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Fabric formwork **– prototype** to **typology**

Abstract

When developmental vernacular practice is telescoped into industrial activity, the role played by construction workers in the honing of a craft is rapidly bypassed. An almost political act is required to maintain the contribution that the hand makes to the uniformity of result that is demanded by the standard classification of typologies of building and technique. Research into fabric formwork techniques conducted by Alan Chandler utilises the flexibility of the concrete mould to explore the meaning of the making 'process' and the workers' role in relation to the formal 'result'.

Chandler's 'Wall One' exemplifies the exploratory **prototype** and its potential for variety and the trace of the hand in making. The shift to a mass production **typology** involved in realising the 325,000 square-metre Heatherwick studio project in Shanghai, presented the problem of how to orchestrate the fabric into a fully industrialised process. Part of the research then became how to make the shift from play to profit - and can anything of craft survive the transition into the international development marketplace? Through managing the inherent variety available to the fabric itself, a fabric based formwork solution for realising a building at the scale of a landscape offered the Chinese form work maker the opportunity to be present within the results of a fully industrialised process – a ghost in the machine. [221]

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Fabric formwork **– prototype to typology**

Prototype: a first, typical or preliminary model of something from which other forms are developed or copied.
Typology: a classification according to general type.

The evidence of contemporary fabric formed concrete technology lies in a network of highly inventive individuals making radical prototypes that deliver an astonishing variety of technical ideas – Mark West and Remo Pedreschi developing structurally efficient beams, Rick Fearn's fast-foot foundation system, and Kenzo Unno's 'Zero-Formwork' walls, as well as my own fabric shuttered rammed earth walls. This area of research is often characterised by an un-stated 'socialism of craft', the exponents of non-rigid formwork actively engaging with the natural hydrostatic pressures of liquid concrete in more or less flexible fabric moulds to explore rather than impose form on a process. When understanding that designed form is often an imposed norm, the process of casting within fabric becomes participatory, not only with the community that may use the work, but with the material itself. Louis Kahn, enquiring what an innocent brick wanted, suggested the kind of underlying theoretical position adopted within fabric formwork research – when pouring liquid into fabric, what shape will it want? Holding it here or there persuades it into this shape or that. 'Persuades' becomes 'insists' through iteration and experimentation. These ideas are often credible alternatives to existing techniques for concrete casting, but in many cases they create systems for concrete forming that deliver results that conventional methods cannot hope to emulate or achieve. What is surprising and perhaps disappointing is that despite singular successes and a raft of papers[1] that explore the cost, time and quality advantage of a technique that omits making a rigid mould, the use of fabric formwork still remains prototypical.

For fabric casting to move from these 'anticipatory prototypes' to a category of construction of its own – a new 'concrete typology' – there are a series of factors that require greater definition for both the fabric innovators as well as the marketplace of potential users in order to move the technology into widespread use. In particular, the use of fabric formwork has too few rules to become commonplace, it needs a creative impulse to determine what is done with it. Therefore the normal contractual requirements of specification in advance of site operations mean that contractors are reluctant to use such open techniques. They require certainty in order to structure logistics and profit and to avoid taking decisions that might incur financial losses. How does such a move towards a 'concrete typology', involving certainty and risk avoidance impact on the activity of innovation itself? What shifts in technology, and in the perception of that technology, are required for an experiment to become a product?

Prototype

Fabric formwork is capable of enabling iconic, revolutionary form, with many of its protagonists responding to the freedom from orthogonality in its operation within ‘natural laws’ of the catenary. It is the aesthetic agenda that is most open to adoption by magazines, the heralds of the mainstream. Photogenic in the extreme, fabric formwork fulfils the first rule of achieving a revolution, which is to create memorable images. When the means of producing architecture is focused on material and technical agendas its revolutionary *output* becomes easily wrapped up in capital processes, substantiated and given credibility by imagery. ‘Creativity’ – the act of creating – can be entirely re-purposed for marketing, used as a noun that is severed from its root ‘to create’, with the potential for democratic participation smoothed out from ‘innovation’ into ‘exploitation’ with seamless efficiency. At one level this should not be surprising. Even the originator of the photogenic manifesto, Le Corbusier, noted 'Architecture or revolution? Revolution can be avoided.'[2] In other words ‘architecture’ is uniquely endowed with the ability to absorb the radical because it is inherently linked to investment and surplus value. Without the material innovation of architectural invention, the marketing of redevelopment and the act of building desirable and profitable structures becomes that much harder. Is the architectural innovation of the prototype as practised by the fabric formwork protagonists valuable as intrinsic acts of human ingenuity, or simply destined for consumption?

