

## Brief Design/Build/Remove Assignments for Structures Courses

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### Abstract

Two types of brief student assignments to design and build rudimentary structures that are big enough to stand under have enhanced understanding of a variety of structural planning, design, and construction issues. Problem statements, grading criteria, and examples of completed projects illustrate the use of this vehicle to augment the study of building stability and behavior of non-horizontal roof structures. Among the benefits discussed are the opportunity to see three-dimensional deformation, develop a feel for forces in materials, and experience some of the ways that the building process influences planning and design decision-making. It is believed that these projects are adaptable to a range of architectural engineering courses and topics.

### Introduction

Engineering and architecture faculty employ a wide variety of assignments to simulate the experience of designing and constructing buildings. Most often these are small models or segments of the process, but some<sup>1</sup> attempt the construction of entire structures. The central objectives of these projects are (1) To help students synthesize and attach physical meaning to the qualitative and quantitative elements of their academic coursework and (2) To foster heightened intellectual and emotional commitment to their studies.

However, it can be very difficult to devise a project that does not require inordinate amounts of faculty and student time when the goal is to illustrate the entire design, build, remove process with structures that are large enough to provide a real sense of building forces. Observations of the beneficial results of two assignments that require relatively little contact time and (if carefully monitored) reasonable expectations for students are offered as examples that may be adapted to illustrate many issues at various levels of architectural engineering education.

There seem to be at least three characteristics of these projects that must be addressed at the outset. First, the size of the constructed object must be appropriate. Structures that have been big enough for adults to stand under with arms outstretched in every direction have proven far more successful than the alternatives. Second, since few students have experienced the entire process of designing and building an object larger than themselves, with others, as a course assignment, the uniqueness of such a task must be balanced by a limited scope of stated requirements. These are the types of projects wherein integrated experience is the greatest reward for the students and positive accounts from “veterans” of earlier years are the most convincing evaluations for the instructor. Third, the assignment is, in itself, a design task for the instructor that requires thoughtful consideration of the “clients”, “site”, and resources. Consequently, the following account of two projects describes the specific context in which they are assigned, provides problem statements of requirements and evaluation criteria, reports some examples of both technical and general learning that may be observed, and offers some concluding remarks.

## **Context**

Students enrolled in a two- or three-year curriculum leading to the Master of Architecture degree are required to take a one-semester, 1 unit (4 credit hours) course titled Structural Planning. The course is intended to help students achieve sufficient understanding that they may participate knowledgeably in the selection of appropriate load-carrying systems for buildings. Since they must have the equivalent of a pre-professional baccalaureate degree in architecture, they are assumed to have had a background in statics, strength of materials, and elementary design of steel, reinforced concrete, and timber structures. However, the extent of their knowledge and confidence in it is ordinarily represented by an extreme range between students in each class. Also, the course serves those students not specializing in architectural structures; consequently, the topic must be presented in a way that appears to be relevant to other, higher priorities. However, they are able to learn computational procedures at a level of complexity represented by the provisions of ASCE 7<sup>2</sup> (e.g.; gravity, wind, and seismic forces applied to a simplified 5-story reinforced concrete structure) and do have substantial backgrounds in architectural design, technology, and history. Perhaps most importantly, they are usually mature and motivated to succeed in their intended profession. Enrollments vary from 25-43 per semester.

The following course outline indicates the topic for each meeting but omits the information that each session consists of two 50-minute periods. The assignments to design/build/remove structures may be identified as “P5: Stability Systems” and “SP<sup>2</sup>”, respectively. Each of the projects requires one period for introduction and the equivalent of one-half to one period, spread over several sessions, to do the planning and design. The Stability Project requires two periods (one session) for presentation and the Structural Planning Project (SP<sup>2</sup>) requires four to six periods (two or three sessions). These projects are built and demonstrated outside. Presentations are postponed only in the event of lightning, severe weather warnings, or temperatures below 0 °F. Initial instructor’s comments about the projects encourage students to anticipate the weather as they consider the advantages of various designs and details that facilitate construction.

