Housing and Concrete, a Design Build Studio

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ABSTRACT: *The need for affordable housing has never been greater: Populations are fluctuating, cost of living is increasing and new typologies for live - work options are needed. This paper will discuss the framework and findings from a design build studio that developed and tested strategies to address these issues using precast concrete as a construction system. The paper will discuss the learning objectives, outcome and challenges of the studio that students selected as an option studio in their 4th year of NJIT's B Arch program. The studio invested in the possibilities of precast concrete construction methods, ideas for new strategies for mass customization, construction and assembly processes that make the use of concrete more efficient and therefore more environmentally and financially sustainable. To do that the studio teamed up with the Precast Concrete Institute PCI, High Concrete Group, BLDGUP a local developer, and NJIT's Concrete Industry Management Program CIM.*

KEYWORDS: Housing, Precast Concrete, Design Build

INTRODUCTION

In 2022, an estimated 420,000 new rental apartments were built in the United States, the highest amount for new multifamily construction in a half-century. The standard construction system for low rise housing in dense urban areas in the US is five wood-frame stories atop one concrete podium, also referred to by the industry as 5-over-1s. Optimizing 5-over-1s towards budgetary constraints from developers, density and zoning requests by cities led to a specific type of building that looks similar across the US to a degree that one would not be able to tell in what city a building is by just looking at the building itself. A specific construction standard of wood framing, very common across the country and a lack of experimentation and exploration of different construction techniques also contributed to such monotony.

The studio investigated precast concrete as an alternative to the typical wood-frame stories atop one concrete podium because of its advantages in performance and cost of construction. Precast concrete is a more fire resistant, durable and robust construction system for housing. It has a better acoustic performance, reducing sound reduction and lowering sound transmissions between dwelling units and external noise such as traffic. Compared to lightweight construction precast concrete also provides a higher level of internal temperature stability. As a solid construction material, it contributes to thermal comfort by absorbing and storing heat and radiating it back during cooler periods. If designed correctly with an effective use of solar control and ventilation, building with precast concrete can help minimize the need for air conditioning.

Compared to cast in place concrete, precast concrete has a series of advantages in the production and in the construction process: Panels can be produced faster and cleaner in a factory. Produced in a controlled environment the production is weather independent and independent to unique site constraints, which allows for the production to be optimized to save time and labor. An optimized process in a controlled environment also allows for better quality. The production in an ideal climatic condition of a controlled indoor environment can also speed up the curing process of concrete. On site the typical erection of a 5-story housing project is 10 weeks, which saves time and reduces construction cost. Once assembled on site wall surfaces do not have to be finished, concrete can be exposed, and the use of exterior insulated sandwich panels save time in the construction process and reduces the number of trades that would typically be involved in the construction of a multi layered façade. Walls can be used structurally, which can save on material and cost over alternative construction methods that are made up of columns and beams as a primary structure and wall panels as a secondary structure.

1. STUDIO FRAMEWORK

Instead of trying to build the prototypes and simulate an industrial construction process in the backyard of the architecture school this studio moved all the production to the industry. Instead of creating a make-believe environment the production of the students' projects was fully integrated into the production process of a precast concrete plant. This created a unique opportunity for students to collaborate with industry partners, learn about material, learn how to coordinate and meet schedules, learn about workflows and learn about the production of building components in a hands-on way.

The studio focused on the development of precast concrete assembly strategies and facade systems for micro housing. The semester was divided into three parts of about four weeks each: 1) Case study analysis and schematic design, 2) Assembly processes and 3) the design and construction of a prototype for a façade panel. During the remaining two weeks students were asked to document all parts of the studio and synthesize and revise their projects. The studio took advantage of the location in the New York Metro area by starting off with field trips to recently completed micro housing projects and discussions with the local developer BLDGUP that is specialized in micro housing projects. Selecting an infill condition as site for the studio allowed to quickly develop a schematic design at the beginning of the semester and to develop projects in more detail. Beside the design of the project students were also asked to create assembly diagrams to discuss the construction process and estimate the construction time and cost. During this time students were connected to engineers at High Concrete, a local precast concrete plant for feedback. In the third part of the studio students collaborated very closely with engineers at the High Concrete Plant to design and build a prototype of façade panels of their projects.

