DISCOVERING THE AESTHETIC DESIGN POTENTIAL OF LIQUID STONE

Craig L. **Hinrichs**, Director, Architecture Graduate Studies, Miami University, Oxford, OH

ABSTRACT

In a standard academic lecture on concrete principles: mixtures, chamfers, draft, air entrainment, form release agents and perhaps superplasticisers are explained. Eventually students understand the role of form release agents and even the obstinate re-entrant corner better if they gain first hand experience by casting components of their own design. If they can gain hands-on experience, concrete will educate them as they wrestle to train and contain this amazing material that has humbled most of us.

However, architecture students, in particular, seem determined to find and bend this conventional wisdom of the industry to create their desired vision. Many students can't wait to incorporate color dye pigments and textures that illustrate command of their new found versatile material. These students relish the opportunity to design and build their own formwork, get dirty casting their own masterpiece and later hatch their creation. In the process, they inherently appreciate the effort, time and skill that are required for formwork design and removal. These lessons are valuable for any novice designer.

What happens when these students break or at least bend some rules? Amazing new concrete castings are produced, if they understood the limits and possessed some degree of skill with their formwork fabrication. Shattered dreams, unceremoniously delivered to the dumpster, if they rushed into a design or fabrication error. With either result, the best self-teaching moments occur when the students present their design intentions with their physical results to their peers who have participated in the same exercise.

Keywords:
Aesthetics and Finishes
Creative/Innovative Solutions and Structures
Research

INTRODUCTION

The paper contains a collection of fantastic discoveries and the educational process that generated them. This is a joint-effort, between a local PCI precast plant, a university professor and architecture students, which is beneficial to all parties. Other PCI members could adapt this educational model to their own circumstances.

PRECAST CONCRETE INSTRUCTION FOR ARCHITECTURE STUDENTS

In order to explain this approach, a description of a typical architecture student might be of value. Many architecture students are indoctrinated at an early stage of their education to challenge standard methods of perception and design. They tend to focus on programmatic, spatial and material finish issues. Economy and the means of construction are normally not significant ingredients in their studio work. That awareness (sometimes) comes later, when and if the student evolves into an architect. Some architects, as some of us are aware, never mature to this stage of their development. In summary, architecture students see things quite differently than most. It was through this lens that this paper describing these experimental successes and mistakes was written.

HOW WE TEACH

A traditional undergraduate course in a university level architecture program will explore the material qualities that one might expect for concrete. It will cover concrete principles: mixtures, chamfers, draft, air entrainment, form release agents and perhaps superplasticisers.
Noted author, Edward Allen divides the topic of concrete into three chapters in his 5th Edition textbook, *Fundamentals of Building Construction Materials and Methods*. He is a widely subscribed author on this topic in the architecture schools in North America.
He devotes a chapter to "Concrete Construction", a second chapter to "Sitecast Concrete Framing Systems" and a third chapter to “Precast Concrete Framing Systems."
This third chapter in 32 pages, is comprised of topics: Precast, Prestressed Concrete Structural Elements; Preliminary Design of a Precast; Assembly Concepts for Precast; Manufacture of Precast; Joining Precast Elements; Fastening to Concrete; The Construction Process: Precast Concrete and the Building Codes; Considerations of Sustainability in Precast; and the Uniqueness of Precast Concrete.

SUPPLEMENTAL INSTRUCTION TECHNIQUES

Over the years, editions of Allen’s book have been the mainstay of my arsenal in my teaching endeavors for a Materials and Methods of Construction class. The information contained in this book is the source for what many accredited schools of architecture cover in their coursework for Precast Concrete. It is well written, but in an effort to supplement the material, I refer to examples from Chapter 1 of the *PCI Handbook*, as well as invite professionals from the local precast plant to the university to share their expertise on current industry practices.

HOW STUDENTS LEARN

Professionals from the precast plant do a fantastic job in a classroom session. Students are exposed to the concepts of the material, multiple uses of formwork, delivery and field erection techniques, as well as the economics and the daily cycle of the plant's operation.

