The Hybrid Bricolage - Bridging Parametric Design with Craft through Algorithmic Modularity

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Figure 1 Hybrid Bricolage process: (a) The designer selects generated patterns using the Honeycomb Smocking Pattern Catalog, (b) applies the patterns using Computer-Aided Smocking (CAS) design software, and (c-d) manually completes the work. (e) A portfolio of honeycomb smocking embroidery bags designed by the first author. Photograph (d & e) by Daniel Shechter.

ABSTRACT
The digital design space, unlimited by its virtual freedom, differs from traditional craft, which is bounded by a fixed set of given materials. We study how to introduce parametric design tools to craftspersons. Our hypothesis is that the arrangement of parametric design in modular representation, in the form of a catalog, can assist makers unfamiliar with this practice. We evaluate this assumption in the realm of bag design, through a Honeycomb Smocking Pattern Catalog and custom Computer-Aided Smocking (CAS) design software. We describe the technical work and designs made with our tools, present a user study that validates our assumptions, and conclude with ideas for future work developing additional tools to bridge computational design and craft.

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INTRODUCTION
Parametric design has gained a central place in today's making trends, from architecture to jewelry making, ceramics, and fashion design. Automatic and semi-automatic generated patterns controlled by a small set of designer inputs can achieve complex aesthetics [27]. However, as these parametric design tools rely on formal knowledge in mathematics, they are not accessible to all designers. Designers from non-digital practices may be uncomfortable with the sterile realm of numbers and code [15, 28], thus avoiding opportunities to explore the new design possibilities the computational domain holds.

Motivated to introduce parametric design to craftspersons, we hypothesize that *the arrangement of parametric design space in modular representation can assist makers unfamiliar with this practice*. Similar to work with a *fixed* set of physical materials, such as beads or fabrics, *Hybrid Bricolage* allows craftspersons to tinker with a limited set of computer-generated *meta-patterns*. Using a catalog of generated patterns, we draw an analogy between computational practices and the workset of traditional craft. Nevertheless, with Hybrid Bricolage, the user can digitally tweak and modify the patterns to fine-tune the design.

To evaluate Hybrid Bricolage, we apply parametric pattern design to the manual craft of *honeycomb smocking embroidery* (see Fig. 1). Because the complexity of this embroidery makes it difficult to automate, it requires manual labor. At the same time, it benefits from computational representation, as it includes extensive use of repetitive patterns.

Hybrid Bricolage consists of two tools: a *Honeycomb Smocking Pattern Catalog* (see Table 1 at the end of the paper), and *Computer-Aided Smocking* (CAS) design software. The catalog assists in the design process by visualizing eight different patterns, allowing the designers to choose between alternatives. Our CAS software allows the designer to choose and fine-tune settings in each pattern and combine different patterns from the catalog. When the design is ready, the stitching instructions are marked on a selected sheet of fabric using a laser-cutting machine, before the maker manually stitches the piece together and completes the design.

This paper is structured around the conceptual background of Hybrid Bricolage, the technical discussion of the catalog and the accompanying software, and the user study. In the next section we present the motivation of the work, before discussing related work in textile technologies, design and HCI research. In *Discretization of the Parametric Design Space*, we introduce the Honeycomb Smocking Pattern catalog, the CAS software, and our experimentations with these tools. The *User Study* presents a workshop in which eight fashion designers evaluated our tools, including a review of its outcomes, and suggests implications for HCI, before we conclude the work in the last section.

BACKGROUND: DESIGN TINKERING

In *The Savage Mind*, Lévi-Strauss discusses bricolage, defining a bricoleur as "someone who works with his hands… he does not subordinate each of [his means] to the availability of raw materials and tools conceived and procured for the purpose of the project… the rules of his game are always to make do with 'whatever is at hand'" [19]. While Lévi-Strauss did not emphasize the relative strengths of the bricoleur, Papert described the advantages of the improvised and intuitive making engagement of the bricoleur, especially when applied to education [10]. Since then, many scholars have discussed bricolage as an epistemological contrast to modern engineering. A relevant discourse has arisen within the design terrain, pointing to the limitations of digital design practice in comparison to traditional craft [20]. The emphasis on the process rather than the final product [12], the un-structural practice, the manual engagement, and the intimacy between maker and raw material are fundamental to craft, but almost neglected in engineering and industrial design. These qualities have encouraged researchers to investigate and study hybrid territories, where craft values and practices are reintroduced to digital mediums [3, 6, 30, 37].

Prior art suggests several ways merging digital and craft practices: constructing physical artifacts made by both practices separately [36, 38]; developing physical tools to allow for limited digital assistance [39]; or developing CAD tools dedicated to parametric design, allowing for continuous and expressive modification of the virtual design [13, 14, 34]. However, none of these options acknowledge that the high degree of digital freedom of most parametric design may discourage traditional makers.

