CONSTRUCTION - RESEARCH - DESIGN - INVENTION
Elastic Behavior in a Moist Environment

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This article describes a decade-long research project that intersects the practices of architecture, engineering, teaching, surrealist methods of collage, and construction technology. Two specific examples illustrate the approach to design/research pursued in this work. The first is a studio teaching environment/method that uses analogue construction materials and processes to discover architectural forms and ideas. The second is a method of forming reinforced concrete structures in flexible fabric membranes that has extraordinary potential for both architectural design and civil engineering. The latter is a technical research practice that is indistinguishable from design speculation, while the former pursues methods of teaching design that are indistinguishable from technical invention.

Three interdependent 'lines' of thought are brought to bear on this design/research practice: an abiding faith in chance, the free fall of imagination, and its emotional pulse; a solemn study of 'natural law;' and an embrace of what can be called a 'builder's sensibility.' These lines are entwined and knotted through the discipline of architecture in a search for new forms and approaches to architectural design. In this way, the disciplines of art, engineering, architecture, and construction are all called upon to bestow their separate gifts on the project of design-research-construction, in the design studio and research laboratory, and in building practice.

Serious Play

In both teaching and research, technologies of chance and recombinatory explorations – methods of searching and finding proper to the arts - are used to unlock unexpected generative techniques and their affects. The methods I refer to rely on a more or less open-ended playing with stuff – the haptic pleasure and stimulation of manipulating various materials. Here, the basic recombinant (and liberating) 'technologies' of surrealist collage play a fundamental role. The willful disorientation and unexpected collisions induced by a 'collage consciousness'— along with its necessary surrender to, and embrace of chance events — facilitates a state of *finding*, in contrast to the activities of orthodox 'designing.' Lautremont's chance encounter of an umbrella and a sewing machine on an operating table is, in our case, transformed into the meeting of a sewing machine and a concrete mixer with a table saw.

1. John Kim hugging his fabric-formed column, Carleton Univ., 1992

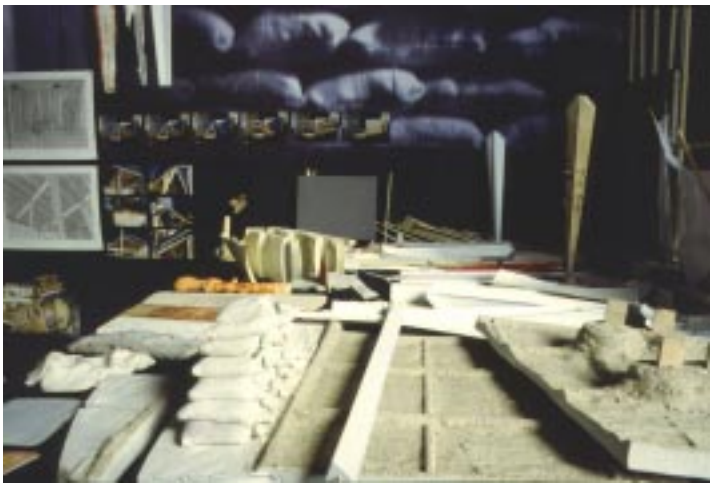
While our 'findings' share the art object's desire for meaning or affect, we are restless for more. The findings generated in this state of play are winnowed through the criteria of usefulness, and focused through the lens of natural law: statics, structural behavior, geometry, material qualities... The cunning intelligence of the builder's sensibility shapes emergent ideas through methods of production that, in turn, re-shapes them and their affects through built form.

This discursive description may suggest a linear sequence or methodology. This is emphatically not the case; unexpected ideas can spring from any line of thought, just as any line of thought can be used to constrain or expand a generative idea. The goal, in any case, is the same: the desire for usefulness and metaphysics to become consanguineous insists on a confusion between the otherwise separately defined realms of technology and poetry, pragmatism and fantasy.

