The Formworker

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The Formworker

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Abstract

The **formworker** is an ideal for concrete creation where roles are blurred and the process of forming and casting concrete is not segregated through its stages. The concept is borne out of innovative research in fabric formwork where cross pollination of skills and concepts from the tailoring, fashion and textile industries are combined in the construction of concrete forms. To fully fuel the adoption of fabric formwork in the industry, to transform it from a proven yet novel research technique to a universally accepted formwork method, there is a necessity for collaborative thinking, linking each phase of construction, through design, formwork fabrication and casting. To that extent it is proposed that we need to consider a new producer, the **formworker**, one who conceives the final output by drawing on a detailed knowledge of the complete process from design to final cast form, and explicitly explores new technologies and methodologies. The paper presents an argument for acknowledging the role of the **formworker** through the evaluation of the methods and practices involved in recent and current research and practice into fabric formwork.

Keywords: Formworker, Fabric Formwork, Tailoring, Concrete, Disruptive Technology, Soft Logics, Tacit Knowledge, Lead User, Sticky Information.

1. Introduction

Fabric formwork has been the subject of much consideration over the last 20 years, there is now an established network of research, with a number of PhD dissertations, international conferences and the formation of ISOFF, the International Society of Fabric Forming. This work has shown that a flexible formwork is practical, can be more efficient in both formwork materials and concrete utilisation, can improve the physical qualities of concrete and can produce new, novel architectural forms. The work has been presented in many academic papers and state of the art reviews such as Hawkins et al [1], Veenendaal et al [2], and books, Chandler and Pedreschi [3], and West [4]. However, despite this there is a lack of take up by industry. Why is this? This paper considers the difference in processes of production inherent in flexible fabric formwork and compares this with conventional formwork systems.

We put forward the notion that a contributing factor for the slow uptake is that much of the construction industry is grounded in traditional technologies and practices and that it is naturally risk averse. There is an implied lack of control in the flexible nature of the fabric that presents a counterintuitive perception to the traditional techniques associated with concrete, namely the carpenter or metal worker, the steel fixer and the concrete squad. Typically, each trade works in sequence often disconnected from each other and with a separate sense of completion, such as the formwork itself, the assembly of reinforcement and, the concrete placement.

In the current use of fabric formwork often the work is completed by the same person or team from design, formwork production and casting. Work by designers such as Mark West, Kenzo Unno and Arrol Design demonstrate such a comprehensive approach and the distinction between design and production is blurred. This type of work follows a history of material innovation in architecture and construction through a close and direct involvement in design and construction exemplified by Pier Luigi Nervi, Felix Candela and Eladio Dieste, Pedreschi [5]. For example, the improbable looking La Gaviota (1976), by

Dieste, was constructed by his own firm and was the product of 30 years practice in building brick structures, Figure 1.

In the context of fabric formwork there is consequently a need to reconsider the process. The current working with differentiated skillsets embedded and involved in the design, development and construction of concrete elements needs to evolve to one where the process is seen as holistic rather than subdivided by traditional trade. In this paper we have defined the term '**formworker**', as someone who brings together the various skillsets and takes responsibility for the production of concrete form. There is a useful further comparison with the French designer of metal structures, buildings and furniture, Jean Prouvé who was often described by others as both architect and engineer, seeking to align his talents with their own professions, he was in fact neither. Trained as a blacksmith he came to describe himself as 'un constructeur'.


Figure 1: La Gaviota by Eladio Dieste

'*When any object needs to be made there must be 'a constructional conception' at the outset. One individual, the constructor suddenly sees it fully finished in three dimensions, He knows his materials and they have inspired him'* Jean Prouvé, Huber and Steinegger [6]

In fabric formwork constructions the flexible nature of the fabric creates particular interactions between the formwork, and the concrete, which can be modified adapted and controlled during casting, in an antithetical manner to conventional rigid formwork where the final form is predetermined by the mould. This does not imply that geometrical accuracy is not possible but ideally is specifically considered and designed for when conceiving the form. Fabric formwork thus disrupts conventional practice and hence is a disruptive technology.

