Folded! High-rise

A Senior Project

Presented to

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Bachelor of Science

by

Alejandra Bravo | Riley Denis

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Project Advisor:

Kevin Dong

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Executive Summary

The authors of this report are undergraduate Architectural Engineering students at California Polytechnic State University in San Luis Obispo. This report documents their experience in an interdisciplinary studio of high-rise building design and the process by which they produced a schematic design of a high-rise residential building in San Francisco. It will address the organization of the studio, the development of concept as well as form and structure, the studies and structural analyses, as well as the review process and the competitions the final proposals were entered in, and include some final takeaways from each Architectural Engineering group member.

Collaborative Studio

The Cal Poly and Skidmore Owings and Merrill (SOM) collaborative high-rise studio was designed as an opportunity for Architectural Engineering (ARCE) and Architecture (ARCH) students to work in teams for the duration of two quarters. The world renowned interdisciplinary firm SOM partnered with the studio to guide the students through the development of the projects and provided important feedback throughout. The educational structure of the studio was comprised of studying precedent tall buildings, researching systems, physical modelling, publishing digital content, presenting to a wide array of designers, and listening to lectures.

High-rise Design

In preparation for teams to develop their own designs, SOM architects and structural engineers primed the students about the different design implications of high-rise design through their lens as a professionally practicing firm. SOM introduced five major design themes that are part of tall building design: tectonic integration, functional typology, urban placemaking, vertical community, and performative envelope. A primary requirement was for teams to integrate architecture and structure (tectonic integration), and the other themes were met with varying degrees of development.

Folded! Project

Project Parameters

The studio teams were tasked with designing a residential high-rise tower in a trapezoidal lot on the corner of Van Ness and Market in San Francisco, CA. This site has seen several failed attempts to bring a new structure to it and poses a host of challenges for the design team to face. The irregular shape of the lot, the poor soil properties of San Francisco, and the BART station located adjacent to the site underground were some of the design implications of this site. This provided not only a simple introduction to design a building of this size, but also required each team to think critically and in some cases come up with innovative design aspects to address the challenges that this site brought with it.

Concept Interpretation

Each team was presented with an abstract idea at which to begin their design. This tower began with the idea of "plaster balloons / solid and void." After some exploration, a close-up picture of the wing of a moth was found that was believed to represent this idea of solid and void while also emphasizing the structural nature of the wing (see Figure 1). The view of the wing presented a complex view of a seemingly homogeneous and solid everyday thing that in fact is far more varied than would initially be thought. The wing which can keep the moth in the air as it flies is in fact full of voids with strong structural spines running the length of the wing adding rigidity. This concept of the moth wing inspired the space frame ribbon seen in the tower.

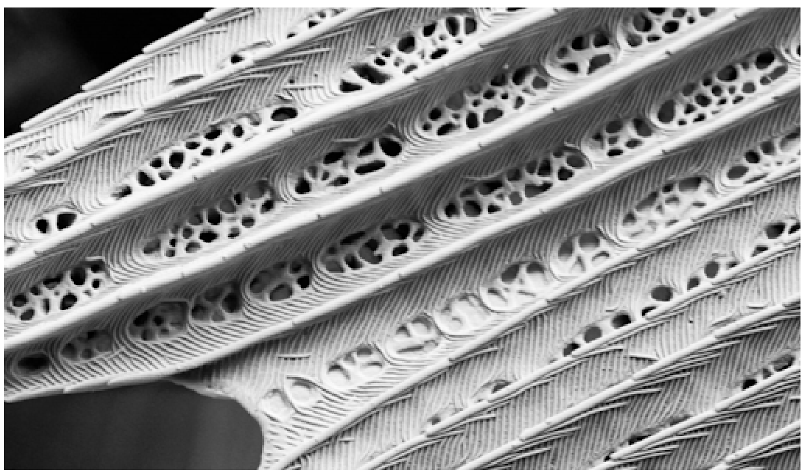

Figure 1. Moth Wing Inspiration

Design Development

During the 20+ weeks of the project, the tower went through nearly countless iterations both the architectural and structural side. The design process began with traveling to San Francisco and visiting the proposed site of the tower at the corner of Market and Van Ness. The visit allowed the observation of foot traffic around the site, and proximity to resources such as the BART station most directly under the site. There were many conversations between architects and engineers resulting in numerous forms to try and balance the aesthetics and the constructability of the structure before reaching the final building concept (see Figure 2 & Figure 3). Each iteration drew not only from the minds of the architects and engineers, but also from the inspiration of the folded moth wing, and from several precedent studies which were performed as a part of the studio

