ABSTRACT

This paper describes the design, fabrication, and assembly process of Centennial Chromagraph: a large-scale installation recently constructed for the centennial anniversary of the University of Minnesota School of Architecture. The project is an exercise in data spatialization; using computational design tools to generate formal and spatial constructions with large quantities of information. Built from 100 plywood ribs and 8,080 colorful No. 2 pencils, the project oscillates between representational and atmospheric readings, serving both as a sculptural installation and as a communicative visualization of the School’s history. In this regard, it represents an alternative approach to notions of “Big Data” within contemporary design practice—one in which the powerful quantitative techniques of computation are leveraged to reveal new qualitative, aesthetic, spatial, and communicative possibilities for architecture.

The paper reviews initial analog research, digital mapping and visualization studies, and the development of tectonic and spatial logics that proved effective both representationally and atmospherically. The project stakes a claim for a new sense of computational craft, in which the techniques of Big Data and the artifacts of the algorithm yield surprising and unexpected tectonic qualities that are contingent upon both the computational and the material. In doing so, it offers a model for contemporary design computation to engage explicitly with age-old architecture notions of detail, ornament, pattern, and effect.

Oliver North, Lake Resources of Panama, and the Iran-Contra Operation, ca. 1984-86, by Mark Lombardi (Hobbs 2003)
INTRODUCTION

“The notion that computers can manage and process huge troves of data is nothing new, but the “big data” approach to computation… may be more disruptive than it appears.” (Carpo 2014)

The value proposition ascribed to the contemporary paradigm of Big Data is commonly understood to lie in the discovery of new knowledge through the collection and analysis of large quantities of information. This data-driven mindset is most typically manifest in market-driven, commercial efforts to understand and predict consumer habits and patterns (Cukier 2010). Within architecture, it is increasingly applied to the building process itself, as architects and consultants attempt to leverage computation to quantify and manage the diverse datasets that define the design and construction process. This has influenced a remarkable proliferation of highly quantitative practices within the profession, ranging from programming analysis and environmental performance optimization to tracking building component inventory and post-occupancy analysis (Barista 2014). This paper explores an alternative approach to Big Data within design practice: one in which the powerful quantitative techniques of computation are leveraged to reveal new qualitative, aesthetic, spatial, and communicative possibilities for architecture.

Centennial Chromagraph, a large-scale installation recently constructed for the centennial anniversary of the University of Minnesota School of Architecture, is an exercise in data spatialization; using computational design tools to generate formal and spatial constructions with large quantities of information. The project, comprised of 100 plywood ribs and 8,080 colorful No. 2 pencils, is both a sculptural installation, intended to serve as a dynamic centerpiece for the School’s centennial celebrations, and an applied research project exploring the possibilities of data-driven design. By both communicating information and producing abstract effects of light and color, it embraces an aesthetic tension between the didactic, literal representation of data and a more qualitative atmospheric experience.

PREMISE: DATA SPATIALIZATION

The project began with a simple brief: to graphically represent the 100-year history of the School of Architecture for the large numbers of alumni and guests expected to return for the centennial celebration. This mandate for representing information presented an opportunity to transcend the purely graphic, two-dimensional language of conventional timelines, bar graphs, and pie charts so commonly employed in data visualization projects. Instead, the project seeks to locate the latent aesthetic potential within the School’s historical data—to represent the information, but also to employ it instrumentally in creating a compelling spatial installation for the centennial celebration.

Several important precedents informed the initial research, data mapping, and design development, helping to inform the project’s dual emphasis on data-driven spatial effects and tectonic assemblies. Of particular interest were examples drawn from the emerging and growing field of data visualization, which increasingly weaves together aspects of computer science, complexity theory, and generative aesthetics (Lima 2011). This includes the work of artists like Mark Lombardi, whose politically charged hand drawings map the interconnected networks of finance, government, and international crime (Figure 1). Although entirely analog, Lombardi’s work is nevertheless fundamentally computational in its rule-based and quantitative logic. Furthermore, these intricately drawn constellations, though two-dimensional, operate spatially as they induce multiple readings based on proximity: “They are both intimate, in terms of the viewers’ need to see them from a close range, and more formal, in terms of their adherence to an overall rational scheme whose clarity and logic are essential to the work’s success (Hobbs 2003).