## **The Stability Project**

The notion of this project stemmed from an attempt to help students understand lectures on the concepts of stability and the behavior of stabilizing systems. The characteristics of buckling, overturning, and sliding can be illustrated by smaller scale models. Also, with a bit more effort, representations of diaphragms and various types of bracing systems can be effective at smaller scales. But, to illustrate the three-dimensional transfer of forces in unsymmetric joints that are influenced by torsion, to see the warping effects of unsymmetric bracing systems, or to experience the sight, sound, and feel of a failed fastener, connector, or member, it is necessary to build at a larger scale.

Students are encouraged to use inexpensive materials and element sizes that will illustrate deformation. For example, cardboard connectors serve well to illustrate bearing, shear, and buckling in gusset plates. Polyethylene sheeting stapled to a frame displays the direction of primary forces and shear flow at the fasteners. Elastic cord, springs, or rubber sheeting at X-brace intersections display alternating tension and compression. When lapped members with

## Structural Planning Course Outline

WEEK	PERIOD	LAB TOPIC	PERIOD	LECTURE TOPIC
1	-----	(M. L. King, Jr. Holiday) -----	1	Introduction
	1	P1: Structural Systems	2	Loads: DL/LL
2	2	..research	3	Permutations
	3	..research	4	Dynamic Loads
3	4	<b>P1 Due: 10 a. Mon., 2/3</b>	5	Precipitation
	5	P2: Gravity Loads	6	..continued
4	6	..continued	7	Wind
	7	..continued	8	..continued
5	8	<b>P2 Due: 1 p. Sat., 2/21</b>	9	..continued
	9	P3: Wind Loads	10	Seismic
6	10	..continued	11	..continued
	11	<b>P3 Due: 10 a. Mon., 3/3</b>	12	..continued
7	12	P4: Seismic Loads	13	..continued
	13	..continued	14	Other Loads
8	14	P5: Stability Systems (Start)	15	Equilibrium/Stability
	15	<b>P4 Due: 1 p. Sat., 3/14</b>	16	..continued
9	16	Equilibrium/Stability	17	..continued
	17	Theory of Planning; SP <sup>2</sup> Intro.	18	Theory of Planning
----- <b>Spring Break</b> -----				
10	18	Floor & Flat Roof Systems	19	Floor & Flat Roof Systems
	19	<b>Midterm Exam, Wed., 4/2</b>	20	Soil Mechanics; SP <sup>2</sup> Teams Due: Thurs., 4/3
11	20	<b>P5 Due 10 a. Mon., 4/7</b>	21	..continued
	21	Return/Discuss Midterm	22	..continued
12	22	P6: Soils/Spread Ftgs	23	Foundation Systems
	23	..continued	24	Reinforced Concrete Systems
13	24	<b>P6 Due: 1 p. Fri., 4/25</b>	25	..continued
	25	Prestressed Systems	26	Steel Systems
14	26	Steel Systems	27	Wood Systems
	27	<b>SP<sup>2</sup> Presentations, 4/30</b>	28	<b>SP<sup>2</sup> Presentations, 5/1</b>
15	28	<b>SP<sup>2</sup> Presentations, 5/5</b>	29	High Rise Systems
	29	Close	----- (Reading Day) -----	
----- <b>Final Examination: 8-11 a.m., Monday, May 12, 1997, 100C Arch.</b> -----				

Required Texts: *Minimum Design Loads for Buildings and Other Structures (ASCE 7-95)*, New York, American Society of Civil Engineers, 1996.  
 Arnold, Christopher. *Buildings at Risk: Seismic Design Basics for Practicing Architects*, Washington, AIA/ACSA Council on Architectural Research, 1994.

Weight of Work in Computation of Grades

Grading Scale

6 Problems:	50%	A+ ≥ 97	B+ ≥ 88	C+ ≥ 79	D+ ≥ 70
1 Midterm Exam:	15%	A ≥ 94	B ≥ 85	C ≥ 76	D ≥ 67
1 Project:	15%	A- ≥ 91	B- ≥ 82	C- ≥ 73	D- ≥ 64
1 Final:	20%				

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TA:

slotted holes are used for knee, K, or diagonal braces, stable and unstable conditions can be quickly and effectively demonstrated.