Figure 2. Form Iterations

Figure 3. Final Form

Parametric Studies

Throughout the design process of the studio, a number of structural studies were conducted on simplified buildings to clarify the effect that certain structural systems on the manner in which the building reacts under influence of the lateral loads experienced by a structure of its size. Many of these studies were conducted on simple rectangular structures that were 500 feet tall. 2 studies were exceptionally usefully while designing the final tower and will have influence over future designs. The first was the investigation of dual systems. In this study, an analytical model was constructed on ETABS that represented a building with 2 lateral force resisting systems that act together to resist the lateral loads applied to it. Certain members of the studio analyzed different systems such as a concrete shear wall core of varying plans and dimensions on the interior with a separate system such as braced or moment frames on the exterior of the building. Observing the reactions at the base of the building revealed what percentage of the load was taken by each of the system, as well as observing the deflections at the top, 2/3, and 1/3 of the structure height to find the differences in rigidity of the systems.

The second was a study in which models were created of different layouts of the concrete shear wall cores. Some were modeled as closed tubes, others as 2 separate ‘C’ shaped cores, and some as separate cores tied together by transfer beams or trusses. This study showed the ways to increase the footprint of the later system while still having it all be on the interior of the building. By cutting a conventional closed tube rectangular core and slicing it into 2 separate ‘C’ shaped sections that are separated as wide as possible then joined together by any means of creating rigid links allows for 1 core section to be in compression and the other in tension. By having these sections further apart than the simple rectangular tube the forces required in the walls by the applied moment of the lateral load will be decreased leading to the ability to decrease the member sizes

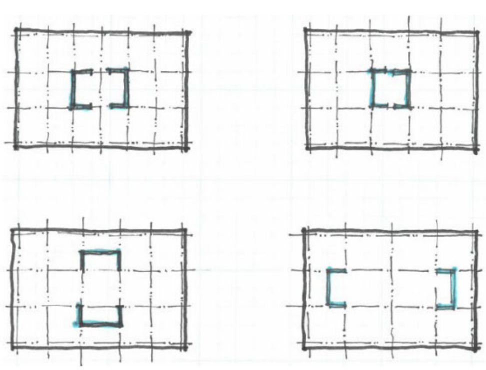

Figure 4. Parametric Study Options

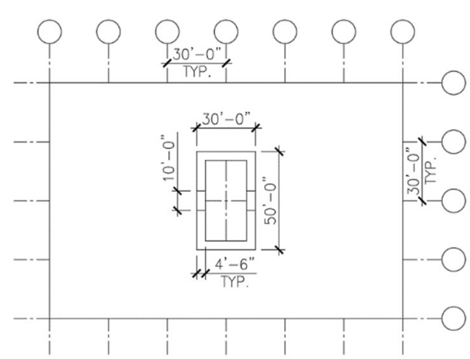

Figure 5. Our rectangular core with openings

Structural Analysis

At several stages throughout the design process when the design had seemed to be narrowing in on an idea, an analytical model was created of the structure to observe its reaction when loads are applied. When running 3D analysis in ETABS the main results that were sought were that our 1st, 2nd, and 3d modes translation, translation, rotation respectively and that deflections at key points, mainly 1/3, 2/3, and 1 of the structure height were under the allowable h/500 set forth in ASCE 7-16 Appendix CC on Serviceability. For the 3D analysis of the structure, ETABS was used and a simplified structure of the tower was input to achieve the mode shapes, deflections, and fundamental periods of the tower (see Figure 4). The results obtained in ETABS were then verified using quick hand calculations to check the relative accuracy and avoid simple errors in the modeling process.

