Perforating Material Performance: Ceiling Cloud

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The focus of this project was to design a ceiling system within a new Materials Resource Center in the Architecture Building that would embody the potential of parametric design and digital fabrication to rethink a generic interior architectural system. The instructors and students in a combined design studio and digital fabrication seminar developed a Ceiling Cloud that clips on to a modified suspended ceiling grid using lightweight folded aluminum panels that are designed to incrementally change dimension and drape into the space below. Constraints and variables within the parametric models allowed for the optimization and extraction of 150 unique panels that are also perforated with their own individual pattern. The variations in the folded surface disburse and dissipate sound through refraction and absorption created by the corrugation in the panels and their perforation. The holes are also calibrated as a gradient to allow more light to penetrate in the center of the space away from the perimeter walls. The project was prototyped by the students as the College of Architecture and partially realized with the help of industrial partners in Houston. The studio was co-directed with Visiting Critic Scott Marble who provided a framework to conduct the studio's exploration and several successful projects as precedent.

Figure 1. Ceiling Cloud. Scale model with lighting

Our work and research into the potential of building parametrically designed alternatives to typical interior architectural systems with fabrication techniques of cutting and forming thin-gauge sheet metal is exemplified in the Ceiling Cloud. The digital design process was initiated after successive physical experiments with a virtual component model that was parametrically linked to a 2D cutting process. An assembly was developed that connects to a typical suspended ceiling grid with a standardized coupler. Material performance, structural analysis, surface optimization criteria and an intuition about inventive detailing were essential tools that we used. Perforation as a precise method of material removal has afforded the manipulation of sheet materials to produce a differentiated array of potential surface geometries. It allows pliant materials to become robust structures that interact with their environment through controlled porosity. Through formal transformation at the scale of the component and logical systems of consistent assembly sequencing, the complexity of construction is managed and explored.

The Ceiling Cloud is a prototypical suspended ceiling system designed for a site-specific condition through the use of parametric software. Our group was retained to build out an existing space into a new Materials Library. Lighting needed to be ambient and/or directional with the ability to alternate throughout the day given different patterns of use from lecture space with directed focus, event space with multiple conversations occurring concurrently or exhibition space with illuminated walls. Our focus became a custom designed and fabricated ceiling system that could clip on to a conventional inverted exposed inverted t-spline railing system that typically accepts acoustic panels. The product could not be much more expensive than the generic material, needed to be performative with regards to lighting and acoustics and installation had to be quick, easy and reversible to allow access to the plenum. The parametric design focused on two scales of modulation. The global geometry of folded panels consisted of an “A” and “B” panel that varied along the free dimensions within a range while maintaining constraints relative to the suspended grid and sheet material sizes for fabrication. A perforation pattern was used to create porosity in the surface for acoustic and lighting performance and to allow the panels to be formed easily into their corrugated shape. The holes vary across the system from large and sparsely deployed to small and dense in the center were activity in the space will concentrate. The parametric design operated on the two scales simultaneously to produce the unique tessellated panels that were constrained within a defined set of limits.

Figure 2. Prototype, full scale. Laser cut aluminum.

The transformation from 3D information to 2D toolpaths to 3D assemblies using folding and forming was the critical path for our parametric process. A system of tessellation was designed where surface faces were constrained to remain planar and angles to fold were maintained consistent through the rules of the parameters. The differentiation of the algorithmic pattern was made legible against a continuous ceiling grid substrate that connected to the building's structure. The Ceiling Cloud performance based design initiated with two basic panel typologies that alternated through the array. One was consistently convex and the other concave in section creating a corrugated spatial system that changed incrementally from edge to center. This was done to affect the acoustics and ambient lighting in the space.

Perforation was used for component transformation as a fabrication strategy. The seams between the planar facets in the Ceiling Cloud are marked with stitch perforations that allow the panels to fold along prescribed locations to exact angles by referencing the adjacent panels. This flat-pack technique of forming by hand was a repetitive condition in each unit that was a consistent presence along with of the variable dimensions produced by the parametric model.

Environmental performance was implicated in the design of the Ceiling Cloud for exploiting acoustic and luminous qualities of the surface above a public exhibition space. The corrugated profile of the panels varied in depth from the edge to the center of the space expanding from a compressed section to a deeply draped module. The texture of this surface is active in fragmenting the low frequencies present in the space and refract them away from the source of the sound. This was coupled with a perforation pattern that varies in size, quantity and density which modifies the high frequencies that tend to pass through the surfaces and dissipate in the plenum cavity above the ceiling. These two systems were integrated and independently controlled through a parametric model that allowed the designers to tune the space to merge performative criteria with aesthetic intuition.