In our work, deflection is embraced as a form-giver rather than avoided as a de-former. Consider that, technically speaking, a 'bend' is the term used for a knot that connects two otherwise separate pieces of rope. This nomenclature makes the act of 'bending' equivalent to an act of binding - a poetic fact that 'centers' our work and serves to expand the definitions of design and research so that they may both occupy the same space at the same time.

Finding design ideas in a sandbox - conducting a simultaneous search for design ideas and construction technologies:

The following fourth-year undergraduate studio project offers an example of this approach by combining design education with a form of analogue construction research. The pertinent goals of this project were: to see how far open-ended play with construction materials and production techniques could go towards generating meaningful design ideas; to push an



2. A few of the constructions collected from the Carleton University sandbox, displayed at the end of term reviews. Many inventions were never used in the students' final projects. Several of these 'rejects,' however, led to new research ideas for further investigation.

3. Two examples of sand-cast foundations. These designs solved actual physical problems of structural support and construction sequence in the (analogue) sand 'earth' rather than merely mimicking the shape of full-scale foundations.

improvisational method of teaching and designing to its limits; to unite questions of program, design, materiality, structure, construction, and their combined affect into a single**,** simultaneous**,** and inextricable complex; and to give design invention a physical source of becoming, uniting it with a form of technical research.

Throughout the semester, a variety of analogue materials and production techniques were used to model full-scale construction materials and technologies (figs. 2, 3, 4). I use the word 'model' here not to refer to a small three-dimensional visual/spatial representation, but rather as a verb. For example, we used paper to model steel, not because it looked like steel, but because paper effectively mimics some basic structural and material qualities of sheet steel: its thinness, its capacity for both elastic and permanent deformations through bending or folding, and its methods of fabrication (shearing, and analogue 'welding' through the use of glue). Concrete was modeled through plaster; asphalt and tar through wax, steel cable through thread, etc.

4. Interior of a ground floor commercial space from the sandbox. By Thomas Macintosh.

The earth was modeled as a large communal sandbox in which students built and designed their own small two-storey commercial/residential building at the periphery of a common space, constrained by basic 'zoning' rules. The activities of building and designing were thoroughly linked and methodologically interchangeable. The design of individual buildings, and the public space formed between them, was not guided by an *a priori* governing concept, but remained in a constant improvisational flux throughout the term.

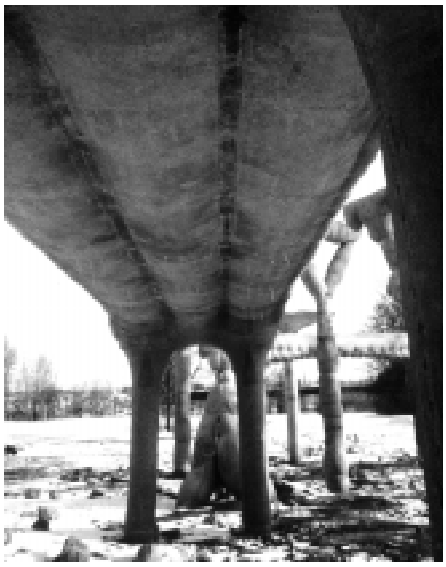
Each student maintained a portion of 'real-estate' as a fabrication yard or factory, and another as a construction site for their built design(s). Nothing was ever thrown away. All failures, scrap, and garbage were stored as a kind of register. Drawings were used to solve problems and to 'construct' parts of the design that were beyond the students' capacity to build physically – that is, to 'project' a design towards completion, or to place it in some specific context. At the end of the term, all projects were structurally loaded to failure (except one, the author of which could not bear to take this final step). These cathartic structural failures were video-taped and subject to a final forensic analysis. End of term.

Through these students' physical experiments, a language of both structure and ornament emerged that was unimaginable before they were uncovered by the work itself. Form and proportion developed as a result of physical behavior and methods of production as much as by questions of aesthetics.