Fig. 1 Forecourt of the Perot Museum of Nature and Science
in Texas located in the Dallas West End

A CASE STUDY APPROACH

I also include a lecture that features images of "cutting-edge" design projects are also very important for architecture students in their understanding of how the industry is evolving and where it might be going next. This year the lecture featured the "Perot Museum of Nature and Science in Texas" by Pritzker Architecture Prize Laureate Thom Mayne and his firm, Morphosis with Good Fulton + Farrell as Architect of Record. This building is impressive in its sustainable performance ratings as well as being an exquisite precast archetype. I recommend that you experience this building in the West End of Dallas first hand, if you haven't already.

Many architecture students find this cutting edge precast design to be very interesting. They see it as validation of their own creative studio work. They are impressed with the sustainable nature of this museum and that it has secured the highest possible Green Globes rating from the Green Building Initiative. Once they understand the range of textures and finishes available in precast they are excited to experiment with this versatile material.

Fig. 2 Exterior wall detail (looking upwards) of the Perot Museum

Novice students are initially uncertain as to what the exterior skin of the building is but are now interested in finding out how it was made. As they learn more, they become interested in closely examining the texture and how natural light and shadow define the building. Students, who understand the concept of the repetitive nature of formwork from the lecture by the local precast plant representatives, then seem very interested in where similar panels occur and how the pattern was established. They also are interested in the casting sequence and what block outs could be utilized. They are intrigued with the seemingly endless palette of materials, finishes and textures.

THE PLANT TOUR

The coordination of forming and stripping start to be comprehended and appreciated in the noisy, aggressive environment of the concrete plant that students find to be complex, intimidating and interesting. They respect the skill and craftsmanship of the professionals at the precast plant. Even those students, who don’t fully appreciate the necessary timing and coordination of the precast plant operation, finding it chaotic, start to appreciate their own privileged situation as a college student.

Fig. 3 Miami University architecture students touring local precast plant

A PROJECT DESIGN STATEMENT

Note: For illustration purposes, a project design statement that was issued to a previous class is attached at the end of this paper. The focus of exploration of this particular exercise was floatation.

Next the students receive a design exercise where they are asked to design and cast an object that meets the design criteria. A typical exercise is designed to focus on a maximum of two of the following attributes of concrete forming at a time in order to understand the limitations Over the years, I have challenged students to explore various design investigations such as using concrete to:

- incorporate integral color(s) dye in experimental ways
- reflect a slick smooth texture without mechanical polishing
- explore soft or fabric formwork
- transmit light and/or view
- develop a dissolvable formwork for ease of stripping
- develop a twisted object
- shape a floatation structure
- achieve a minimum thickness

TEACHING RATIONALE

My requirements are to examine and understand the rules, and then bend them one at a time. Bending or twisting the rules is the preferred method in which to find and stretch the boundary limits.

I feel that if students can experiment with concrete in unusual ways that are more in keeping with the ways they approach design and problem solving, concrete can transcend it's common reputation in the eye of the public, that thinks "cement buildings" are grey.

REVERSE ENGINEERING

I encourage the student to first draw/design the end result, then to "design backwards" to envision a formwork that can be easily stripped to easily hatch the object without damage and minimal effort. The next stage is to refine the formwork to be easily built and disassembled while remaining stabilized, upright, watertight and texturally relevant.

SMALL CASTINGS LEAVE BIG IMPRESSIONS

The experimental pieces are intentionally small so that the student can physically build the form, cast and strip the form without the use of lifting machinery. The weight of concrete is appreciated, if the student can lift the relatively small object, albeit with substantial effort. If the concrete experiment is too large and a crane is effortlessly employed, the experiment is no longer portable and several learning opportunities are lost. Rotation of the object is usual since the finished side is normally, but not always, cast face down. The irregular top surface of a casting is one lesson that catches many students by surprise. Eventually students better understand the role of form release agents. Even the obstinate re-entrant corner if they gain first hand experience by casting components of their own design.