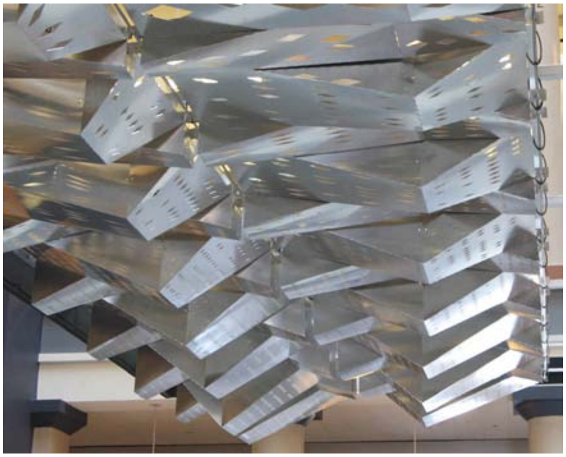

Figure 3. Prototype, full scale. Laser cut aluminum.

Designing Parameters

This project utilized parametric design systems as a technique to connect and correlate the qualitative relationship between interior ambient lighting and performative acoustic performance. This was achieved

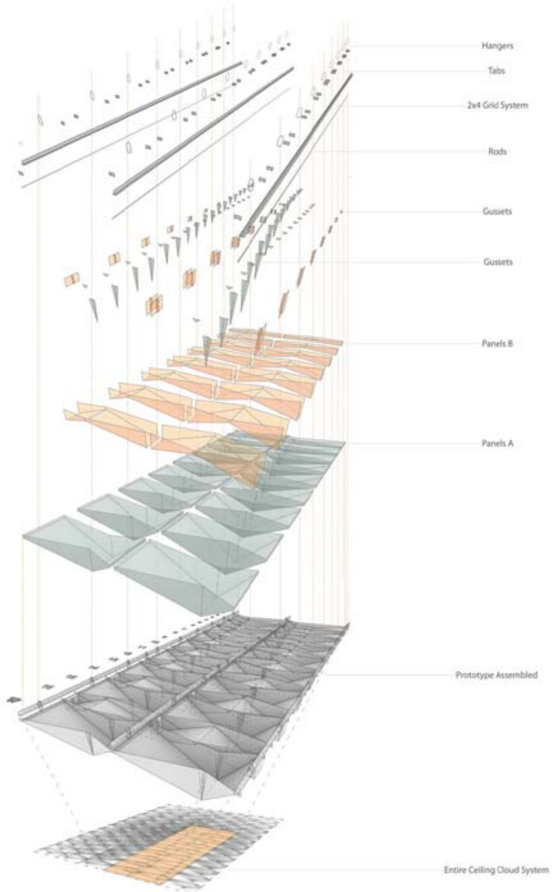

Figure 4. Designing Assemblies.

with a model that maintained a quantitative relationship between modularity and patterning of the ceiling system. In broad terms, parametric systems are used to manage complexity and have been utilized in architecture either as a generative technique to quickly and efficiently produce design options based on a limited set of algorithmic variables or as an organizational system to manage designated constraints between components. Constraints and variables within the parametric models allowed for the extraction of 150 unique folded panels that are also perforated with their own individual pattern.

Nested parametric models are essential in using interactive software to address design criteria on different scales simultaneously. The Ceiling Cloud's aforementioned variegated paneling and algorithmically changing perforation pattern was driven by separate sets of variables that were nested within each other. The global paneling strategy was linked to the deployment of holes through quantitative links that allowed a fluid connection between the two or each could be unlinked and designed independently.

Designing Assemblies

In contrast to the modernist logic of built up details or managed assembly by combining standard pre-manufactured parts, we worked toward a logic of designed assembly from the performance of specific parts that fused concept, design, fabrication and assembly. The correlation of the effects created by slight variations between individual adjacent panels is legible over the entire ceiling when seen in its totality.