For me the most revolutionary potential for fabric forming is not its visual appearance. The primary purpose of my fabric formwork research is the democratisation of technical processes. The responsiveness of the technique allows the simple constituent parts of the formwork to bring the maker into the role of designer. Even with the systematisation of production, the use of fabric makes space for differentiation and variety within the results, particularly with in-situ work. This aspect of the revolution is unable to be captured in the advertising image, as its impact is not merely photographic but lives within the experience of the workers who pleat, clamp and strike concrete forms that bears a visible relation to their effort. Its use provides a radical challenge to habitual site processes, a form of leitmotif for re-addressing the relation between the maker and the designer, its site operations delivering inflections that are intrinsic to making, not merely reproducing the absent draftsman’s dictatorial lines. What is clear is that there is no single framework of revolutionary interest within this fabric practice, rather overlapping *interests* that engage the formalist, community builder and the Situationist alike. This potential to address form generation (visual appeal) at one end of the revolutionary spectrum, and the politics of participation in a new, democratic building process at the other is unique.

When devising ‘Wall One’, built at UEL in 2003, the intention was not only to test the self organizing potential of fabric used to form liquid concrete, but also to exploit the malleability of the fabric to explore how the formworker could influence the result as the concrete was being poured. The process inverted common vernacular practice where formwork is specified and fabricated in advance – building two walls in order to

achieve only one (fig. 1). The choice of technique alters the potential meaning of a process. Fabric formworking techniques that achieve the 'socialisation' of repetitive and pre-specified work back into craft, whilst retaining a compliance with modern technical parameters are documented in my book, *Fabric Formwork*.

Lloyd-Thomas proposes that 'new realities' of materials can re-articulate how processes and outcomes relate, and that this is clearly demonstrated in the elaboration of Wall One, where the 'image' of the work was wholly determined at one scale – dimension, language and material palette – but entirely open in the articulation of those elements. What is particular about Wall One is that the placement and judgement about the technical constraints for the concrete were finalised as the concrete was being poured. This is not 'parametric' in the accepted sense, although the inherent logic of each element of the piece is dependent upon given performative parameters such as distances, dimension and elasticity. Digital parametrics establish a model of consequences **before** the act of making as multiple simulacra from which to choose, whereas reserving the right of the maker to contrive the result at the moment of making means there is only one option – the one that is chosen. Research into the digitisation of fabric formwork is already underway, but is simply a sophisticated version of the development of 'specification' charted by Lloyd-Thomas. Risk amelioration is the vein that runs through the history of 'specification' – the risk that the result will not achieve technical performance requirements or conform to the image 'in the mind's eye' of the designer.

'Wall One' was a key example of establishing a prototype that both achieved a stated formal goal, but did so through means inflected and informed by the responsiveness of the material and the flexibility of the fabric formwork. Is this multi-facetted radicalism a strength, or a weakness? To what extent does it make fabric formworking difficult to absorb into the mainstream, and what are the consequences of the incorporation into the 'mainstream'? The enthusiasm its protagonists have for fabric formed concrete is often centred around its aspect of radical dialogue, the protagonists scenting a *revolution* on many fronts*,* but the actual test of the validity of the 'revolution' comes within the requirements of capital where the risk of investing in a piece of architecture requires the avoidance of risk in executing the piece of architecture.

