Blown Away: a Case Study in Modulating Airflow through Digital Modeling and Fabrication

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Abstract

This paper describes an interdisciplinary project: the design and fabrication of a HVAC diffuser for the University of Louisiana Lafayette School of Architecture and Design. The project acts as case study on data collection, research, and design for environmental factors. Students learned how to frame a research question, follow an organized practice of data collection and analysis, relate that data to industry-established standards, hypothesize about solutions through prototyping, test those solutions through digital analysis, and then verify hypotheses through empirical collection of data once their design was installed. This methodology allowed students to relate benchmarks established by ASHRAE's standards for comfort to the qualitative experience of their own design. Additionally, this project serves as an example of cross-disciplinary research, and provides a model for college initiated grant development, specifically tailored to STEM research.

Introduction

In a data driven world, energy and systems courses' digital modeling and analysis evaluate thermal comfort, but the experience of that comfort remains difficult to understand. Students can only imagine the experiential outcome of their projects. Holistically and pedagogically, it seems the best practice would be correlate empirical study with digital analysis. At University of Louisiana Lafayette, we devised a project that provided the opportunity for digital analysis, empirical study, and, perhaps most importantly, a project which gave students the chance to improve their own community, teaching students to value the consideration and design of thermal comfort.

The site for the project was both convenient and optimal. Fletcher Hall, home to our college, was constructed in 1976 and underwent a first phase of renovations five years ago. A second phase of construction anticipates renovation of the HVAC system. Eight air-conditioning diffusers distribute ventilation across the first floor's open plan. Traveling at high velocity, the air conditioning has a history of blowing directly on students' desks, creating extremely cold adverse working conditions. Here existed a design opportunity that the students know all too intimately, and which drove home the importance of properly controlling environmental systems. The project: design an attachment to the current diffusers that dispersed the ventilation evenly across the studio.

"My first semester was spent in the midst of a frozen whirlwind. I dreaded coming back to my desk just to find models scattered around the studio like artifacts in an adventure movie. After retrieving them, spelunking in the depths between the desks, I returned to sit in front of a glacial phenomenon." – Stephen Corcoran

Cross Disciplinary Experience

Within the school, industrial design, interior design, and architecture students share no interdisciplinary coursework beyond first year; our professional curricula are too straightjacketed by accreditation requirements. Yet a project like this served all three disciplines: it mediated the environment but also was a designable product. To capitalize upon the collaborative nature of the work, this project occurred outside of the curriculum on weekday evenings as a voluntary effort. Students were excited to do research that would have a direct impact on their studio space, which was associated with a grant, and had the possibility of publication. Additionally, three students received honors credit for their studio work. Industrial design, architecture, and mechanical engineering faculty led the meetings collaboratively.

We were surprised by the level of student interest. Sixteen students initially came forward, and twelve participated through completion. The group included: three industrial design upperclassmen; one mechanical engineering upperclassmen; and twelve second year architecture students.

To manage this large group we adopted a distributed way of working. To accommodate variation in schedule, we established two meeting times: Monday | Wednesday; or Tuesday | Thursday. This led loosely to two groups working on the project. We also established early on that students could plug in and plug out based on availability, and without judgement. This format worked well for data collection, but became more difficult as students attempted to build upon each other's ideas during conceptualization. Once the group selected a design, the faculty broke the construction work into two-hour sessions, leading again to relative ease in management between the two schedules. The relative shortness of the working sessions reduced student burnout, and we believe led to greater student participation. To manage schedule, we used Groupme to communicate and schedule meetings. Groupme also allowed our mechanical engineering student, who was largely working off-site, and our visual arts student videographer to come and go with perfect timing.

The project presented a distributed network of both students and faculty with regard to visual and verbal communication and in design and research interest, from data collection and analysis, to design thinking, to working with materials and constructing, to digital modeling and analysis skills. We made no attempt to break down perceived silos to create baseline equality. Instead, we built an infrastructure of communication and respect across these silos to give agency to those with individual knowledge while building confidence in those who had less expertise in a particular method or area or ability.

As one might expect, we found the representational language of industrial design and architecture differ. Industrial designers use a process of ideation, which heavily emphasizes drawing, especially in perspective, in the early stages of design. By contrast, the architecture students tended to focus upon model making and their sketches remained less synthesized, instead utilizing either plan or section. The industrial designers clearly emphasized the development of an object or product, whereas the architects exhibited more interest in the behavior and control of the wind, and conceptual opportunities of conditioning the entire space.