Fig. 4 Precast foreman suggesting additional reinforcement
for student's formwork prior to casting.

POURING CONCRETE TO REINFORCE LEARNING

Most students relish the opportunity to get their hands dirty and build. They enjoy working with tools. I find that the student will appreciate and respect the skills of the professional craftsmen more if they have endured the limitations and failures of trying to craft quality formwork themselves.

However, architecture students, in particular, seem determined to find and bend this conventional wisdom of the industry to create their desired vision. Many students can't wait to incorporate color dye pigments and textures that illustrate command of their newfound versatile material. These students relish the opportunity to design and build their own formwork, get dirty casting their own masterpiece and later hatch their creation. In the process, they inherently appreciate the effort, time and skill that are required for formwork design and removal. These lessons are valuable for any novice designer.

To embed the lessons learned in the short time available, I find that allowing students to pour concrete is both therapeutic and educational if done on a small scale and in a controlled environment.

Some instructors I have met, feel that this is best done by having the students hand-mix, pour and finish concrete slabs in order to intimidate them with labor intensive processes and achieve less than acceptable concrete finishes. In my opinion, this approach lends little to further exploration in the design potential of concrete.

THE CASTING PARTY (AT THE PLANT)

With the technical expertise and assistance of a few dedicated professionals, we set forth to explore the limits and beyond of the material they work with every day. We return to the precast plant at the end of the workday and inhabit a small area adjacent to the mixing room. There is no shortage of volunteers from the plant that stay behind at the end of their day to advise and reinforce shoddy formwork. The workers enjoy the "weirdness" of the pieces of formwork that the students have built in their studio. Many students use recycled and discarded materials in their formwork. The craft of the formwork ranges from exquisite to shoddy with forms held together with super glue, drywall screws, duct tape and imagination.

Fig. 5 Student at the precast plant with custom dye (color) mix

Our architectural precast concrete "bartender" dispenses advice and mixes small quantities of white cement ready for the student's request for a specific color. He helps each student mix the preferred color and quantity of cement dye from his shelves. The exotic cement dyes are catalogued and stored on shelves and were noted by students to be reminiscent to bottles of liquor, hence, he is known as the "bartender".

Fig. 6 "Stripping Party" at University working from precast company's flat bed truck which is strategically parked close to the dumpster.

JOY OR DISAPPOINTMENT AT THE STRIPPING PARTY

A week later, the collection of weird forms are delivered to the university by the precast plant for the much anticipated "Stripping Party". Students are anxious to strip out their masterpieces. Again no shortage of volunteers from the plant comes along to see what hatches out of the forms. The truck parks close to the dumpster, as a matter of convenience (or lack of confidence?).

Regardless of my intent, some of the best results are fantastic discoveries. Some are structural failures that become post-mortem discussions before the project is interred in the dumpster or reduced to colorful aggregate with a sledgehammer. All give opinions when a project breaks during the stripping operation

Fig.7 Stripping formwork is not as easy as it looks.

WHY

What happens when these students break or at least bend some rules? Amazing new concrete castings are produced, if they understood the limits and possessed some degree of skill with their formwork fabrication. Shattered dreams, unceremoniously delivered to the dumpster, if they rushed into design or fabrication error or didn't appreciate the weight and seepage of wet concrete. With either result, the best self-teaching moments occur when the student presents their design intentions with their physical results to their peers who have participated in the same exercise. Their peers can discuss which aspects failed and how others were able to achieve success. If students can gain hands-on experience, concrete will educate them as they wrestle to train and contain this amazing material that has humbled most of us.

"Don't have your first failure in your career - have it in school."
-John Hartray

DESIGN CREDITS
All projects are from original sources, designed and fabricated by Miami University architecture students and advised by the author or designed and fabricated by the author unless otherwise noted between 1997 and 2010.

