DRESSMAKING TECHNIQUES FOR PNEUMATIC FORMS

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Abstract: This paper explores a process for digitally designing doubly curved geometry out of flat textiles. The development of computational modeling techniques, such as NURBS and sub-division modeling, has made it easier to create complex curvature in the computer. Yet fabrication methods and materials are still catching up on the ways to fabricate these types of complex geometries, particularly when working with woven textiles that have little or no stretch. These doubly curved surfaces are typically achieved by complex panelization patterns that can closely approximate the curvature. For this research, complex panelization is exchanged for more simplified patterns and articulate sewing techniques as a new way to create curvature. Inspiration for working with shaping textiles is drawn from the traditional craft of dressmaking, in which two-dimensional fabrics are cut and sewn in different ways to fit around the curvature of the human body. These techniques from dressmaking also allow for other decorative qualities to emerge from the fabric manipulations. The project uses computational modeling software from the fashion industry for its integration of these sewing techniques into a three-dimensional digital design environment and seamlessly output patterns for production. This project explores the possible use of these programs and workflow for architectural pneumatics design. The results are compared to the computer designs to better understand the deviation between the digital and physical models. Three prototypes are created, that each explore different techniques as a test set. They use various manipulations of the techniques to study their possible advantages to create shaping. The goal is to adapt the techniques and computational tools from the discipline of dressmaking, developing a new workflow to designing complex curvature on architectural pneumatic membranes.

Keywords: Computational design, fabrication, pneumatic, membranes, sewing

INTRODUCTION

Pneumatic structures reached a high level of popularity in the radical architecture of the 1960's, and has continued to fascinate architects as seen in a recent publication *Bubbletecture: Inflatable Architecture and Design*; the book highlights art, industrial design, and of course pneumatic architecture (Francis 2019). Perhaps this new interest is because of computer modeling and the three-dimensional forms that these NURBS and Sub-division modeling can easily produce. The geometries of so called *blobitecture*, that is curvy and bulbous, is possible to build with some pneumatic membranes. Pneumatics are also light weight which provides reduction in carbon footprint as they are easy to transport and build, though they have different construction constraints than typical architecture. They can be sewn out of two dimensional textiles, which is in contrast to the desired resultant form of the double curved geometry. Fabric manipulation techniques from dressmaking, such as pleats, darts, and gathers; are used on dresses and clothes to create shaping around the curved forms of the body. Dressmaking is traditionally a household feminine practice, which is perhaps why it has yet to be much explored as a possible approach to architectural design. Three-dimensional CAD-CAM software for fashion design offers new computational methods for integrating the dressmaking sewing methods and pattern making techniques into the architectural design process. Utilizing Clo3D, as a tool to design and integrate sewing techniques for approximate double curvature on architectural pneumatic structures, can allow for a workflow that dialogs back and forth easily between the pattern output and the simulation of the three-dimensional design. The goal is not to create a complex pattern of panelization pieces but to create simple panels which are sewn in different ways to create this curvature. As a result, they are not smooth minimal surfaces but with desired decorative expression of the fabrics' materiality. Three prototypes were created to explore various techniques of sewing darts, pleats, tucks, and gathers (figure 1). The results are analyzed for their details and a side by side comparison of similarity between the physical to the digital simulations, to get a better understanding of the deviation in the results. The potentials of these techniques are in their early phases, but they ultimately explore a new, novel approach for integration of techniques from the discipline of dressmaking into the workflow and fabrication of architectural pneumatics.

Figure 1: Detail photos of prototypes. (Author 2019)

1. PNUEMATICS

1.1. HISTORICAL CONTEXT

First records of inflatable structures begin with hot air balloons from the mid-eighteenth century in France, reaching a large popularity in the 1960's with speculative designs by radical groups such as Archigram, Ant-farm, and Utopie (Topham 2002). These architectural activists hoped to reject the hard concrete of Brutalism with new softer materials that were temporary, mobile, and ephemeral. In 1967, The University of Stuttgart, Germany, held the 1st International Colloquium on Pneumatic Structures between May 11th and 12th (Dessauce 1999). Shortly after in 1968, Utopie's *Structures Gonflables* exhibition took place in Paris. The 1970 World's Fair in Osaka, Japan, was an exuberant display with several pneumatic structures, including the Fuji pavilion by Yutaka Murata and Maroru Kawaguchi (Mclean 2015).

