Tailoring fabric formwork

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Abstract

The paper reports on a current programme of study: exploring techniques, processes and materials translated from the textile and fashion industries to create sculptural architectural elements from concrete cast in a flexible fabric formwork. The scope of work looks to prototype many different column forms using tailoring techniques.

Previous research at the University of Edinburgh has often used a simple geometry for the fabric with the use of external constraints for impressions and to create form. This new research centres on using tailoring and textiles solely to create form. The project is cross-disciplinary working across both textiles and architecture. The programme has created a series of prototype columns scaled to study particular articulations of geometry and following a defined formula that allows for the easy comparison of the differing techniques utilised in constructing the formwork.

Complex two-dimensional cutting patterns are stitched together to form organic three-dimensional elements that respond to the hydrostatic pressure concrete exerts on the formwork. The research also involves analysing the use of internal webs of textile as tension elements to control these pressures and as another vehicle for creating form. The internal tension webs operate form actively, as opposed to the previous research where external restraints were inefficiently resisting compression forces.

The body of work emphasises the inherent nature involved in concrete casting, exposing the process that is driven by natural gravitational force and controlled restraint and relaxation. The aim is to develop an appropriate paradigm for tailored concrete formwork that maintains the inherent simplicity of the process and constructive logic.

Keywords: tailoring, textile, fabric formwork, fashion, darts, webs, integral constraint, internal restraint, pattern cutting.
1. Introduction

This paper forms a report on the current progress of ongoing research into tailored fabric formwork.

The research poses a series of questions: How can the treatment and manipulation of the textile influence concrete to control its form and show its materiality? Can we remove the reliance on other actors in form creation to allow the fabric itself to be the sole form creator? It seeks to demonstrate the dynamic relationship between the fabric and concrete involved in its creation. Current explorations of fabric formwork have relied to various degrees on external control, often quite dependent on a complementary rigid formwork working in conjunction with the fabric formwork. However there is logic to drive toward a fully textile formwork.

There is a dance between the malleable formwork and the liquidity of concrete that tussle to find a state where hydrostatic equilibrium is achieved with all the actors in balance to create the form. If the formwork acts completely in tension, as a fully textile formwork would, then it acts in its most efficient way.

The research proposes a new paradigm that applies knowledge from the textile and fashion industries to produce fabric formworks that exhibit sophisticated control of the form creation of concrete elements. The paper will present a shift from reliance on external constraint for fabric formwork towards integral constraint and internal restraint. This work applies a new language appropriated from the fashion world to articulate the discourse on fabric formwork, a process for describing the treatment of formwork to achieve a desired form.

A flexible fabric formwork can afford the concrete itself a more defining role in its form creation. Rather than resisting the hydrostatic forces in compression, which is the role of traditional rigid formwork, fabric formwork can respond to the pressures and forces to work form actively, resisting them in tension. Not only a more honest expression of the concrete’s properties but also a more efficient method of casting.

Concrete needs to be addressed not just as a material, but as a process. Often the most important actor in its form definition is discarded and thrown away, leaving only an impression of how it was created. Fabric formwork puts the liquid stage of the process at the forefront of the story of concrete’s form defining process. It allows for the understanding of where the concrete wanted to move and escape to, only to be constrained by the tensile strength of the fabric. Concrete attains its materiality, tectonics, form, character and its language from this process.

2. Context

External restraint has been a key factor in controlling fabric formwork; this ranges from clamped rigid materials, used to form voids or impressions in the casts to complete exoskeletons controlling and restricting the expansion of a fabric form. The idea that construction can move away from this external reliance is the basis of this research.

An examination of the author’s previous work and that of other practitioners, for instance Mark West at C.A.S.T at the University of Manitoba, shows various examples of such work where complementary rigid formwork partners with fabric to create the forms. Figure 1 shows a column where an exoskeleton of fins constrains the fabric from bulging out at its capital to create a form that resembles a four leaf clover in section. Figure 2 shows a column restrained by plywood clamps before the fabric is allowed to bulge out to form the column.
Figure 1: Fin Column, Keith Milne and Tom Ferm, University of Edinburgh

Figure 2: Y-column, C.A.S.T, University of Manitoba
Source: http://www.umanitoba.ca
The textile and fashion industries have developed many techniques to manipulate fabric to envelop a form, namely the human body. Clothes directly respond to body forms, therefore there is a language and methodology that can be translated to fabric manipulation for concrete formworks. The analogies and similarities between flowing forms in fashion and the freedom of the constructed language of concrete cast with a fabric formwork, can encourage the discourse on the development and recognition of fabric formwork.