A PORTFOLIO
OF MOSTLY INTENTIONAL MISTAKES AND DISCOVERIES
IN CONCRETE CASTING

Fig. 8 A bi-color mix poured in a cylinder started out as a pastel blue, was rodded and a tan pastel mix added on top to complete this pour.

DEFORMED AND TWISTED CYLINDER

Primary Focus
- warp a cylinder shaped object while retaining a soft form

Secondary Goal
- use of two fully mixed dyes but to cause them to bleed into each other by rodding the concrete

Material
- white Portland cement without aggregate, cement dye

Primary Formwork Material
- clear plastic cylinder formed and shaped with a heat gun
- formwork could be used only once and had to be sliced away from object

Placement
- clear cylinder provided a view to aid in color blending operation

Number of trials before success
- several to get the desired contours and color blending techniques

Success
- the concrete is a very smooth, slick finish without mechanical polishing

Ability to transfer technique to building components
- potentially difficult, labor intensive, but intriguing
- requires more investigation

Fig.9 Accent of color dye swirled into the formwork is reminiscent of yogurt

INSPIRED BY FOOD

Primary Focus
- a planar Plexiglas formwork on four sides

Secondary Goal
- slight accent of dye color swirl

Material
- white Portland cement without aggregate, cement dye

Primary Formwork Material
- cut flat sheets of Plexiglas held together with strapping tape
- formwork could be used only once and had to be sliced away from object

Placement
- clear Plexiglas form provided view to determine how and where color blending was desired

Success
- the concrete is a very smooth, slick finish without mechanical polishing

Ability to transfer technique to building components
- potentially difficult, labor intensive, consistent application of dye would be difficult between adjacent panels
- requires more investigation

Fig.10 The dye pattern was absorbed into the paper formwork which created a negative image of the pattern.

CAMOUFLAGE 1

Primary Focus
- exploration of color blending

Secondary Goal
- exotic bright colors

Material
- white Portland cement without aggregate, contrasting cement dyes

Primary Formwork Material
- absorbent paper
- formwork could be used only once and had to be sliced away from object

Success
- negative form transferred stain into the paper formwork that mirrors concrete object

Ability to transfer technique to building components
- potentially difficult, not immediately apparent, but intriguing
- requires more investigation

Fig.11 This simple white/charcoal color mix that was cast on a piece of rigid insulation board that had been distressed with a dinner fork prior to casting.

CAMOUFLAGE 2

Primary Focus
- exploration of texture

Secondary Goal
- elegant blend of inexpensive color additives

Material
- white Portland cement without aggregate, cement dye

Primary Formwork Material
- distressed Styrofoam insulation board

Success
- after several trials, Styrofoam was removed effectively using a power wire brush

Ability to transfer technique to building components
- not yet apparent, Styrofoam debris was hard to contain
- requires more investigation

Fig. 12 A soft (fabric) form lined with light wire mesh was very inexpensive.

DEFORMED CYLINDER

Primary Focus
- roll a cylinder shaped object while retaining a soft form

Secondary Goal
- deform the exterior surface with light gauge wire mesh

Material
- white Portland cement without aggregate

Primary Formwork Material
- wire mesh rolled into a loose cylinder and lined with black polyethylene secured with strapping tape

Placement
- was placed into a vertical pipe sleeve prior to pouring

Stripping
- relatively easy to strip, cut mesh with snips and slice away polyethylene

Success
- the concrete is random and bumpy with a very smooth, slick finish without mechanical polishing

Ability to transfer technique to building components
- potentially difficult, labor intensive
- requires more investigation

Fig. 13 Color dye that is not fully mixed gives an interesting texture on this slick formed panel.