This use of computational data analysis to produce novel spatial effects is also evident in “Living Light”, a public artwork completed by The Living in Seoul, Korea (Figure 2). The project draws upon real-time, crowd-sourced air quality data collected from Seoul residents via a web interface. The data is used to illuminate panels of a sculptural canopy that takes its form from the city’s plan; the lit panels represent air quality changes in specific neighborhoods.
In addition to driving the project’s interactive behavior, the urban data informs the installation at a much finer scale of detail and assembly: the canopy’s structure, designed parametrically and constructed entirely of digitally fabricated steel members, suggests a compelling template for linking external datasets to tectonic assemblages of variable componentry.

DATA MAPPING:
ANALOG/QUALITATIVE

The initial stage of research consisted of identifying possible datasets, and exploring precisely which aspects of the School’s history offered the most compelling and evocative visual possibilities. An informal conversation among a lively group of alumni and faculty yielded a multitude of anecdotes and memories of the School, which were collected in an impromptu timeline (Figure 3). This exercise, along with a subsequent survey that solicited input from hundreds of alumni, raised a number of questions about how to represent the School’s history and impact over time. What aspects of the School resonate most in the memories of alumni returning to their alma mater? What kinds of quantitative metrics best tell the story of the School’s past, its evolution over time, and its outlook for the next hundred years? These questions greatly informed the design process as it transitioned into a more quantitative and computational mode.

DIGITAL/QUANTITATIVE

The quantitative analysis of the School’s history began with the archive of the School’s 5,000 plus alumni since its inception in 1913, which proved to be the most comprehensive dataset related to the school’s history. Using the Grasshopper parametric modeling platform to link this raw data to a 3D modeling environment, the design team began an iterative process of visualizing the alumni archive in relation to class sizes, degree types, and geographic locations of the School’s graduates through time (Figure 4).
The model’s capacity to test different techniques of using the large alumni dataset to inform geometry in the software environment facilitated a rapid and almost intuitive process of analysis and evaluating which aspects of the data yielded the most promising visualizations. Through a series of interactive demonstrations and consultations with alumni and faculty, the parametric data visualization model proved to be a critical tool for quickly cross-referencing datasets and identifying any latent correlations that could yield relevant or compelling conclusions about the School’s history or impact over time. Through this process, the model provided a means for addressing many of the questions raised in the early discussions about ways to best map the School’s history.

This process yielded several important findings that helped inform many of the subsequent design decisions. First, it was evident that mapping degrees granted over time provided a compelling understanding of the School’s history, especially when the degree data was mapped chromatically. The changing composition of its degree programs speaks to both the School’s internal evolution and also its response to broader changes in architectural education and the profession at large. For example, the institution of the Bachelor of Science degree in Architecture and Decoration in the 1910s is notable since it included many of the School’s first female graduates, and the long, fifty-year dominance of the Bachelor of Architecture degree until its transformation into the Master of Architecture degree in the 1990s echoes similar curricular transformations occurring throughout the country.

The second important conclusion from the mapping phase was that the finer grain of the alumni degree data was most compelling and legible when seen in relationship to a series of broader eras in the School’s history—in particular, three recurring “data-sets” in alumni feedback and recollections: the tenures of heads of the School, the buildings it occupied throughout its history, and the parent college (within the broader University) to which it belonged. This dynamic—the multitude of degrees juxtaposed with the broader, big-picture ranges—became the basis for the next phase of the design process: materializing and spatializing the information.