![Figure 3: Haute couture dress designed to wrap around body form](image)

*Source: Elie Saab*

### 3. External constraint vs. integral constrain vs. internal restraint

It is important to define constraint and restraint when factoring in the role of the textile in form creation. Rigid formwork constrains concrete, placing limits and restrictions on where the concrete can flow. The same can be said for a rigid external exoskeleton applied to generate form using a fabric formwork. The rigid exoskeleton constrains the fabric formwork, pushing it back preventing it from expanding to find its natural form. The fabric formwork then in turn constrains the concrete within the exoskeletons limits. Here is where the paradigm of this research is applied, by removing the exoskeleton, can the fabric be tailored to constrain the concrete by itself?

The methodology proposed, to allow fabric formwork to play a more active role, addresses the concept of integral constraint, part of the textile membrane, differing from external restraint applied to the outside of the fabric formwork. This constraint is not applied subsequently to the formwork; it is inherent within the textile itself. It is a constraint that is completely integrated in the fabric.

Finally the research proposes internal restraint where textile is applied to prevent the fabric formwork from finding its natural relaxed form, pulling it back, resisting the pressures causing the form to
expand. Tensile textile webs applied internally are stitched to the outer textile formwork to achieve this restraint.

4. Prototypes
A series of prototype studies was undertaken to explore the effect of integral textile restraint on form and expression.

The prototype production follows a simple formula to allow comparison of each of the cast elements. The fabric is consistent throughout, as simple woven cotton textile. Each column is based around a cylinder that is 500mm high and 150mm in diameter. These dimensions are chosen to:

- accentuate the curvature of the elements,
- provide a scale that is manageable and repeatable a multitude of times,
- produce a diverse prototype pool, and
- fuel the discourse whilst exhibiting a responsive timeline that articulates the developmental iterative process undertaken in the research.

The move away from external restraint to the more efficient and form active method of resisting the forces in tension, becomes the sole generator of form when the formwork is stretched between two circular holes cut in plywood forms top and bottom, thus only the fabric envelope and liquid concrete create the form in between.

This results in moving the tacit knowledge required to create these forms upstream, where all the form decisions are taken when manufacturing the ‘fabric sock’. Thereby allowing a person with relative inexperience to cast complex forms simply by attaching the fabric formwork to an uncomplicated plywood form and tensioning to a denoted line on the fabric. This avoids all the hurdles of adjustment and reinforcement required of a plywood exoskeleton that experiences shifting and increasing compression forces during casting.

Exploring textile and fashion techniques, there are some techniques for controlling fabric that immediately jump out as potential form defining factors for fabric formwork, such as:

- single and double pointed darts;
- single, opposite and all side gathering;
- godets;
- pleats;
- partially seamed tucks, and
- surface cording.

These techniques could all be considered as integral methods where they form the fabric structure. There are also a couple of techniques that straddle the concept of integral and external constraint; rigilene boning reinforcement and corseting - both working externally, but importantly, in tension rather than compression. Additionally there is also the prospect of using patternmaking to create a form whereby two dimensional pattern elements are stitched together to create the form, the same process used to create clothing.

The initial series of prototypes produced thus far has focused on the application of darts, understanding their effect and influence on the form.

5. Dart columns
Darts are an established technique in textile manipulation that are often used to sculpt a garment around the human body. The purpose of a dart is to produce a tuck in the fabric coming to a point that allows an essentially flat piece of fabric to respond to form. One common use of darts in the fashion industry is a bust dart where the fabric is pinched in around the breast to create a neat body form following garment.
Extrapolating from dart use in fashion, the use of double pointed darts allows the controlled and focused removal of fabric. When this is used vertically in a column formwork this effectively reduces the circumference of the column at certain points. If this applied asymmetrically it creates forms that twist and turn across their axis adding eccentricity. When applied horizontally it shortens the length of the vertical side in which it is placed, therefore the fabric has to adjust to compensate for it.