This paper briefly considers some examples of projects from the University of Edinburgh through which ideas of fabric formwork can be explored. To date most studies of fabric formwork have evolved from the traditional architectural and building practice, adapting carpentry techniques to incorporate textiles. The second part of paper further explores the role of the **formworker** with more detailed study of fabric formwork through the lens of 'Soft Logics', taking the position of the tailor, as one skilled in cutting and assembling textiles as the key determinate of form through an extended study of prototype columns.

2. Fabric Formwork as a Disruptive Technology

The term disruptive innovation was first proposed by Christensen [7]. The characteristics of disruptive technologies are:

- They are typically cheaper, simpler, smaller, or more convenient than those established by the dominant technology.
- Traditional users often don't recognise disruptive technologies
- Traditional users often find it difficult to adapt to disruptive technologies

Another related concept that is relevant to disruptive technologies is the 'Lead User' as proposed by Von Hippel [8]. Lead users often develop their own approach to particular solutions differentiated from conventional or traditional processes, this in turns creates 'tacit' knowledge that makes it difficult to translate to other parties. Such information is 'sticky', difficult to transfer to those not experienced in the relevant techniques.

'An art which cannot be specified in detail cannot be transmitted by prescription, since no prescription for it exists. It can be passed on only by example from master to apprentice…' Von Hippel, [8].

A recent example of the disruptive nature of fabric formwork concerns a practical workshop with a major producer of conventional formwork systems. The second author, Pedreschi, together with Alan Chandler from the University of East London, were asked by the company to construct a demonstration wall at their premises as a means of developing and showcasing the techniques of flexible formwork. Based on previous work, Chandler and Pedreschi [3] prepared a design for a wall approximately 2.0 metres high by 3.0 metres in length.

A series of simple sketches, was prepared, from which the various components were dimensioned and key junction details and connections established, Figure 2. The formwork comprised one face consisting of a flat surface with a large bulge formed with a cut out in the plywood face. The other face was formed using polypropylene fabric tied back to the plywood using steel restraint rods to create a controlled undulated surface. It took approximately two hours to produce the sketches from which a detailed component list was prepared. With the assistance of two technical staff from the company the complete formwork including steel mesh reinforcement was constructed within 6 hours and cast the following day, figure 3.