2. CASE STUDY ANALYSIS

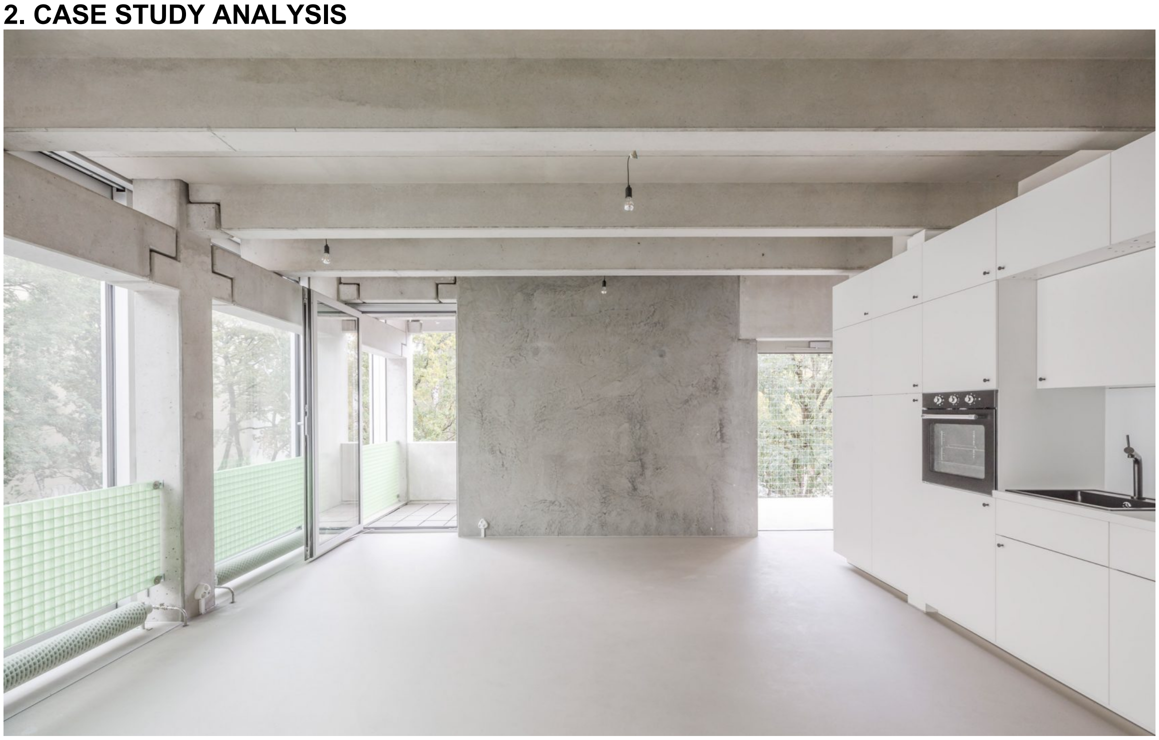

Figure 1: Wohnregal by FAR. Source: (David von Becker 2020)

The studio started by analyzing a wide range of case studies for five to eight story precast concrete housing projects. The projects were grouped into three different categories: column beam systems, panel systems and mixed construction systems. An example of a case study for a column beam system is the Wohnregal, a six-story housing block in Berlin, Germany. The project is using a precast concrete system to create an environment that can be highly customized. Instead of structural walls the project was constructed from precast pillars and TT beams that are supporting precast concrete slabs. Celebrating typical precast concrete details, the goal of the project was to create wide-open rooms. A span of 42 feet allowed for a maximum of transparency and flexibility to insert drywalls and divide the space according to individual lifestyles.