Some of the more interesting structural schemes have been developed for the platform in an effort to control cost. Carpet tubes cut in half also serve to illustrate the behavior of cylindrical shells and boxes from bicycle shops offer a resource for cardboard employed to fabricate plate girders or folded plates. Some students have fashioned strutted beams or cable trusses. Some glued cardboard assemblies have illustrated rolling shear.

The cost limit is also important in that students quickly discover that time and creativity are required; the quick, easy route of buying plywood and bolts will prove too expensive. The students do have access to a woodshop and usually can borrow the necessary hand tools rather than renting equipment. Although a few have said this project was their first experience in using simple hand tools, the necessary construction skills are minimal and sufficiently common among the students not to create any limitation.

Team size is limited to three because the project is too simple to warrant more. At least two are required to promote discussion, provide experience in teamwork, reduce costs to no more than \$20/student, and to merge the available skills and tools. Ideally, the number of projects built should not exceed ten in order to sustain student interest for the duration of the demonstrations. Fifteen projects is a limit for a two-hour session; consequently, class sizes larger than forty would require another approach.

The project evolved over the years to illustrate these effects in a safe, but reasonably dramatic way. However, care must be exercised to control the risk before the lateral load of one instructor is applied. Intent on emphasizing a point, the author did not detect a knot in a column of an eccentric brace system which erroneously detailed the shear link in the column. The speed and sound of the resulting collapse drew gasps from the students, particularly the one on the platform, and made the instructor's heart jump. While that level of drama is inappropriately extreme, the beneficial side is that none of those students is likely to miss noticing an improperly placed shear link. As required, the platform was one foot off the ground; that was high enough to make a point and low enough not to cause harm. It has provided occasions to emphasize shear failures in fasteners, various behaviors in connectors, and flexure and shear failures in members. Collapses help greatly to underscore the meaning of code requirements for structural integrity.

## Stability Project Assignment

The objective of this problem is to demonstrate the 3-dimensional interplay of structural elements which maintain stability under vertical and lateral loads and to simulate the structural planning process.

**You are asked to demonstrate the performance of stabilizing systems by building a structure having  $\geq 4$  sides that:**

- Defines a space that encloses one team member standing with out-stretched arms at any angle and facing any direction;
- Can support the entire team standing at a level  $\geq +1$  ft. above grade without anyone touching another or any vertical support while experiencing a lateral load applied by one instructor;
- Remains stable while carrying a gravity load of one student and lateral load applied by one instructor;
- Contains at least three types of stabilizing systems;
- Is independent of any existing natural or artificial projections from the ground; and,
- Permits, within 30 seconds, the disengagement, detachment, or disassembly of selected stabilizing elements in order to exhibit vertical instability in each of two orthogonal directions and rotational instability in a horizontal plane.

### Additional Requirements:

- Teams shall consist of two or (preferably) three persons;
- Structures shall be erected in the mini-quad immediately north of Temple Buell Hall by 10:20 a.m. on the specified day;
- Structures shall not damage existing materials;
- Structures shall be removed by 10:00 a.m. on the day following presentation;
- Cost shall be limited to no more than \$40;
- Immediately before demonstration, each team shall submit a data sheet which includes the following:
  - Names of team members;
  - Perspective sketch, 3-D CAD, or photograph of structure with system names indicated;
  - Summary of gross expense less deductible for amortized use.

### Other Notes:

- The presentations will not be postponed as a consequence of inclement weather; therefore, the influence of weather on erection and the desire for shelter are factors that may warrant consideration.

- Structures that dramatize deformation of stabilizing elements will be rated most successful.
- Job safety is a concern at every stage on any job, no matter how small. Be careful during fabrication and erection; ensure that hazards during demonstration are minimized.

