LIGHT TRANSMITTING PRECAST CONCRETE PANELS

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ABSTRACT

The topic of a recent design brief issued to Architecture Students caused great interest in a University course of Materials and Methods of Construction. Students were asked to design and build a concrete wall panel that would be able to transmit natural or artificial light. How could something so heavy and dense, let light pass through it?

They were excited by the possibilities of designing, building formwork and casting solutions that answered a seemingly oxymoronic riddle. The paper is illustrated with castings that are a delightful combination of ignorance and innovation, which created interesting results. As expected, several failures did occur when the formwork was stripped. The disappointment of the student was personal, albeit educational.

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. 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.

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 design work at the undergraduate level. That awareness comes later, when and if, the student evolves into an architect. However, some architects 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. The subject matter that is so important to the reader is necessarily reduced to serve as an introduction.

SUPPLEMENTAL INSTRUCTION TECHNIQUES

Over the years, editions of Allen’s book have been the mainstay of my arsenal for teaching a “Materials and Methods of Construction” class to architecture students. The information contained in this book is 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 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.

A CASE STUDY APPROACH

I also include a lecture that features images of "cutting-edge" design projects that are 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. 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. The case study is presented by a graduate student to reveal the architect's design concept which was inspired by a geological sedimentary stratum that is smoother and casts less shadow as the eye progresses upwards to the top of the building.

Fig. 1 Exterior wall detail (looking upwards) of the Perot Museum of Nature and Science in Texas located in the Dallas West End

Students are initially uncertain as to how the exterior skin of the building was constructed 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. An exercise to determine how many times a form could be used by altering the length and texture of the panel is a powerful learning exercise to reinforce the repetition of the form for economy. 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 what degree of repetition occurs in order to establish the exterior wall panel pattern. They also are interested in the casting sequence and what block outs and infill areas could be utilized in the formwork. They refer to this project later when they get the chance to design their own formwork.

THE PRECAST 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 are intrigued with the seemingly endless palette of materials, finishes and textures. 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. They are amazed at the complexity of the operation and the coordination necessary to cycle a plant in 24 hours.

Fig. 2 Miami University architecture students touring local precast plant

FURTHER LEARNING - A HANDS ON APPROACH

Once they see the range of textures and finishes available in the precast plant, they are excited to experiment with this versatile material first hand. The casting of a small personal panel that the student has designed is a great educational tool which brings to bear the previous lessons.

A PROJECT DESIGN STATEMENT

The students receive a design/build 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

Note: For illustration purposes, a project design statement that was issued to the class is attached at the end of this paper. The focus of exploration of this particular exercise was the transmission of light through the panel, achieved by transparency, translucency or a void.

TEACHING RATIONALE

My requirements are to examine and understand the rules, and then bend the limits 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. In this way, concrete can transcend it's common reputation in the eye of the public, that thinks "cement buildings," as they call them, are grey and uninspired.

Fig. 3 Precast foreman suggesting additional reinforcement for student's formwork prior to casting.

REVERSE ENGINEERING

I encourage the student to first draw/design the end result, then to "think backwards" in sequence to envision and design the relevant formwork that can be easily stripped to hatch the object without damage and minimal effort. The next stage is to refine the formwork to be easily built and disassembled while remaining stabile, upright, watertight and texturally relevant. This is a hands on exercise that most architectural students find to be a very satisfying. However, in their exuberance they tend to design something very intricate or complex for what the envision will be the ultimate object to prove their brilliance. This stage of the project is high in optimism. Humility and patience are not traits that most students have developed at this point in their career.

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 cast "face down". The irregular top surface of a casting is one lesson that catches many students by surprise. Eventually students better understand the rules of formwork design and the role of form release agents. Some might even try to solve the obstinate re-entrant corner if they gain first hand experience by casting components of their own design.

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 lessons are lasting by having the students hand-mix, pour and finish concrete slabs in order to have them appreciate the 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.

Fig. 4 Students at the precast plant with custom dye (color) mix

THE CASTING PARTY (AT THE PRECAST 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. Students are encouraged to use recycled and discarded materials in their formwork. The craft of the formwork ranges from shoddy to exquisite with forms held together with super glue, drywall screws, duct tape and no shortage of imagination.

The architectural precast concrete “bartender” dispenses advice and mixes small quantities of white cement ready for the student’s request of 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 of bottles of liquor, hence, he is known as the “bartender”.

Fig.5 Stripping formwork is not as easy as it looks.

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 stripping occurs near the dumpster, as a matter of convenience or lack of confidence. This facilitates the clean up. 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 students give opinions when a project breaks during the stripping operation.