Very different applications for precast concrete are jail and prison cells in correctional facilities in the US. Because of the spatial requirements of small spaces panel systems are commonly used. They are built from precast concrete because of its durability, strength, and fire resistance. There are two different techniques used to build jail cells from precast concrete: Wall and floor panels and modular construction, where the entire cell is assembled from panels off site in a factory and brought to the site as a module. Both techniques can be customized to meet specific requirements to include built in beds, toilets and sinks. Differentiating between load baring panels, sheer wall panels and non-load bearing panels allows to construct the entire building without any columns or beams.

Most precast concrete housing projects are a combination between column beam systems and panel systems. Typically, columns and transfer beams are used for the first floor to accommodate for programs that require larger spaces such as stores, restaurants or lobbies and panel systems are used for apartments because of the shorter span. An example for such a mixed construction system is the eight-story student housing project currently under construction at the edge of NJIT's campus in Newark. Columns and transfer beams were used in the first floor of the project to respond to the required long spans to accommodate for parking, a student lounge and stores. The upper floors of the apartments were assembled as a column fee load bearing panel system. Since the project was in the middle of construction during the semester of the studio, students could follow the process of assembly. Since High Concrete was the company that built the project students also had access to detail drawings of the project which helped to understand typical construction methods with precast concrete early in the semester.

Students compared different case studies and discussed possible advantages and disadvantages of using different precast concrete construction systems. An advantage for a panel system for example is cost, a disadvantage is the limited size for windows and flexibility in geometric complexity. An advantage of a beam column construction is the flexibility of floorplans, a disadvantage is cost. The advantage of mixed construction is the flexibility to respond to different program types. The disadvantage is cost.

3. ASSEMBLY PROCESS

Since one of the main goals of the project was to decrease the cost of housing students tested the three different strategies and different combinations of these strategies against the micro housing program. In the discussions with engineers from High Concrete student developed strategies to respond to the challenges of structure, spatial quality, speed of construction and cost efficiency.

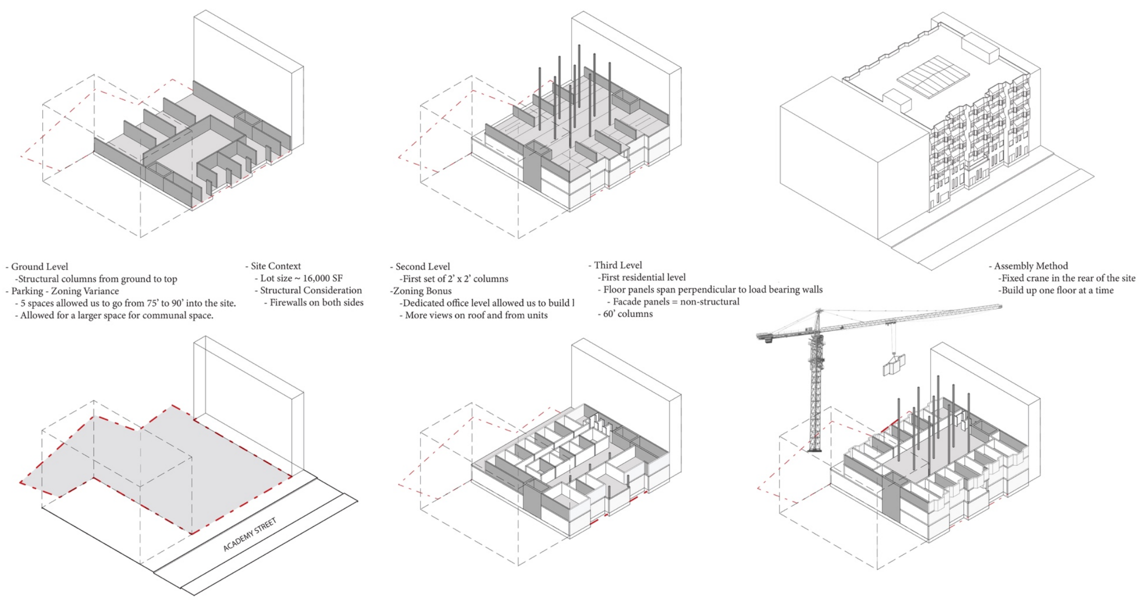

Figure 2: Project by Samantha Volpicella and Abdurahman Oudeh. Source: (NJIT 2022)