Typology

If there is a revolutionary aspect in the use of fabric formwork techniques, can that revolution move beyond the prototype to become a typology that will influence the making of standard/specification led concrete architecture? In 2013 Heatherwick Studio approached me to help explore the formwork design for an already-designed 325,000 square metre seismic resistant concrete framed development in China. Heatherwick Studio wanted the technique of casting the visible structural frame, up to 100 metres at its highest, to have a quality of variety and uniqueness within its surface and detail, delivered through the logistical constraints of a commercial building project. In this short research project radical prototyping shifted to

mainstream typology, with the solidity of revolution melting into air. The role of innovation, the status of the innovator, the recipient of innovation and its ultimate purpose became open to critical examination.

Heatherwick Studio wished to accommodate the expression of gravity within a manageable, orthogonal concrete casting system required by the contractor to achieve the programme. The challenge was to deliver repeatability and reliability whilst wanting to make space for a perceptible degree of natural ‘expression’ in the hundreds of columns and planters. Each column element is square in section with generously radiused corners that were ‘pinched’ into metal bands corresponding to slab level day-work joints. Each column expanded into an inverted, banded pyramidal planter at the top of each column with each one to hold a single tree aloft, adding up to a vast building resembling a forested mountain range.

In Shanghai a 1:1 concrete demonstration piece was cast into CNC milled polystyrene, which delivered an exact regularised three-dimensional surface from the CAD model. The curvature of the concrete was entirely symmetrical where it met the bands so did not provide or express the essence of the ‘pinched’ shaft that the design team desired. With the notion of a natural landscape embedded in the whole concept of the building ‘as a terrain’, it is clear why a fully repetitive construction language would fight against the idea, and why there was a desire on the part of the Studio to take the natural analogy into the detail. The design team’s wish to explore the issue of gravity in the finalisation of the framed system for the Shanghai project appeared to be intuitive, but pinpoints the critical problem of buildings inevitably defying natural forces in order to stand against gravity and the elements. The dilemma of natural expression within unnatural construction leads ultimately to the issue of rationalism itself.

The use of fabric in conjunction with a partially rigid containment provided a mechanism for achieving both expression and efficiency, potentially providing an alternative formwork design to be as simple to strike as a conventional formwork system, with the use of fabric needing to be as repetitious and standardised as an ‘off the shelf’ product. The added complication was that within the seismic region in which Shanghai lies the reinforcement cage must be a maximum of 50mm from any point of the concrete surface – somewhat antithetical to the traditional legacy of a free fabric formwork dialogue between ‘material and forces’. The sometimes beautiful, sometimes grotesque bulging of the concrete that naturally occurs between points of containment simply could not be allowed to occur in an uncontrolled way. A new discipline in fabric formwork was necessary at this interface between on-site industry and workshop innovation.

With this alternative fabric-hybrid formwork needing to prove itself very late in the procurement process, the limited window of opportunity for proof at 1:1 meant that the task became both prototype and standard construction system at the same time, every screw or fold becoming both an invention and potentially an illustration in a Chinese construction manual. Our research drew on a longstanding experience of

the fine interactions between contained concrete and containing cloth in order to re-engineer the earlier polystyrene version. If the research could deliver 1:1 results with the variety required by the Heatherwick Studio, then the geometric rules our work determined would become the basis for the concrete, but more importantly also for the rebar cage design. To achieve the required proximity to the surface, the surface needed to be accurately defined. Within polystyrene formwork this is a given, when fabric is used there needs to be the same degree of predictability, or the manufacturing tolerances of the reinforcement cages cannot be met.

We determined a simple method – to use a fast ‘trial’ cast to resolve the ‘pinch’ points in a manner that allowed for reusability and simplicity of assembly/disassembly, tested at 1:1 but at a reduced height and without reinforcement. Should the ‘trial’ form fail, a relatively small amount of concrete and time would be wasted. A cast concrete plinth with upstand allowed for the ‘trial’ piece to effectively build upon a lift, thereby testing the ability to achieve a travelling formwork. The continuity from one lift to the next was a key consideration for our researchers, with vertical repetition on previous projects being an issue that was often resolved with small, bespoke elements, not detailed for the brutality of a fast-track building site.