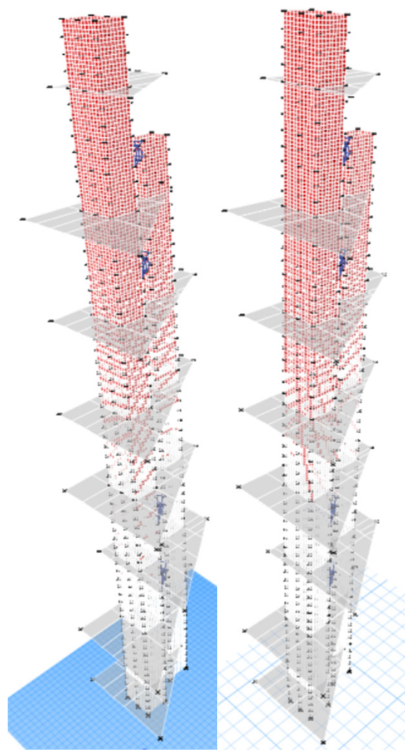

Figure 6. Simplified ETABS model deflected shapes

Reviews

Throughout the design process there were several formal reviews and exponentially more desk critiques. These reviews served to touch upon the points of the projects that were and were not working for each proposed tower by having input from other students, professors, and design professionals. Since the studio was part of a partnership between Cal Poly and the design firm of Skidmore, Owings, and Merrill (SOM), each team had several opportunities to get feedback of the projects from design partners Mark Sarkisian (engineer) and Leo Chow (architect), as well as other members the SOM design team, who were able to give a more outside view of the projects as many of the other reviewers were members of the studio who had seen the projects nearly every day. These SOM views also gave an amazing insight from men and women who have worked on projects at or above the scale of the proposals being presented to them.

Design Competitions

Student design competitions were also a part of this collaborative studio, as the designs were developed to a reasonable degree.

2020 Steel Competition

The 2020 Steel Competition is hosted by the Association of Collegiate Schools of Architecture (ACSA) and sponsored by the American Institute of Steel Construction (AISC).

The competition is open to both undergraduate and graduate students, and along with an entry category that poses a specific design challenge for students to tackle, there is also an open category which allows students to take more charge in their design by not being locked into a certain site or building type. The open Category is where the high-rise created in this project is submitted. This competition sets forth to push students to face the challenges presented by steel construction and requires the use of a steel structure that contains long spans to try and push competitors to create innovative designs to deal with the challenges presented.

2020 CTBUH Student Design Competition

The Council of Tall Buildings and Urban Habitat (CTBUH) hosts an annual Student Design Competition which is open to all students that are currently enrolled in a university. This competition strives to introduce students to the true value of tall buildings and how they affect the society in which they are constructed. CTBUH pushes the competitors to explore how such a large structure is able to have a synergistic relationship with the site and community that it will be placed in. They push for the students to take into account all aspects of designing a tall building from structure, and architecture, to material choice and the buildings environment created.