One example of responding to these challenges can be discussed in the project titled "Townhouse" by Samantha Volpicella and Abdurahman Oudeh. The team of students were interested in a façade that is more complex with large windows, which made it impossible to build the façade as load bearing precast panel structure. The student team responded by rotating the span of the ceiling and using every second interior wall between the micro units as load bearing walls. The façade was broken down into horizontal panels that span the length of each section of the total of five sections of the building. Tying the complex façade panels into the interior walls allowed for a complex façade with large bay windows, which created a unique spatial quality for the micro units. The team also aligned the load bearing walls with the walls of the first floor which saved cost as no transfer beams or columns were needed. Strategically cutting openings into the load bearing in the first floor allowed for programs such as a cafe that required more square feet. The façade was divided into five vertical sections to appear as five separate buildings. The prefabricated façade panel spanned the entire width of a section. This allowed for a design that responded to the characteristics of historic townhouses nearby. Leaving a large atrium in the middle of the building spatially connected all the residents into one community The atrium was occupied by common functions such as shared office spaces, lounges, a fitness center and other amenities.

In a series of axonometric drawings students were asked to visualize the assembly process of the building. During a series of reviews, students and engineers discussed different strategies for panel sizes, the location of the crane and the sequence and speed of the construction. In the case of Samantha and Abdurahman's project one crane was used to assemble the project layer by layer with the façade panels being the last components that would be brought to the site. Based on the feedback of the Up to 40 hollow core floor panels could be assembled on a single day. For the more complex façade panels 10-15 panels could be assembled per day which would allow for the entire building to be assembled on site in less than 12 weeks.

4. FAÇADE PROTOTYPE

Currently 30% or all housing projects in the US are precast concrete, most of them in states with tornados and hurricanes. Also, there are clear benefits for precast concrete for low-rise housing such as fewer labor costs and shorter construction time the default for 5-over-1s is wood-frame stories atop one concrete podium. This may have to do with the appearance of a precast concrete façade versus traditional finishes and historic associations and tradition. Precast concrete is often associated with prison architecture, student dormitories and post-war housing in Europe, that had to be erected fast and cheap after the world war. All this resulted into an unnecessary stigma being attached to precast concrete. Especially during the design of the façade students used the plasticity of the concrete to develop and test new aesthetic characteristics for housing projects that would replace current associations of precast concrete with new associations such as possibilities for a new lifestyle or performance benefits of precast concrete as a construction system.

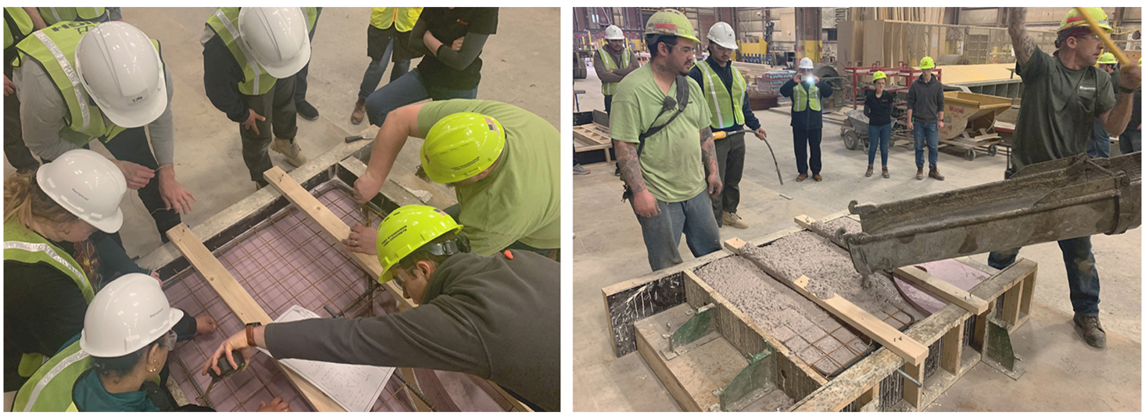

Figure 3: Production of Prototypes at High Concrete Group. Source: (Gernot Riether 2022)