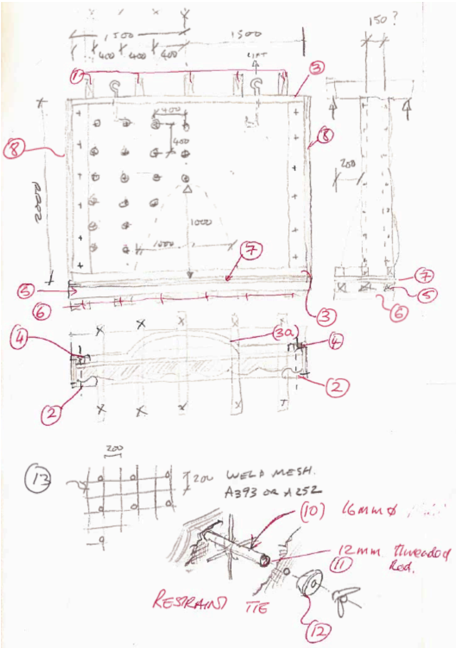

Figure 2: Example of design sketch

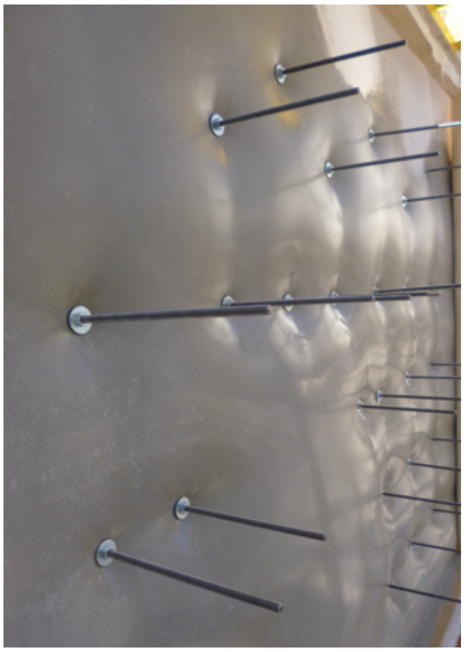

Figure 3: Wall and formwork after cast

Subsequently the company repeated the construction a few weeks later and the formwork failed during casting. The formwork was essentially the same with only a few minor changes. This exercise demonstrates clearly the disruptive nature of fabric formwork, the tacit knowledge of the lead user and the significance of sticky information.

A second example of the importance of being able to visualise the form and its execution are the panels created for the Fenchurch Garden for the Chelsea Flower Show 2009, developed by the authors in collaboration with Alan Chandler. This project required a total of 19 large pieces running horizontally across the garden and vertically in between pre-prepared vertical planting. Dimensional accuracy was important as everything, including the vertical planting was produced off-site. Yet the panels had to be differentiated from each other to ensure an ‘organic’ appearance. Design time was limited as the final layout was agreed only 6 weeks before the garden opened. Again, a simple generic construction sketch was prepared, figure 4, developed from an earlier prototype study. This was adapted to suit the predetermined dimensions of each piece.

The front and back of each formwork was determined using a series of individual plywood sections produced using a CNC router. The sides and intermediate ribs were produced using plywood fins over which fabric was draped. The curves of the ribs were developed by bending the plywood fins during casting. Vertical undulations along the length of were developed by changing the sequence of pouring, pouring in one section applies pre-tension to the rest of the fabric and hence allows variable articulation of form, Figure 5. This project demonstrates the opportunity to develop form during the process of casting and the disruptive nature of the process as the pieces would not have been possible to produce in the timescale using conventional rigid formwork.

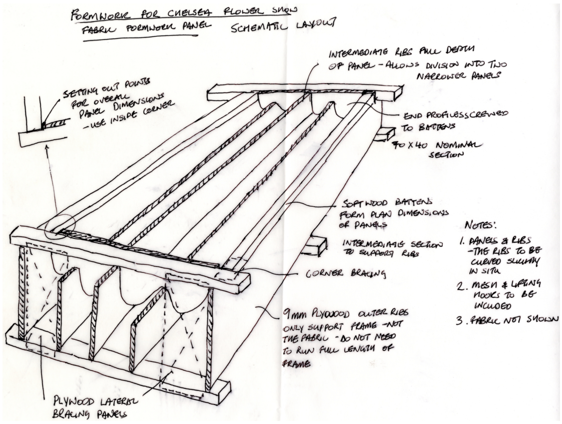

Figure 4: Schematic sketch of formwork

Figure 5: Concrete panels from RHS Chelsea

3. Development of 'Soft Logics'

The previous examples illustrate the use of fabric formwork as evolving from a more traditional construction relying on the use of carpentry in combination with textiles. 'Soft logics' suggests another approach, Barnett [9].

'If there is a logic of boxes, perhaps there is a logic of sacks. A canvas or jute sack ... is supple enough to be folded up in a sack with all the other folded sacks ... I believe that there is box-thought, the thought we call rigorous, like rigid, inflexible boxes, and sack-thought' Barnett [9].

This leads to an approach to fabric formwork, based primarily on the construction of textile. An example of this is the single cast fabric wall constructed by three Masters students, Chan, Bush and Powell [10]. Their study led to the construction of a large complex prototype wall with minimal carpentry. The final design was developed from a series of studies at progressively larger scales to understand and control the fabric, it's response to the concrete pressure and sequence of casting. The formwork comprised a single piece of fabric, folded and stitched to form a complex pattern of ribs and voids based on information obtained from previous studies. Figure 6 shows the layout of the formwork and figure 7 the completed cast.