Jacobs and Zoran, in their work with a group of former foragers, suggested that "in seeking ways to make digital tools that better facilitate exploratory modular practices, one approach is to design domain-specific CAD tools that enable designers to reconfigure virtual and physical modular parts through a small number of operations that are derived from the topology of the parts themselves" [15]. Hence, we propose modifying the digital planning stage to virtually resemble bricolage procedure, while still retaining the CAD hierarchy of planning before (physically) building.

Our work follows these lines and suggests a paradigm to make tools that facilitate exploratory modular practices. Complementing the line of STEM projects that encourage a bricolage practice within the digital realm [28], we seek a hybrid procedure that manipulates parametric design in the same *tinkering* manner. Thus, we contribute a paradigm of discretizing parametric design space in the form of a catalog containing a finite set of patterns that function as a toolset for the designer (the bricoleur).

RELATED WORK: DIGITAL FABRICATION AND TEXTILE

As fabrication technologies and textiles have been intertwined for millennia, it is not surprising to see the development of new digital projects involving textiles. Johnson and Hawley studied the influence of the Internet on quilters in 2004 [16]. More recent projects allow users to customize sweaters [18], apply mathematical patterns to scarves [1, 32] and design garments interactively [5, 7, 23]. The endless options of textile design encourage researchers to seek ways of integrating textile products with electronics [2] or develop new materials to allow textile-based sensing [26]. Considering the fabrication process, Hudson [11] and Peng et al. [25] suggest 3D printing with traditional textile materials, while Melnikova et al. [21] developed a system for 3D printing textile-like structures using polymers. Nervous Systems created parametric design tools for 3D printing foldable forms composed of articulated modules [17], and Sosanya has presented a 2.5D weaving machine [33]. Though it is not a textile project, Mueller et al. have used a laser-cutting machine to explore new design possibilities [22] in a manner similar to our work.

HONEYCOMB SMOCKING PATTERN

Here we focus on the honeycomb smocking pattern. Smocking is an embroidery technique whose basic form, the honeycomb pattern, was invented to provide an elastic quality to non-elastic fabrics in laborers' clothes in the 18th and early 19th centuries [4, 8, 9]. By the late 19th century, smocking embroidery had become popular for aristocrats' clothing, due to its decorative look, and several non-elastic smocking stitches had been invented.

Today, smocking is not a common design practice. It is an old, difficult and time-consuming handicraft technique. Yet, a few specialized designers utilize smocking patterns in some of their works. Moroso, for example, took the traditional smocking technique and integrated it into the company's industrial process, resulting in a small collection of special furniture [35].

While there are pleating machines that can speed some parts of the creation of a honeycomb smocking pattern, their contribution to the process is minor; most of the work will still be handmade. Like origami, the maker is constantly changing the fabric position and form while sewing a honeycomb smocking pattern. Although robots with high degrees of freedom might enable automation of this process, most industrial manufacturers are looking for easy and inexpensive ways to produce products. Because smocking does not meet these criteria, it does not hold a central place in today's design.

Yet, while the production of smocking is hard to automate, the grid of points that creates it is easy to represent numerically, making it a good platform for our research. As our aim is to create parametric tools that engage craftspeople, smocking embroidery is a medium that benefits from computational representation, but still requires manual labor.

DISCRETIZATION OF THE PARAMETRIC DESIGN SPACE

The implementation of Hybrid Bricolage combines computational honeycomb smocking patterns with manual craft, using a catalog and special software. While researchers have already investigated the use of a style-based design exploration tool [29], our intent is to search for a possible revision to common computer-aided design (CAD) processes, focusing only on the part we wish to study: *designing patterns for craft using a computer*. We rely on *pre-fabrication design* process, a common approach in CAD practices. While many craftspersons choose to work differently, the art of honeycomb smocking is based on careful pattern planning *prior to execution*.

This section presents our investigation and development of Hybrid Bricolage. After designing the patterns using the computer, we transfer computerized sewing instructions composed of lines or points to the fabric. The designer then finishes the work manually. We use two methods to transfer the instructions to the fabric:

Transfer paper Printing the instructions onto transfer paper, then pressing it against the fabric. This enables us to transfer the design onto large expanses of fabric.

Laser cutting and marking Cutting or marking thin fabrics such as canvas, or thick ones like felt or leather, with a laser-cutting machine. This method is advantageous for synthetic fabrics, as the laser sears the edges to produce a high-quality finish. Although this method limits the size of material we can mark at one time, we rely on it for most of the work.

Hands-on investigations preceded the development of the catalog and the software. Therefore, we start by discussing the lessons learned in this early stage, then present the catalog, the software, and a portfolio of bags that demonstrates the quality of the results.

Smocking Investigations and Design Constraints

To embroider honeycomb smocking, the user draws a two-dimensional grid of points with equal distances between them on the fabric, and then sews neighboring points in a consistent order (see Fig. 3(c-e)). During the sewing process the fabric twists into a manifold in 3D space and reveals an interconnected diamond pattern in which the diamond edges are ridges, and the diamond diagonals vertical to the sewing direction are valleys (see Fig. 2(a)). We define these stitches as triples $(\vec{r}, \vec{v}, \Delta)$, where r is a vector that starts on the origin and ends at the beginning of the stitch, v is a vector from the beginning of the stitch to its end, and Δ is the length of the stitch (Fig. 2(h)). Then, a pattern p is simply a set of n stitches $p = \{s_1, s_2, \ldots, s_n\}$ where $s_i = (\vec{r_i}, \vec{v_i}, \Delta_i)$.

