Dwelling and Earthquake

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INTRODUCTION

This paper describes a teaching collaboration that took place in the Department of Architecture at California State Polytechnic University at Pomona during the fall and winter quarters of the 1995/96 academic year. Pedagogical and logistical links were made between two separate courses—an upper division design studio that explored a suburban housing prototype and a course in seismic design that investigated strategies for addressing earthquake hazards at various phases of the architectural design process. The two courses were offered independently using projects from the design studio, a relatively small class with high contact time, for further exploration in a large enrollment technology course with a studio workshop format. To strengthen the conceptual link between the two courses, principal design concepts of the studio projects were referred to as critical departure points for decision-making in the ensuing technological analysis. To accommodate curriculum scheduling, student teams in the seismic design course analyzed studio projects other than their own, thereby eliminating conflicts that would arise if all participating students were required to enroll in both courses.

THE DESIGN STUDIO: THE GROW HOUSE

The Grow House project began with an open studio forum in which students could both assess their own personal biases and reveal their fantasies about dwelling in the Los Angeles metropolitan area. Each student was asked to design a small living unit confined to a 20' x 20' x 20' cube as his or her own personal dwelling place. Three to four of these small houses were linked by a common linear circulation core with 20' x 20' courtyards between the units, allowing students to develop parts of the project collaboratively while maintaining their own individual design realm. The living unit modules could be added to the core independently, allowing the house to grow incrementally over time. Thus the name: "Grow House." After heated debate the class configured all 22 units with a total of six cores in a linear formation. The resultant compact linear residential street provided the basis for discussion about multi-unit vs. single family housing, particularly in a suburban context. Basic planning issues and their social ramifications emerged as a precursor to clarifying individual needs and desires. Students were encouraged to address first principles of planning—examining classic aspects of community and privacy. Within the units themselves they sought to resolve essential ergonomic issues,

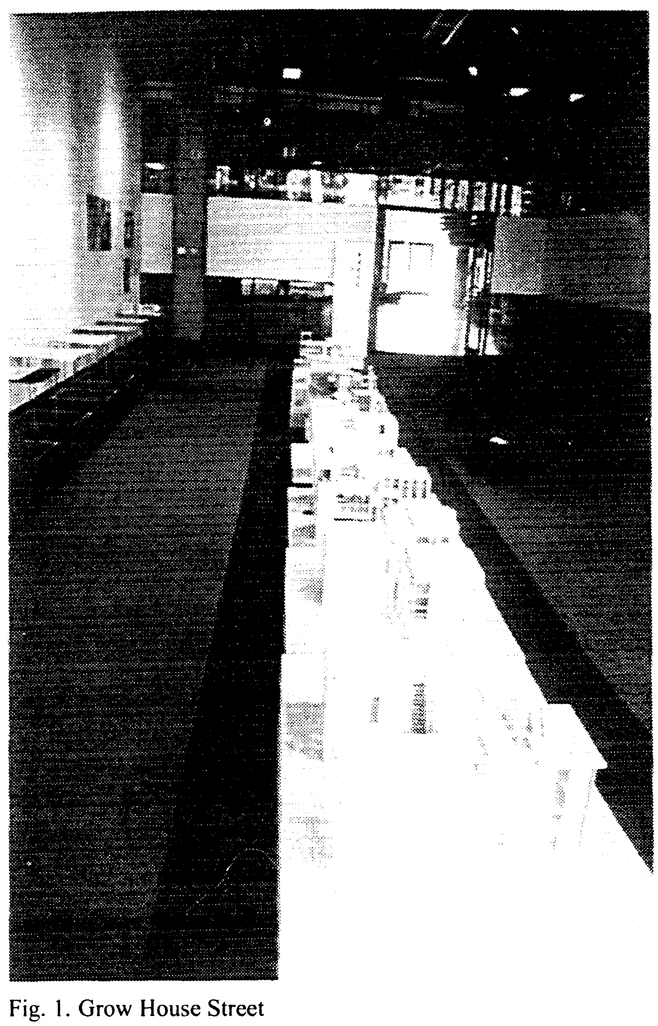

Fig. 1. Grow House Street

again referring to fundamental human responses to both fundamental needs—eating, sleeping, bathing as well as visual and spatial possibilities.