SOFT LANDSCAPE 1

Primary Focus
- achieve a contour relief from soft forms

Secondary Goal
- use of unmixed dye powder in the bottom of the formwork

Material
- white Portland cement without aggregate and cement dye

Primary Formwork Material
- Plexiglas formed and shaped with a heat gun
- formwork was easily removed but was not re-usable

Placement
- several trials were needed to get the desired contours

Success
- the dye remained gritty while the concrete is a very smooth, slick finish without mechanical polishing

Ability to transfer technique to building components
- potentially difficult, labor intensive, dye would continue to dissolve in exterior conditions
- requires more investigation

Fig.14 A slick finish pastel panel illustrating a variable thickness from 2” to 0”
The edges around the holes are paper-thin.

SOFT LANDSCAPE 2

Primary Focus
- achieve a contour relief from soft forms

Secondary Goal
- explore variable thickness of concrete to zero

Material
- white Portland cement without aggregate and tan cement dye

Primary Formwork Material
- Plexiglas formed and shaped with a heat gun
- formwork was easily removed

Placement
- several trials needed to get the desired contours

Success
- the concrete is a very smooth, slick finish without mechanical polishing
- some concrete is thin and translucent when “back-lit,” resembling alabaster
- the concrete adjacent to holes is paper thin

Ability to transfer technique to building components
- potentially difficult, labor intensive, not readily apparent, but intriguing
- requires more investigation

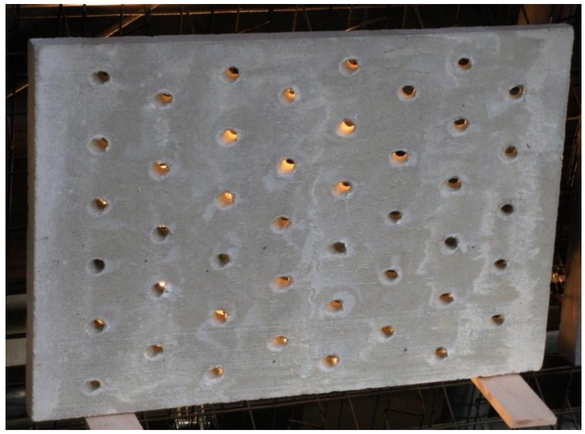

Fig. 15 This panel was self-stripping.
The angled light tubes were formed with Mostaccioli pasta,
which dissolved in the curing process

CONCRETE SCREEN 1

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of texture and grids in a panel
- self-stripping panel

Material
- natural grey Portland cement without aggregate

Primary Formwork Material
- the angled light tubes were formed with Mostaccioli pasta, which dissolved when soaked during the curing process

Placement
- the angle of the cut pasta established the angle of the light tubes
- a grid of skewers pushed into a Styrofoam panel held the pasta in place during pour

Success
- the angled light channels are well formed since the pasta is very uniform

Ability to transfer technique to building components
- potentially difficult, labor intensive, not readily apparent
- requires more investigation

Fig. 16 Panel was contour formed in a sand bed with embedded plastic cups, which can be popped out and reused.

CONCRETE SCREEN 2

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of texture and openings in a contoured panel

Material
- natural grey Portland cement without aggregate

Primary Formwork Material
- the tapered light tubes were formed with embedded plastic cups, which are reusable

Placement
- light tubes were placed perpendicular to contour of panel surface

Success
- the light channels are well formed since the plastic cups are very uniform

Ability to transfer technique to building components
- moderate, reinforcement would be difficult with random pattern
- requires more investigation

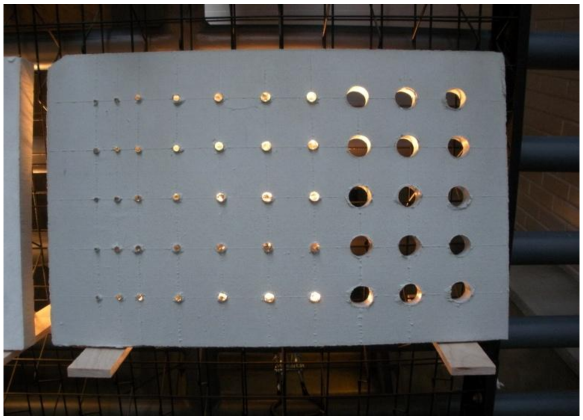

Fig. 17+18 Stripping formwork is a hands-on experience that can prove to be more difficult than anticipated.