To achieve new results, we physically explored about a hundred different test patterns based on transformations of the original embroidery. Some of these experiments led to new patterns, while others were less appealing but revealed important constraints (see Fig. 2(b-g)). These experiments allowed us to define the following design constraints for a set of four neighboring stitches $\{s_0, s_1, s_2, s_3, s_4\}$, where $s_0 = s_4$ (see Fig. 2(i)), to result in a single elastic diamond after sewing it:

1. There exists a vector $\vec{v}$ such for every $0 \leq i \leq 3$:

$$\vec{v_i} = \Delta_i \cdot \vec{v}$$

2. For every $0 \leq i \leq 3$:

$$\frac{\pi}{2} \leq \theta_i \leq \frac{\pi}{2} + c$$

   When θ_i is defined as (see figure 2(i)):

$$\theta_i = \max\left\{\cos^{-1}\left(\frac{(\vec{r_i} + \vec{v_i} - \overrightarrow{r_{i+1}}) \cdot \vec{v_i}}{\|\vec{r_i} + \vec{v_i} - \overrightarrow{r_{i+1}}\| \cdot \|\vec{v_i}\|}\right), \cos^{-1}\left(\frac{(\overrightarrow{r_{i+1}} + \overrightarrow{v_{i+1}} - \vec{r_i}) \cdot \vec{v_i}}{\|\overrightarrow{r_{i+1}} + \overrightarrow{v_{i+1}} - \vec{r_i}\| \cdot \|\vec{v_i}\|}\right)\right\}$$

   And c is a small constant depends on the elasticity and thickness of the fabric.

3. For every $0 \leq i \leq 3$:

$$\min\left\{\frac{\Delta_i}{d_i}, \frac{\Delta_{i+1}}{d_i}\right\} \geq 1$$

   When d_i is defined as (see figure 2(i)):

$$d_i = \min\{\|\vec{r_i} + \vec{v_i} - \overrightarrow{r_{i+1}}\|, \|\overrightarrow{r_{i+1}} + \overrightarrow{v_{i+1}} - \vec{r_i}\|\}$$

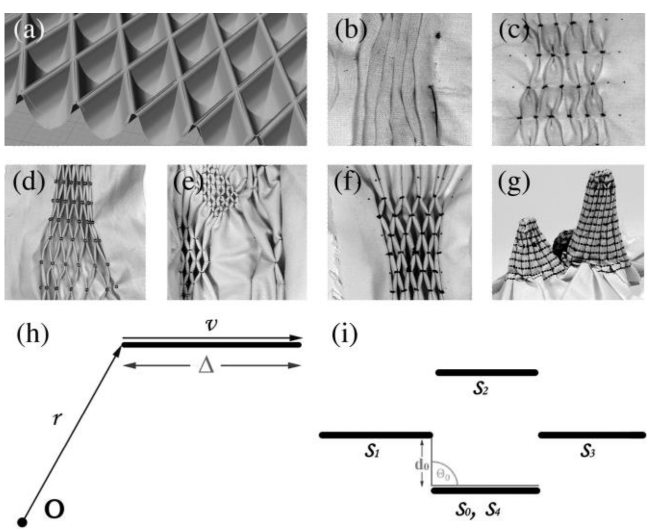

Figure 2 Analyzing the honeycomb smocking pattern: (a) 3D Grasshopper simulation of the basic honeycomb pattern, (b-g) examples of our early investigations with smocking, (h) basic smocking stitch triple, and (i) a representation of four neighboring stitches.

While incompliance with these constraints will damage the pattern or its elasticity, it may also produce interesting results. For example, choosing $\theta_i > \frac{\pi}{2} + c$ may produce an elastic pattern with diamond-like shapes that appear only when the fabric is stretched; sewing non-parallel stitches in circles produces an attractive, inelastic 3D cylinder. Other designs may impact the intrinsic forces that (as a function of the fabric type) mold the fabric into a 3D form or make the pattern looser at rest.

All the above make the creation of advanced honeycomb smocking patterns by hand very difficult. They demand a lot of experience, or mathematical skills and technical engagement. Yet, because these criteria are easy to translate into code, software can assist smocking novices and facilitate their work.

Digital Smocking Design Catalog

Our work focuses on traditional craftspersons unskilled with smocking embroidery. We wish to evaluate to what extent the computer can assist them in parametric design. Such designers (1) may be not familiar with the technical constraints, and/or (2) may not be comfortable working with computers. To close this gap in knowledge and skills, we pack computational outcomes into a traditional frame: a physical design catalog. The catalog presents available design possibilities in an accessible visual format, while limiting the possibilities to a small (and therefore mentally digestible) set of options. In a sense, this allows for design tinkering, as the parametric space being presented acts as raw material for a modular making process.