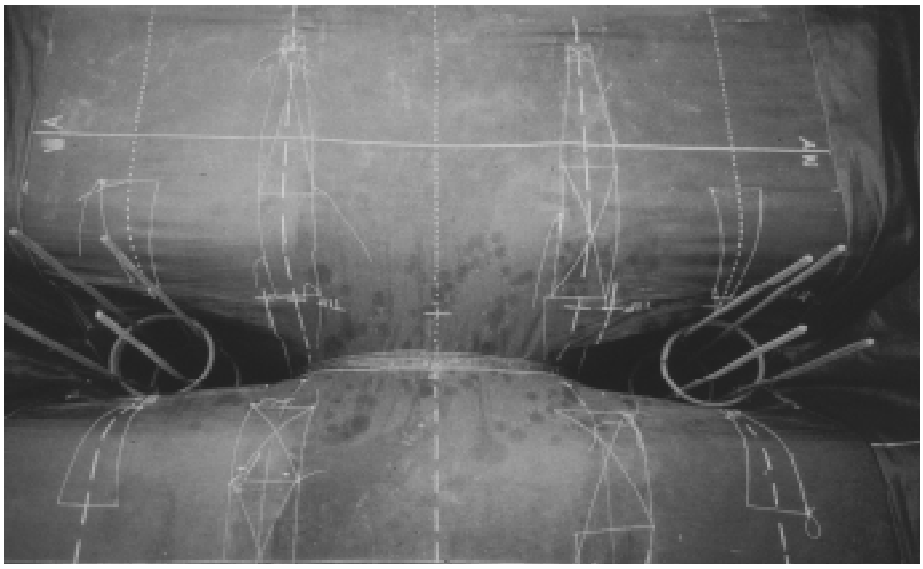
Fabric-formed concrete

My work in reinforced concrete structures with flexible molds emerged out of the kind of play I asked my students to do in their communal sandbox. My own play with material and processes revealed several opportunities for new ways of forming buildings. The most compelling was the use of flexible formworks.

To date, this research/design



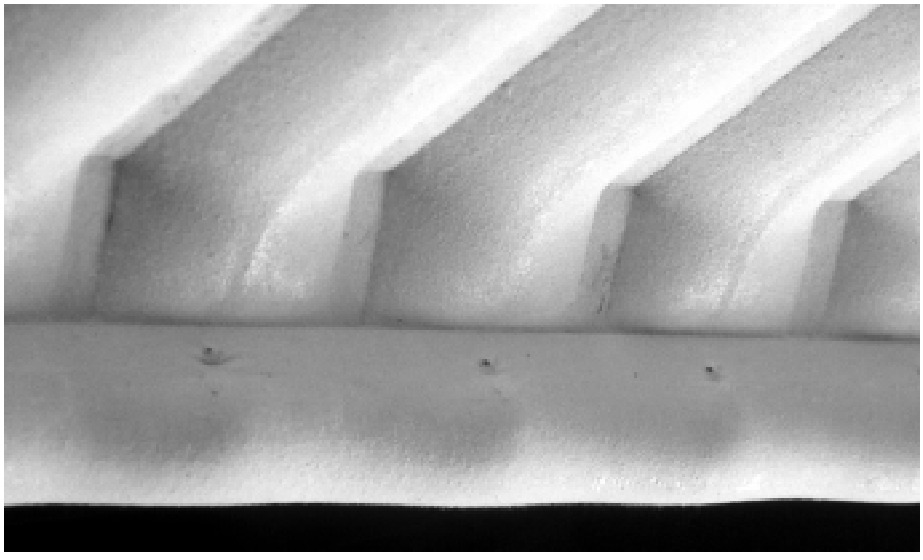
5. Underside of full scale, fabric-formed test slab with integral beams and columns. Formed from three flat sheets. 1992



