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Concrete Form[ing]work: Integrating patterns in flexible formwork for cast concrete

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Abstract

This paper outlines the design methods in the research project Concrete Form[ing]work, and seeks to contextualize these methods within design research. First, it examines current design methodology in practice and situates this research within existing work. The second section provides an overview of ongoing and planned probes, while the third reflects on future uses and practice-based design applications. Concrete Form[ing]work explores the integration of smocking and cast concrete to investigate novel techniques for creating architectural elements (Figure 1). While traditional formwork for custom or sinuous concrete structures is often costly or impossible to fabricate, this research looks at numerous techniques to custom-tailor fabric for casting. These include traditional hand smocking as well as more recent research into custom knit structures that can react and transform in response to heat, water, or electrical currents. The integration of such methods advances new possibilities of design research and fabrication techniques with regard to what can be achieved with state-of-the-art fabric formwork. It also speculates on additional research that could introduce robotics and sensors to further explore issues of repeatability, scale, and economy.

Keywords

Flexible formwork, Concrete, Parametric patterning, Materiality, Digital craft.

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Introduction

Concrete construction has always defaulted to the economy and simplicity of rational, planar elements. Because of the ability to rationalize and evaluate planar formwork, and standardized assembly processes in the construction industry, efficiency in building has been valued over experimentation. Designers have chosen to default to what is "known" instead of re-imagining novel methods of using existing materials. With the technological revolution in the second half of the 19th century came a shift away from the fabrication of forms that were logical slabs, beams, and columns. Instead, construction methods developed expressive personalities of their own based on a material's characteristics. Designers began to recognize that such simplified elements did not use the material in the most rational means, but did not trust cost evaluations for these novel construction methods. Eladio Dieste, one of the pioneers of vaulting and thin shell concrete construction, expressed his concern of designers settling for fabricating planar elements because of the simplicity in testing and evaluation. While he recognizes that it is critical to have an analytical evaluation of construction methods and economy, he argues that simplification of construction is "unjustified," and that it is not enough of a reason to default to simple, economical structures in practice-based design research (Dieste, 2004).

Dieste argues that while architecture is a construction, it is also an art. An engineer himself, he looked to architecture and design to solve problems that were inherently structural. "For architecture to be truly constructed, the materials should not be used without a deep respect for their essence and consequently for their possibilities" (Dieste, 2004). There must be a relationship between rationality and expressiveness in order to achieve progress. By re-envisioning material possibilities and resisting the temptation to only build simple, economical structures, designers choose innovation over certainty. Over the next few decades, Dieste dedicated his life to the investigating the essence of materials and their mysteries and applied these economically. Keeping an artistic inquiry inherent in design, research raises new problems and research questions that would emerge otherwise.

Reflecting on the difficulties of testing and disseminating novel construction methods, designers and architects must continually develop evaluation methods for their research, particularly as new methods of fabrication evolve. Mette Ramsgard Thomsen and Martin Tamke note that inherent differences between architecture and engineering, as well as the varying levels of inquiry, require designers to develop more cyclical methods of evaluation. The recent advancement of digital machines and fabrication has shifted the means in which we conduct design research; we must create new methods in evaluating material evidence in relation to architectural practice. Thomsen and Tamke present three types of material evidence as means of evaluating research within our field: the design probe, the material prototype and the demonstrator (Ramsgard Thomsen and Tamke, 2009).

Because architecture is always embodied by the material, these three modes of material evidence allow architects to apply a dimensionality to a given design question and solution. While the design probe is more speculative investigation of design criteria, the material prototype explores the material behavior and extrapolates upon the criteria set up by the probe (Ramsgard Thomsen and Tamke, 2009). The demonstrator then builds upon this further, taking the wandering and sometimes fragmented prototyping process and applying real-world constraints to construct a more conclusive investigation. By arguing that utilizing the integrated approach of research by design and emphasizing the implementation of physical demonstrators, architects can aptly position their research to create a more cyclical and reflective connection between design, analysis, specification and fabrication

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Figure 1.
Cast concrete probes

(Ramsgard Thomsen and Tamke, 2015).
Coupling the understanding of materials with complex rather than static behaviors, we can work with the fears of innovation as observed by Dieste, and use demonstrators and full-scale architectural installations to realize new material practices. This reflection must also be used when evaluating the complex relationship between digital and the physical prototype. Material testing and probes must be developed simultaneously with digital models. Data from physical testing is used to inform the digital tools and in turn, the digital models help develop an understanding of material behaviors and structures not achievable by prototypes. What is critical is that we must verify our computational models by simultaneously developing both physical and digital tools in order to evaluate the appropriateness and precision

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of our experiments. Figure 2 shows a comparison between the digital model of CITA's Dermoid and final scan of the demonstrator. Even after fabrication is complete, reflection on the validity and precision of the digital model is vital.