Based on our early investigation, we reduced the portfolio to a set of eight *meta-patterns* that constitute our catalog (see Table 1 on the last page). The patterns in the catalog allow a limited degree of parametric tweaking, varying from basic options—elastic/non-elastic—to more complicated ones, like a pattern of varying diamonds that allows the designer to create a good approximation of any new diamond-like pattern, even something non-symmetrical and curved.

The purpose of this combination of basic and complicated patterns was to give the designers maximum freedom in choosing their building blocks. This way the users can rely on basic/low-level building blocks (patterns a-e, h), or customize high-level building blocks (patterns f-g). For every pattern in the catalog, we included a short explanation, sewing instructions, photos to illustrate the sewing results (front, back, front in stretch, and back in stretch), and the pseudocode we used to implement it (dropped from Table 1 due to limited space). For example, here is a pseudocode of the varying diamond pattern:

```
Input: diamonds_grid (any diamonds grid)
Let V be the set of all vertices in diamonds_grid
for every point p in V do
   min_dist = ∞
   for each neighbor np of p in diamonds_grid do
      dist_x = np.x – p.x
      if dist_x < min_dist then
         min_dist = dist_x
         Draw a line of length 2*min_dist starts at point (p.x – min_dist, p.y)
Scale obtained image according to fabric params
```

The learning curve for manual smocking may be long, but we believe the catalog can significantly shorten the time needed for a successful outcome, inviting manual practitioners to use our software without engaging with the design constraints and/or the parametric procedural code.

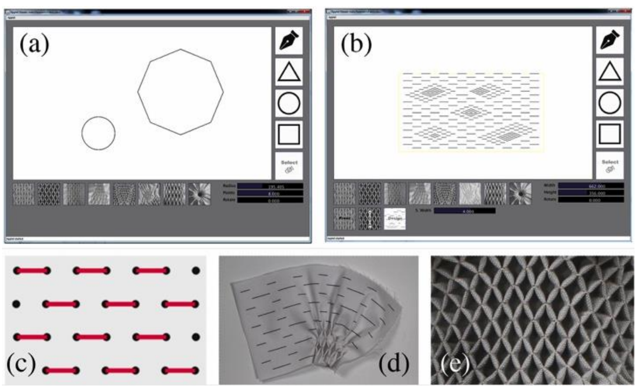

Figure 3 (a-b) Computer-Aided Smocking Software (CAS) GUI, (c) virtual stitching instructions (d) transferred to a fabric using a transfer paper, (e) and the final pattern after sewing.

Computer-Aided Smocking Software (CAS)

While the catalog communicates and visualizes our discrete set of pattern design possibilities, a dedicated CAS allows the users to implement their designs on a virtual sheet after browsing the catalog and selecting patterns from it. Based on the initial exploration stage, together with the prior theoretical discussion on tinkering and design, we defined the following software requirements:

1. A simple, direct-manipulation GUI.
2. A small and limited (yet not limiting) number of smocking patterns, based on the catalog.
3. A high degree of freedom in placing, tweaking and combining these patterns.
4. Smooth and easy implementation of the transition from digital design to physical sewing.

While early investigation relied on *Grasshopper* (a plugin to Rhino), we implemented the final version of our software in *Processing*. It includes a simple GUI that lays out a virtual canvas, corresponding to a 100x70 cm sheet of fabric (Fig. 3(a-b)) The software allows the designer to choose different design primitives (polygon, ellipse, free pen tool), manipulate them (drag, rotate, resize, delete), apply a pattern to them, and tweak its inner design if possible (patterns (f), (g)). After applying a pattern, the user can easily change its parameters, and combine it with another pattern if possible. For example, pattern (a) (non-elastic) cannot be combined with pattern (b) (elastic), while pattern (e) (separating axes) can be merged with patterns (a), (b) or (d). Using these tools, the designer defines the general outline of the work and composes his or her own patterns.

The transition from digital design to physical sewing relies on two exported files from the CAS (Fig. 3). One, in SVG format, contains instructions for the laser-cutting machine indicating which points need to be cut or printed on the fabric; a second PDF file contains instructions for the designers on sewing the digital fabricated points. We chose to mark only points on the fabric, instead of including full instructions in the form of lines, to minimize unnecessary marks.

Honeycomb Smocking Embroidery Bags Example

To self-validate our Hybrid Bricolage prior to conducting the user study, the first author designed and hand-sewed a collection of eighteen honeycomb smocking embroidery bags based on our catalog and using the CAS (see Fig. 1 and 4). This selection of bags, in particular, demonstrates the elasticity of the sewn fabric, an important quality in honeycomb smocking patterns: an elastic bag is a very useful container that grows and shrinks according to its content and use.

