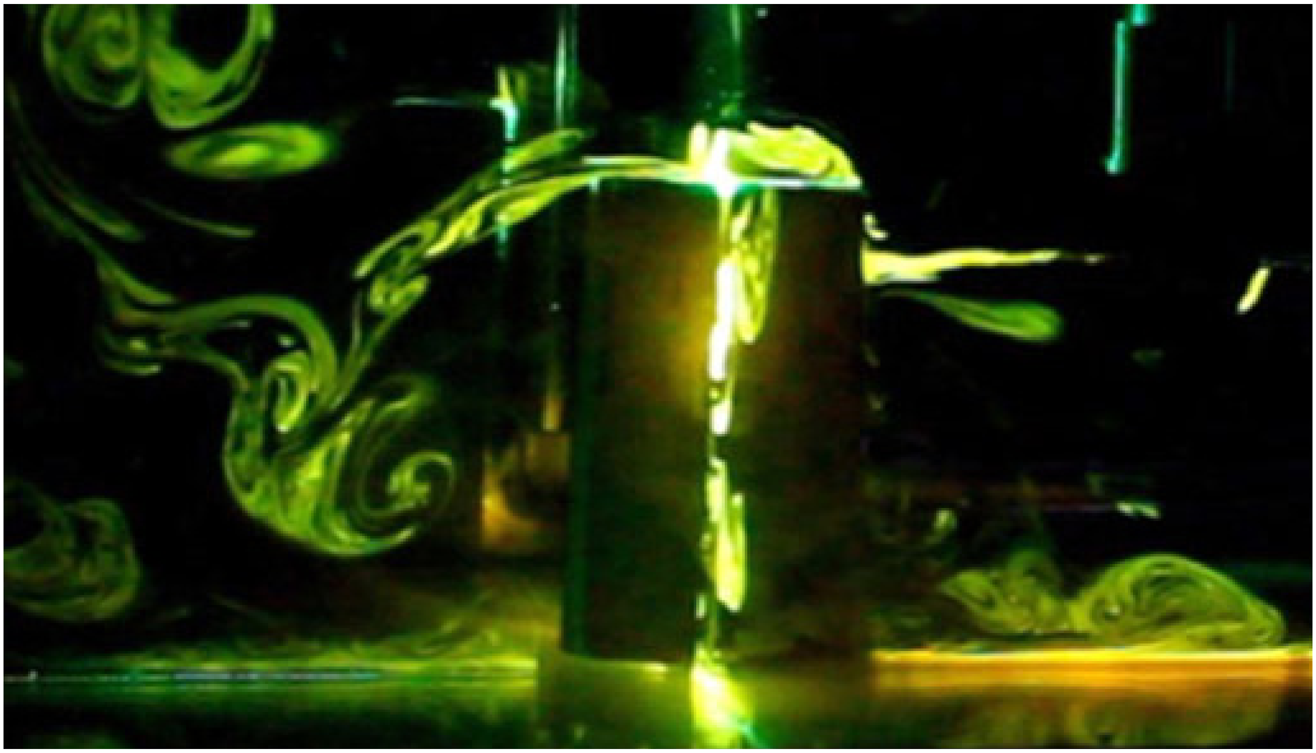
Injecting vegetable dye into moving water is a technique long used by scientists and engineers to visualize flow patterns. It was our initial choice for student visualizations because it is safe. Food coloring however, has limits. Despite precautions like nitrile gloves and rubber aprons it stains everything, skin, clothing, equipment, carpeting, etc. and in closed systems like our shallow tank; it quickly reduced contrast between the flow pattern and the water into which it was introduced. When different color dyes were used to make different conditions visible, the recirculating water quickly became murky or opaque. Student complaints and other issues like time consuming maintenance prompted a search for an alternative to food coloring.

Some fluids can be made to glow-in-the-dark. Consequently, a wide variety of fluids were casually tested for their fluorescent potential. Ultra-violet light emitting diodes, fluorescent black light, incandescent infra-red bulbs and, red, green and blue-violet laser pointers were used to induce fluids to fluoresce. In time, a home brewed fluorescing liquid to be used with compatible green and blue-violet lasers was developed. It is neutrally buoyant and made by mixing a powdered optical brightener, vitamin B_{12} with quinine extracted from the bark of the Peruvian cinchona tree, distilled water and grain alcohol. This liquid fluoresces adequately but not as intensely as other commonly used fluorescing liquids like Fluorescence. We believe however, that it is safer for our undergraduate students to use for most of their air movement simulations than Fluorescence.