Designing the assembly sequence as an integral part of the process is key to an effective translation of the digital components to physical integers of construction. The Ceiling Cloud had to connect to a conventional suspended ceiling grid for ease of installation and for future maintenance. A layered system of parts created a critical path of assembly that allowed the panels to be formed and placed very quickly without cutting or measuring in the field. Gussets and tabs completed the alignment of the folding faces for closure and to complete their structural form. The perforation allowed the forming to be completed quickly and accurately.

Designing Performance

Proof of concept was in the analysis of the Ceiling Cloud during design optimization using acoustic simulation and parametric software in tandem. The variegated surface and micro-perforation pattern were developed to dissipate and absorb noise at low and high frequency ranges using particle animation. This will be tested empirically after the full realization of the project beyond the 20% of the system that we prototyped. We will compare the acoustic performance of the actual constructed system with the visual and quantitative data observed in the simulation software as a case study for further understanding of how to interpret these tools.

Lighting performance was tested in analog models instead of rendering software. Physical models are always part of the design process and in this case were the drivers of surface morphology and perforation strategies. Individual panels and arrays of them were tested with varying types of light from above and below the ceiling datum. Ambient indirect light was coupled with direct lighting to create atmospheric effects that could change according to programmatic use.

A flexible and integrated method of design emerges from the concept to installation of the Ceiling Cloud. The use of the modeling software to accurately extract components allowed the project to go seamlessly from prototype directly to production. The use of parametric software allowed for minor changes and infrastructural adjustments to be made to accommodate the acoustic and lighting criteria as well as the adjacent mechanical equipment. The revisions update through the entire assembly which is a series of associated parts that reference each other. The analysis software was used to test the performance on the global faceted system and the micro perforation pattern on specific areas on the design and to inform the next iteration of the variable design.

product of our broader research. We see these parametric tools as a means to tease out new potentials in generic materials and architectural systems through digital fabrication.

Influences

We referenced several works of architecture and art in the initial research phase to set of the direction to design on the ceiling system. The dramatic effects that Bernini's work achieved through the control of light from discrete sources into spaces of extreme surface modulation and material and geometric contrast were studied. The fluid form of the gown and concealed body of St. Teresa in contrast to the vectors of light and angel's spear that penetrate her were strong dichotomies that we sought to carry forward into this work.

The atmospheric effect of the luminous cloud-like quality of Tara Donovan's work with nested Styrofoam cups creating hive-like aggregations in the corners of rooms was another interesting example to our team. These served to influence our perforation system that would allow for subtle contrasts between the surface of the panel in the foreground and the existing building slab beyond that is ambiently illuminated from lighting above the ceiling datum. The swelling effect that Donovan

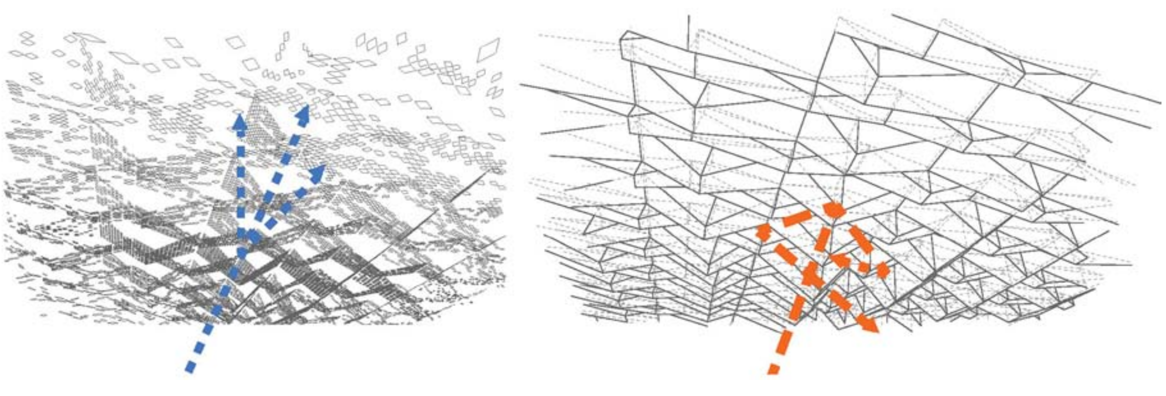

Figure 5. Designing Performance: Ceiling Cloud. Scale model with lighting

achieved with geometry was achieved in our case with varying the size, quantity and density of perforations

The digital design strategy and fabrication tactic of perforating sheet material to engender performance is a across the expanse of the ceiling.