The construction type was restricted to timber frame, the prevalent construction material for low rise suburban residences in the United States. In student discussions, constructed and natural regional plagues—the pervasive dilemma of single family dwelling, suburban sprawl and the ever-present hazard of earthquakes—surfaced as simultaneous concerns. Students were asked to address these negative phenomena in the design process by exploring the formation of compact residential communities and by examining potential paths for gravity and lateral forces in timber frame construction. This, in addition to the small scale and constrained geometry of the units, began to set the stage for a project which stimulated structural design creativity and enabled a rigorous structural analysis.

Within a ten-week period, all 22 students progressed from a planning scale of 1" = 40' to an architectural scale of 1" = 1'- 0. The resulting large scale models lent themselves well to tectonic study of construction, finish detailing and the structural analysis which would occur in the seismic design studio workshops.

Geometric Constraints

Although the Grow House project had very specific geometric constraints, the program within each unit was geared to individual interpretation and a wide range of spatial solutions were open for exploration. These constraints and opportunities encouraged students to generate simple but not simplistic structural forms. The 20' x 20' x 20' cube also focused the seismic analysis by eliminating some kinds of configuration irregularities. The analytic strategies used to assess the Grow Houses were fundamentally the same and could be readily addressed in discussions and assignment guidelines.

Technological Constraints

At the completion of the design studio phase, the Grow House projects had well-developed gravity-resisting structural systems which took advantage of the flexibility of lightweight timber frame construction to achieve complex spatial configurations. Most designs incorporated elements of the structural framing into the tectonic expression of the project. Although efforts were made to incorporate shear walls, the students had not, at this stage, developed complete three-dimensional lateral force resisting systems. This was, in part, due to the studio's emphasis on approaching light timber frame experimentally while searching for innovative architectural configurations. It also reflects some of the common difficulties students encounter when learning to design for lateral loads.

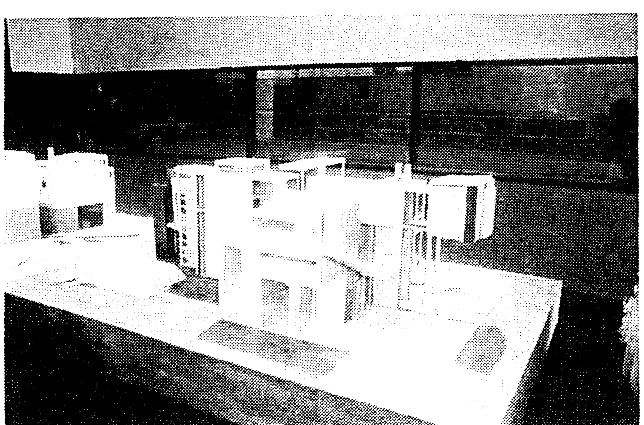

Fig. 2. Grow House designed by Daniella Khadarian, Bach-Mai Cao, Chris Thorlin

Seismic Design Learning Implications

Unlike the constant, familiar force of gravity, lateral loads caused by earthquakes and wind are temporary and, for many students, counter-intuitive. Although students were encouraged to build upon their intuitive understanding of gravity by visualizing how the structures would behave as horizontal cantilevers, this kind of simple analysis is complicated by the fact that lateral forces can come from any direction. When students in the seismic design course assessed the Grow House projects for lateral load paths, they observed that several schemes needed revision in only one direction.

Light timber frame construction is often perceived to be more simple, structurally, than it actually is. For students, the very flexibility of a system for which a repetitive structural module or bay system is not necessary presented the greatest challenges for structural understanding. In these projects, structure could not be separated from surface. Students had to develop an understanding of how a structural box is made stable by the interaction between planar diaphragms in three dimensional space. This understanding was further developed and rigorously tested as students analyzed the complex configurations developed in the design studio.

In many projects the inclusion of 20' x 20' garden courtyards in a Southern California climate provided the impetus for opening large areas of the exterior walls to view and light. Most student designers also attempted to make the interior of their 20' x 20' x 20' home appear larger and more open by making the entire volume of the cube visible. The design intention to maintain open visual contact between spaces on different levels coupled with design strategies incorporating multiple floor and ceiling levels and unusual elevations created some of the following structural design challenges:

Discontinuous horizontal diaphragms. In plan, horizontal diaphragms were entirely disconnected by either slots in floors or large openings. In section, floors and ceilings were stepped. These discontinuities prevented or limited the horizontal transfer of shear from one area to another and left some horizontal diaphragms floating without adequate connection to vertical shear-resisting elements.