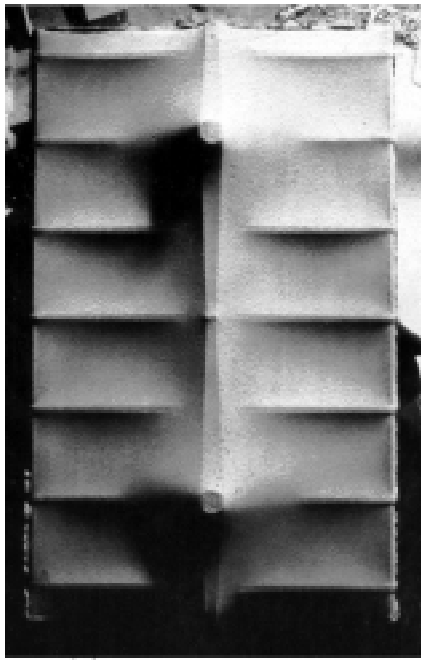
6. Detail of full scale test slab showing flat fabric sheets forming column - beam - slab junction. Shown here before placement of slab reinforcing steel or concrete.

practice has produced methods for forming reinforced concrete columns, walls, beams, and slabs, and several full-scale demonstration projects, public sculptures, and building structures built by myself or my students. A research laboratory dedicated to fabric formwork technology is currently under construction at the University of Manitoba, supported by approximately $1,000,000 (CN$) in public and private sector funding. The establishment of this laboratory has led to research and teaching partnerships with practicing and academic architects, engineers, mathematicians, and various sectors of the construction industry.

The flexibility of these membranes awakens concrete to its fluid origins, creating several important effects: the creation of a new class of highly efficient, complex**,** and easily formed structural shapes based on precise geometries of tension and compression; a new and unprecedented level of refinement in the surface finish and texture of cast concrete; the production of stronger and denser concrete surfaces; a new 'language' of architectural form that opens a radically different understanding of reinforced concrete architecture; a method through which the hand of the builder is reborn as the source for an intrinsic vocabulary of architectural 'ornament' (figs. 10, 11, 12, 14, 15, 16); the opportunity to make a structural textile (glass or carbon fibre) serve as both formwork and tension reinforcement,



7. One-way ribbed slab model: slab and beam formed from a single flat sheet of fabric.



8. Compression shell slab model cast from inverted fabric-formed precast mold.

9. Facade alteration: Storefront for Art and Architecture, New York, NY, 1992. With the assistance of Araya Asgadom

10. University of Manitoba students building a precast column designed by Jaspal Atwal for a new children's theatre building in Winnipeg, MB.

eliminating the need for both steel reinforcing and the removal/disposal of formwork; and the use of a very cheap, extremely light-weight, globally available formwork material in place of wood**,** which is generally hard to find in building economies that rely on reinforced-concrete construction.

A detailed discussion of flexible formwork research must be saved for another venue. I will, however, offer two illustrations of the virtues of this yielding approach to construction and 'form-making.'

1) By abandoning rigid prismatic molds, the relatively massive structure required to limit deflection in traditional formwork becomes unnecessary (fig. 13). By embracing gravitational forces and the inevitable deflections they cause as form-givers, rather than as de-formers, we are able to use the natural 'intelligence' of the materials themselves as they 'find' their own appropriate geometries of resistance. These geometries — minimum surface tension geometries, and their inversion — funicular**,** compression-shell geometries — are achieved with relative effortlessness as the materials 'fall' into place according to their own innate calculus (fig. 8).

Efficient structural shapes tend to follow curved lines of isostatic force, producing members with sections that vary

11. "Aneurism" column produced by the formwork shown in fig. 12 at right.

12. Formwork for the precast column shown in fig. 11. A 'spandex' liner is allowed to deflect through openings in non-stretch liner.