LASERS

Mixing architecture students with chemicals and lasers has the potential to produce exciting yet unfortunate results like permanent retinal damage. Red, green and blue-violet laser pointers were assessed on the basis of power, compatibility with different potential fluorescing fluids and cost. Laser pointers with a maximum power output of 1 milliwatt (mW) were selected for most student investigations and class demonstrations because of their low power. Small group demonstrations are conducted using either 1 milliwatt blue-violet or green lasers or a focusing 5 milliwatt green laser. At any time there may be as many as twenty-five lasers operating in approximately 1000 square feet of space. Laser safety glasses are required.

A typical laser pointer's optics project an invisible line in the air which appears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as a point on surfaces. Our laser pointers have been modified with a removable lens cap that enables them to project a two dimensional plane, a so-called laser sheet. The sheet is invisible in air, appears as a line when projected on a surface and appears as a plane in water mixed with a fluorescing fluid. Laser sheets are used to cut two dimensional slices through fluorescing three dimensional liquid flows. This technique, PLIF, displays the two dimensional cross-sectional contours of three dimensional flows in detail. Modified blue-violet lasers are used by students in most of their routine hands-on air movement simulations.

Lasers pointers use diodes, not bulbs. Some of our simulations with ultra-violet LED and fluorescent black light have shown that three dimensional flows enhanced with optical brighteners fluoresce as more visually coherent flows than they do when they are induced to fluoresce by laser pointer light sources. Some current research is directed toward looking at the coefficient of utilization of fluorescent black light bulbs. Other simulations using black light to illuminate three dimensional flows and slicing them with multiple PLIF sheets to better visualize nuances in flows at specific locations in the path of flow have been conducted.

PLIF slices are precise. They reveal aspects of turbulent flows like vortices in detail. Typical student PLIF visualizations involve completely immersing a small clay massing model mounted on an acrylic plastic base in a ten gallon tank of water. Each typical water tank is equipped with an internal fluorescent fluid dispensing apparatus equipped with one or more needle injectors and one or more external stand mounted green or blue-violet laser pointers. Depending upon the investigation to be conducted the laser pointer optics may be modified or unmodified and used in combinations. The external support stands are typically arranged to make horizontal or vertical laser sheets located where PLIF slices through the 3-D flow are desired.

Typical two dimensional PLIF flow visualizations use apparatus setups similar

Figure 1: Typical PLIF Image: Russell Southard, Tony Wade, Vo Thinh

to those used in three dimensional visualizations. The clay models however, are significantly different. They are typically a building or a landscape plan, or cross-sections sandwiched between parallel sheets of clear acrylic plastic. These models are usually designed to accommodate only horizontal or vertical laser sheets when submerged in a water tank.

The cross-section of the fifteen-gallon demonstration tank is similar in its dimensions as the cross-section of the typical ten-gallon student tanks but it is considerably longer. It is equipped with removable hot and cold coils to induce water in the tank to move horizontally and / or vertically at very low velocity by convection. Neutrally buoyant fluorescing fluids are usually introduced into demonstrations as a plume via a single vertical gravity feed tube equipped with one or more needle tips. If however, a specific part of a model is to be investigated a fluorescing liquid may be spot injected.

EXTRACTING QUANTITATIVE DATA

PLIF visualizations are two-dimensional cross-sectional slices of three dimensional flows. Quantitative data may be extracted from them using MATLAB, a widely available software application. MATLAB may be scripted to import digital images of PLIF slices and to filter the imported visual data. Filtered data may be expressed numerically in a table or visually as either a contour or a surface plot. Quantitative data like flow velocity may be extracted from the tabulated filtered data or the plots. Visual learners often disdain tabulated wind velocity data in favor of visual data like the NOAA wind roses. Visual expressions reinforce their preferred learning style but even visual learners like architects and landscape architects recognize that the ultimate value of any qualitative wind visualization lies in the quantitative utility of its application.

COMMUNICATION

Effective communication is essential to design pedagogy. Several venues were discussed as vehicles for communication among the students, and with the faculty and the architecture librarian. A cloud based electronic drop box, which the students initiate, manage, and maintain, was selected as the preferred vehicle because of its simplicity and ease of access. It has emerged as a dynamic repository for course related information continuously augmented and updated with the primary and secondary outcomes of in-progress student research to be shared and supplemented with other information anytime the need arises. The university Blackboard learning management system may be able to serve the same purpose as the commercial drop box product preferred by the students but it is inadequate for the storage requirements of multiple large graphic files accumulated over the course of a semester.