Fig. 6 “Stripping Party” at University loading dock adjacent to the dumpster.

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.

Fig.7 Approximately a 1/4 of the students encounter problems during the stripping process. These are unceremoniously delivered to the dumpster.

DESIGN CREDITS

All projects are from original sources, designed and fabricated by Miami University architecture students and advised by the author, unless otherwise noted, between 1997 and 2014.

A select portfolio of:
ARCHITECTURE STUDENTS' DISCOVERIES, SUCCESSES AND CREATIVE MISTAKES DURING THE PROCESS OF CASTING CONCRETE

Fig.8 A slick finish pastel panel illustrating a variable thickness from 2" to 0"
The edges around the voids are paper-thin.

"SOFT" LANDSCAPE WITH VOIDS

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 in one piece and could be-reused

Placement
- several trials were needed to get the desired contours

Success
- the concrete has 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
- the training of the craftsman will require experimentation to insure visual continuity from one panel to another

Fig. 9+10 The creation of voids through a wall panel for view and light transmission.
The texture is created by the folds in the thin plastic sheeting.

WRINKLED PANEL WITH VOIDS

Primary Focus
- achieve a panel with soft form voids for view and light transmission

Secondary Goal
- create textural panel using thin plastic sheeting

Material
- white Portland cement without aggregate and black cement dye

Primary Formwork Material
- Styrofoam panel with plastic sheeting that penetrated top of formwork
- formwork was easily removed
- the plastic portion of formwork is not re-usable

Placement
- the plastic sheeting was easily formed and shaped during the concrete placement to achieve the desired contours

Success
- the concrete is a very smooth, slick finish without mechanical polishing
- the finish texture of the panel resembles the wrinkled quality of the formwork
- each panel is unique but can easily possess similar design characteristics

Ability to transfer technique to building components
- potentially good, but the plastic sheeting should be placed by one skilled individual
- the training of the craftsman will require experimentation to insure continuity from one panel to another

Fig. 11 A corrugated form liner was used with uniformly spaced grid of penetrations.

MULTI-COLORED CORRUGATED SCREEN 1

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of color, texture, pattern and a grid in a corrugated panel

Material
- white Portland cement without aggregate and cement dye mix

Primary Formwork Material
- a corrugated metal liner and a grid of wood dowels that were coated with a form release agent

Placement
- dye color concrete was poured into center of form while white concrete was being poured at the edges

Success
- the light channels are well formed since the dowels are very uniform

Ability to transfer technique to building components
- potentially difficult, labor intensive
- the ability to connect the pattern from one panel to an adjacent one requires additional planning in the pouring process and erection sequence

Fig. 12 The holes in this panel were self-stripping.

CORRUGATED LIGHT TRANSMITTER 2

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of texture, pattern and a grid in a corrugated panel

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- a corrugated liner and a grid of pasta noodles that were self stripping when soaked for a couple of days

Success
- appearance is altered when back-lit from interior

Ability to transfer technique to building components
- potentially difficult, quite labor intensive
- works well in a 2-D plane but requires a special panel to turn a corner