MATERIALIZATION & PROTOTYPES: INITIAL STUDIES

The first attempts at testing techniques of spatializing the School’s historical data occurred within a four-day design computation workshop with graduate architecture students, taught in collaboration with Nathan Miller of CASE. In the context of this short workshop, the goal was to develop a set of potential material and tectonic strategies capable of representing the various datasets...
from the alumni archive. The student teams experimented with a number of different approaches, from a triangular metal truss to stacked cardboard tubes to interlocking plywood modules (Figure 5). These initial attempts, although limited in scale and resolution, were critical to the project’s development in testing techniques and workflows of prototyping full-scale materializations of data.

**PENCILS AS PIXELS**

Given the effectiveness and legibility of chromatic mapping in the early data visualization studies, the focus of the material research shifted towards simpler tectonic systems that could accommodate large numbers of variably colored components. Colorful No. 2 pencils were ultimately selected as the primary tectonic element; in addition to the obvious iconography of the pencil as an architectural drawing implement, pencils were logical for their relative economy and ease of reuse. Additionally, the pencils, which are colored in each of the eleven degrees granted by the School over its 100-year history, could be imprinted with the Centennial logo and eventually distributed as souvenirs for alumni (Figure 6).

Through a series of full-scale prototypes, the design team developed a tectonic system consisting of standard No. 2 pencils spanning two plywood ribs. An inch of spacing between the pencils was determined to be the optimal tectonic “resolution” that would ensure both a robust structural armature and the minimum required density for the pencils to read as a field of color from afar. Additional mockups confirmed joinery methods and assembly tolerances. These parameters gleaned from the prototypes were subsequently fed back into the digital model as constraints for the next phase of the design process.

**LOGICS OF DATA SPATIALIZATION: SPATIAL LOGIC**

Two primary design strategies—spatial and chromatic—emerged from the mapping and early prototyping phases. The first focused on generating spatial constructs using the broad historical ranges mentioned previously: the tenures of the School’s leadership, the buildings it has occupied, and the colleges it has belonged to. This information, rendered as a simple timeline of adjacent circles representing each range, was diagrammatically abstracted into a series of superimposed curves. These curves, mirrored and pulled apart in the z direction, were then lofted to generate a pair of intersecting, curved surfaces which constitute the formal volume of the installation. Finally, these mirrored surfaces were sectioned into 100 planar ribs, each of which represents one year and corresponds to the original timeline layout (Figure 7).
These global formal logics were incorporated into the digital parametric model, which allowed the design team to adjust and refine the curvature and resolution of the surface geometry with a high degree of control. Although a rather straightforward use of the time-based curvature to generate lofted surface geometry, this process proved effective for several reasons. In addition to producing a two-sided volume appropriate for the project’s central siting in an interior courtyard, it yielded a sculptural form that preserved much of the legibility of the original two-dimensional circular timeline. For example, the large swell in the center of the form is a direct representation of the long thirty-year tenure of Ralph Rapson as Head of the School. Similarly, the more gradual curvature along the base of the form provides a legible reference to the three buildings that have housed the School of Architecture over the past one hundred years.

CHROMATIC LOGIC

In contrast to the larger eras that define the project’s overall form, the more granular dataset of degrees granted by the School drives how the colored pencils are distributed throughout the installation (Figure 8). Each of the 100 ribs represents a year between 1913 and 2013, and each vertical “column” of pencils expresses the proportional distribution of degrees for the corresponding graduating class. This logic of chromatic variation operates at multiple scales: from a certain distance, one can perceive the proportional composition of each graduating class mapped onto the 100-rib structure, yet with greater proximity, the data dissolves into a more abstract field of color. This perceptual ambiguity is amplified by a custom sorting algorithm developed within the computational model that enabled the design team to articulate a gradation effect by refining the precise amount of shuffling between colors within each “column” of pencils (Figure 9).