Embracing Materiality

After examining the design methodology as outlined by Dieste and Thomsen, it is possible to more critically question traditional concrete formwork. Design research by architects and engineers such as Mark West, Remo Pedreschi, and Alan Chandler look to merge the process of, making as a craft, with the importance of delivering a precise form in industry. As noted above, contractors are reluctant to embrace techniques outside conventional rigid formwork because of a lack of precision and predictability. Projects such as West's beams, Chandler's Wall One, and Pedreschi's Kate Moss column (Figure 3) utilize flexible formwork to incorporate both an expression of materiality of concrete while simultaneously adhering to an acceptable manner of repeatability and reliability (West, 2017; Chandler and Pedreschi, 2007). Their experimental applications of flexible formwork to construct traditional architectural elements such as beams, walls, and columns investigate what aspects of these elements need to be precise for industrial applications, and those that have the possibility of being be more unpredictable and dynamic. This delicate balance is achieved through simultaneous physical experimentation and informed intuition of material behavior.

These projects utilize fluid-responsive formwork as casting techniques to allow the engagement of materiality and rheology within the construction process, and re-envisions the workers' role to be much more active in the design. Upon embracing the inherent rheological qualities of concrete rather than constraining them to rigid formwork, the material and fabricator are allowed to take an active role in the more dynamic casting process.

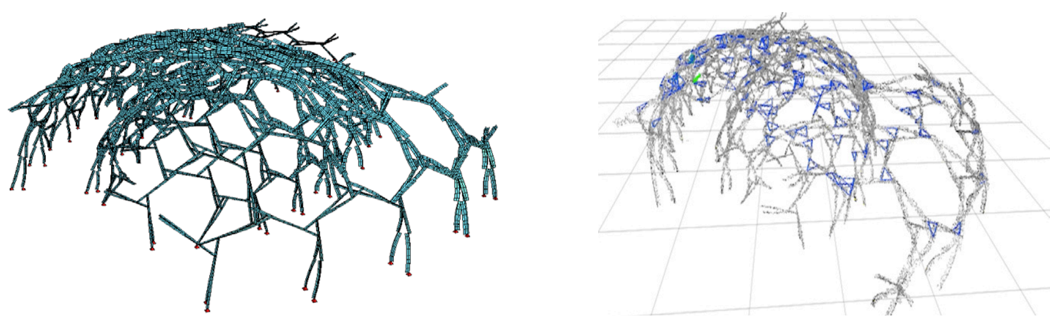

Figure 2.
Comparison of Dermoid digital model and scan, CITA

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Figure 3.
Traditional concrete elements constructed from fabric formwork by A. Chandler, and R. Pedreschi
Image: Dirk Lellau (left), Remo Pedreschi (right)