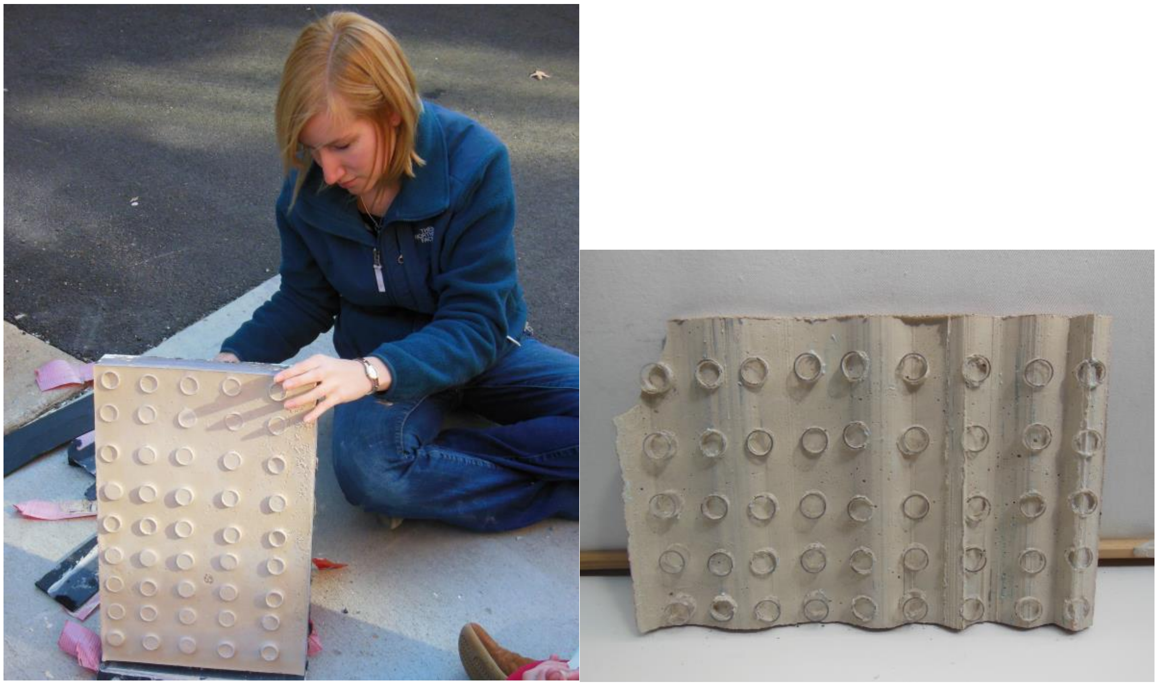

Fig. 13+14 The Plexiglas tubes transmit rings of light

CORRUGATED LIGHT TRANSMITTER 3

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of color, texture, pattern and a grid in a corrugated panel

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- a corrugated liner and a grid of Plexiglas tubes

Success
- Plexiglas tubes transmit rings of light even though their centers are filled

Ability to transfer technique to building components
- modularity is required in building façade proportions and openings in order to keep from having partial panels
- works well in a 2-D plane but requires a special panel to turn a corner

Fig. 15 Panel was contour formed in a sand bed with embedded plastic cups, which can be popped out and reused.

CONCRETE SCREEN 1

Primary Focus
- view and 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
- reinforcement would be difficult with random pattern
- requires more investigation

Fig. 16+17 Stripping formwork is a hands-on experience
that can prove to be more difficult than anticipated.

CONCRETE SCREEN 2

Primary Focus
- view and 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

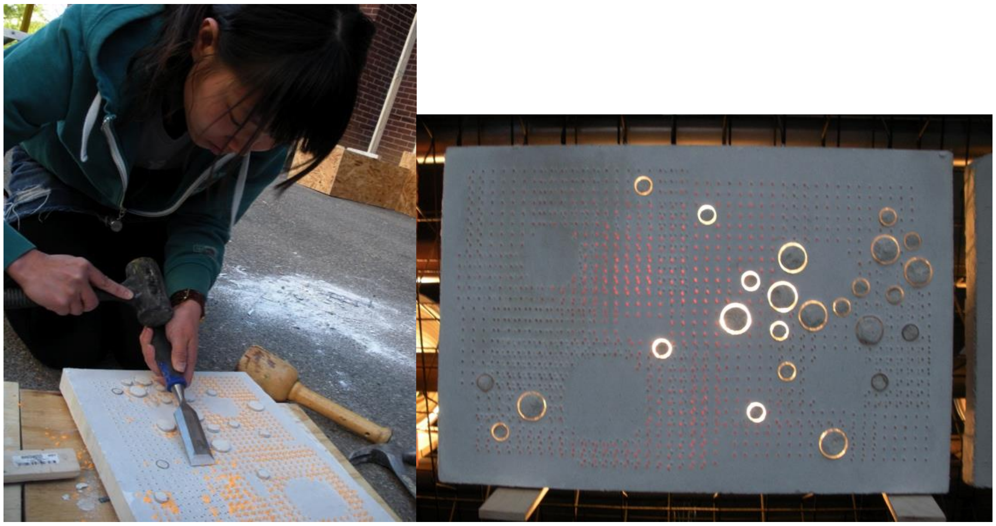

Fig. 18+19 An elegant grid of fiber optic whiskers and Plexiglas tubes to transmit light proved to be quite labor intensive to strip the form.

FIBER OPTIC 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 investigation

Fig. 20 fiber optic whiskers with LED light source

FIBER OPTIC LIGHT TRANSMITTER 2

Primary Focus
- light transfer from inside so that appearance is altered with artificial light

Secondary Goal
- casting a simple clean reveal to divide modular panels

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

Primary Formwork Material
- voids formed with Styrofoam

Success
- 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. 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 skin from the hollow interior.

FIBER OPTIC LIGHT LIGHT TRANSMITTER 3

Primary Focus
- contrasting textures from different formwork substrates

Secondary Goal
- light transfer from inside so that appearance is altered with artificial light

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+23 Panel immediately after removal from form.
It collapsed during transport, minutes later.