CONCRETE SCREEN 3

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of texture and grids in a panel with various size penetrations

Material
- natural grey Portland cement without aggregate

Primary Formwork Material
- the tapered light tubes were formed with embedded plastic cups, which are reusable

Placement
- light openings are perpendicular to panel face

Success
- stripping wax-coated cylinders proved more difficult than anticipated

Ability to transfer technique to building components
- potentially difficult, labor intensive, not readily apparent
- requires more investigation

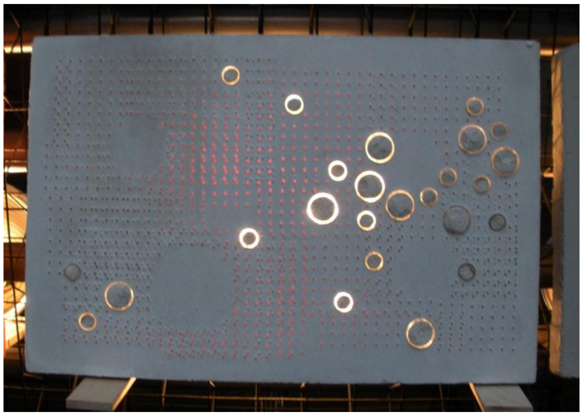

Fig. 19+20 An elegant grid of fiber optic whiskers and Plexiglas tubes to transmit light proved to be quite labor intensive to strip the form.

LIGHT TRANSMITTER 1

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of texture and grids in a panel

Material
- natural grey Portland cement without aggregate

Primary Formwork Material
- plywood with form release agent

Success?
- trimming of light conduits to be flush required more labor than the student expected.

Ability to transfer technique to building components
- similar method is being currently used in various small-scale applications
- requires more refinement

Fig. 21 Contrasting textures were created with Styrofoam forming the upper portion and a duct tape liner at the bottom. Glowing red and green fiber optic whiskers penetrate the wall from the hollow interior.

LIGHT TRANSMITTER 2

Primary Focus
- contrasting textures from different formwork substrates

Secondary Goal
- appearance altered with artificial light from interior

Material
- white Portland cement without aggregate, uniform cement dye mix
- red and green fiber optic whiskers with LED light source

Primary Formwork Material
- upper portion formed with Styrofoam
- lower portion formed with duct tape

Success
- the fine detail of the duct tape substrate transferred to casting
- duct tape provides a very smooth surface but all joints and wrinkles show
- glowing fiber optic whiskers are apparent in low ambient light conditions

Ability to transfer technique to building components
- potentially difficult, labor intensive, not readily apparent
- requires more investigation

Fig. 22 The creases at the bottom of this crushed cylinder form are paper-thin.

PARODY OF A CYLINDER COMPRESSION TEST

Primary Focus
- achieve a minimum thickness equivalent to knife's edge, if possible

Secondary Goal
- transition between "soft" and "hard" edge forms

Material
- grey Portland cement without aggregate

Primary Formwork Material
- thin paper cylinder, held with tape and crushed
- Formwork was removed by tearing and soaking

Placement
- it required coordination of two people to guide and control the thin paper cylinder while it was being poured and simultaneously crushed

Success
- the creases at the bottom of the cylinder form range from 1/16" thick to paper-thin

Ability to transfer technique to building components
- potentially difficult, labor intensive, not readily apparent
- requires more investigation

Fig. 23+24 This student learned that corrugated cardboard is inexpensive as a form liner, but quite labor intensive to strip the form.