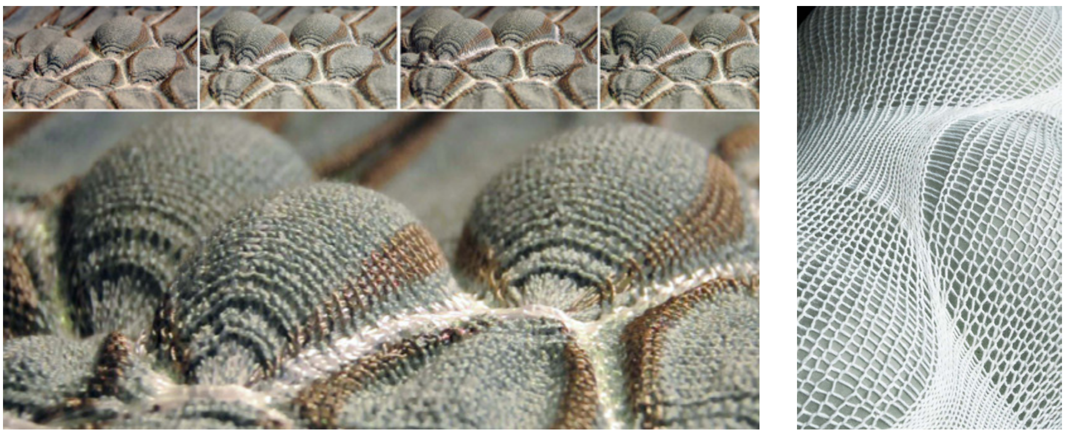

Figure 4.
Mette Ramsgard Thomsen's *Listener* and Yuliya Baranovskaya *Knitflatable Architecture*
Image: Mette Ramsgard Thomsen (left), Yuliya Baranovskaya (right)

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In addition to a more interactive fabrication process and expressive final form, fabric formwork evokes drastically different possibilities for construction, inherently sustainable in both material usage and formwork cost. Mark West's points out the material waste in standard, cross-section beams, and demonstrates that fabric formwork can be used as an easily-deployable, low-cost solution to manufacturing variable sectioned elements. Material density, strength, and durability of the cast object increases as a result of excess water allowed to wick through the pores of the fabric. Furthermore, portability becomes an option. Materials can be fit into duffel bags that can be easily transported for efficient, on-site deployment and later re-used for future projects (West, 2017).

Projects such as Mette Ramsgard Thomsen's *Listener* and Yuliya Baranovskaya's *Knitflatable Architecture* (Figure 4) take textile research one step further, examining the implications of programming material with inherent, varied elasticities and material properties. Envisioning these coupled with cast concrete, fabric textures and seams could leave their own trace on the form and articulate structural mass and depth with sinuous bumps and bulges. When pressure is applied to this differentiated material, either hydrostatic or pneumatic, the once-flat pattern is transformed into a complex, differentiated volume. By differentiating areas of varying elasticity, these techniques can be coupled with flexible formwork for concrete, allowing the hydrostatic pressure of the material to act as both a form finder and form giver.

Smocking

In an effort to integrate current fabric formwork research with more specified material differentiation as seen in *Listener* and *Knitflatable Architecture*, *Concrete Form[ing]work* investigates patterning techniques to formally manipulate flat sheets of fabric. This project examines smocking (Figure 5), a embroidery technique of gathering fabric to increase elasticity, and questions how this technique can be applied to differentiation of fabric formwork. Used in the absence of elastic, smocking refers to the gathering and stitching together of fabric in a wide variety of patterns, commonly used in clothing applications for cuffs, necklines, and waistlines. It reduces the size of the fabric to roughly one third of its original size, and these techniques can be applied to flexible formwork to specify varying areas of elasticity as well as differentiate global geometry.

Research Development

In order to better understand this process and potential architectural applications, a series of smocking patterns were produced by hand. The jersey cotton fabric was laid out on a grid and points of connection were marked with a felt pen. These areas were hand-stitched with a cotton thread to create a variety of different textures and forms, a few of which are exhibited in Figure 6. Some patterns proved to have too complex of folds or overlapping to allow the cast concrete to easily flow and were discarded. In partnering with the The Swedish Cement and Concrete Research Institute, a SCC (semi self-consolidating concrete) mix was developed with a 600-650mm spread. This mix comprised of a ratio of 1:1.2:.5:.4 (cement: fine aggregate: L 40 Lime: Water) with an additional 0.1% VMA and 0.1% superplasticizer. Limestone counteracts the tendency of particles to separate with the addition of the Superplasticizer (Master Gelenium 51), which increases fluidity without adding more water to the mixture. The VMA (viscosity modifying agent) is used as a starch to produce a homogenous composition and maintain cohesion. All of these modifications to the mix allow for fluidity and strength, while also producing a more durable and economically sustainable cast. This mixture will continue to be developed, based on the rheological needs of each particular smocking pattern and construction.