The introduction of the subject matter of environmental factors to second year architecture students provided both opportunities and difficulties. Lacking previous experience, we found the students approached the subject matter with outside of the box thinking in lieu of typical solutions. At the same time, during the design phase, the students spent a long time considering the behavior of wind abstractly, and it took some concerted effort by the faculty to get the students to produce initial designs. By contrast, the upper class industrial designers had a firmer grip on functionality: they were far more willing to jump in and start designing, but this resulted in more expected and traditional solutions. For all of the architecture and design students, the introduction of the mechanical engineering student was magic: employing his acumen allowed them to visualize the function of their designs within the computational fluid dynamics environment, introducing an entirely new tool to ten out of the twelve students.

With regard to modeling and fabrication, our second year architecture students also had no previous experience with the digital fabrication equipment. By contrast, the industrial design students understood the patterning, fastening, and fabricating within the digital environment. While, the upperclassmen industrial designers were familiar with digital modeling software, most of the architecture students were receiving instruction in rhino in a support class simultaneously with the commencement of the project.

Project Process

"The vent blows very cold, forceful air that can be felt from as far as ten feet away. In my first semester of freshman year, I sat in the direction of the air flow and I often found myself unproductive and unencouraged to work.”

– Kristen Lyon

To distribute the ventilation properly, we, as faculty, were agnostic about the students’ selection of form, materiality, and production of the detachable diffusers. To prompt the students, we asked “What if the designs are not rigid, but instead take form when operating? Could kite technology be a precedent?” We felt it was important to throw the possibilities open wide. Additionally, because the diffusers were envisioned as a temporary installation, with a life expectancy of 2 to 3 years, we asked the students to consider issues of permanence versus impermanence – including durability, weight, and options for connection.

The faculty members felt it was important to introduce standard research methods. The project taught students how to frame a research question, collect and analyze the data, relate that data to industry-established standards, hypothesize about solutions through prototyping, test those solutions through computation fluid dynamics analysis, and then verify their hypothesis through empirical collection of data once the design was installed and tested. At the same time, the process allowed for fun, creativity, and real time problem solving.

Because this project was not within the curriculum, we emphasized understanding rather than ability in for each learning outcome. This introductory, project-based, interdisciplinary approach kept the project from becoming stymied when the students were unfamiliar with the particularities of a certain computer program. Eschewing minutiae while being proactively involved, the faculty leveraged the students’ knowledge to focus on big takeaways while always moving the process forward.

Data Collection

To begin the design process, we charged the students to record data measuring the air velocity around the diffusers using an anemometer. To locate station points for measurement in the studio, the students made use of an existing ceiling grid to develop the x and y dimensions, and then clipped standardized lengths of yarn to the intersections. (Fig 1) Our plan was to take measurements with an anemometer, recording the data for the digital model. It is with this first step that the students learned how our expected model of research and reality could diverge. This project was conceived in early fall when the air conditioner operated at full force. By the time we received approval, the entire building had become still. We contacted the Facilities Office to turn on the air handler for our data collection. The response was unexpected – we were told the air handler was on, and that it was forty-year-old equipment in dire need of emergency repair. When we relayed that it did not seem to be working at all, the facilities manager inspected the unit, and instructed his workmen to replace what were termed as “very old filters and slipping belts.” The handler had been spinning in place – causing no air to distribute through the building.

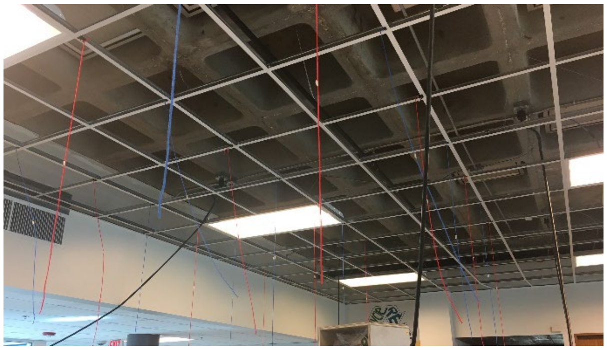

Fig. 1. Yarn segments showing wind velocity.