Figure 6: Single piece formwork

Figure 7: Final Cast

The single fabric formwork was suspended from a metal form to ensure the correct overall height and position of the ribs. The sequence of pouring into individual ribs was prepared and mapped onto the formwork itself to ensure the correct pre-tension in the fabric was maintained.

4. Tailored Fabric Formwork

Following the last example, the idea of soft logic was developed further in a detailed sequence of prototypes. These were predicated in adopting a counter position to that of the carpenter, by considering techniques traditionally associated with tailoring and the fabrication of textiles. A limited series of tests was presented in an earlier paper Milne el al. [11] and more fully reported in Milne [12].

As a result of research into fabric formwork being grounded in the architectural and engineering community the language of construction and tectonics tends to follow the process. Terms such as 'form tie' and 'impacto', adapted from a rigid material practice, harking back to conventional formwork. As part of 'Tailored Fabric Formwork', Milne [12], there is an exploration of the language of concrete and it proffers that some of the descriptive words that are common place in fashion and textiles are much more akin and suitable for effectively describing the actions and goals of fabric formwork. These words can tell us much more about the process than the imposed language from the tradition of rigid formwork. Darts, seams, tucks, pleats and pinches seem much more kindred to the language of fabric formwork. The fashion industry's basis is shaping fabric to respond to form.

Of course, tailors and dress makers don't normally design concrete formwork and therefore need to learn new skills in making to understand the interaction between the fabric and the pressure generated by the wet concrete. Thus taking a mature technology, tailoring, and applying the transfer of knowledge to form a disruptive technology in the construction industry follows the thinking of the **formworker** where their collective oversight and tacit application of knowledge and expertise creates a new market sector catalyst within the mature market of concrete forming, disrupting the prevalent technology.

In response to the current state-of-the-art fabric formworks and for the purposes of this research the corresponding author has coined the term, *hybrid fabric formworks*. It is observed that the majority of fabric formworks require a significant amount of complementary rigid support in their formation. *Hybrid fabric formworks* is a term that is used to address fabric formworks that require supplementary or additional material, often in the form of an exoskeleton, be it rigid or not, over and above that of the basic textile formwork, to act in the process of form definition.

Here is where the paradigm of tailored formwork research is applied, by removing the exoskeleton and reducing any rigid support to its absolute minimum, can the fabric be tailored to constrain and form the concrete by itself? Will this encourage intuitive form creation? A tailored fabric formwork requires the most minimal rigid prop to be hung from and it presence is not read in the resultant form. All articulation and expression of the form is provided by the textile itself.

The methodology is adopted and adapted from the textiles and fashion industries, acknowledging expertise of the third author, (Director of Textiles, Edinburgh College of Art). Thus the study starts from the position of 'soft logics', rather than 'box' thought' approaching the discourse from an understanding of textiles and fabric processes. The fabric formwork is tailored to create the form in anticipation of the effect the pressure of the wet concrete will impose on the formwork.

In a tailored formwork, constraint is provided entirely by textile membrane. Such formwork is the minimum material solution for a particular form. There is no redundancy, that can be removed without loss of the intended form

5. Column Prototypes

The project then developed the concept of the **formworker** with Milne (Architect by training) embracing skills and techniques from textile design and production. A series of prototypes was developed to explore the effect of integral textile constraint and internal textile restraint on the form and expression of architectural elements.

A key developmental aspect explored with these prototype column forms explores symmetry. Creating controlled and intentionally asymmetric pieces as well as being able to produce symmetric pieces and exploring the animated interaction between the two.

The prototype production followed some simple geometric constraints to facilitate comparison of each of the cast elements. With the exception of some initial material studies, the fabric was consistent throughout. The overall dimensions were standardised, based on a cylinder 500mm tall and 150mm in diameter. Depicted below, Figure 9, are the nineteen prototypes numbered and shown in chronological order. They represent a logical progression as knowledge of tailoring, concrete casting and architectural from expressed through the **formworker**.