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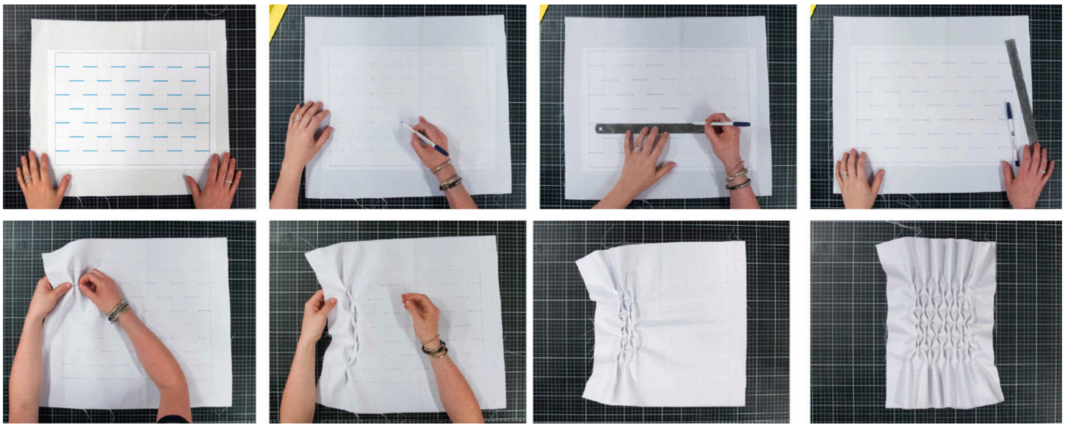