With each of these bags, the process included an early manual sketching step based on the catalog; another step preparing the files prior to cutting and marking the instructions on the fabric; and finally, a manual sewing step to complete the work. This collection spans the variety of designs enabled by our tools. For example, an urn-form bag, which is narrow at the top and wide across the body, uses two patterns: the elastic diamond pattern on the top and bottom, and a non-elastic diamond pattern in the middle. Another bag has two faces; one side contains topological holes, while a second, exaggerated side, contains spikes. The spikes/holes diamond pattern is used here several times. Finally, an entirely different example is a tree

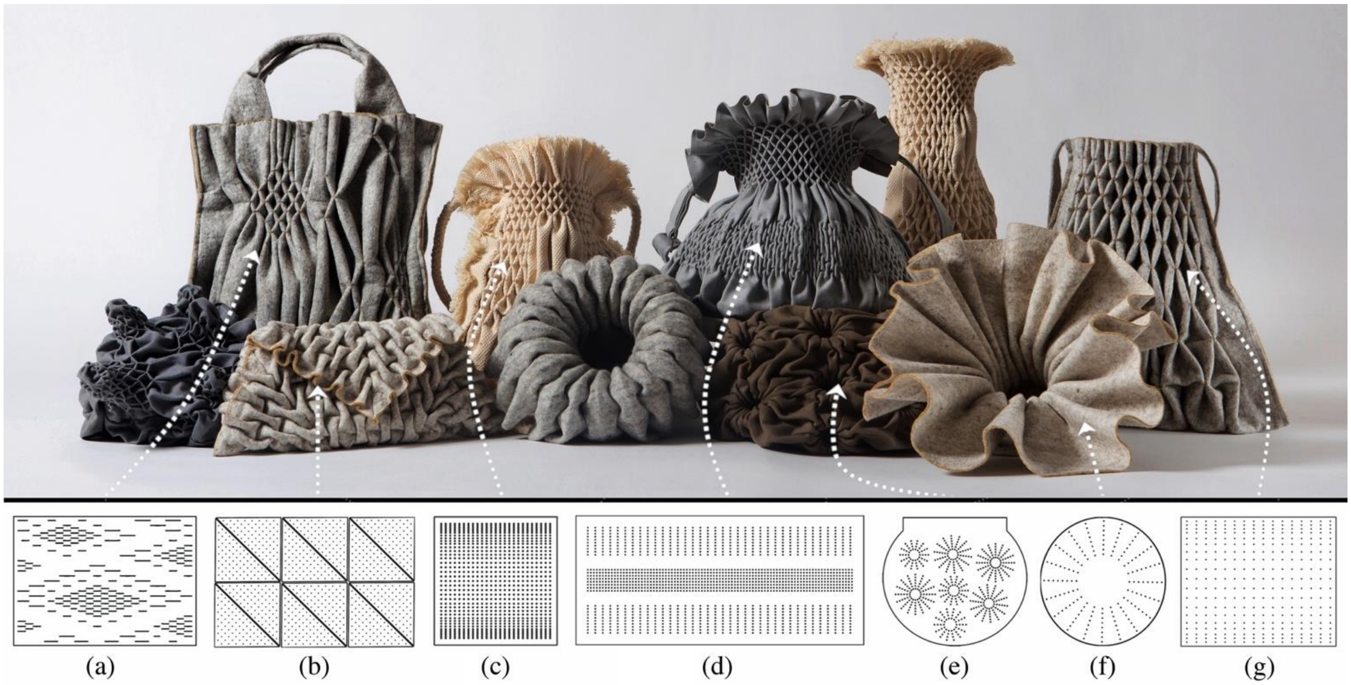

Figure 4 (a-g) A portfolio of honeycomb smocking embroidery bags designed by the first author, based on the Digital Smocking Design Catalog and the Computer-Aided Smocking Software (CAS). Below are CAS generated instructions sent to the laser cutting machine for marking. Photograph by Daniel Shechter.

trunk bag; while the other two bags were composed of several basic patterns, this one comprises a single varying diamonds pattern.

USER STUDY

Our initial hypothesis was that *the arrangement of parametric design space in modular representation can assist makers unfamiliar with the parametric design practice*. To validate this, after constructing the catalog and the CAS software, we conducted a study with a group of skilled fashion designers who were familiar with computers, but not with honeycomb smocking embroidery or parametric design. We evaluate the ease of use of our tools, the integration of the Hybrid Bricolage paradigm in a traditional craft workset, and the quality of the outcomes. In addition, we use this opportunity to study general qualities of the Hybrid Bricolage paradigm and our new tools.

Methodology

We led a two-day workshop in which the participants designed and hand-sewed their bags. The workshop contained eight fashion design students (seven female and one male), varying in age from 21 to 27. All of the participants had experience in fashion design, and six of them had prior experience in designing bags. They all had experience in designing with a computer, but none had ever worked with parametric design tools nor with honeycomb smocking embroidery (one designer, M., had a modicum of experience in a different smocking technique). Selecting a group of textile- and computer-literate craftspersons helped us evaluate the contribution of Hybrid Bricolage to skilled makers.