Each student team had to build a real scale prototype of their façade system. Casting small scale models and creating a full-scale prototype student learned how to operate within the limitations of horizontally casted panels. At the same time the design of bay windows, a folded façade and extrusions showed how such limitations can be challenged and resolved. Student teams were responsible to build the form liner of the mold. The other components of the mold were built by High Concrete, the reinforcement was designed by High Concrete engineers. This required close coordination and effective communication between the students and our industry partner and the engineers. Deadlines were set at the beginning of the semester that allowed for error. Student teams were introduced to High Concrete's engineers at the beginning of the semester which started a conversation between student teams and our industry partner that lasted for the entire semester. Two months into the semester students finalized the design of the mold leaving one month for the production of the mold components. The drive from the architecture school to the concrete plant in Denver, Pennsylvania was 2.5 hours one way. To be able to produce the molds at the plant during studio time required good coordination and planning with the courses students had before the studio in order to leave early but also using the time there in the most efficient way possible. The studio did two trips: One to cast the panel and one to document the final piece.

In the case of Ella Martz and Karly Savinon's project the windowsill was extruded into a narrow spatial condition, which created a double curved surface on the exterior of the building. The team laminated panels of foam and used CNC to create the mold of the double curved surface. Also, the project took advantage of the plasticity of concrete as a material, it raised the question of using an alternative material for the mold that could be recycled.