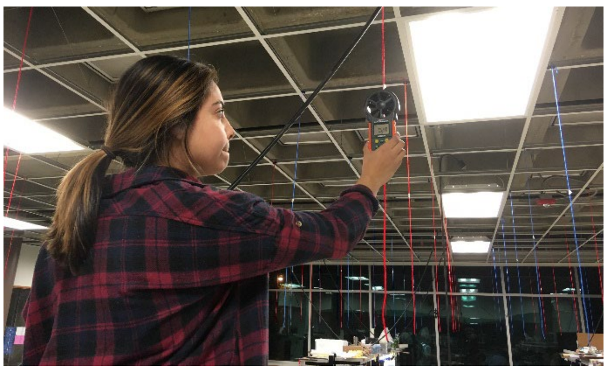

Fig. 2. Measuring wind speed with the anemometer.

Much to our surprise the deferred maintenance of changing filters and belts resulted in the system distributing the air more evenly. In our attempt to turn on the air handler – had we actually solved the worst of the ventilation issue through a simple maintenance call? While velocity diminished, the airflow from the diffuser remained particularly concentrated and uncomfortable over several desks near the diffuser, while desks at the far ends of studio now received no ventilation. As of publication, we do not yet know if the original speeds will return once the chiller engages this summer.

Acquainting the students with the ASHRAE thermal sensation scale they were able to rate their desk locations within the studio on a range from Hot (+3), Warm (+2), Slightly Warm (+1), Neutral (0), Slightly Cool (-1), Cool (-2), Cold (-3) that directly correlated with the wind speed coming from the ductwork.

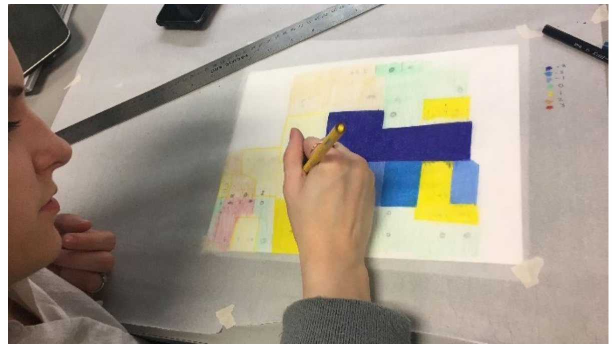

Fig. 3. Student mapping the ASHRAE thermal sensation.

Fig. 4. Full-scale test of a student's design.

Measurements from our anemometer produced readings between .2 m/s and 1.72 m/s in the area down the center of the studio. (Fig 2) The studio periphery measured at 0. According to the IAQ Guide, distributed by ASHRAE "Air distribution systems should be designed to achieve an appropriate air velocity near the occupants (sometimes referred to as terminal velocity), which is often about 50 fpm (.25 m/s)."[1]

Utilizing the CBE Thermal Comfort Tool[2] based on ASHRAE Standard 55-2017, at a measured temperature of 72% and humidity of 50%, and assuming working at ones desk in typical interior appropriate clothing (trousers, short-sleeved shirt), the student found their collected data did not comply with the ASHRAE standard. The data did align with the student's ratings of their desks on the thermal sensation scale. (Fig 3) In addition to collecting the numerical data, the student observed the movement of the lengths of yarn in response to the airflow. This movement traced to trajectory of the air, identifying both where the velocity was strongest and showing movement felt on the skin but which was below the threshold of the anemometer's sensitivity.

Design

Once the students could visualize the movement of the air, they began brainstorming and hypothesizing on how best to control the air. The segments of yarn aided in visualizing the fluid character of the airflow. Several designs provided variations on ductwork typology, featuring perforations or shaping flanges to distribute the air. The duct-like solutions sought to concentrate and enhance airspeed – propelling the air forward while allowing a portion of the air to filter through perforations or slots. By contrast, three designs employed rudders or fins and waterfall-like shelf structures to create spouts, conceiving of the air as a fluid, similar to water. (Fig 4 & 5) Both of these designs did not attempt to close the upper portion of the duct. Fins or rudders widened the airflow in the horizontal direction. Base plates for these two designs acted as a shelf for the air to flow over – allowing the velocity to gently slow and fall. The students' re-envisioning of ductwork typology would have been perfect to propel the air to the far reaches of the studio if that had been the task; but the task was to spread and slow the air and the waterfall like solutions seemed destined to be most successful.

After initial design and digital modeling in Rhinoceres by the students and faculty, our mechanical engineering student ran computational fluid dynamics on the six designs. (Fig 5) The results showed what we had hypothesized. The ductwork based solutions did an excellent job of propelling the air, whereas the more shelf like versions resulted in a distributed free-flowing result. Additionally, the size of the circular solution resulted in the most even slowing and distribution of airflow. This was a first introduction to computational fluid dynamics, and the students were excited to see how their hypotheses played out in these models.