To get a broad understanding of the participants' experience, we administered formal surveys before and after the workshop; interviewed the participants before, during, and after the workshop; and documented the process and its final outcomes. In the surveys we asked participants about their backgrounds and design preferences, their experience with the workshop, general reflection on technology and craft, and so on. Where relevant, the participants ranked their answers on a quantitative scale between 1 to 5 (where 1 was the lowest mark and 5 was the highest).

On the first day of the workshop we provided the participants with a general explanation of smocking embroidery, and a one-hour tutorial in which they practiced some basic honeycomb smocking examples. Afterwards we practiced more basic smocking, introduced the catalog and CAS, and asked the participants to design their own bags with CAS. As the same patterns appear in both the catalog and CAS, the participants could search for patterns before starting to design, or ignore the catalog and approach the CAS directly. Two participants immediately started using

Figure 5 (a-f) Outcomes of the Hybrid Bricolage workshop made by 6 designers.

our CAS, while others sketched their initial ideas manually. All of the participants browsed the physical catalog *while* investigating their designs, each of which corresponded to the presented patterns. During this stage participants also choose their preferred fabric type and color from a given collection we supplied.

After the participants completed their designs, we applied the instructions to the fabric with a laser-cutting machine, marking and cutting the outline of the bags. On the second day of the workshop, the participants sewed their chosen fabric according to instructions generated by the software. All of the participants needed more time to complete their designs and continued to work at home.

Workshop Experience, Outcomes and Reflections

A diverse portfolio of final bags is presented in Fig. 5, demonstrating the variety of design possibilities and styles that came out of the workshop. These outcomes diverge from the original collection we created: one participant made a bag with replaceable covers with different smocking patterns (Fig 5(d)); several participants explored the application of smocking patterns to 3D shapes, such as a vase-like form that could be opened from the bottom (Fig. 5(b)), or a pyramid-shaped bag (Fig. 5(a)). One participant made a hole in the center of the bag, which functioned as a small pocket (Fig. 5(e)). Another participant (who did not complete her bag) tried to draw the New York City skyline using the smocking embroidery. Two participants picked a pattern and applied it to the fabric prior to designing the general form of the bag: they simply used the pattern as a raw material, and only after preparing this new "material" did they move forward designing *for* it manually (Fig. 5(c,f)).

Six of the eight participants invested between ten and thirty *extra hours at home*, and arrived at an additional closing session with their finished products, and/or visited our lab in between the official meetings. Moreover, we witnessed a good atmosphere throughout the workshop, with lush social interactions. When we asked the participants if they would like to continue working at home, they all preferred to stay together at the lab. All of the participants indicated they would like to participate in a similar workshop in the future, and six of the eight rated their enjoyment of the workshop as a 5. Furthermore, many of the participants said they were excited to continue working this way in the future and use what they learned in their regular work process. They *all* wished to have future access to the software.

"I really like my bag and I am going to produce several more, it's definitely going to be part of my portfolio..." (S, a week after the workshop ended)

Mastering traditional honeycomb smocking embroidery requires a lot of experience. Considering the lack of previous experience for our participants in parametric design or smocking, the complexity and diversity of the designs support our initial hypothesis: our tools improve the accessibility of computationally enhanced parametric smocking craft for novices in parametric design. Yet, the joy of our creative participants and their beautifully designed projects may positively bias our observations. Thus, we now investigate to what extent Hybrid Bricolage empowers makers, what needs to be improved, and what other lessons can be learned from the experience.

The Hybrid Bricolage Paradigm

Discretizing the design space into a catalog with a limited number of meta-patterns maintained the practicality of the concept, but may have harmed the designers' sense of freedom. An early work by Oehlberg et al. discussed creative freedom with respect to generative and non-generative design [24], pointing to the power of hybrid practices. With Hybrid Bricolage, users can combine several generative and non-generative design options: (1) the outline of the design is unlimited and the designer can sew any desired shape; (2) the user selects from a fixed set of raw materials and generated meta-patterns; (3) each meta-pattern allows for a limited degree of parametric tweaking; (4) the designer is not bound to complete the pattern instructions and can improvise in real-time.

To gain a better understanding of this quality of the Hybrid Bricolage, we asked the participants to rate their *sense of freedom* in the design process. Seven of the participants rated the two relevant questions at least 4. However, when asked to rate their sense of freedom to insert changes while sewing, the answers were not as absolute—two rated it 5, three rated it 4, one rated it 3, one rated it 2, and one rated it 1.

"At the beginning... I didn't know exactly what I wanted [...] I chose a pattern to work with and wanted to replicate it several times on the fabric… I tried to sew only part of the points, while leaving other points free. I felt a total freedom while sewing and designing the bag and I really liked it." (N.)