Out-of-plane offsets and in plane discontinuity in shear walls. Shear walls did not continue straight from the top of the structure to the foundation but were shifted out of plane to accommodate changes in spatial arrangements between upper and lower floors or shifted in plane to accommodate changes in fenestration and partitions. Frequently these shifted elements were not adequately linked. In some cases shear walls were completely eliminated from some levels without compensating lateral load paths, leaving shear walls floating, unable to transfer their loads to the foundation.

Discontinuity in capacity—weak story. Occasionally severe discontinuities in capacity created an undesirable weak or more flexible story or zone below a stiffer, stronger one.

Inadequate capacity. Many designs were unable to meet maximum achievable shear wall and diaphragm capacities for this construction type. In addition, excessively slender diaphragms and shear walls were common, particularly in places were floors were pulled back from exterior walls. Short shear walls also created overturning capacity problems.

At the end of the 10-week design studio phase of the Grow House project, none of the designs had a complete, feasible lateral load resisting system without any of these problems.

THE SEISMIC DESIGN COURSE

The seismic design portion of the Grow House project was offered as a ten-week course which met one day per week in the design studio. It had an enrollment of 65 students, including many of the 22 students who had completed the Grow House design studio. Outside of class, students completed *Buildings at Risk: Seismic Design Basics for Practicing Architects*, a self-directed continuing education training program produced by the American Institute of Architects. In the studio, a series of four exercises giving students practice applying principles introduced in the text were employed. They included:

Building Configuration: Prototypes for Parti Design. This exercise introduced students to fundamentals of guiding configuration and load paths, identified similarities and differences between wind and seismic loads and developed skills in assessing systems using preliminary design tools. It included a case study analysis.

The Built Environment: Natural Hazards and the Urban Fabric. Through an analysis of the university campus, students learned how to integrate natural hazard concerns into the broad range of issues concerning the building site, their impact on site selection, and the location and configuration of buildings and open spaces.

Building Dynamics: Design Through Computation. In this exercise, students developed an understanding of structural behavior, including dynamic phenomena, through the use of computer-based structural analysis. Students used computer based modeling in conjunction with approximate calculations to study a mid-rise steel frame building.

The Structural Box: Form, Articulation, and Detail. In this 4-week exercise, based on the Grow House Studio; students learned to identify and resolve the interactions between the structural and architectural issues at several levels of scale in a small light wood frame building. The exercise was divided into the three activities described in the following sections.