STARBURST

Primary Focus
- to provide transparent voids using glass inserts

Secondary Goal
- color dye exploration

Material
- white Portland cement with fine sand aggregate, cement dye

Primary Formwork Material
- plywood box with form release agent
- formwork could be re-used but glass inserts are cast in-situ
- placement labor could be expensive

Placement
- the glass inserts were glued into the formwork prior to placement.
- the thickness of the panel was limited to the diameter of the glass inserts

Success and Failure
- the concrete surface was accented with the geometric pattern of glass inserts
- the spacing of the inserts required a reinforcing matrix, that was not anticipated by the student
- the piece fractured along predictable fault lines that served as a valuable lesson

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

Fig. 24 Geometric voids in a modular panel which
when reversed and stacked create a larger module of 4 panels

MODULAR PANEL 1

Primary Focus
- casting a series of simple clean reveal to create modular panels

Secondary Goal
- appearance altered when back lit from interior

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- voids formed with Styrofoam

Success
- another similar mold is reversed to create a book-matched larger module of 4 panels

Ability to transfer technique to building components
- modularity is required in building façade proportions and openings in order to keep from having partial panels
- works well in a 2-D plane but requires a special panel to turn a corner

Fig. 25 Glass shelves contrast the mass of the concrete panel

LIGHT SHELF

Primary Focus
- transmit natural light down the face of the wall

Secondary Goal
- appearance altered when back lit from interior

Material
- white Portland cement without aggregate, uniform cement dye mix and glass strips

Primary Formwork Material
- Styrofoam insulation board of same thickness as the glass projections

Success
- glass shelves contrast the mass of the concrete panel

Ability to transfer technique to building components
- modularity is required in building façade proportions and openings in order to keep from having partial panels
- works well in a 2-D plane but requires a special panel to turn a corner
- difficult to transport due to fragile nature of glass and the mass of the concrete

Fig. 26 The formwork remains to frame the soft shape of fabric formed concrete pillows

FLOATING MODULAR PANEL

Primary Focus
- casting a simple clean reveal to divide modular panels

Secondary Goal
- soft form casting contrasting the formwork frame

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- fabric draped intorigid framework

Success
- appearance altered when back lit from interior

Ability to transfer technique to building components
- modularity is required in building façade proportions and openings in order to keep from having partial panels
- works well in a 2-D plane but requires a special panel to turn a corner

Fig. 27 Plastic bottles inserted through formwork directs light without providing a view though the panel

TEXTURAL PANEL WITH VOIDS 1

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of color, texture, and pattern

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- Styrofoam with plastic bottles protruding at a skewed angle through the formwork

Success
- Plastic bottles inserted through formwork directs light without providing a view though the panel
- smooth surfaces at voids

Ability to transfer technique to building components
- passing plastic conduits through formwork provides smooth channels for light to pass through

Fig. 28 Repeating a form insert component that has some voids partially filled

TEXTURAL PANEL WITH VOID 2

Primary Focus
- light transfer through concrete

Secondary Goal
- exploration of color, texture, and pattern

Material
- white Portland cement without aggregate, uniform cement dye mix

Primary Formwork Material
- various plastic strips with texture altered to creat pattern

Success
- repeating a form insert component that has some voids partially filled

Ability to transfer technique to building components
- modularity is required in building façade proportions and openings in order to keep from having partial panels
- works well in a 2-D plane but requires a special panel to turn a corner

APPENDIX: SAMPLE PROJECT STATEMENT

ARC 418/518 Construction Methods 2014
Professor Craig L. Hinrichs
100 A Alumni
Class: 10:00-11:20 am TTh
Office Hours: 11:30 am-12:30 pm TTh
or by appointment 513-529-7036
hinriccl@muohio.edu

Issued: 6 March 2014
Due: 13 March 2014

design exercise #3a (alternate)
a concrete panel that transmits light

With the technical expertise and assistance of [redacted] *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. The projects will be judged on the basis of the tripartite formula of function, constructability and aesthetics.*

Project Statement.
Design/build a precast panel that is 1+/-"x12"x18". The concrete panel must transmit either natural or artificial light. A perforated concrete screen can be an elegant solution to this problem. Additional explorations of color and texture can also be a part of your panel.

Calendar

4 March	*concrete basics- Dwayne Robinson,* [redacted]
13 March	*Plant tour and* ***Casting Party*** *in Springboro at 11:00 am*
18 March	***Stripping Party*** *at Alumni Hall at 10:00 am*

References
LiTraCon Translucent concrete

Reminder
This material will be presented to the Construction Methods class and will reside in the stairwell with previous student work. It will become part of the Department of Architecture Archives.
ch/14