13. Column formwork loaded with wet concrete. This same form has been used multiple times to cast various column designs.

along their length according to the changes in magnitude and direction of the various forces within the member. The physical constraints of rigid panels preclude the economic construction of these variable section members, thus imposing higher dead-weight loads and material costs. These kinds of variable section members are easily formed using fabric formwork, either by pouring directly into the fabric, or by inverting an initial pour and using it as a mold for pre-casting compression-shell geometries. Our current work with pre-tensioned fabric forms is particularly interesting in this regard, because we can induce specific and desirable 'forms of resistance' by imposing our own generative forces upon the formwork membrane. In this way, we can produce structural shapes reminiscent of a variety of biological structures endowed with the capacity to proportionally locate material in response to stress concentrations.

2) Vastly improved surface finish and strength is achieved by an analogous yielding: when permeable fabrics are used to hold wet concrete, they act as filters, allowing air bubbles and excess mix water to bleed out, leaving an immaculate, cement-rich paste at the surface. This has the added result of significantly improving the water-cement ratio at the surface of the member, providing a denser and stronger 'case hardened' concrete. It is also a surface that beckons touch, and promises pleasure.

An integral method of approach

True to the method of this research, fabric-formed concrete can be understood as sculpture, as efficient structure, and as a means of expedient construction. It can simultaneously satisfy the dictates of all three, putatively separate, frames of reference because it was *developed by engaging all three at the same time.* It may be worth reiterating here that the sandbox design studio was designed to bring a version of this approach into a teaching environment.

Simultaneity is at the heart of this design/research practice. In this way we rediscover the world of materials and methods as an instigator of, otherwise unimaginable, ideas. Using the material realm as a source of imagination serves to invest the ideas thus found with the physical means required for their realization — a most compelling virtue for those who wish to build.

The usual alternative to this integration, particularly common in design studio education, is to develop ideas of architectural form according to a conceptual or theoretical model in a manner more or less aloof (or at least temporarily aloof) to questions of physical means. The problem of construction then requires a difficult and often painful post-design rendering of these formal ideas in materials and methods of construction. More often than not, this results in a necessary 'corruption' of the original conceptual idea, seen in tragic terms as 'a loss of purity.'

According to this common approach to design, the problem of physical means tends to belong to a separate 'technical' realm distinctly different from that of 'design.' In this way, the deeper meaning, or conceptual intent of a design is sacrificed to the rude limitations of economy, calculation, and construction — the realm of the technician.

The traditions of technical education play their own role in maintaining this unnecessary divorce. The standard of Realism, traditionally carried in the name of building technology education, can easily be misused to crush ideas — particularly those of a young designer who has little defense when charged with being unrealistic. There are critiques of Realism, however, that should be heeded by those who seek to eschew illusion. The critique offered by Surrealism, for example, has particular relevance to the integrated approach presented here in reminding us that that which commonly passes for realism may, in fact, be the most insidious and alienating of illusions.

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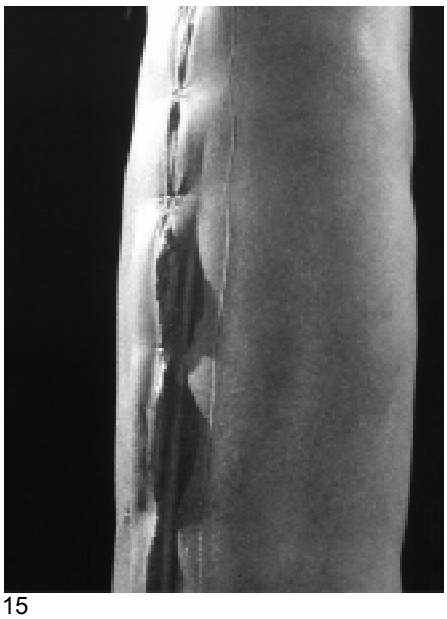

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14, 15, 16. Three examples of different geometric patterns given by different formwork connection details: Each method of connection and restraint produces its own 'signature' pattern, as does each fabric chosen for the formwork membrane.