1.2. CURRENT INTEREST IN PNEUMATICS

Although there has been some lasting interest in pneumatic design, it hasn't seen the same exuberance of the 1960's. Walter Bird continued to develop his designs from the 1960's with his company Birdair Structures Inc. in Buffalo, New York. He developed many large free span structures with pneumatics, often for pools, tennis courts, and military buildings. In the art world, artist like Yayoi Kusama playfully utilized brightly colored polka dot inflatables in her work (Topham 2002). For these same playful qualities, architects such as Atelier Zundel Cristea have adapted the use inflatables for their temporary structures (Cristea 2016). Other qualities, such as the ephemeral light that can penetrate through a fabric membrane, have been explored in the pneumatic structures of Architects of Air and Pnuehaus (Francis 2019). There are some architecture firms exploring pneumatics for their reduced amount of material, which can be more sustainable than traditional building methods, as it reduces carbon footprint during transportation, construction, and overall material consumption. Furthermore, because of the fascination with new technology, contemporary architects are using computer aided parametric design software such as Grasshopper and Kangaroo to aid in the design of paneling systems for pneumatics. But much of the design process is ultimately dependent on a feedback loop between prototyping and digital design (Thomsen 2019). The time and energy to make prototypes as well as the use of lots of materials in the production of failed design tests is a wasteful process. In addition, much of the research is still focused on form finding and optimization of paneling to create smooth membranes. For example, *Inflated Restraint*, a project by CITA, explores a free-form membrane and a minimal cable restraint. The project utilizes Kangaroo for Grasshopper to create new panelization patterns for performance of a smooth membrane. (Thomsen 2019).

1.3. TECHNICAL CONSTRAINTS OF PNEUMATICS

Pneumatic membranes are fully in tension. Frei Otto studied soap bubbles, which are pneumatic membranes, for their form that naturally evenly distributes the pressure across the membrane and forms a sphere (Dent 1972). This distribution of pressure forces the material out from the center and shapes the membrane into a circle in cross section. For example, given a cube that is inflated, the cross sections would push out evenly and attempt to achieve a circle in shape (figure 2). This means that pneumatic structures made from two-dimensional woven fabrics are being evenly pressurized and they will always try and achieve a double curved surface. The result is that non-stretch fabrics will have points where there is high pressure on certain parts of the fabric and others with less pressure, resulting in the high pressured fabric being in tension and wrinkling in other parts where the fabric is more lose. This is controlled by the exactness of the patterning and panelization to the desired curved form. As a result, instead of trying to hide these effects, this research allows the material to express these types of forces by encouraging moments of smooth, highly tensioned fabric and allowing wrinkling. These elements expressed on the surface can potentially be decorative and ornamental.

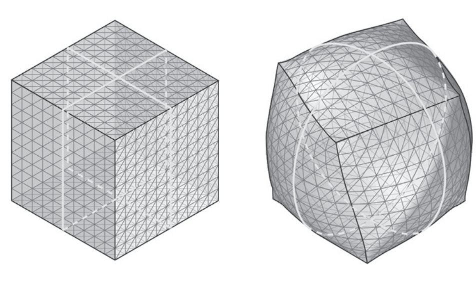

Figure 2: Simulation of inflated cube showing cross sections. (Author 2019)

2. DRESSMAKING

2.1. HISTORICAL CONTEXT

Dressmaking methods have changed over time with different fashions, styles, and development of new technology, but the basic techniques of manipulating fabric to form over the curvatures of the body for fitting remain the same. Dressmaking has also historically been feminine work and was one of the few early careers available for tradeswomen in the mid-1800s (Gamber 1997). Often, this relationship to femininity has made the craft in dressmaking something that is overlooked in research and history (Burman 1999). Moreover, dressmaking in particular has the potential as being relevant to architectural design for pneumatics, but perhaps has yet to be discussed partially, because of the low percentage of female representation in the field.