The breathing space that a full size ‘trial’ offers is crucial, with even a single iteration giving invaluable learning potential. The one metre high ‘trial’ piece gave the team the possibility to try different ‘tuck’ patterns on each corner to gather the fabric. This creates the right amount of capacity for expansion to give the desired three-dimensional curvature where the radiused vertical corners met the narrow bands that expressed the day-work joints. The full size three metre high formwork was prepared in parallel to the ‘trial’ piece in order to move directly to construct a full storey height lift with an Arup-designed rebar cage within. The ‘trial’ yielded key insights into details around the management of the pour at the corners of the formwork, the tucking pattern and the important aspect of fabric clamping around the day-work collar. A stitching pattern for the basic fabric sleeve was also tested, as much for its appearance as its strength under load. Using sail making skills and thread parallel lines of stitching secured the vertical seam.

The ability to clamp the fabric within collars has long been a requirement of fabric casting, and has delivered various methods that achieve a watertight and predictable fringe to an often unruly form. In the test piece the clamping around curved corners made for a complexity of connection between the elements that made up the collar, such that the fabric on the trial piece was given the ability to pull up under pressure. The amount of ‘give’ at the corners was critical – too much slack and the pressure bulge would ruin the order of the form, too little and the pinching of the band would fail to register. With bolt-through ties running across the parallel sides of the form within the ‘band’, the corners were left with only friction clamping between the fabric and curved ply strips.

Upon removing the collar following a two week fabrication process and an impeccable pour, the extent of pull at the lower four hemispherical corner points of

this cubic metre of concrete was evident, readable in the inflected warp and weft markings left on the surface by the geo-textile. The tuck pattern worked with all four corners even though the number of tucks varies on each corner from three to five, meaning that the tuck itself had little to do with the overall geometry that each area of fabric assumed under loading. Crucially, even with only a metre lift the vertical shaping of the column with the fabric became apparent. With the pressure dropping nearer to the top of the lift, the fabric was not pressed hard onto the four vertical retaining sides uniformly, giving a slight tapering and narrowing of the shaft as it reached the top band – much like entasis. This purely classical device for the connoisseurship of structural appearance became an entirely natural geometry that informed the definition and specification of the rebar cage bending schedule.

Following two further weeks of construction teamwork between the Studio and our researchers, the finalised collar and side restraints were developed and built to execute a complete three metre lift with a full seismic rebar cage for the column, and two of the three stages of the planter head, again with reinforcement designed by Arup. The single pour gave no problems with leakage, with the fabric swelling to the predicted curvature at the corners of the column. Determining the diameter of the basic fabric cylinder such that it would follow the overall square section but deliver the required radius on the corners was part calculated, but partly based on experience of the deflection experienced in the ‘trial’. The pour confirmed both the collar strategy but also the dimension of the fabric sleeve, which was simply replicated on the final column.

The planter head was the most dynamic of the pieces, the lateral expansion out from the column head meant that the containment of the fabric required vertical as well as horizontal resistance – hard for cloth against liquid stone. Here the cloth required finer tailoring than with the basic tube of the column liner. Experience allowed a manipulation of the weave direction to ensure the best possibility for the concrete to swell the fabric to the desired curvature at the corners, whilst minimising the amount of tailoring or complex pattern cutting.

Of interest on the planter head was the anticipation of the ability of the bias orientation to cope with the corner undulations. To avoid introducing complex pockets we anticipated that introducing the fabrics ability to stretch two ways when the warp and weft were arranged diagonally would be sufficient to develop three-dimensional curvature. Again this was achieved, with the fabric pulling away from a uniform contact with the rigid four-sided enclosure. The ability for the fabric to reorganise the vertical section was not anticipated at the outset, but is what gives the fabric formwork the ability to connect the rationalised structure to the expression of natural forces.

The casting of twenty-seven tonnes of seismic resistant concrete during our workshop provided both proof of result and a documented construction process for the Chinese contractors. With the reality of the full size, full weight and fully reinforced pieces as reference points, the Studio team took the opportunity to

commission 3D scans of the 1:1 pieces. This provided digital models of the real forms that were mapped into their CAD models, allowing a comparison between the original CAD models and the realised concrete casts. The subtle but exquisite contribution that gravity makes to liquid in a fabric sheath meant that the rebar design could be fully modelled and fabricated with the same ease as the original (fully orthogonal) design and achieve the required coverage tolerances.