# Stability Project Evaluation Criteria

## STABILITY SYSTEMS CHECKSHEET

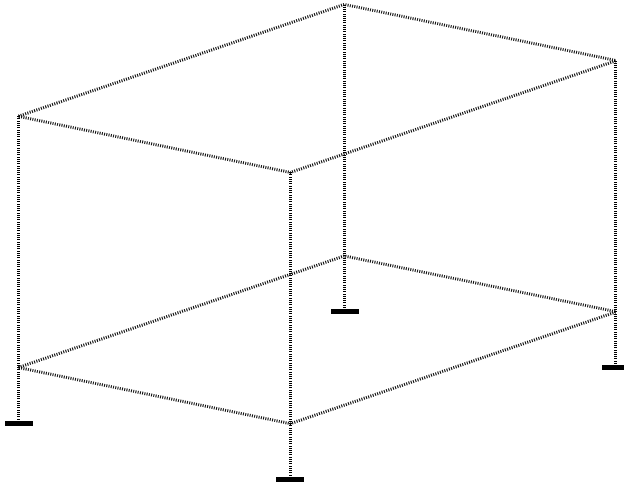
TEAM:

### 80 points: COMPLIANCE WITH REQUIREMENTS

- Y N 1.  $\geq 4$  sides
- Y N 2. Defines Adequate Volume
- Y N 3. Supports Entire Team W/O Touching
- Y N 4. Stable 1 & 1
- Y N 5.  $\geq 3$  stabilizing systems
- Y N 6. Independent of ground projections
- Y N 7. Vertical Instability Demonstrated?
- Y N Direction 1:
- Y N Direction 2:
- Y N 8. Rotational Instability
- Y N 9. Data Sheet Provided
- Y N 10. Cost  $\leq 40\%$
- Y N 11. Removed by Noon next day

### 20 points: ADDITIONAL FEATURES

- \_\_\_ 1. Versatility and Scope of Demonstration
- \_\_\_ 2. Effective use of Resources
- \_\_\_ 3. Joint detailing and workmanship
- \_\_\_ 4. Aesthetic qualities
- \_\_\_ 5. Other factors





### **The Structural Planning Project (SP<sup>2</sup>)**

This project simulates part of the structural planning process and extends through construction to include a three day performance observation period. The planning component is shortened because experience proved that students must begin with a real building design in order to not spend all of their (and the instructor's) time designing. However, the use of substitute materials to construct an element of a building at a different scale led to the discovery that sufficient planning, design and creative thinking was required to justify the strategy. Students also develop a real appreciation for the importance of details, significantly enhance their ability to visualize three-dimensional relationships, and learn more about the work of gifted architects and engineers. For example, most architecture students avoid curvilinear forms in their studio work, but many will attempt them here. One team even modeled the movable roof of the Kuwaiti Pavilion (by Santiago Calatrava at the Seville, Spain Expo) and adapted a garage door opener to illustrate the operation.

Teams of three or four work best for this project. Sufficient class time is allotted for presentations (about 20 minutes for each) to exhaust all descriptions, questions, and explanations. Every combination of process management usually is exhibited and, because the project is due near the end of the semester, those who neglect process management suffer. As can be seen in the problem assignment sheet, deadlines are set for the formation of teams and identification of the basis for the prototype.

Thus far, no cost limit has been set for this project, but is under consideration. The problem of reconciling time for creative detailing with cost has led to excessive spending. For example, large diameter plastic pipe tees are expensive solutions for torsion joints. Also, this project is particularly susceptible to the ratcheting upward of expectations that can get out of control. The consequences are that some will spend too much money, completely outclass others, and generate enough negative feelings about the experience to obscure the educational objectives.

The application of gravity and lateral loads in these structures is left to nature, although some testing for adequate stability is done during presentations. Wind and rain have provided some dramatic demonstrations and, when the opportunity arises, students enjoy applying snow loads. It is necessary for the instructor to monitor the projects in order to minimize the risks from flying objects or structural collapse. Of the many structures built in the past, only one was potentially dangerous enough to people that it had to be dismantled immediately following the presentation.



## Structural Planning Project Assignment

This project offers an opportunity to simulate the structural planning process, enhance understanding of the relationship between structures and architecture in 20th Century buildings, explore the seemingly infinite variations of non-horizontal roof systems, and further develop the skills required to translate ideas into physical objects.

You are asked to do the following: (1) Form teams of 3 or 4; (2) Identify a building (or proposed building) of this century that has included a **non-horizontal roof** system deemed important to the aesthetic impact of the building; (3) Construct a prototype of a portion of the structure; (4) Present the prototype to the class; (5) Observe its performance for 3 days; (6) Remove it and restore the habitat; (7) Submit a summary report.