The School’s historical data is thus employed to drive two aspects of the project: its spatial form and its coloration (Figure 10). The careful calibration of data-driven design techniques with material properties and perceptual effects results in a blend of representational and abstract agencies within the project. While Ralph Rapson’s 30-year tenure and the 60-year prevalence of the B.Arch degree are legible from afar in the large bubble and the multitude of red pencils in the center of the piece, the project exudes a much more atmospheric reading as one approaches (Figure 11).

SYNTHETIC DESIGN AGENCY

Although the project employs complex computational techniques in spatializing the historical data, it is important to note that the design process is far from a purely automatic transformation of
In this regard, Centennial Chromagraph avoids two common tropes of contemporary design computation: the purely generative and the purely intuitive. While the former often relies solely upon logics of mathematics or optimization and risks the complete marginalization of design agency, the latter embraces authorship to the point of arbitrariness. Instead, this project posits a synthetic approach: one that is both automatic and intuitive, one that employs generative, algorithmic processes punctuated with moments of intuitive choice.

In particular, the design process incorporated four important phases of intuitive decision-making and critical judgment. First, the data visualization and mapping studies, although computationally generated, were evaluated solely by intuitive and cognitive criteria. Only those mappings that proved to be both legible and visually evocative among members of the School community were carried forward into the design stage. Second, the tectonic development of the pencil and rib assembly began as an entirely analog process that was evaluated based on aesthetic and common sense structural implications. Third, although the installation’s global formal logics were based on curvature derived from the broad historical ranges (leadership, building, and parent institution), these curves were subject to a highly intuitive process of sculpting and refinement in order to achieve optimal formal results. And lastly, the sorting algorithm used to modulate the coloration of the pencils allowed the design team to choose the aesthetically optimal degree of gradation between colors. These moments contribute to a productive feedback between automation and intuition in which each conditions the other, and in which neither entirely dominates the design process.
FABRICATION & ASSEMBLY

The one-half inch Baltic birch plywood ribs were fabricated with a CNC router, which was used to cut the rib profiles, carve the pocketed lap joints, drill over 17,500 holes for each pencil’s attachment, and engrave labels on each component (Figure 12). 2D tool paths for each rib were nested on thirty sheets of 4’x8’ plywood. The integrated digital model and its parametric functionality greatly streamlined this workflow, as all fabrication information was output directly from the same model that was used throughout the design process. The model also produced detailed shop drawings that contained color-coded sequential instructions for the assembly of each rib and every pencil, to ensure precise coordination with the global chromatic pattern (Figure 13).

The fabrication and assembly process occurred over a ten-day period (Figures 14 & 15). Custom temporary spacers were fabricated and installed between ribs to maintain proper spacing and consistent tolerances throughout the assembly process. The precision afforded by the integrated model and CNC fabrication ensured that the installation came together without any misaligned holes or clashing pencils.

COMPUTATIONAL CRAFT

The influence of the data, while most immediately evident in the representational agency of the project’s form and color, persists even at the scale of the detail and assembly. This moment—where the logics of Big Data merge with the logics of assembly—becomes a locus for an emergent sense of craft that is contingent upon both the computational and the material, and impossible without either. This notion of computational craft demonstrates how “computation and robotic fabrication, when coupled to algorithmic design methodologies, enable an explicit and bidirectional traversing of the modern division between design and making, establishing novel pathways and feedback between mind, hand, and machine.” (Maxwell and Pigram 2012).