2.2. TECHNIQUES

Darts are used to fit fabric around the curves of the body (Talbot 1943). Triangular or diamond shaped slits are cut into the fabric and sewn back together forming the two-dimensional fabric into a three-dimensional shape. This technique is often used around the bust, hips, small of the back, or on necklines to create a concave fitting (Talbot 1943). For example, in a fitted block dress, a few darts at the small of the back, the neck, and in the torso area transform simple cuts of the fabric into a fitted waistline, while allowing more fullness in the bust and hips (figure 3).

Tucks also control the fullness of the fabric by, instead of cutting away fabric, folding and stitching parallel lines to reduce surface area (Talbot 1943). This is more decorative and can create thickness and structure in areas as well. Tucks are often seen on delicate sheer fabrics, such as in undergarments, necklines, yolks, and on blouses.

Pleats are often used to create dramatic contraction and expansion of fabric for skirts. Pleats fold the fabric over itself in small repeating layers. There are several different types of pleats depending on how the fabric is folded, for example, knife and box pleats (figure 4). Top, middle, and bottom layers, can overlap at varying amounts. The most common pleat is the full pleat, where all the layers are folded to the same length (Shoben, 1980). Some pleats are given a top stitch to emphasize the folds or keep the folds together for a length down the fold.

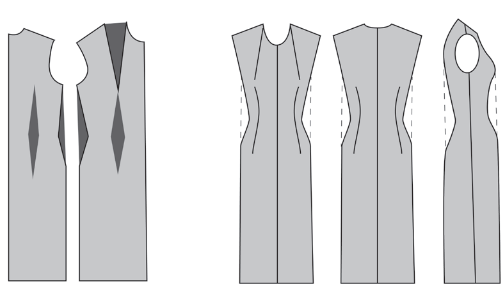

Figure 3: Fitted dress made with darts. (Author 2019)

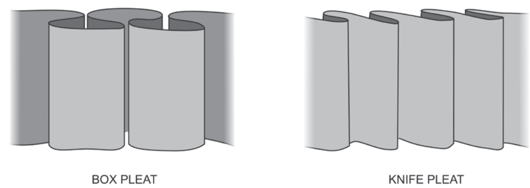

Figure 4: Diagram of knife pleat and box pleat. (Author 2019)

Gathering is used to create fullness, by sewing a longer fabric to a shorter piece of fabric. A running stitch is sewn through the fabric. The thread is then pulled to bunch the fabric up along the stitch until desired length is achieved to match the shorter piece of fabric (Talbot 1943). This technique results in a softer ruffled look, compared to the ordered layering of pleats (figure 5). This is also often used on skirts, necklines, and on puffed sleeves (Talbot 1943).

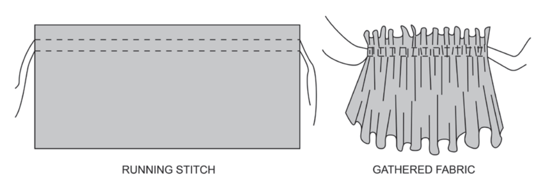

Figure 5: Diagram of gathering. (Author 2019)

Ruching is a type of gather that bunches fabric along a stitch line but in the middle of the fabric rather than along a seam. It can also include elastic to have more flexibility for movement. Ruching creates fullness and can be used more decoratively such as on the bodice of dresses or to create modesty on typically tight fitting clothing such as bathing suits. It can be sewn in repeating parallel lines to create texture and visual appeal.

2.3. DIGITAL TOOLS

Computational modeling has been integrated into the fashion industry; these types of three-dimensional modeling software open the possibilities for faster design and streamlined production. There are several software available such as: Browzwear, Vstitcher, Clo3D, Marvelous Designer, and more. For this project Clo3D was used. Each program has many similarities.