### Due dates and times:

	TEAM	BASIS	PRESENTATION	END OBSERVATION	END REMOVAL	REPORT
TIME	Noon	1 p.m.	10:15 a.m.	Noon	Noon	5 p.m.
GROUP 1	4/3/97	4/14/97	Wed., 4/30	Sat., 5/3	Sun., 5/4	Tues., 5/6
GROUP 2	4/3/97	4/14/97	Thurs., 5/1	Sun., 5/4	Mon., 5/5	Wed., 5/7
GROUP 3	4/3/97	4/14/97	Mon., 5/5	Thurs., 5/8	Fri., 5/9	Sun., 5/11

### Supplemental requirements and information:

**Identify the basis for the prototype:** List the building name, location, architect, and structural engineer. Provide sources of information about the building, one copy of an image (properly referenced) of it, and one copy of an image or sketch that indicates the region to be modeled by the prototype.

**Construct:** The prototype is to be built in the yard (**not** the paved area) west of the Buell Hall Atrium. It is to be large enough that the team can stand under it, use inexpensive materials, and include at least a partial representation of the roof surface.

**Present:** Presentations will be made at the site of the prototype. Each should communicate images of the original building, demonstrate the behavior of the structure, and describe noteworthy aspects of the project. Each team's preference for presentation date will be honored in the order received until five are reserved for that day. A final schedule will be issued by 4/14/97. Failure to deliver and present the completed project on time will be evaluated as a component of a team's success in managing the project.

**Observe, then Remove:** Intermittently monitor the structure during the observation period to learn from its performance. Ensure that any deterioration poses no risk to persons or property and remove litter. Following the observation period, dispose of all materials and restore the

habitat to its original condition.

**Report:** Expand on the information previously reported; include dimensioned drawings and at least one color photographic print of the prototype; summarize the similarities and differences between the prototype and the actual building; describe interesting construction and performance characteristics of the prototype; itemize expenses; evaluate the team's project delivery strategy; and, identify the principal contributions made by each person.

### Structural Planning Project Evaluation Criteria

DATE:		TEAM:		BUILDING:		ELEMENT:		
LOCATION:			Architect:			Engineer:		
REQUIREMENT	EVALUATION							
	N.A.	WEAK.....STRONG		COMMENT				
<b>Choice of System</b>		.....						
<b>Preliminary Information</b>	.....	.....						
Data	.....	.....						
Images	.....	.....						
References	.....	.....						
<b>Presentation</b>	.....	.....						
	.....	.....						
	.....	.....						
<b>Prototype</b>								
3-D Development	.....	.....						
Completeness	.....	.....						
Simulation	.....	.....						
Details	.....	.....						
Stability	.....	.....						
Endurance	.....	.....						
Removal	.....	.....						
<b>Report</b>								
Observations								
Actual/Proto..Simul./Diff.	.....	.....						
Construction	.....	.....						
Performance	.....	.....						
Expenses	.....	.....						
Project Delivery	.....	.....						
Contributions	.....	.....						
Drawings	.....	.....						
Photographs	.....	.....						
References/Document'n	.....	.....						

<b>Conclusion</b>	
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## Summary

Two design/build/remove projects have proven very effective in illustrating many aspects of instruction in the engineering of buildings. They are thought to be somewhat unique by virtue of the combination of a human-sized scale of construction, need for relatively little in-class time or indoor space, ability to accommodate limited building skills, and expenses sufficiently low to be borne by the students. Copies of the course outline, problem assignments, and evaluation criteria provide additional information. Grading is fundamentally subjective and usually generous with few scores dropping below 90.

Course evaluation questionnaire comments have indicated that most students appreciated these projects. A few complaints have registered objections to having too little class time allotted for work on the projects, spending too much money, or building in inclement weather. Selection of the basis for the prototype is particularly critical to the time, cost, and on-site construction of the Structural Planning Project and choices must be made by the instructor to decide the level of consultation to offer at this stage. Because these are advanced students, the author coaches relatively little but does try to prevent excessively negative lessons on weak project planning. Undergraduate students would require more advice at this stage and more class time unless the course included a strong construction management component.