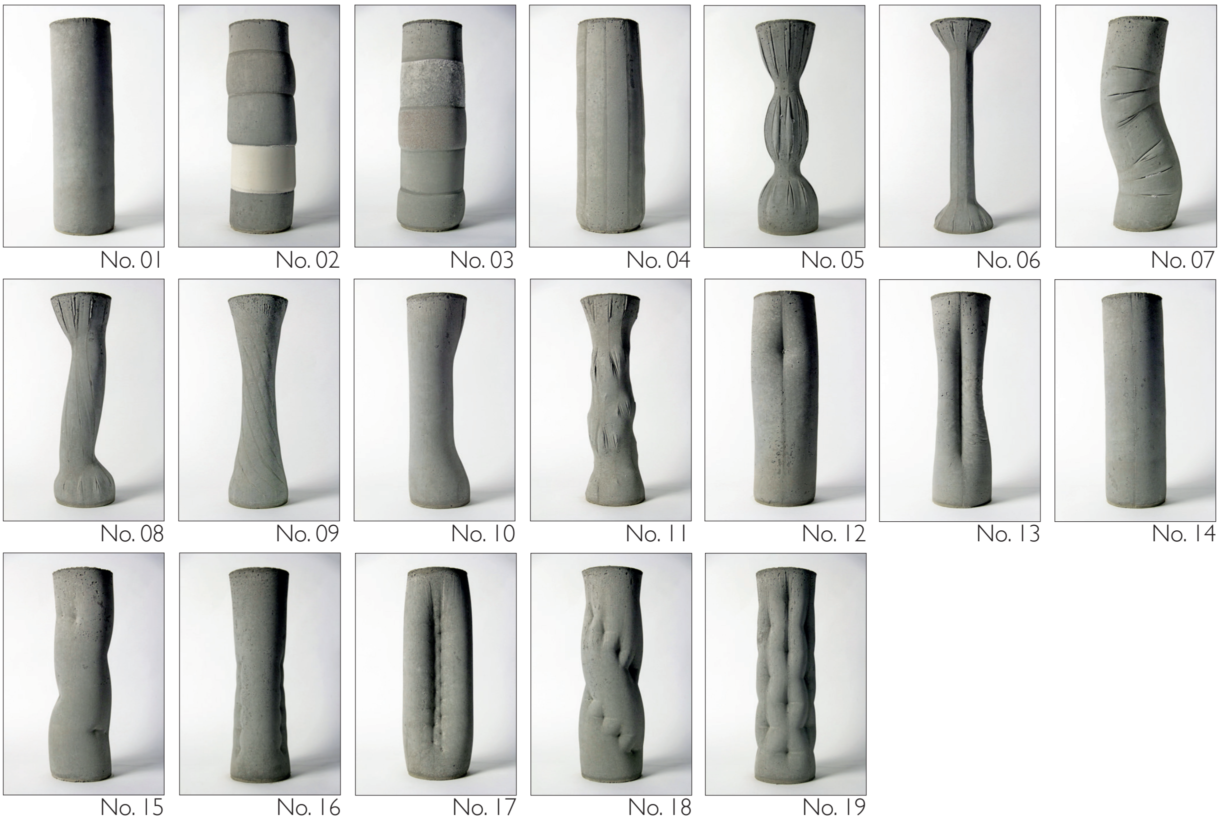

Figure 8: Nineteen scale prototypes from Tailored Fabric Formwork, Milne [12]

Thus, the prototypes draw knowledge from architecture, construction, textiles, tailoring and fashion. All prototypes show a consistency in production that leads to a clear expression of the tectonic approach. Embedded in the process is the tacit and 'sticky' knowledge to react based on the prior experience of concrete production. Neither architect, tailor, concreter, nor carpenter could produce these forms based on their accepted skillsets. Returning to Jean Prouvé's 'constructeur', the role of the **formworker** becomes clearer.