SCORCHED CARDBOARD

Primary Focus
- exploration of texture and voids in a panel

Secondary Goal
- exploration of texture and voids in a panel

Material
- natural grey Portland cement without aggregate

Primary Formwork Material
- recycled cardboard

Success?
- Cardboard substrate absorbed water and proved difficult to release.
- Dissolving formwork by soaking was recommended but flame burnishing appeared more exciting to the student

Ability to transfer technique to building components
- not readily apparent, potentially difficult
- requires more investigation

Fig.25 Two sides of a plywood box were filled with a block of ice of variable thickness. Due to the heat of hydration, the form was self-stripping.

GLACIAL REMNANT

Primary Focus
- investigate self-stripping formwork

Material
- white Portland cement without aggregate and uniform cement dye

Primary Formwork Material
- pre-formed block of ice
- open-sided plywood box

Placement
- several trials were needed to get the desired form

Success
- the resulting concrete casting has an eroded glacial character that remains chalky

Ability to transfer technique to building components
- potentially difficult, labor intensive but educational
- requires a two-stage preparation since ice block is pre-formed
- requires more investigation

Fig. 26 Corrugated metal formed the sides of the formwork clamped together at the ends only. The mass of the uncured concrete created the intended entasis at the center.

PARODY OF AN IONIC COLUMN WITH ENTASIS

Primary Focus
- achieve a contour relief to mimic the “entasis” (swelling) of a classical fluted column

Secondary Goal
- use of galvanized metal formwork that is easily removed

Material
- white Portland cement with fine sand aggregate and uniform cement dye

Primary Formwork Material
- galvanized metal formwork clamped together at the ends only

Placement
- form was easily stripped by loosening the clamps and peeling the flexible metal skin

Success
- concrete is quite smooth and welcomes to be touched

Ability to transfer technique to building components
- moderate, metal form easily stripped and re-usable
- could be used in variable radii applications and perhaps as a concrete masonry unit
- requires more investigation

APPENDIX: SAMPLE PROJECT STATEMENT

DESIGN SEMINAR: ARC 406/506. A

Professor Craig L. Hinrichs

Project #5 The incredible "lightness" of concrete

With the technical expertise and assistance of Concrete Technologies of Springboro, Ohio, the course is about to reach the dirty stage. ***Yes, we are going to build!***
This exercise is intended to explore one of the most plastic of the common building materials..

Precedents
The ancient Romans invented concrete. They discovered a silica and alumina-bearing mineral on the slopes of Mt. Vesuvius that when mixed with limestone and burned produced a cement that exhibited the unique property of hardening underwater as well as in the air. Knowledge of concrete construction was lost with the fall of the Roman Empire. In 1824, in England, Joseph Aspdin patented an artificial cement that he named Portland cement. Reinforced concrete was developed in the 1850's by several people simultaneously who built reinforced concrete boats in Paris in 1854. ***In their honor, 150 years later we are going to build floating concrete boats!***

Project Statement
Design/build a single precast floatation device that is exactly 1'-3" long. As you know, concrete weights 150 lb /cubic foot. Your sculpture (boat) will float if the volume of water that it displaces weighs more than your boat and its cargo of 1 brick, remains upright and is water-tight. If not, it will "sink like a chunk of concrete"!
The projects will be judged on the basis of the tripartite formula of function (flotation), constructability and aesthetics that has become our basis of this class.

Calendar

31 Mar	*concrete basics- Mark Fusani, PE*
7 April	*concrete innovations – Mark Thurnauer*
14 April	*complete formwork sign-off*
21 April	*last refinements to formwork, and*
	Casting Party *in Springboro at 6:00 pm*
	(Concrete is curing while you finish studio design projects).
28 April	***Stripping Party*** *at Alumni Hall Loading Dock at 6:00 pm*
	Dunk testing *immediately thereafter!*

Extra Credit.
As an extra opportunity for those who really like a challenge, the following option is offered. Translucent concrete will raise your grade of this project or any other project by a whole letter grade!

Reminder
This material will be presented to the Details class. It will become part of the Department of Architecture Archives.
ch/04