The genesis of this kind of emergent feedback in this project lies in the careful negotiation of the data-driven design process with the pragmatics of how materials are fabricated and joined together. Specifically, the most pressing challenge was to resolve the abundance of clashing pencils as they connect with the plywood ribs, especially where the installation’s volume intersects itself. The initial instantiation of the 8,080 pencils across the ribs yielded over 2,000 clashes, a number far too great to correct through manual adjustment and deletion of pencils. A recursive clash-detection script was incorporated into the model; sequentially scanning each rib, the script intervenes at clash points to insert...
enough space between pencils so that they no longer collide. This, of course, affects each subsequent rib (since each pencil connects to two ribs), producing a subtle yet nonetheless noticeable domino effect of irregularity throughout the installation (Figure 16). Where a pencil encounters clashes at both ends or lies too close to the edge of an intersecting rib, the script removes that pencil altogether, resulting in a sprinkling of gaps throughout the piece. Like the meander of the pencils, these gaps are subtle, but, once noticed, they become quite conspicuous (Figures 14 & 17).

This dimension of the project demonstrates the potential for contemporary computational techniques to engage with a sense of craft—something that has remained conspicuously absent in much of today’s architectural design computation. And yet, it also represents a departure from traditional notions of craftsmanship, perhaps best defined by David Pye as a process of making in which “the quality of the result is continually at risk” (Pye 20).

Pye’s understanding of risk, positioned in contrast to the precision and predictability of standardized mass production, is predicated upon the presence of the hand and the ineffable qualities present in manual labor. The sense of craft explored by Centennial Chromagraph embraces a different type of risk: one rooted not in manual labor, but rather in the vast quantities of data that define our contemporary culture. The project demonstrates how quantitative processes of mining and computing large amounts of information can yield a certain measure of unpredictability. Just as Pye celebrated “workmanship of risk” present in manual production, this project embraces a similar sense of risk that can be found in the negotiation of material constraints with computational modes of design and production.

CONCLUSION

Centennial Chromagraph employs data-driven design and the careful calibration of material tectonics with spatial effects to produce a structure that oscillates between the purely representational and the purely abstract. In doing so, it suggests several points of departure for future evolution of computational practices in architectural design. First and perhaps most obviously, it emphatically embraces architecture’s representational agency. This echoes architects as diverse as Robert Venturi and Denise Scott Brown—“It’s not about space: it’s about communication” (Venturi and Scott Brown 2004)—and Patrik Schumacher—“All architectural spaces are conceived and designed as communications” (Leach and Schumacher 2012). However, this reaffirmation of architecture’s communicative capacity is framed within the context of Big Data—specifically the potential for data-driven analysis and design to open up possibilities for architecture to engage with its public audience in new ways.

In addition to these representational and communicative goals, the project’s notion of data spatialization is equally committed to exploring the latent spatial and aesthetic possibilities that lie within large datasets. It seeks an alternative to the orthodoxy of
optimization that presently reigns in data-driven design computation, and suggests that rigorously mining the excessively quantitative logics of Big Data can ultimately yield truly compelling qualitative results in spatial form and material effect. This is facilitated through a synthetic design process that punctuates automatic, generative design techniques with moments of intuitive choice.

Finally, the project stakes a claim for computational craft, whereby the artifacts of the algorithm—the subtle gradation of color, the slight meander of the pencil holes along the rib, the deletion of pencils that would otherwise collide—produce an emergent synthesis of immaterial and material logics. This sensibility is rooted in computational processes, yet it transcends the purely digital by interfacing directly with age-old architectural notions of detail, ornament, pattern, and effect.

ACKNOWLEDGEMENTS

Design Team: Adam Marcus, Daniel Raznick
Fabrication: Adam Marcus, Daniel Raznick, Jordan Barlow, Sam Daley, Kevin Groenke
Computational Design Consultant (March 2013 Catalyst Studio): Nathan Miller, CASE
Prototyping and Design Studies (March 2013 Catalyst Studio): Will Adams, Philip Bussey, Sam Daley, Matthew Enos, Derek Gallagher, Mohsen Ghanbari, Dantes Ha, Hwan Kim, Benjamin Kraft, Wei Liu, Daniel Raznick, Stuart Shrimpton, Christina Smith
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REFERENCES


IMAGE CREDITS


Figure 3-20: Adam Marcus/Variable Projects (2013).

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