Configuration Charette

This entailed an in-class sketch exercise in which all students

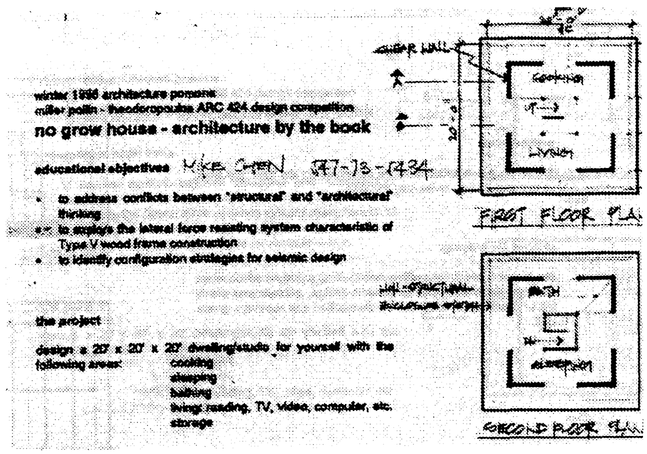

Fig. 3. Charette Exercise by Mike Chen

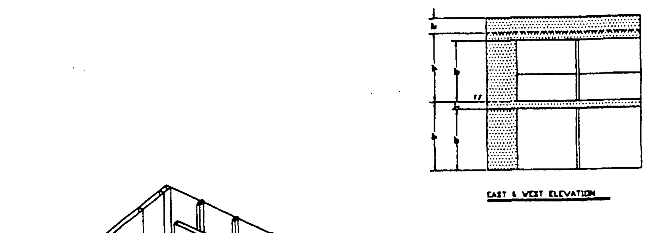

Fig. 4. Structural Diagram of Regular Grow House designed by Miki Iwasaki

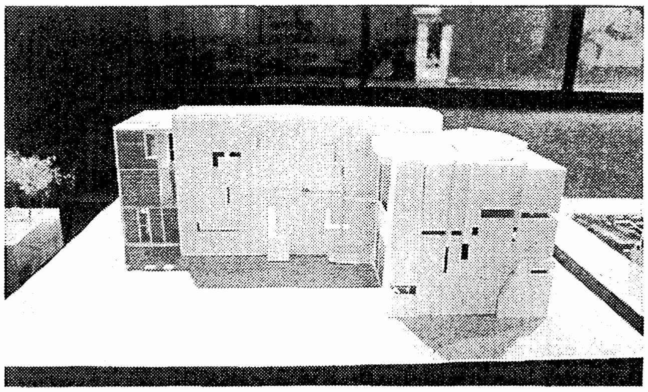

Fig. 5. Model of Grow House designed by Miki Iwasaki

were asked to prepare a Grow House design of their own, using the same live/work program and geometric constraints. However, they were required to develop a design with a regular configuration. This helped students identify conflicts which frequently arise between "architectural" and "structural" thinking.

Analysis of a Regular Grow House

A Grow House with a regular configuration was selected by faculty on the basis of its architectural and structural merits. Teams were asked to perform a capacity assessment of a critical shear wall based on the equivalent lateral force procedure outlined in the Uniform Building Code.

Grow House Assessments

Six of the original Grow Houses completed in the design studio were selected by faculty for further analysis. In their evaluations of the seismic feasibility of these designs, students performed configuration assessments which are primarily qualitative and capacity assessments which are primarily quantitative. In addition to the geometric and construction constraints established initially in the studio, a hypothetical set of site related worst case conditions were identified. By keeping the soil profile type and seismic zone constant, the seismic design coefficient used in the Equivalent Lateral Force Method was the same for all schemes. Building weights were nearly identical. In class discussions and team presentations, the volumetric and construction similarity between schemes made comparative analysis especially useful in illustrating the structural implications of various arrangements of vertical and horizontal diaphragms. This simultaneous exposure to several projects enabled students to easily identify grossly incorrect and unexpected results caused by conceptual or computational errors in their work.