The ability to use the prototype to confirm a subtlety of form extends also to the detail. At the corner of each column section there was a requirement for a naturally geometric three-dimensional curve. The creation of this swollen geometry depends on slackness in the fabric, allowing an expression of a tighter band that pinches the column at every floor plate. This detail needs additional fabric into which the concrete can flow and swell, the management of this ‘freedom’ for the liquid concrete was developed on the initial test piece through using four variants for pleating the fabric, all of which worked, implying that the requirement for precise specification could be eased, allowing for interpretation. The collars creating the pinch-points in the design are regulated, but given the variable flow of concrete into each pour, the way in which each fold is made and tucked by hand, and the ability to specify “between three and five tucks” rather than exactly the same throughout the project gives a unique moment on each detail, meaning that across many hundreds of columns shafts, no two corners will ever be alike. This moment of handcraft, taking only seconds for the fabric at each corner to be folded into the collar, is a lasting testament to the moment the worker fitted the formwork, and an almost silent subversion of the vast economic structure that orchestrated the project in the first place. The principle is akin to Anthony Gormley’s site specific art installation ‘Asian Field’ (2003), with two hundred and ten thousand miniature clay figures all made in the same regulated way but with different hands leaving traces of differentiation and identity within the uniformity of the overall work.

Reflecting on the revolutionary potential within the prototyping culture of its innovators, fabric formwork presents fundamental challenges to the technical positivism of the construction industry. Fabric’s adaptability, economy, form-finding potential and scope of application becomes entirely disadvantageous however, when the demands of standards-based applications of regularised technology require ‘one answer to one question’ in a manner which can deliver copyright protection and profit based on volume of sales. The friction between technical potential and technical acceptability is at its most obvious when reflecting on the shift from casting prototypes to a formwork typology. It is almost impossible not to conclude that it is the regime of production that ultimately gives technology its meaning. At the time of writing the Shanghai project has started excavation and groundwork, the production information, details and 3D digital scans of the prototypes passed on to China, the transition from making concrete prototypes to making a concrete typology requiring a suppression of expression and a focus on the mundane. As with ‘Asian Field’, there is the potential to retain craft within even the most uncompromising of situations, but only by managing the inherent variety of a fabric based formwork solution could the

Chinese formworker have any opportunity to be present within the results of a fully industrialised process, but even then only as a ghost in the machine.

3814 words

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Figures

Fig.1 Casting Wall One using Fabric formwork, cast in 2004 under the direction of Alan Chandler and Remo Pedreschi at the University of East London. The steel cable restraints are visible, which in conjunction with paired ply discs on threaded ties restrain the concrete. Achieving a 2m x 4m wall that was straight at the top but sinusoidal and self-supporting at ground level was the brief, the means of restraint determined in principle, but the placement and manipulation of the restraints and the surface was a free design by the makers at the point of casting the liquid concrete. Copyright: Dirk Lellau

Fig.2 Complete 31metre retaining wall at Small Hopes Farm, Norfolk in 2011. Copyright: UEL/Wilf Meynell

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[1] Diederik Veenendaal, Mark West, and Philippe Block, “History and Overview of Fabric Formwork: Using Fabrics for Concrete Casting,” *Structural Concrete* 12, no. 3 (September 1, 2011): 164–77, doi:10.1002/suco.201100014; Alan Chandler, “A New Vernacular,” in *Second International Conference on Flexible Formwork icff2012* (presented at the Second International Conference on Flexible Formwork, Bath University: BRE CICM, 2012), 78–83, http://opus.bath.ac.uk/30079/; Alan Chandler, “Building Walls: A Philosophy of Engagement,” *Arq: Architectural Research Quarterly* 8, no. 3–4 (December 2004): 204–14, doi:10.1017/S1359135504000259; “International Society of Fabric Formworking,” *International Society of Fabric Formworking - Research Papers*, accessed September 23, 2014, http://www.fabricforming.org/research_papers.html.

[2] Le Corbusier, *Towards a New Architecture*, trans. Frederick Etchells (London: Butterworth Architecture, 1989), 269.