Some of the students work two nineteen hour per week jobs and have three daily commutes between the university and work. Several students have commented anecdotally that being able to review the quality and quantity of work classmates produce at any time of day or night prods them not to fall behind. The convenience of the drop box and the transparency of its contents invite others, curious students and faculty, and staff, to drop in electronically to see what's going on thus extending the communal aspect of what they are doing or learning well beyond the classroom. Our architectural librarian has on more than one occasion offered timely information to assist students with their research and / or work in progress, and adjunct faculty teaching elective and

Figure 2: Urban Street Canyon Wind Flow Study, Thinh Vo, Russell Southard

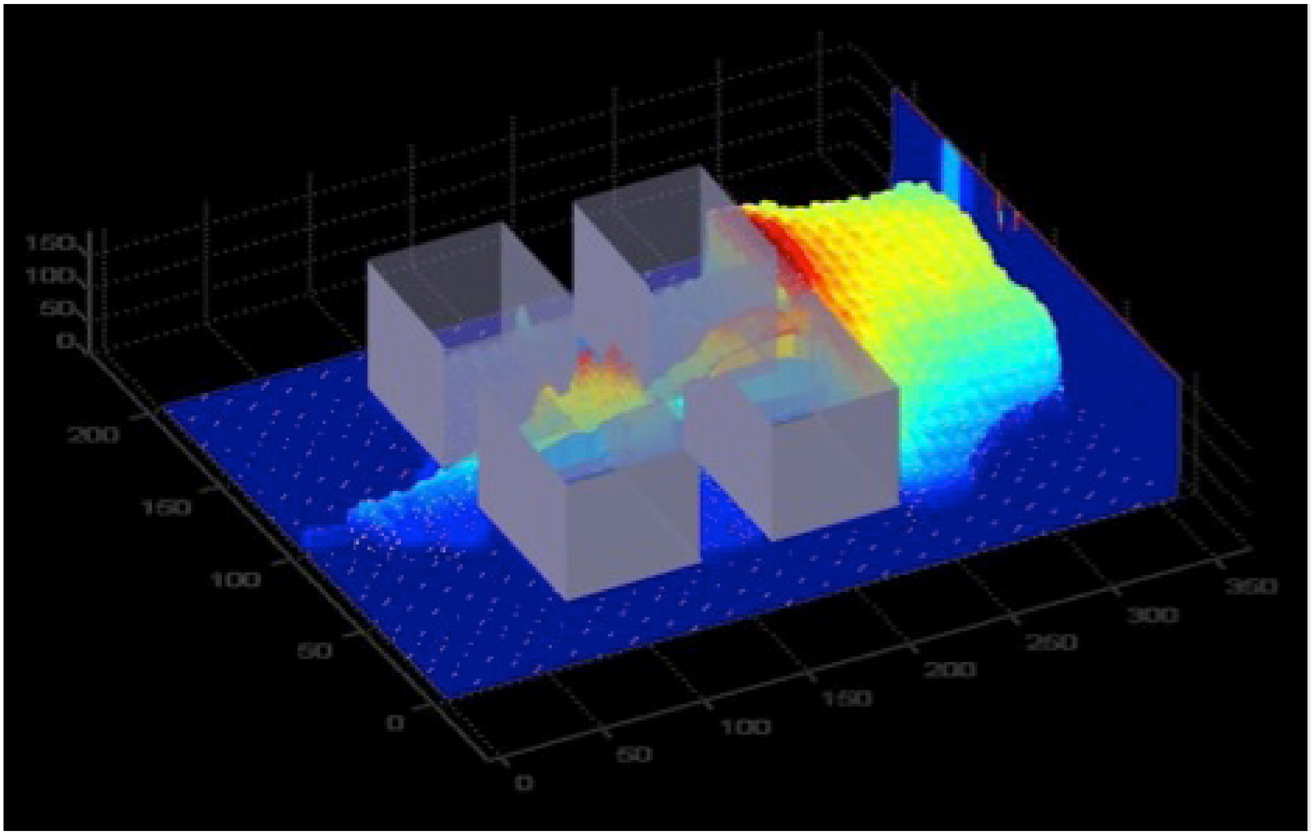

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Figure 3: Typical LIF Image: Vo Thinh, Russell Southard

corollary course work in areas like building construction or passive energy have dropped by to offer direction and opinions to about student work in progress.

STUDENT SIMULATIONS AND LESSONS LEARNED

Disparities between ultra-violet LED, LIF and PLIF investigations conducted by the class and the air flow patterns depicted in an image of a building massing model published on the web teased the curiosity of some students in the special topics class. The web posted image showed an aerodynamic building form bathed in a field of linear smoothly flowing parallel sinuous arrows. The students duplicated the mass model of the building and water tank tested it using ultra-violet LED light sources.