They are based on CAD-CAM modeling, utilize mesh modeling, and they have built-in physics simulations to allow for previews of the designs with real world material properties and forces. The physics simulation is more specific to the textile industry than that of Kangaroo or MAYA, as there are preset fabric properties to apply to the simulations. There are also many environmental simulations such as gravity and wind that can be applied. There is also a feature to add pressure to simulate inflation, which is useful for designing pneumatic forms. Furthermore, there are built-in ways to visualize the stress and strain on a material. This is integrated into the program to get the fitting correct but can also be used to explore the pressure points on a pneumatic model. The necessary tools to create sewing, earlier discussed techniques such as pleats, tucks, darts, and gathers are integrated into the program to make the workflow of dress designs easy. The program works in a two-viewport mode, where you can simultaneously preview the three-dimensional simulation and the two-dimensional pattern (figure 6). While using Clo3D, it is useful to have experience and understand pattern making and three-dimensional digital modeling, as well as knowledge of how paneling techniques and unrolled geometry relate to three-dimensional models. The two viewport mode also allows for a seamless back and forth workflow, where you can edit the pattern and the three-dimensional model changes in response. This creates a design method where the pattern is not just an output of a three-dimensional design but can be the source of the design. Nevertheless, these tools and techniques can create a new approach to the design methodology of pneumatics.

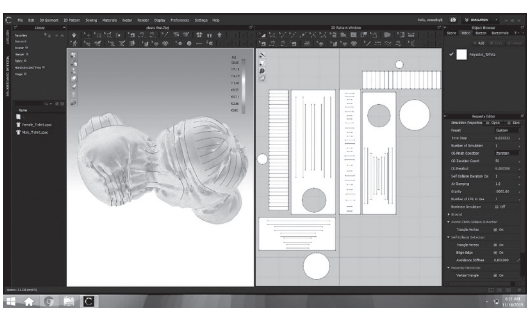

Figure 6: Image of Clo3D. (Author 2019)

3. GOALS

3.1. SIMPLE PATTERNS COMPLEX SEWING

Through a set of three pneumatic prototypes, a few ideas are explored. Mainly reducing the need for complex pattern generation but adding the more articulate sewing techniques from dressmaking, just a few rectangular sized pieces of fabric and circles to close the ends were used to generate the designs. Each of the prototypes focuses on only one type of dressmaking technique at a time (figure 7) to allow for experimentation in size, spacing, and execution of the technique. The manipulation of these can result in different effects on curvature and form. Clo3D allows you to work from the pattern so most of the design came from the pattern design and the three-dimensional result was not predetermined, but a result of the play of the variations in stitching. Moreover, by adapting dressmaking techniques to architecture, the hope is to ultimately create more expressive qualities in the fabric rather than hiding it and developing a new aesthetic quality for pneumatic designs that challenges the typical approach of smooth membrane structures. Finally, through this process a new workflow is developed by using the three-dimensional computer software, from the fashion industry, from digital design, to simulation, to pattern, to physical models, without the need for several prototypes, creating a new streamlined process. The physical prototypes are compared with the computer simulations to see how closely the final results are to the software simulations, to get a better understanding of the success of this process.

4. PROTOTYPES

4.1. DARTS

The first prototype explores darts as a way to generate and shape through convex forms. The pattern created uses eight pieces of fabric, four rectangles and four circles. The darts are explored differently in each of the rectangular pieces of fabric to test the possible results and the forms that can be generated. One of the larger pieces uses triangular edge darts and they graduate in size to see the effect of asymmetry (figure 7). I had predicted that this would create a twisting effect, but it did not. The other larger piece uses diamond shaped darts in the center of the fabric lined in a row to create a pinch in the middle and bulging at the sides. This effect was successful and reflected the appearance of the simulated model. The smaller pieces explore both edge

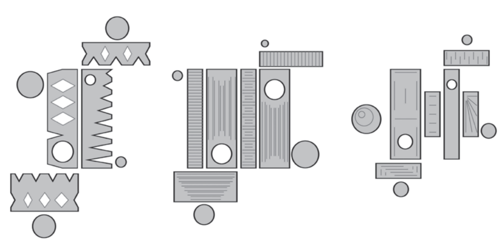

Figure 7: Diagram of pattern designs for the pneumatic prototypes. (Author 2019)

darts and central darts, with different spacing and sizes. Since darts do not have much overlap in the fabric or create too many wrinkles, the resulting model appeared mostly smooth, although at the points of extreme curvature, the darts on the fabric appear to bunch a bit and perhaps the prototype is not as smooth as a more panelized model. Perhaps working with smaller darts would produce a more refined approximation of curvature (figure 8). The shape seems boxier as the fabric is approximating the curvature through the air pressure forcing it from the center to a circular curve in section. Overall, the general form of convex and concave curvature is successful at creating complex curvature from a few pieces of fabric.