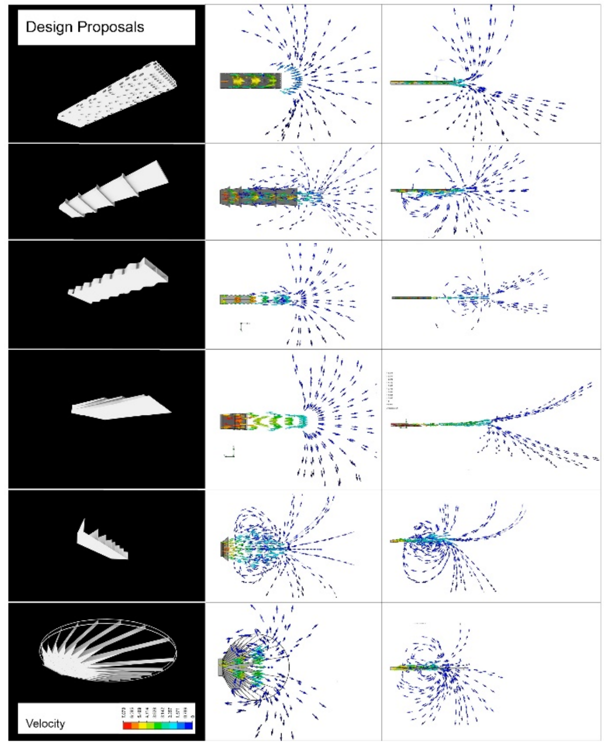

Fig. 5. The six design options and their CDF analyses.

The next step: choose a design. Partially because of the CFD results, partially because it would be the biggest design statement, and partially due to ease of constructability, we selected the circular shaped design.

The design we chose was large – eighteen feet in diameter. (Fig 6) Typically, ventilation systems act as an infrastructural system in support of architectural design. In this case, the diffuser design became the focus of the space, removing one's gaze from the detritus of ceiling grid, grid hangers, electrical conduit, sprinkler pipes, and discolored waffle slab. It not only served to condition the space but it also acted as a design intervention, a focal point that created a sense of identity within the studio environment.

Fabrication

"The creative energy that we students should be applying to our project is instead going to jerry-rigging contraptions that redirect the air." – Jacob DeJean

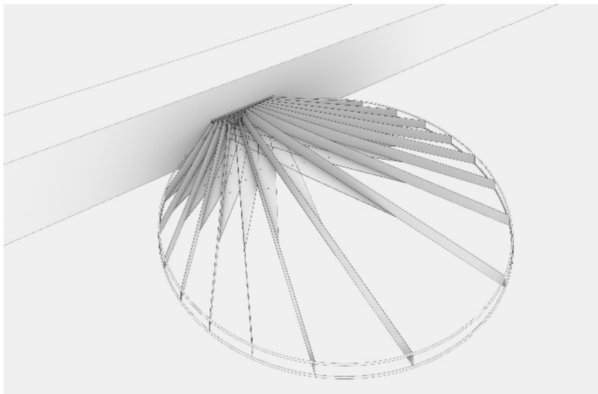

Fig. 6. Digital model of selected diffuser.

Fig. 7. Diffuser installed.

Because of the short duration of the project, it was impossible to provide time for material testing and selection. Instead, the faculty suggested a shortlist of possible materials that preserved the character of the Rhinoceres model. The faculty proposed ¾” PVC pipe to maintain rigidity of the frame, to offer the correct amount of visual weight to the project, and to provide ease of workability. For the bottom surface, initially the group considered canvas, but there was concern that it would not maintain rigidity under pressure from the HVAC. Instead, the faculty suggested 4 millimeter corrugated plastic, which provided strength and stability but also had little weight. Initially, the faculty recommended sheet metal for the fins, but the students voiced a concern that they might generate noise. As a group, we discussed canvas, but this choice seemed too heavy and not sleek enough for the project. Finally, the faculty decided upon a greenhouse grade mylar, with little weight. White on one side and reflective on the other, it gave the project presence within the studio. Additionally the mylar reflected light, an attribute seen as attractive when the group initially considered sheet metal.