They were unable to duplicate the results depicted in the web posted photo. Their tests show significant air turbulence about and on the surface of the model. Among other things, the contrast they observed between the posted image and their documented attempt at duplication made them more aware of the potential negative effects of turbulent air flows in the wakes of buildings. Wake turbulence may negatively affect not only the immediate surfaces of buildings but also the adjacent and nearby spaces and surfaces of buildings down wind. Future study of wake turbulence caused by aerodynamic forms proposed by students will include extracting quantitative velocity data from turbulent flows.

Linking their visualizations to scientific concepts, theories, laws and principles they already know enables students to demonstrate to themselves that their design decisions are not isolated from the abstract realities of a theoretical understanding of natural science. The process of self-demonstration is straight forward. Students setup a flow study to simulate a wind condition. Ultra-violet


3

LED visualized flows and / or PLIF slices are recorded digitally and saved to an electronic drop box. The process is then repeated with one variable changed while all other variables remain the same. Before and after digital images are compared and probable causes of observed differences are advanced. Verification of a probable cause usually involves some library research followed by some empirical testing of a possible cause or causes. Testing often leads to rediscovery of a known physical theory like Bernoulli's or Venturi's principle. When satisfied with their explanation students write a synoptic report and post it to the drop box. When they invest more of their sweat in rediscovering what they already know from pre-requisite course work, students seem to begin to grudgingly appreciate the potential of theories expressed in a language more abstract than the graphics of descriptive geometry.

Some phenomena like energy transfer are not easily linked to known underlying causes. Investigating them often requires directed study and considerable research. Even after additional research, it is not unusual for the identity of an underlying cause or causes to remain elusive. One area of interest emerging from the special topics course that has merited directed study is fog fencing. Fog fences are surfaces that have been successfully used to condense water from fog in some mountainous sub-tropical regions (International Development Research Center (Canada), "Collecting Fog on El Tofo"). One landscape architecture graduate student's interest in fog fencing has led to the formation of a small working group to experimentally investigate visualizations of energy transfer and air movement. Another graduate student explored impacts of green roofs and walls to climate change in urban environments.

Although long term outcomes are still emerging from their investigations, their preliminary work suggests that architecture, landscape architecture, and / or urbanism may benefit from sustainable design practices. It may mitigate some of the undesirable aspects of the urban heat island effect on microclimate in subtropical regions. For instance, under some localized conditions applications aimed at making water from fog could reduce pressure on potable water consumption and make self-sustaining, naturally irrigated (literally) green energy saving walls and roofs in cities possible. In certain rural subtropical regions on the other hand, fog fencing provides opportunities to enhance the water supply for local agriculture, village life and ultimately contribute to self-sustaining global reforestation.

CONCLUSION

Anecdotal feedback about these two courses is relatively positive and the simulation experiments encourage students to learn visually and adapt new technologies. Combining old and new tools for visualizing environmental factors provides them with a better understanding of design conditions for subtropical climates. For example, simulations enable students to comprehend built environment conditions such as wake turbulence that affects not only the immediate surfaces of buildings but also the adjacent and nearby spaces and surfaces of buildings down wind, indicating further study. These investigations and findings not only allow students to visualize energy transfer and air movement but to consider mitigating some of the undesirable aspects of the urban heat island effect on microclimate in subtropical regions. Student simulations also give results such as three dimensional flows being more visually coherent when fluoresced with black light rather than laser pointers, also suggesting further investigation. Although we hardly consider these explorations a paradigm shift, we feel that research based design is critical in studying architecture to advance practice and education. Given that our students will be designing for increased population in urban subtropical centers in the future, the pedagogical approach introduced here is essential to ensure responsiveness to climate change and promote quality of life.

Albert Einstein once remarked rhetorically that, "If we knew what it was we were doing, it would not be called research, would it?" (Dejavanne. *Einstein's Lament*, xx) Design research is usually one phase of a major design studio exercise and its value as intellectual property is often unrecognized by faculty. One consequence of this is that the outcomes if not the research method is often undervalued by its student authors. Simulations of seasonal sun and wind patterns have engaged some of our students. Hopefully, their visualizations of these two most natural of all natural resources will prompt them to question some aspects of their own prevailing cultural attitude toward research as intellectual property when forming and expressing reasoned arguments about important issues like sustainability. Critical thinking after all, involves some form of reasoned argument.

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