Figure 8: Pneumatic Darts Prototype. (Author 2019)

4.2. PLEATS AND TUCKS

The second prototype explores pleats and tucks. The pleats fold the fabric into three layers, thus the design is dependent on the proportions of thirds. The length at the open end of the skirt is three times that of the pleated end. The pleats in this design are used on the edges because of this drastic scalar difference between the pleated and the open end of fabric. The pattern has four long pieces in the main body and two smaller ones. The pleating being at the ends results in the circular pieces used there being smaller. On the longer pieces of fabric, parallel tucks are used to create a similar overlapping effect of pleats and make the fabric contract in size (figure 7). Different sizes of pleats and tucks are used, as well as lengths, to explore their potential effects on curvature. The resulting physical prototype sees more emerging qualities of the fabric, due to the fact that the nylon fabric that was used has thickness. The layering of fabric on the tucks and pleats, creates more rigidity in the form, which inflates to a boxier look. This unexpected structure is not well represented in the simulated computer three-dimensional model. Furthermore, this rigidity is very apparent when touching the fabric and feeling bumps created by the folds. Also the translucent quality of the fabric is not well represented in the computer model, but the result of the overlaying of fabric created moments of more opacity in the fabric. Finally, the pleats do create unique wrinkles, texture, and expression of the fabric, as it shapes into the pressurized three-dimensional form (figure 9).

Figure 9: Pneumatic Pleated Prototype. (Author 2019)

4.3. GATHERING AND RUCHING

The final prototype utilizes gathering and ruching to create a ruffling effect. Gathering and ruching can be a bit more free-form in the proportions of expansion versus contraction. To simplify the set of results, the gathering ratio was set to fifty percent so that all the lengths would be gathered to be one half of their original length. This constraint helped focus the testing to the spacing, and patterning of the gathers and ruching. The design used six rectangular pieces of fabric, two long pieces and two shorter pieces (figure 7). Gathering is used at the seams to reduce the edge length of the longer pieces to match with the shorter pieces and ruching is used in the middle of the fabric in each piece to test different approaches to manipulating curvature. Parallel lines, shifted parallel lines, radial lines, and switching between x-axis and y-axis lines are all tested. These techniques result in several unique effects. Several small parallel ruches did create some curvature in the form, but overall it creates more billowing effects throughout the form. The physical prototype ultimately has many wrinkles and puckering in the fabric due to the cinched effects of the gathering and ruching; it almost never reaches any moments of smooth geometry. This creates a grotesque, but beautiful design, where the wrinkles really generate an overall surface texture and emergent qualities in the membrane's materiality (figure 10).

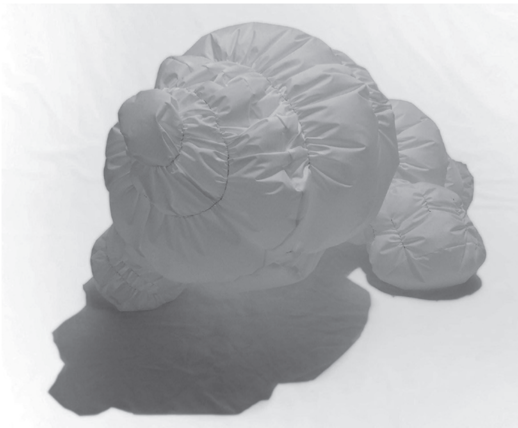

Figure 10: Gathered prototype. (Author 2019)