Prototype studies started with some simple textile formworks to act as control samples so that the developments of the programme of study are easily articulated and discussed. The first column cast, **No. 01** represents the control piece, where, by utilising the formula outline for the prototypes without any tailoring, the column creates a prismatic cylinder. In this cast the fabric automatically generates a circular cross section due to hydrostatic pressure. Three further columns, **No. 02 - 04** showed examples of the utilisation of multiple textiles, through formworks with a series of identical bands, each band using a different fabric. This examines the influence of fabric properties, such as stiffness and weave, its adherence to the concrete and the resultant concrete finish.

No. 05 – 11 dart series columns, previously reported in Milne et al. [11], apply darts as a method of developing the integral constraint. These prototypes study the effects of various cut and stitched patterns on column form. 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.

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 it reduces the circumference of the column at certain points. If this is applied asymmetrically it creates forms that twist and turn across the column's axis adding eccentricity. When applied horizontally it shortens the length of the vertical side generating curves and bulges.

No. 12 – 14 utilise internal textile restraint webs, Figure 9. The casts have great potential but there a few technical hurdles to overcome to fully exploit this opportunity. Identified earlier, hybrid timber and fabric formworks use external constraint which complicates the assembly of the formwork. A key innovation proposed in this research replaces exoskeleton constraint with internal restraint to simplify fabrication. Internal ties are pre-attached to the formwork as chords or webs. These remain embedded in the hardened concrete with fragments left on the exposed surface of the prototype. The study explored the use of a dissolvable fabric to eliminate this problem.

Figure 9: No. 13

Using a dissolvable fabric for the internal webs means that once the formwork is struck the remnants of the internal web can be dissolved generally by the use of high temperature water to leave a clean surface free from tufts of fabric.

No. 15 – 19, the pinch columns, introduce internal tension ties that restrain the fabric membrane, placing a restriction on its movement in precise locations with a pinpoint impression that cannot be replicated with external constraint, Figure 10. The work of these prototypes seeks to minimise the point of restraint so that it is perceived as a force acting within the concrete rather than as a force pressing on the exterior of the formwork.

Figure 10: No. 19

The nature of a woven fabric, the perpendicular cross weave of the warp and weft, allows for carefully instigated punctures of the surface without damaging the integrity of the textile. The most ubiquitous and simple example of this is the stitch, where a pointed needle opens one of the gaps between the yarns in the weave to allow a thread to pass through. This is then returned through the textile from the opposing side in the same manner repeatedly until you have a running stitch. This method can be used to join two sections of fabric together.

The pinch prototype columns play with this idea by carefully enlarging a gap in the weave to allow the passing of a thin nylon rope where the fibres are braided together. This rope construction allows for greater tensile strength than straight fibres or threads themselves. The punctures are strategically placed in anticipation of where the form will want to bulge in resistance of the concrete's gravitational and hydrostatic forces to create well defined and highly controlled forms.

Each of the nineteen columns explored different aspects of minimal restraint for concrete. In doing so knowledge from complementary industries is utilised whilst anchoring the output in recognisable architectural elements that have a functional use. It is this that really defines the **formworker**, applying 'soft logic' to a traditionally hard and robust material. The possibilities of tailoring as a formwork technique represent a disruptive technology; where it can provide a cheaper and simpler methodology to current rigid formwork construction. A significant amount of tacit and 'sticky' knowledge in a tailored formwork is moved upstream, off site, where the tailoring of the formwork is performed before the simple suspension of the form on site for casting, thus removing some of the risk factors involved in the process.

In a tailored formwork, constraint is entirely performed by the textile membrane. This constraint is not applied subsequently as rigid parts embedded in hybrid systems; it is inherent within the textile itself. A tailored fabric formwork is the bare minimum constraint needed to provide a predetermined form. There is no redundancy, nothing can be removed without failure of the formwork or loss of intended form.