To start we took measurements from the Rhinoceros model for the PVC frame. The students and faculty made the cuts, and cleaned the PVC, and then the students assembled the framework, developing a method of assembly that kept pieces perpendicular while affixing them with the PVC glue. Next came the fabrication of the fins. Because the fins had a geometric warp, and were very big, it would have taken a prohibitively long time to construct drawings of them on the mylar. Instead, printing templates from the Rhinoceros model was fast and easy. Armed with paper patterns the students were able to cut out all the fins in about four hours. Testing the behavior of the fins, we discovered that they cupped and rolled along the span. Instead of strengthening the top and bottom of the fins, one of the students solved the problem by adding vertical dowels every two feet, disguising them with white duct tape on the white side of the mylar. We then used the Rhinoceres templates to cut the pieces for the corrugated bottom plate. Discussion centered upon laying out of the bottom pieces to ensure book matching of pattern, while white duct tape was once again used to join the pieces.

With all individual parts assembled, full installation occurred during a final eight-hour marathon. (Fig 7) All of the fins were attached to the vertical struts of the frame with white duct tape, keeping the fins rolled until final installation. The students identified anchors for the ceiling tile grid and used them to hang the frame. Next, the team attached a Plexiglas grill, which had been laser cut, to the original diffuser using commander strips. The students then unfurled and affixed each fin to the grill.

The final challenge was attaching the corrugated plastic baseplate. The faculty developed a detail of 3D printed fasteners for threading with paracord. While the fasteners did a good job of supporting the board, it was impossible for the students to tie them as the faculty initially envisioned – the students could not work blind and beyond arms reach. Flipping the way the fasteners worked, the students located the knots on the underside of the panels – providing what became an additional finishing detail.

During installation, we also discovered that it was impossible to keep the bottom base plate flat without adding fasteners. Instead, the students decided that the endpoints should be brought up taut, allowing the base plate to curve gently. The entire group agreed that this change, attuned to the pliant character of the material, provided a much more elegant solution – creating a curving surface as a counterpoint to the slight warp of the fins.

All agreed that the new diffuser decreased the velocity of the air substantially and distributed it more evenly across studio. Once the chiller engages, the students are eager to take new measurements to confirm the comfort level now falls within the ASHRAE standard.

"I'm interested in designing a solution to the problem because it would boost the morale of the community in Fletcher Hall, and prevent the airflow from inhibiting our workflow." – Kristen Lyon

Funding the Project: Leveraging a Single Project to Serve the Broader Goals of the University

This project exists as a case study within the larger trend across design academia to engage in STEM practice based research. It also serves as a model by which individual universities can develop methods of financial support. Anticipating the increased inclusion of research into design education, our university developed a competitive grant within the college that annually awards money to faculty who collaborate on projects that incorporate digital resources and STEM based learning methods to produce creative works. The grant program gives special emphasis to interdisciplinary projects. With our college providing grants of up to $4000, this initiative provides significant support for practice based research.

Two paid-admission public events underwrite these projects with an annual revenue of $40,000, with one of the events featuring TEDX style presentations by the faculty. In addition to materials, we are able to purchase equipment and to fund a videographer to record the process of the project. The university will use the video for recruiting. Finally, this project will serve as a case study for our new research institute for Industrial Design as it cultivates work with the community.

Conclusion

“To me, solving small problems makes the most significant impact. Right now, I think about those vents constantly. But what if we solved the problem and everything normalized? That uncomfortable reminder would be replaced by complacency in everyone's mind and that interests me.” – Stephen Corcoran

As a case study, this project provided students with an introductory level understanding of applied research. It taught students how to frame a research question, follow an organized practice of data collection and analysis, relate that data to industry-established standards, hypothesize about solutions through rapid prototyping, test those solutions through digital analysis, and then verify their hypotheses through empirical collection of data once the design was installed and tested. This methodology allows students to relate benchmarks established by ASHRAE’s standards to qualitative experience. Additionally, it challenged students’ tendency to view the outcomes of digital analysis as sacrosanct. By having the students relate the digital model to the final installation, the students could reach conclusions about the strengths of digital modeling, and the opportunities of full-scale fabrication.

Most importantly, this project taught each student, as a citizen of the school, that designing environmental control can make their community a better place to be.

Notes:

1 American Society of Heating, Refrigerating and Air-Conditioning Engineers, et Al. *Indoor Air Quality Guide, Best Practices for Design, Construction and Commissioning* (Atlanta Georgia: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 2009): p 585.

2 Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, Cheung Toby, Moon Dustin, and Steinfeld Kyle, 2017, CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley, http://comfort.cbe.berkeley.edu/ (accessed February 1, 2019)