Six columns have been cast using different dart techniques; each cast is designed to offer understanding of the effects and influences of darts on the formworks in different circumstances. Figure 5 shows the patterns and stitching guidelines for the series of dart column prototypes.
Figure 5: Dart arrangement for prototype columns
5.1. D1 – Double waisted column
The double waisted column is split into fifths over its height and two of these rows are filled with darts to create a double waisted pattern in between which the fabric can return to its original circumference. The resultant cast resembles a stone balustrade, something that would have to be painstaking produced on a lathe. The cast exhibits many pinch points in the fabric as a result of the waisting of the form being too pronounced over such a short distance. As a consequence some fabric is left in the pinches, as some are too tight for removal. Should this be considered unsatisfactory the options would be to reduce the rapid nature of the transition employed for the waisting or to further tailor the formwork to remove the excess fabric that formed the folds and got caught in the pinches.

Figure 6: Double waisted column front, side and oblique views

5.2. D2 – Flared capital and base column
This column significantly flares out to meet its base and capital and is envisaged as an elegant way to resolve the junction between the floor and soffit in a building context. The first attempt to construct the formwork for this column resulted in failure, the textile bursting along the seams during stretching between the plywood forms top and bottom. This was a result of the fact that the waisting was designed with an excessively rapid transition of geometry. To remedy this, the second formwork reduced the acuteness of the initial gradient of the dart to allow for a more gradual transition, reducing the pressure excreted on the transitional darts that caused the initial failure. The resultant column has a tightly controlled central shaft, one-third the diameter of its flared capital and base.
5.3. D3 – Bust dart column

Bust darts, described earlier, are arranged horizontally to constrain around a bulge. This column uses similar darts in a coherent pattern placing a group of darts together on one side one-third of the way down its height then alternating to the other side further down the column. This distorts the form into an S-shaped profile. Shortening one side allows the other to bulge but this is counteracted further down the height of the column where the other side is constrained creating a form where the forces, constraint and relaxation transition over the height of the column. There is a slight instance of pinching of the fabric in this example, nevertheless in this context it accentuates the shifting mass and can be considered to add to the aesthetic. Extending the darts from only half the circumference, enveloping the full circumference would eliminate this pinching.
5.4. D4 – Offset capital column

The offset capital column is the most technically demanding column for formwork design prototyped thus far. It builds on the design of the flared base and capital column; it is a waisted column that flares out at its base and capital. However, the central column emanates at opposing offsets from the centre in the base and capital creating an inclined central column. The formwork involves different sized darts and intersecting darts that run up the height of the column. In this case the hydrostatic force on the formwork is highly evident with the base fully filled and bulging, whereas the capital appears slightly under filled with some evidence of initial folding that could lead to pinching. The transition of the central column transversally across the central axis from base to capital is smooth and refined; the fabric naturally resolves all the complex geometry in between the integral constraint defined by the darts.

![Offset capital column front, side and oblique views](image)

5.5. D5 – Twist column

This column explores the use of curved darts that taper out in opposing directions, creating an approximately S-shape dart. This created a twisted column where the parallel seems of the centre of the formwork wrap transversely around the column, rather then running vertically. This resulted in a smoothly curved column that waists towards the centre of its height. The seam work exposed in the casting accentuates the complexities involved in achieving what is read as a simplistic form. A form like this would be very difficult to construct with external constraint, the tailoring of the formwork allows for much greater uniformity of the geometry.
5.6. D6 – Asymmetric waist column

One side of the column, one semi-cylinder, waists towards the midsection of its height whilst the fabric on the other half remains full. This provides a form that in section is straight from base to capital on one side while the other is pulled in. This could be envisaged in a building to punctuate a space surround by columns that waist to depict is existence yet, from outwith the space, they look just like standard cylindrical columns. The inherent ability of the fabric to deal with the transition from waisted to regular exhibits a sophisticated language of geometry that would be difficult to replicate with an external constraint.
6. Summary of outcomes
The prototypes thus far have exhibited the inherent nature of forces and materiality involved in concrete casting, exposing the process that is driven by natural gravitational force and controlled fabric restraint and relaxation. The orientation of the darts in relation to the gravitational force acting on the concrete can be manipulated to cause the direction of its axis to shift, such as in the bust dart column. The hydrostatic force and gravitational force are evident in some of the prototypes with bases fully filled and capitals under filled. These factors could be taken into account in the formwork design stage, constraining the base more and the capital less to get a more balanced form.