Hybrid Bricolage seeks to provide a balanced experience using CAD and manual practice: the maker determines the pattern to be designed in the software, while the sewing is all done by hand. The importance of manual craft practice has been widely discussed elsewhere, but the application of Hybrid Bricolage to honeycomb smocking embroidery presents a unique case. Here, craftspersons apply manual techniques to implement a repetitive generated mass of elements, instead of a digitally automating their production. Moreover, the outcome cannot be reproduced nor easily predicted, since it depends on real-time decisions and the precision of the maker:

"In the beginning […] I thought I would sew all the points... Then I understood I was too optimistic… so I […] sewed just some of the points and the outcome was kind of a surprise for me." (N.)

Looking more closely, we noticed two different creative approaches. Some people arrived with a concept design and continued with their ideas even though they did not fit the smocking embroidery constraints, while others developed their designs while using the catalog. We theorize that the participants from the first group were fixed on prior assumptions about the elasticity of the computer-aided design process. Hence, they did not properly adapt to virtual tinkering, and were less satisfied with the results. When asked "How much do you feel the physical catalog was a tool in designing your sketch?", most of the participants in the first group marked 3, while all of the participants in the second group marked 4 or 5. Moreover, none of the participants in the second group followed the instructions in their entirety. In stark contrast, the students in the first group did, and when asked to rate their sense of freedom to insert changes during sewing, they rated it significantly lower than the participants in the first group. Moreover, when asked to rate the originality of their bags and the reasons for it, the answers of the participants in the second group were based on the uniqueness of the embroidery, while the answers in the first group didn't mention the embroidery at all.

"The form, the details, the color combinations and the gatherings that are getting deeper and making the bag narrower are all special." (M., second group)

Creative investment and ownership maintain a complex affiliation. Although the computer optimizes part of the process, the smocking embroidery still requires a significant manual investment, which none of the participants predicted properly beforehand. The average amount of time invested in sewing a bag was twenty hours, varying from nine to forty hours. We noticed a curious, yet likely, link between the time invested in the bag and the sense of ownership. As Hybrid Bricolage assists makers in implementing parametric design into their craft, but does not alter the manual making practice, these observations are in agreement with prior knowledge on traditional craft practice, where investment, intimacy and engagement impact the quality of the practice and the sense of joy and ownership [31].

Interaction with CAS Software and Its Outcomes

All of the participants stated that the manual instructions were easy and straightforward, and rated the clearness at least 4. Our CAS was ranked as intuitive (two rated it 5, four rated it 4, two rated it 3) and unintimidating (four of the participants rated their fear 1, one rated it 2, and three rated it 3). The Hybrid Bricolage procedure is simple, accessible, and does not require prior knowledge.

While most of the participants showed no interest in knowing more about the underlying constraints and the mathematics, their use of CAS allowed them to create a varied set of new patterns that would have been difficult to achieve without a computer, and spared them the tedious work of marking the points on the fabric by hand. Most of the participants said they could not reach the same results without a computer. When asked to rate the usefulness of the marked points, however, they were slightly more restrained: four participants rated it 5, one rated it 4 and three rated it 3.

" If I had to mark them [the points] by myself, it would send me into despair..." (M.)

Yet, we noticed that almost all of the participants would have liked a visual simulation of the predicted outcomes. This specific requirement may have derived from their prior technological experience and knowledge in CAD, which raised their expectations:

"I would add an option […] that enables to sew or unpick stitches and see the result simulated on the screen." (N.)

Prediction and Expectations

Our CAS currently produces instructions to assist in the manual labor of smocking embroidery rather than final design renderings. Yet there is early evidence that the participants tend to expect computational assistance in the design process, rather than the manual fabrication. The participants' lack of experience with smocking embroidery probably influenced them to seek information minimizing the unpredictability of the final artifacts in a form of 3D simulation rather than our 2D planning. While our participants were all familiar with virtual design simulations and computer renderings, Jacobs and Zoran did not observe similar expectations in their workshop with former hunter-gatherers [15], demonstrating that users' expectations of technological agency depend on cultural context. Along the same lines, participants fixated on a preliminary design were less satisfied with the outcome of the workshop. To summarize, there is evidence of a link between preliminary expectations and satisfaction from the process and its outcomes.

Hybrid Bricolage contributes a new arrangement of the parametric design space, and does not supply a prediction of the process and its outcomes. As with traditional bricolage, creative freedom is constricted by a fixed set of raw patterns and materials, and a successful practice requires mastering these existing sets of design primitives. Moreover, the intuitive practice of traditional bricolage consists of *trial and error* rather than *planning and prediction.* Nevertheless, we see future potential in extending our paradigm to designers who wish to stretch this domain, allowing them to predict the aesthetics and required labor of the planned work, and enabling alternatives modes of working.

CONCLUSIONS

Within this work, we present Hybrid Bricolage, a new parametric design paradigm using a fixed set of computer-generated, tweakable meta-patterns. After experimenting with parametric design and honeycomb smocking embroidery, we developed a physical Honeycomb Smocking Pattern Catalog and Computer-Aided Smocking design software, and evaluated them in a user study, while presenting a diverse portfolio of bags. This work draws on other studies in the realm of hybrid design, aiming to link traditional creative practices with contemporary technology. While the concept of tinkering or bricolage already influences HCI and STEM projects, we build upon prior work and contribute a new perspective, replacing the presentation of mathematical (or code-based) formality with a discrete set of given patterns.