One of the most rewarding aspects of these projects has been the interest shown by those not in the class. Random passers-by often observe demonstrations and other faculty and students examine the structures. Several faculty have been complimentary(!) and have expressed the opinion that the work was an important component of the School's programs.

## References

1. Belcher, M. Clay. "Building Students...Building a House", *1995 ASEE Annual Conference Proceedings*, American Society for Engineering Education, 1995, pp. 1364-1368.
2. *Minimum Design Loads for Buildings and Other Structures (ASCE 7-95)*, New York, American Society of Civil Engineers, 1996.

## JAMES E. SIMON, AIA

Professor Simon received a B. Arch. (1963) and M. S. in Arch. Eng. (1964) from the University of Illinois. He has professional experience both as an architect and structural engineer, is a registered architect, and is an Associate Professor of Architecture. He has taught architectural structures courses for Seniors and Graduate students for over thirty years in the School of Architecture at the University of Illinois at Urbana-Champaign.

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## BRIEF CURRICULUM VITAE

### Degrees

B.Arch. '63, University of Illinois, Urbana, IL  
M.S. Arch. Engr. '64, University of Illinois, Urbana, IL

### Professional Registration

Licensed Architect, Illinois (1965- )

### Professional Employment

Simon, Rettberg & Garrison, Architects, Carbondale and Champaign, IL  
Skadden, Sheehan, and King, Architects, Danville, IL  
C.F. Murphy Associates, Architects and Engineers, Chicago, IL  
Samartano & Robinson, Consulting Engineers, Chicago, IL  
Stephen J.Y. Tang, Consulting Engineer, Champaign, IL  
James E. Simon, AIA Architect, Champaign, IL

### Academic Employment - University of Illinois at Urbana-Champaign

Assistant, Associate Professor, School of Architecture (1966- )  
Teaching Assistant, Department of Architecture (1963-64)

### Courses Taught

Reinforced Concrete Design I, II, III; Prestressed Concrete Design; Steel/Wood Design; Structural Planning I, II; Seminar on Curvilinear Architecture, Experimental Model Testing

### Recognition for Teaching

Included in "...List of Teachers Ranked as Excellent by Their Students" (Several semesters); 1987 Excellence in Graduate Teaching Award (School)

### Publications/Research

Building evaluation/structural system selection; Fabric structures; Domatic systems; Computer and calculator applications; Structural model testing

### Professional Service

ASEE Architectural Engineering Division (Various positions 1993- )  
Architectural Fabric Structures Institute (Various positions (1982-86)

**Administrative Appointments and Academic Service**

Appointments to terms as *Chair*: Structures Division; Graduate Cmte (School)

Elections to terms as *Chair*: Senate Council; Faculty Advisory Cmte (Campus)

Extensive service on numerous committees at all levels of the University

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Max:

My submission for the ASEE ArchE session follows. I'll try to get a printed version and the short bio in the mail by Tuesday. Naturally, I'll welcome comments.

Jim

Title: Brief Design/Build/Remove Assignments for Structures Courses

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Abstract:

Two types of brief student assignments to design and build rudimentary structures that are big enough to stand under have enhanced understanding of a variety of structural planning, design, and construction issues. Problem statements, grading criteria, and examples of completed projects illustrate the use of this vehicle to augment the study of building stability and behavior of non-horizontal roof structures. Among the benefits discussed are the opportunity to see three-dimensional deformation, develop a feel for forces in materials, and experience some of the ways that the building process influences planning and design decision-making. It is believed that this sort of project is adaptable to a range of architectural engineering courses and topics.

(Sent to Max 12/8/96 by e-mail)

December 9, 1996

Dr. W. Max Lucas  
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Dear Max:

Enclosed please find an abstract and brief C.V. submitted for consideration as a presentation in our technical session at the 1997 ASEE Annual Conference.

I am aware that the call for papers suggested a longer abstract and a biography, but operated under the assumption that you might welcome something concise enough to review in a very short period of time. I can always add words if you prefer.

Thanks for encouraging me to do this. However, if it doesn't fit with the other papers for the session, don't be shy about saying so. It is not a problem for me to leave a paper off of my "Do Before New Year's" list.

Have a good holiday season.

Sincerely,

James E. Simon, AIA  
Associate Professor

Enclosures