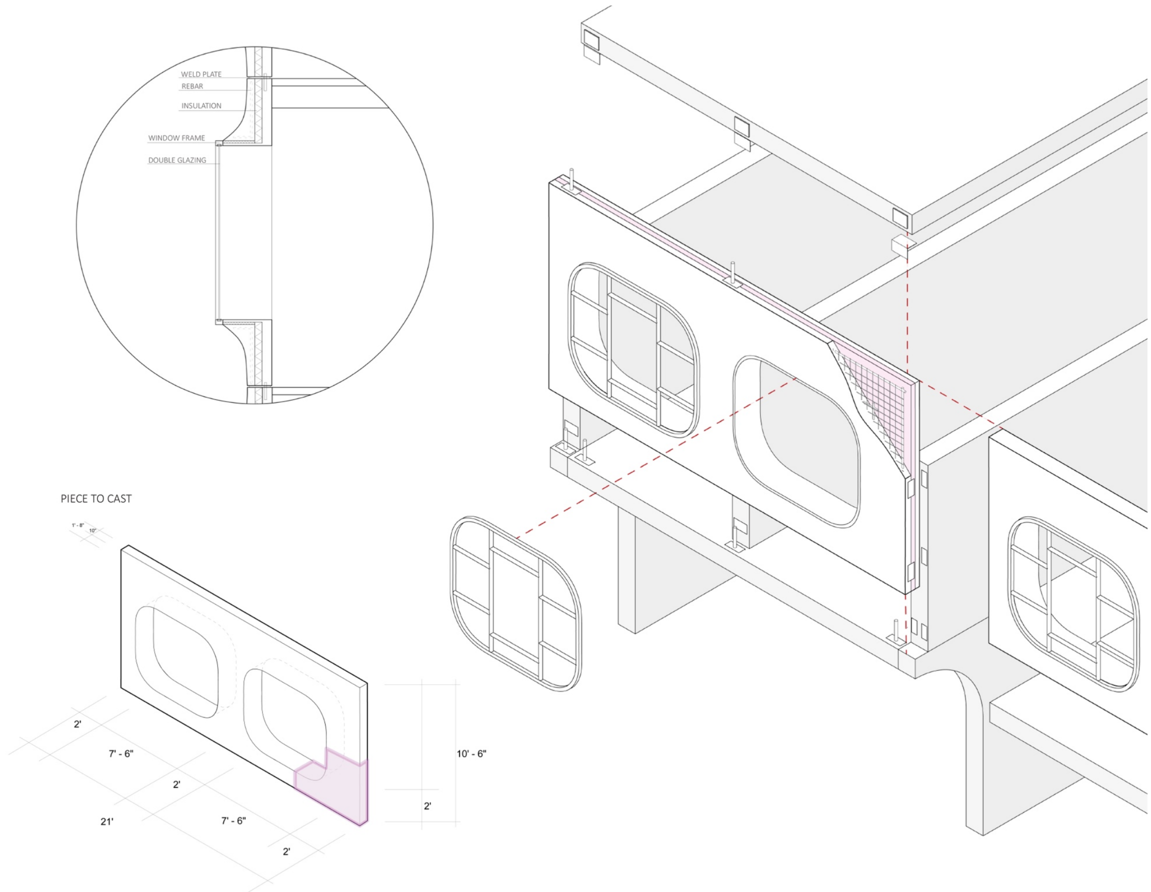

Figure 4: Project by Ella Martz and Karly Savinon. Source: (NJIT 2022)

While students built the form liner, the part of the mold that defined the double curved surface, High concrete produced the frame of the mold and prepared the reinforcement and connection details. Every change in the design had to be coordinated. Students learned how to effectively communicate with the fabricator with shop drawings. When students brought their component of the mold to the precast concrete plant everything had to match perfectly. Within two hours at the precast concrete plant the molds were assembled and the concrete cast.

Details were also added to allow for the prototype to be lifted from the mold. Students used smaller models to find the center of gravity of their prototype and tested with strings attached to small scale models of how one would lift and assemble the component with a construction crane. A week after students casted their prototypes students traveled back to High Concrete to see the final result. The casts were taken out of the mold, finished with a light sandblasting and exhibited at the exterior showroom at High Concrete.

5. FINAL REVIEW

The students' presentations of all three parts, the case study analysis and schematic design, assembly processes and the design and construction of the prototype. This allowed for a great discussion between architects, the developer, representatives from the precast concrete industry and engineers about advantages and disadvantages of precast concrete as a construction system for housing in comparison to other construction systems. Beside the possibility for students to be in the center of that discussion the review also presented a possible model for an architecture school to act as a platform for debates between investors, industry and architecture and a platform for research.

With the Precast Concrete Institute, PCI we also established a "People's Choice Award" of the best project from the PCI design build studio which provided the opportunity for students to travel to the annual PCI Mid-Atlantic Summer Membership Meeting in Williamsburg, Virginia, where the students from the best team presented the studio to the PCI industry and found a new network within the construction industry.

CONCLUSION

This paper presented a framework for a design build studio to design and test prefabricated concrete construction systems for micro housing. It discussed examples for strategies to use precast concrete construction to make housing more financially and environmentally sustainable. Developing real scale prototypes for façade systems and working closely with the Precast Concrete Institute and the Concrete Industry Management Program students were able to identify challenges and solutions and at the same time learned about construction systems and gained a hands-on experience of the production of precast concrete building components. Students also learned how to communicate ideas effectively and to develop solutions as a team member with industry partners and engineers. The focus of the studio was on the development of precast concrete assembly strategies and facade systems for micro housing. Further explorations will compare the building performance of precast concrete housing with conventional construction techniques in more detail.

ACKNOWLEDGEMENTS

Students of 2022 PCI Research Studio: Kashish Dalal, Hunter Grimm, Siluni Karunaratne, Lucas Konradparisi, Ella Martz, Abdurahman Oudeh, Kumayl Qureshi, Timothy Ramnanan, Joseph Rocker, Karly Savinon, Samantha Volpicella, Dominique Wiktorowski.

Collaborators: PCI Research Studio 2022: Dawn Decker, Executive Director, PCI Mid Atlantic; Lauren Rose, Design Team Leader, High Concrete Group.

Consultants: Chad Hollinger, Design Engineer, High Concrete Group; Harry Nash, Design Engineer, High Concrete Group; Brittany Colmery, Design Engineer, High Concrete Group; Eric Rowits, Sales Representative, High Concrete Group.

Guest reviewers: Andrew John Wit, Tyler School of Art + Architecture, Temple University; Michael Gibson, Kansas State University; James Kerestes, Ball State University.

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