Our user study validated our assumption that such modular presentation can be easily integrated by craftspersons who are novice parametric designers, although the results pointed to important future work in improving the flexibility and predictability of our digital bricolage paradigm. Additionally, we envision a design process where makers could import external patterns into CAS. While our emphasis on computationally enhanced labor seems fruitful, the participants also showed interest in articulated visualization to predict the completed designs. We hope this work will encourage others to continue investigating the development of tools incorporating wide creative audiences, and provide accessibility to hybrid approaches to craft.

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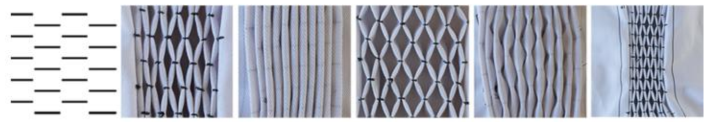
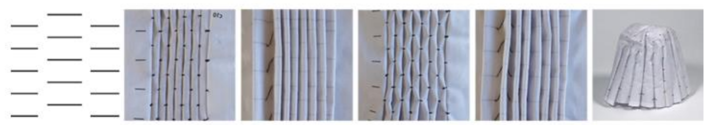
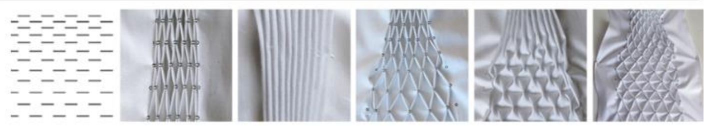
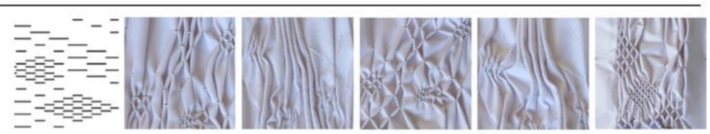
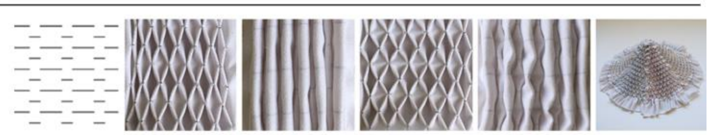
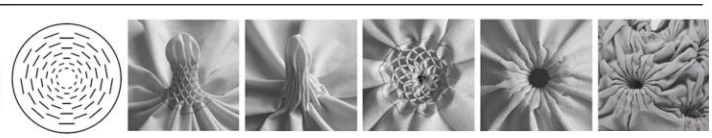
Name	Technique	Characteristics	Sewing instructions	Front	Back	Stretched front	Stretched back	Object
(a) **Elastic diamonds**	To create a pattern of elastic diamonds: $\frac{stitch\ width}{rows\ distance} \geq 1.5$ (= 2.5 for maximum elasticity)	Very elastic pattern that returns to its original state after stretching. Requires approximately 250 percent more fabric than a non-elastic pattern.						
(b) **Non-elastic diamonds**	To create a pattern of non-elastic diamonds: $\frac{stitch\ width}{rows\ distance} = 1$	The pattern remains opened after stretching. Of all of the patterns in the catalog, the non-elastic diamonds consume the smallest quantity of fabric.						
(c) **Diamonds only when stretched**	To create a pattern of visible only when the fabric is stretched, there should be a limited non-overlapping area between every two neighboring diagonal stitches.	There is an element of "surprise" when stretching this pattern. The pattern returns to its original state (with no visible diamonds) after stretching.						
(d) **From narrow diamonds to wide**	To create this kind of pattern, the ratio between the width of the stitches and the distance between the rows should grow slowly from 1 to 2.5.	The pattern is tight and elastic on one side and loose and non-elastic on the other.						
(e) **Diamonds with separating axes**	To create a pattern with diamonds separated by axes, the different parts need to be completed separately, with a relatively small gap between them.	The elasticity depends on the different patterns in each part. The axes allow a wider range of motion.						
(f) **Varying diamonds**	To create a pattern of varying diamonds, the sewing instructions should be produced according to a given algorithm that enables the creation of any non-homogenous diamonds pattern.	The elasticity of the sewn fabric varies along the pattern.						
(h) **Diamonds of varying depths**	To create a diamond pattern that varies by depth, the length of the stitches should change along the sewn rows. Long stitches will result in deep diamonds, while short stitches will result in shallow ones.	The elasticity of the sewn fabric varies along the pattern.						
(g) **Diamonds with spikes or holes**	to create a spike or hole, the pattern should be sewn in circles, from the center to the outside.	The sewn pattern has four interesting states: (1) spike, (2) hole, (3) inverse spike, (4) inverse hole. The elasticity of the sewn pattern depends on the distance between the circles and the number of stitches in each circle.						

Table 1. Honeycomb Smocking Pattern Catalog

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