Council on Tall Buildings and Urban Habitat

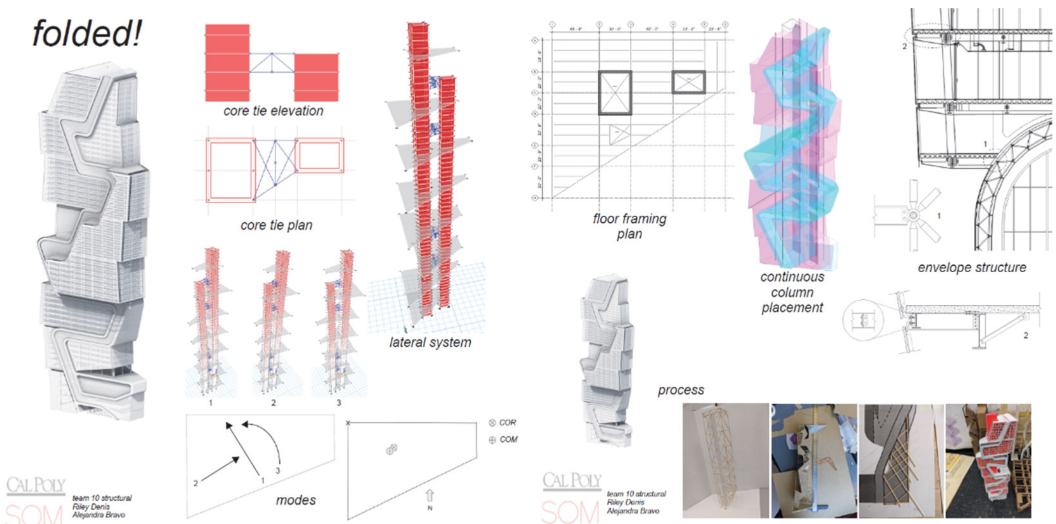

Figure 7. Competition Structural Boards

Reflection

Riley Denis: This studio has exposed me to a completely different style of design than I had experienced up to this point. In all my past design labs we have been given a generalized architectural template to work off and teamed up with another architectural engineer we have created the structural design to match the proposed architectural layout. For this studio experience being teamed up with not only another ARCE, but also with a team of 2 architects was a completely new experience that changed the design process drastically. Instead of being handed a completed architectural design and being told to design the structure to fit it, we had the chance to work with the architects to develop both our structural design and the architectural. This process involved a lot of communication and back and forth between us engineers and our architecture counterparts to balance the architectural design to find a form that would be innovative architecturally, but would also be able to be built and have a reasonable structure.

This was also the first time since freshman year when I was taking architecture studio that I have had to present my ideas for an in person (or virtual) review. In the design labs it is usually just a process of doing the required calculations and coming up with what you believe is a good choice then turning them in to get feedback that is usually based on whether or not the calculations were done correctly, and occasionally talking with the professors about what might be the most efficient way to design a structure. But now having to put all my ideas into words and pictures rather than just having numbers that are backed up by my calculations. This forced me to think a lot more about why I was taking the steps I was because more often than not there would be a question about why we were planning on using the system we were and whether we had explored anything else. The SOM reviews also presented a new experience for me as these were professionals who have actually spent their career designing buildings on the scale that we were just now being introduced to, so to get their input on what they thought of our ideas and the ideas that they had when looking at our tower was immensely helpful and almost invaluable.

My final, and arguably most valuable takeaway from the last 2 quarters, is the fact that even with a structure as complex as an 800 foot tall high-rise, when analyzing the structure it can be simplified to key elements and still produce valid results. My first attempts at creating an ETABS model for our structure I tried to model every floor with every column and brace thinking that this was the only way to get accurate results. This made the modelling even harder on me since at the beginning of this course I had never used ETABS before so was teaching myself while trying to model an extremely complex and large structure. Then during this quarter through talking with Kevin I was introduced the fact that we can simplify the structure drastically and still receive outputs that would represent the structure well. Examples of these simplifications are such as taking groups of floors and compressing about 10 floors into a single diaphragm that is modeled to represent the properties of all the floors needed. Also when modeling for lateral analysis it is not necessary to model all the gravity system, so a model that used to include 60+ floor plates, hundreds of columns, 2 cores, and a number of braces, was reduced to the 2 cores, 8 slabs, and a few columns, beams, and braces for our core ties. This saves hours of modeling and my mental sanity.

Alejandra Bravo: Taking this course will be a memorable part of my college career, as it differs significantly from most other major courses in ARCE. The collaborative requirements of an interdisciplinary team effort facilitated important life lessons and the development of skills that will be applicable in a professional work environment. I also found it educational to witness the progress of other tall buildings in the studio because it was inspirational to see different strengths and varying design priorities. Overall, I learned that design is a unique process that can be executed differently between any given two people and as a team there is an opportunity to iterate through stages more quickly and implement the best ideas.

In terms of technical knowledge, we explored things differently from what I initially expected, and I am appreciative of the approach to structural design that we learned in this course. In contrast to other major courses where we follow analyses of structures from a macro perspective of applying building loads to a micro design of a specific member or connection, in this class we focused on proposing reasonable big ideas and validating them with simple calculations or studies. It was rewarding to be able to reinforce some fundamental ideas by applying them to a project we were so invested in developing.

Finally, I am grateful to all the professional designers that dedicated time to our efforts and thoroughly engaged with our projects, providing meaningful constructive criticism throughout the duration of our two-quarter long project.