Figure 5.
Smocking technique

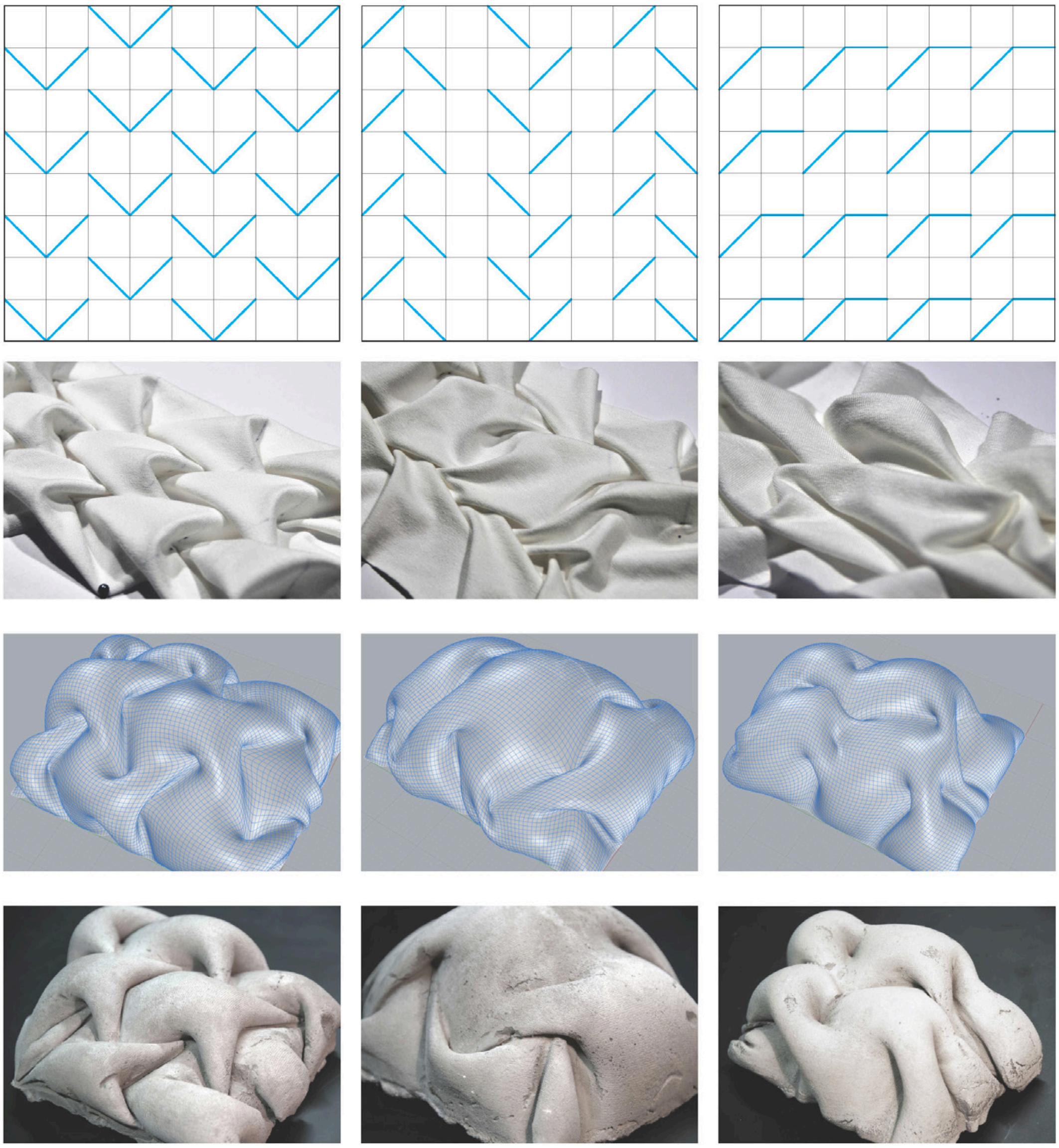

Figure 6.
Smocking patterns of "arrow," "leaf," and " fish scales," respectively in addition to sewn fabric, digital simulation, and final cast

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This research is currently in the process of creating a catalogue of potential smocking techniques that could be used in this manner. After rigorous testing of the application of smocking to two-dimensional surfaces, the next steps will apply these patterns to architectural tectonics, as investigated by West, Pedreschi, and Chandler. Looking at the application of smocking in the form of beams, columns, and walls brings a greater understanding as to how these techniques could be applied to architectural elements. This learning through fabrication technique will undoubtedly produce a series of unforeseen results, which will inform the design decisions that must be made, when scaling up and adding multi-dimensionality to global forms. Such parameters could include:

- concrete slump under larger weight and hydrostatic pressures
- fabric selection to avoid connection breakage
- improvement and specification of rheology of the concrete mixture
- evel of detail that can be achieved without cracking of concrete
- parameterization of patterns
- application of smocking for both ornamentation and topology

METHODS OF EXPERIMENTATION

During this experimentation, a series of research questions were developed:

How can fabric formwork be re-envisioned through smocking to create novel casting techniques?

How can smocking be parameterized and differentiated to articulate new methods of fabricating architectural elements?

What are the opportunities for applying smocking at multiple scales, and how can this be transferred to an industrial context?

In developing these questions, it is critical to specify and reflect on how current methods of experimentation are carried out and evaluate their relation to the research questions at hand. Peter Krogh's "Ways of Drifting" describes an applicable series of research methodologies that can be used to evaluate experiments carried out to test a hypothesis. He describes a few methods of "drifting" for designers to evaluate learning from findings: accumulative, comparative, serial, expansive, and probing (Krogh, Markussen and Bang, 2015). When looking at *Concrete Form[ing]work's* methodology, the most logical means of experimentation lie somewhere between comparative and serial (Figure 7).

The *comparative* typology, as developed by Fogtmann and Ross, explores a number of cases to evaluate results in an overarching comparison. It involves testing central design cases in both identical and wide ranges of design context. The application of such typology results in exposing the complexity of an experiment by applying the design scenario in a multitude of situations (Krogh, Markussen and Bang, 2015). The application of smocking to a variety of architectural typologies will take this comparative approach.

Serial experimentation compliments the comparative method, where this "denotes how design experiments are being carried out in a certain order or logic of locality determined by how neighboring experiments in a sequence influence one another" (Krogh, Markussen and Bang, 2015) This chronological approach continually builds upon the previous experiments and "systematizing local knowledge." While a portion of *Concrete Form[ing]work* will be comparative, this serial typology is

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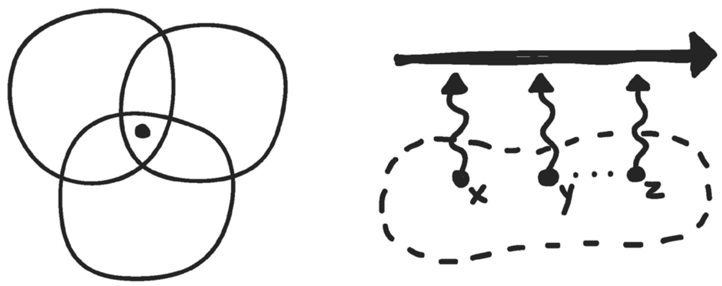

Figure 7.
Comparative and serial typologies as outlined by Krogh

also useful in evaluating the value of each experiment. New constraints and unknown discoveries will come about as more fabrication experience is amassed, and this will aid in determining the feasibility and fabrication of complex smocking patterns on multiple scales. Over the course of this research, fabrication intuition will be improved and tuned, and further experimentation of smocking's relation to concrete rheology and materiality build upon previous results.