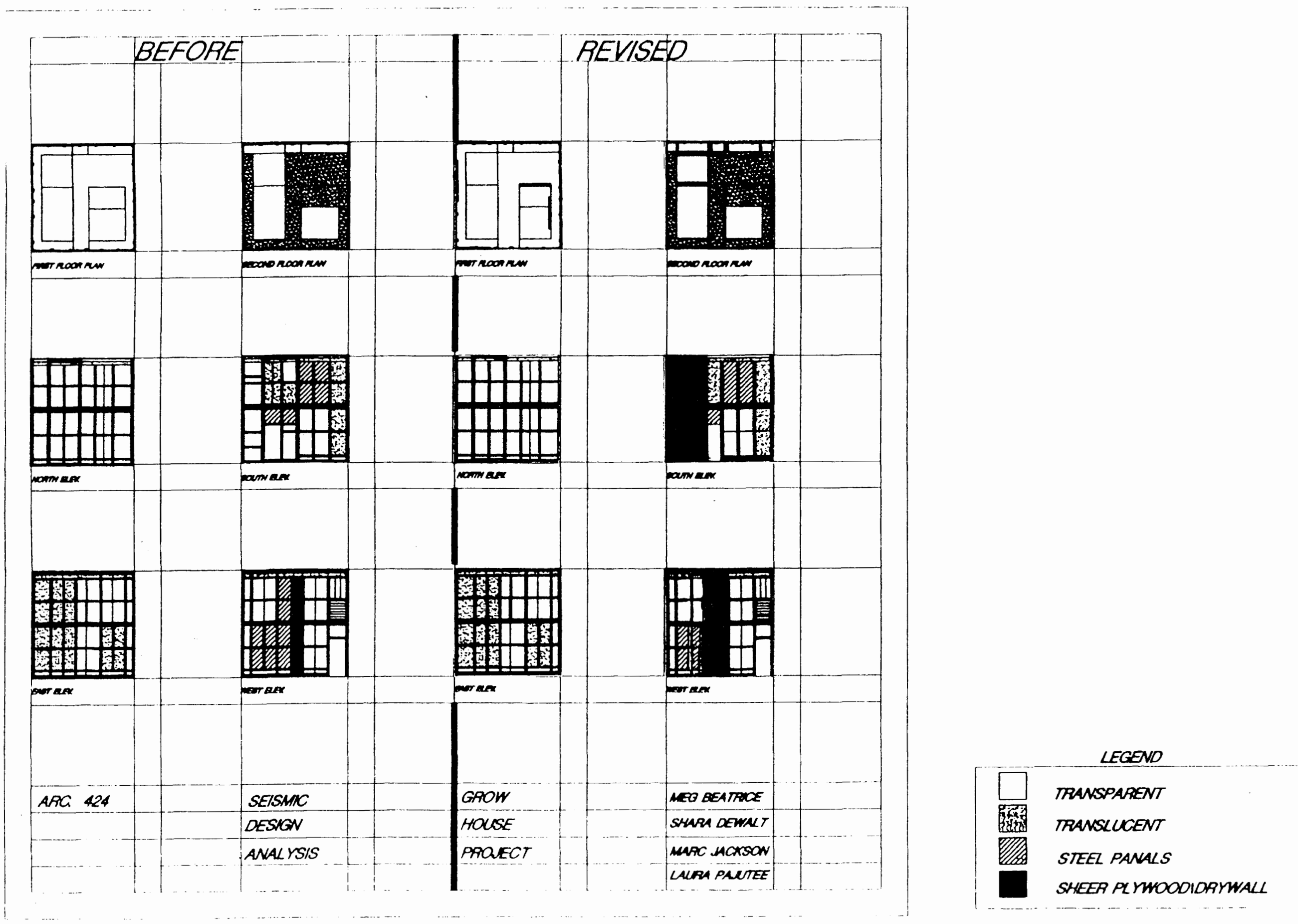

Fig. 6. Revision Matrix for Grow House designed by Kenya Isogai

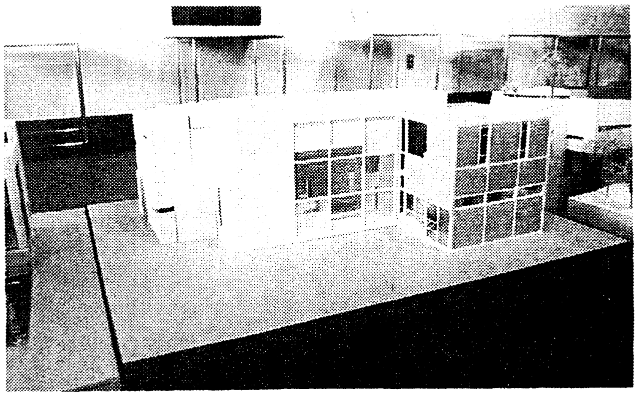

Fig. 7. Model of Grow House designed by Kenya Isogai

In conclusion, students prepared a memorandum to the designer explaining how their proposed revisions were consistent with the original architectural intent. Explanations based on structural need alone were not acceptable. Meg Beatrice, a second year graduate student, wrote:

> ...In order to achieve this shear wall placement, the door must be moved to the right by one module, however, this does not affect the circulation within the structure. The south facade was chosen for this shear wall due to solar considerations. The result is an elevation which is more closed, providing a contrasting aesthetic to the north elevation. It is as minimal as possible while still providing seismic stability and working within your module system...

> ...Every attempt was made to make as few changes to your minimalist elevations and interior open plan as possible. All shear wall dimensions were specified to comply with the module system you designed. The opacity of the exterior walls will increase by only 8% and changes to the interior will affect only the second level. Two elevations were left completely unchanged....

CONCLUSION

We present this work as an ongoing collaborative investigation between educators who share an interest in teaching all aspects of design from first principles without compromising the potential for ingenuity in the design process. The basis for selecting projects for this type of curricular connection appears to lie in a balanced combination of constrained parameters such as size, program complexity, building envelope, siting conditions, construction technology, and an open array of choices in architectural expression and spatial concepts. In retrospect, the Grow House project has served both ourselves and our students as an architectural and technological primer. As we look forward to the next iteration, we speculate on how we can use the outcome of this effort as literal primer upon which our students can rely as they engage in the design of an architecture than serves a broader range of social, technological, and environmental circumstances.

TEXTS

The following texts were assigned in the seismic design course.

Arnold, Christopher, et al *Buildings at Risk: Seismic Design Basics for Practicing Architects*. Washington, DC. AIA/ACSA Council on Architectural Research, 1994.

The American Institute of Architects, et al *Buildings at Risk: Seismic Design Basics for Practicing Architects Workbook*, 1994.

International Conference of Building Officials, *The Uniform Building Code*, Whittier, California 1994.