5. ANALYSIS

5.1. COMPARING THE DIGITAL TO PHYSICAL RESULTS

The resulting prototypes were fabricated based on the computer-generated three-dimensional models; the prototypes each have their own merits in creating texture and curvature. Whether the use of these simulations can result in a successful prediction is important to understand, as this could reduce the amount of prototyping and testing that is often needed in the design of pneumatic structures. The digital and physical models are compared side by side, with photographs of the physical prototype next to a rendering of the digital model from a similar angle (figure 11). The results show that some extra gravity and material weight are not expressed in the digital simulation. Certain parts of the digital model sag more due to simulated material weight, while other parts seem to float more than the physical. As well, the material build up in the tucks in the middle of the prototype became more rigid. Overall, it does seem that the simulations and the models do have a good amount in common in terms of the overall form finding and basic understanding of the resulting form. Adjustments can be made to the density of the mesh of the model to become more detailed and have a higher quality resolution, which could result in even better predictions. Ultimately it is the emergent material properties, such as light and material thickness, that really need to still be investigated through physical prototyping.

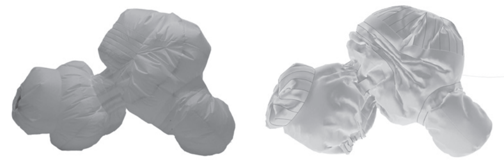

Figure 11: Photos side by side comparison of physical and 3D computer simulation. (Author 2019)

CONCLUSION

This set of pneumatic prototype, utilizing different types of dressmaking techniques and fashion design software, offers a new approach to designing pneumatic structures. The results create a new workflow by adapting software from the discipline of fashion design. By working with the Clo3D software one can work from the pattern to the design, rather than the pattern being a result of the form. The software also does a good job simulating with material properties and physics to predict the resultant form of the model. This allows for a feedback loop in the computer, rather than producing many prototypes to see the design results. The software streamlines production by being able to plot patterns with all the necessary information about cut lines, stitch lines, and seam allowance. Ultimately, working with this new software for pneumatic architectural purposes has the potential to create new methods of working and form finding for these types of designs with textiles. By using the traditional sewing techniques from dressmaking, curved geometry was created without requiring complex paneling of many pieces of fabric. Darts, pleats, tucks, and gathers each created different effects and did result in creating the desired three-dimensional curvature. Darts make more concave forms, while pleats allow quick expansion and contraction of fabric, and gathers create a more free-form and the most wrinkles in the fabric. These sewing techniques generate new opportunities for textures to be part of the design and expression for pneumatic structures. Future research could continue to explore more dressmaking techniques with the potential to create other types of geometry, as well as combine different techniques together to achieve an more complex structure overall, with varying qualities across a form. This research has a lot of potential to affect the way architects design with pneumatics and textiles. The next phase is to test these results at an even larger architectural scale.

REFERENCES

Bergman, Barbara. 1999. *The Culture of Sewing: Gender, Consumption, and the Dressmaking Trades.* Oxford: Berg.

Cristea, Irina and Gregoie Zundel. 2016. *Time For Play: Why Architecture Should Take Happiness Seriously.* New York: Actar Publishers.

Dent, Roger N. 1972. *Principles of Pneumatic Architecture.* New York: Halstead Press Division John Wiley & Sons, Inc.

Dessauce, Marc, ed. 1999. *The Inflatable Moment: Pneumatics and Protest in 68.* New York: Princeton Architectural Press; New York: The Architectural League of New York.

Francis, Sharon. 2019. *Bubbletecture: Inflatable Architecture and Design.* New York: Phiadon Press Inc.

Gamber, Wendy. 1997. *The Female Economy: The Millenary and Dressmaking Trades, 1860 – 1930.* Urbana: University of Illinois.

Talbot, Constance. 1943. *The Complete Book of Sewing; Dressmaking and Sewing for the Home Made Easy.* New York: Book Presentations.

Thomsen, Mette Ramsgard, Martin Tamke, Phil Ayres, and Paul Nicholas. 2019. *CITA Complex Modeling.* Toronto: Riverside Architectural Press.

Topham, Sean. 2002. *Blowup: Inflatable Art, Architecture, and Design.* New York: Prestel.

Shoben, Martin and Janet Ward. 1980. *Pattern Cutting and Making Up: The Professional Approach.* London: Batsford Academic and Educational Limited.

Mclean, Will and Pete Silver. 2015. *Air Structures*. London: Laurence King Publishing.