These methods of "drifting" are not the only means of assessing the value of experimentation. It is important to view a research hypothesis as provisional and changing. The critical aspect is how the hypothesis evolves; being certain to learn from careful and methodical, rather than unsystematic, experimentation. Whether experimentation is conducted with one of Krogh's typologies or is simply an isolated probe with a novel approach, evaluation changes over time and often includes post-rationalization. What is most important is the rigorous process in which a designer must compare experimentation and research questions, and consistently check to make sure the two correlate.

CNC Knitted and Smart Textiles

While fabric formwork with concrete has evolved in the last half century, there has been very little experimentation with differentiation of materials. The past few decades have shown a huge increase in the fabrication of smart-textiles that are "augmented with the power of change and have the ability to perform or respond" (Verbüken, 2003). With the aid of computing technology and CNC knitting machines, it is possible to integrate "smart" materials with textiles (Figure 8, 9). This can, in turn, question the current research into fabric-cast architectural elements.

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In a partnership with KTH, The Swedish School of Textiles in Borås has been investigating novel methods of developing interactive textiles, with an emphasis on various interactive expressions such as water, heat, electrical and touch reaction. With the use of industrial weaving and knitting machines, there is the possibility of fabricating more complex, reactive formwork that could open a new realm of possibilities when working with cast concrete. Such exploration could include a blend of a base material and reactive materials such as:

- PVA: a fabric that dissolves when in contact with water
- Pemotex: a material that hardens when heat is applied
- Polyester or nylon blends that shrink when heat is applied
- Nitinol or Flexinol integration that actuates or shrinks when heat or electrical current is applied (Satomi, 2014)

These shape-changing materials could change traditional design to fabrication methods to one, which is interactive and iterative throughout the casting process. Formwork could be pre-programmed to harden or shrink, when it comes into contact with the moisture of the cast concrete. After a form is cast, heat or electrical current could be applied to continually sculpt the formwork even after the concrete has been poured. The exploration of textiles that have pattern differentiation with structure-changing properties, whether it be shrinking, stiffening, dissolving or actuating, could have significant architectural and industrial applications. These untapped possibilities will be explored in the coming year with KTH's partnership with the Swedish School of Textiles.

Robotics and Industrial Applications

The added complexity of integrating smart textiles brings up the question of industrialization and mass-production. Currently, these material probes are sewn by hand, in order to develop an understanding of smocking patterns and their fabrication. While analog experiments are vital to a significant understanding of material behavior, it is important to critically question the industrial applications when working with these techniques on a larger scale. More rigorous testing of hand-fabricated elements will uncover the limitations of what is possible to fabricate with smocked formwork.

Arcane knowledge of fabrication with industrial robot arms previously belonged to specialized engineers. This recent transfer of this knowledge and accessible interfaces has allowed architects, designers, researchers, educators, and artists to take up their own robotic projects within the creative industry. Robotic arms signify a new type of tool and a possible shift away from a conventional linear workflow. Previous conventional workflow was linear - design to fabrication - in which robotics were simply used in the fabrication of a predetermined design. With industrial robot arms, we can see the emergence of bi-directional workflows that supports the possibility of designer-robot-interaction. Figure 10 catalogues some recent uses for industrial robot arms and demonstrates the huge breath possibilities for their use in architecture.