Arabesque patterns were also influential in the way we indexed the differentiation of panels and perforation while maintaining self-similarity throughout the system. The patterns that populate the surface of Islamic architecture often transform from 2D tiling to 3D vaulting as they move up the ground and an project horizontally over spaces. The coupling of rectangular and radial arrays with alternating colored tiles creates larger complex patterns within the aggregation of simple repeated units. We sought to overlay the rectangular array of the ceiling panels with the radial expansion of the perforation patterns to conflate the two systems in one composition.

Finally the generic suspended ceiling system of the modern office space was a constant presence that had to be appropriated and absorbed. The ubiquity of aluminum t-rails and expanded cellulose arranged in 2’x2’ grids emerged in the 1950’s as systems that informed the modulation of open office plans by informing the placement of interior partitions and furniture. The regimented control of corporate space created a predictable and flexible way to expand the workflow of capitalist efficiency and eliminate the chaos of the exterior urban condition. Our goal is to appropriate and literally connect to this type of system while teasing out the latent potential to modulate along the z-axis to deal with acoustics and lighting in an alternative manner to greater dramatic and performative effect.

Pedagogy of Collaboration

Architectural education is moving away from the classic example of one student working alone on an entire building for a semester with the professor acting as the master to the apprentice. Collaboration as a model observed in actual architectural practice between

Figure 6. Influences: St. Teresa in Ecstasy, Bernini; Tara Donovan, Untitled and Set of MadMen

designers, consultants and clients is now being engaged and is expanding to include fabricators, software developers and other types of engineers beyond structural and mechanical. Students now work in larger collaborative groups and instructors organize the workflow as a lateral effort rather than a sequential linear one. This allows for projects of rich layering and greater complexity to be achieved with a high degree of resolution. Students become specialists in an aspect of the process while observing the amalgamation of the groups efforts into a realized project. In this project, five design teams were organized around Lighting, Acoustics, Modulation, Patterning and Display. A critical path was then initiated to manage the schedule along the development of performance, parameters, assemblies and prototypes. This collaborative model proved to be effective in that the project was completed and 20% of the final product was fabricated and installed for display at the end of the semester. The balance of the project will be installed in the material resource library in the near future.

Figure 7. Installation into ceiling grid

Expanded Alliances

Visiting Critic Scott Marble worked with the instructors and students and employed a studio instruction model that he initiated at Columbia GSAPP. This approach was used on their award-winning projects for the Fine Arts Slide Library project and Stabile Hall School of Journalism on the Columbia campus. Scott initiated the discussion with the following excerpt from a report on integrating collaboration and technology in an architecture studio and applying this expertise to projects on university campus projects:

> *Schools of architecture have pioneered the first digital revolution through exhaustive formal experimentation and elaborate visualizations of these new forms. While this was occurring, the construction industry has focused more on stream-lining the manufacturing and building processes through CNC technologies with little or no emphasis on innovation beyond efficiency. The core goal of Expanded Alliances is to foreground the potential and urgency of a younger generation of architects to begin pioneering the second digital revolution in architecture. Because this revolves around actual building itself, the only effective way to do this is to build...at full scale. More important is the application of digital technology as a tool to generate the organization of projects, to form networks of collaborators to realize projects and finally to design, manage, fabricate and assemble innovative architecture.*

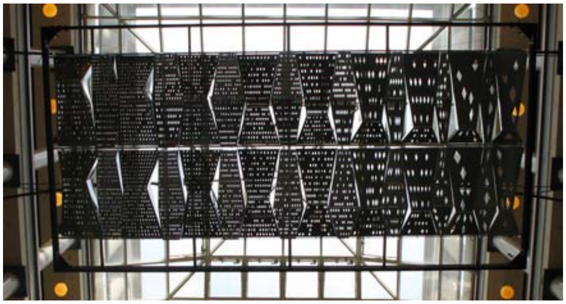

Figure 8. Prototype, full scale. Laser cut aluminum.

Conclusion

Proof of concept will be achieved with empirical analysis of the acoustic properties of the space once the Ceiling Cloud is installed. We seek to compare date from digital simulation software with the built project in order to understand the potentials and limitations of these tools to predict the outcome of complex relationships between the system's performative potentials in the environment. Perforating material performance seeks to merge a qualitative understanding of materials and fabrication with a quantitative set of parametric and simulation digital design tools.