6. Conclusions

Conventional techniques for concrete production are discontinuous with the form 'locked in' before casting, whereas with fabric the form can be altered during the casting. The nature of fabric formwork during the cast dictates that the form is yet to be decided and the actions and choices of the practitioner can have a profound effect on the outcome.

The traditional approaches to concrete castings are juxtaposed to casting with fabric formwork, where when the formwork reaches a comparable stage, the point at which it is ready to cast, the form may yet to be completely defined. The nature of casting in fabric requires the addition of liquid concrete to fill and interact with formwork, working in equilibrium to define the form. This automatically encourages a cohesive practice that requires a continuation of knowledge and input from start to finish, and which would likely be less successful with the current segmented practices.

This need for interaction with form, beginning with design all the way through to casting provides as positive argument that the **formworker** is not only the most suitable descriptive term but also the appropriate actor to make this a success, encompassing knowledge from complementary industries. The application of tailored fabric formworks allow the casting constraint to be taken to its bare minimum but this is only possible with a holistic approach to the process where the **formworker**, designs, fabricates and casts the element.

It is here where the paradigm of the **formworker** is at its most evident. Not only do they construct the fabric form but they must also understand, through practice, the nature of concrete mix design, placement and curing. Returning to the exemplars mentioned at the beginning of the paper, Nervi, Candela, Dieste and Prouvé, although they work across a range of materials through concrete, brick and metal they share an important common principle, complexity of form through simplicity of production. Consequently, their output is also noted for its economy. Through the 19 prototype columns presented two things are apparent: firstly, that the range of potential forms is extensive and it would be difficult to suggest an effective limit. Secondly the consistency of production of the prototypes is clearly the product of developed expertise and tacit knowledge with an evident simplicity in process. The transfer of the current research in fabric formwork will always be hampered without a shift in the current paradigm of discontinuous production and responsibility towards recognition of a new skill set implied by the **formworker**.

References

[1] W. Hawkins, et al., *Flexible Formwork Technologies – A State of the Art Review.* Structural Concrete 17, no. 6, pp 911-35, 2016.
[2] D. Veenendaal, M. West, and P. Block, *History and overview of fabric formwork: using fabrics for concrete casting,* Structural Concrete, vol. 12, no. 3, pp. 164-177, 2011.
[3] A. Chandler and R. Pedreschi, *Fabric formwork.* London: Riba Publishing, p. 87 pages, 2007.
[4] M. West, *The fabric formwork book: methods for building new architectural and structural forms in concrete.* London; New York: Routledge, 297 pages, 2017.
[5] R. Pedreschi, *Form, Force and Structure: A Brief History*, Architectural Design, vol. 78, no. 2, pp. 12-19, 2008.
[6] J. Prouvé, B. Huber, and J. C. Steinegger, *Jean Prouvé : prefabrication : structures and elements.* London: Pall Mall Press, p. 212 pages, 1971.
[7] C. M. Christensen, *The innovator's dilemma.* Boston, Mass.: Harvard Business School Press, 252 pages, 1997.
[8] E. v. Hippel, *Democratizing innovation*. Cambridge, MA ; London: MIT Press, 2006.
[9] P. Barnett, (2012), "Folds, fragments, surfaces: towards a poetic of cloth," in *The Textile Reader*, J Hemmings, Ed. London, Berg, pp. 182-190, 2012.
[10] T. Chan, R. Bush, and A. Powell "Single Cast wall," MArch project, Dept. Arch., University of Edinburgh, 2011.
[11] K. Milne, R. Pedreschi and L. Richardson, "Tailoring fabric formwork," in *Proceedings of the International Society Of Flexible Formwork (ISOFF) Symposium* IASS2015*,* Amsterdam, 2015.
[12] K. Milne, "Tailored Fabric Formwork" MScR thesis, Dept. Arch., University of Edinburgh, 2017.