While there are a huge range of existing applications for robotics, it is important to view a robot as a tool with limitations. That being said, it can be used in conjunction with *Concrete Form[ing]work* to develop processes that might not be possible by hand. Robotics could be

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Figure 8.
Pemotex hardening with heat, M. Bobeck, shrinking textiles at the Swedish School of Textiles in Borås, and integration of heat-shrinking thread in custom-knit textiles, D. Dumitrescu and A. Persson
Image: Malin Bobeck (left), Delia Dumitrescu (right)

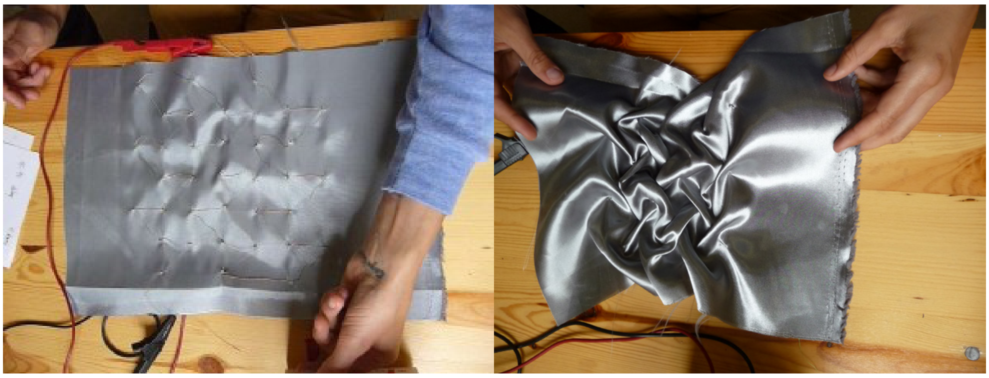

Figure 9.
Reversible Nitinol actuation with textiles (E-textile summer camp)

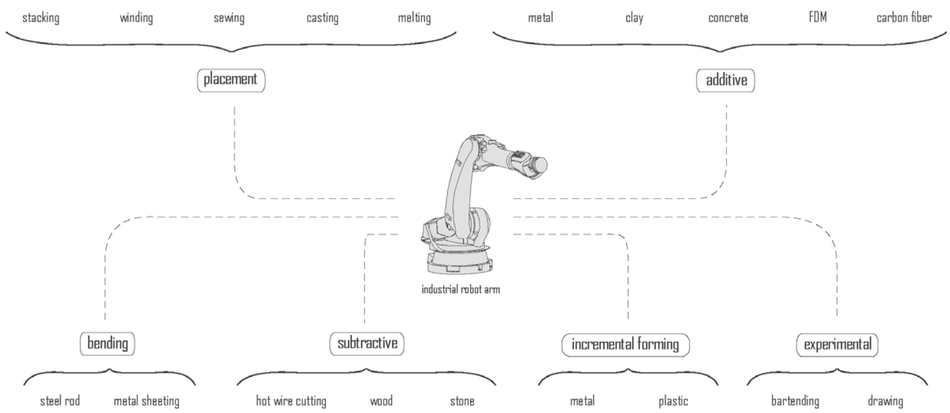

Figure 10.
Robots in architecture applications

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integrated in a way to take advantage of its precision, whether it is creating an industrial smocking technique, or using the robot to sense and accurately apply heat or other inputs to manipulate both local and global geometry to a cast form.

Conclusions

Through these design explorations and considerations, *Concrete Form[ing]work* seeks to evaluate existing casting techniques and re-envision these in the context of smocking, smart textiles and robotics. While current flexible formwork mainly focuses on simplicity of form, the introduction of CNC knitted textiles can bring about a similar ease of fabrication, as well as introducing local and global articulation. Varying scales of smocking applications, and the exploration of parametric patterns will produce a new vocabulary of spatial structures possible with flexible formwork.

With the possibility of integrating heat, touch, or electrical responsiveness, this research challenges conventional workflows of design to fabrication by employing a more iterative and interactive production process. A new method of making enables the fabricator to take an interactive role in the design of the form, rather than producing a product according to exact, pre-determined specifications. This participatory fabrication process allows the capacity to maintain craft while applying flexible formwork to industrial contexts. Furthermore, the correlation between probes and digital simulation augment this transition to industry, enabling fabricators to have confidence in the validity of their models and a reasonable amount of predictability.

The ability of flexible formwork to both express gravity and materiality of concrete, coupled with the increased predictability for industrial applications, is largely unexplored in architectural research. *Concrete Form[ing]work* fills a niche of articulated surface differentiation, while simultaneously addressing issues of repeatability, scale, and economy. Coupling reactive formwork and expressive materiality of concrete exposes a myriad of new possibilities of fabric cast forms and seeks to blur the line between where design ends and fabricator begins.

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