The paradigm that has been developed for these tailored concrete formworks maintains the inherent simplicity of the process and constructive logic. The darts as a methodology of tailoring provide a great range of opportunities, yet in some cases further refinements may be necessary. It was noted that in some cases the darts alone could not fully resolve complex transitions of geometry as exhibited in some pinching and geometric anomalies. Further refinement of the darts, the use of other tailoring techniques or pattern-cutting for the formwork may aid in the resolution of these anomalies. It is clear that the production of these forms is eased by the application of fabric formwork as opposed to rigid formwork. What is newly evidenced is that the fabric itself can be manipulated to define the form and the way the textile membrane is tailored has a significant effect on the constraint and generation of the form.

7. Direction of research
The results from the prototypes are encouraging and would suggest further exploration of darts as well as the other fabric manipulation techniques identified earlier could lead to other significant outcomes. As the research continues, more prototypes addressing these techniques will be developed.

The other main area of focus for the subsequent research will be the utilisation of internal textile restraint webs. There is a key innovation proposed here to remedy one of the main drawbacks of internal restraint. It is proposed to use dissolvable fabric so that once the formwork is struck the remnants of the internal web can be dissolved away leaving a clean surface free from tufts of fabric that would otherwise remain. For these webs, a woven textile has been sourced that has the property of dissolving in 60°C water but remains structurally sound in cold water. Therefore, in theory the column could be cast, the formwork struck and the remnants of the web dissolved with boiling water, leaving a blemish free concrete form. There are also other options under consideration for these tensions webs, such as textiles that dissolve in water at higher temperatures and textiles that can be dissolved with a chemical solution.

Another area of research could focus on additive methods of form control. The preceding techniques discussed have focused on subtractive methods for controlling the form by removal of formwork material, reducing the volume of the basic cylindrical cast defined by the prototype formula. However, the fashion industry also shows us how to add material to develop form so this could be an avenue of exploration. This development would apply pattern-cutting techniques to create the formworks - three dimensional forms from two dimensional pieces of fabric stitched together.

There are other opportunities to borrow knowledge from the fashion world that could translate into fabric formwork. Importantly for these to follow the rational of fabric formwork, creating the form the most efficient way, they should follow the simple formula of performing in tension to restrain the forces. There are techniques in corsetry and underwear production that lend themselves to such a study, although other researchers have initially experimented in this area. Interestingly these techniques can be considered as exoskeletons, yet they perform completely in tension as opposed to resisting compression forces that are exhibited traditionally by ridged exoskeletons.
8. Tailored fabric formwork in industry

The possibilities for the design, production and mass manufacture of fabric formworks utilising the tailoring process explored in this research are very promising. The prospect of successful commercialisation could be provided by a finished formwork that only needs to be tensioned between top and bottom plywood constraints and yet creates organic forms that can be clearly defined and consistent. Value for money is also achieved as these types of fabric formworks offer the opportunity for efficient and cost effective mass customisation of building elements that are traditionally simple and standardised forms.

There is precedent for production such as this in the fashion industry where the process is relatively similar. The architectural possibilities for tailored fabric formwork could see a large selection of forms mass-produced from a product catalogue to capitalise on economies of scale, an ‘off the shelf’ design, yet there could still be opportunities for the high end ‘haute couture’ market of individual one off designs.

Another avenue of development could focus on the textile. Combining digital printing onto the formwork textile there is the scope to produce a textile printed with the cutting and stitching pattern designed to create these forms along with casting directions. A practitioner could simply order a textile roll of patterns for a building element and proceed to construct the formwork themselves, following the printed directions on the fabric, much the same as the process followed in this research where the pattern was defined on the fabric during construction, figure 5. This also offers the chance to combine other advances in printed textiles such as concrete pigments printed onto the textile before casting to transfer a pigmented pattern on the surface of the cast concrete.

9. Conclusion

The paper has reported on the ongoing work addressing tailoring as a form-defining tool in the process of concrete cast using a fabric formwork. It provides the catalyst for continuing research expanding the prototype pool to demonstrate the method in practice. Points identified in this paper will be used to direct the subsequent prototype columns, which will in turn influence the direction of the research thereafter. The prototypes will be used to build the paradigm and language for the use of tailored fabric formwork in construction and architecture.