PatchProv: Supporting Improvisational Design Practices for Modern Quilting

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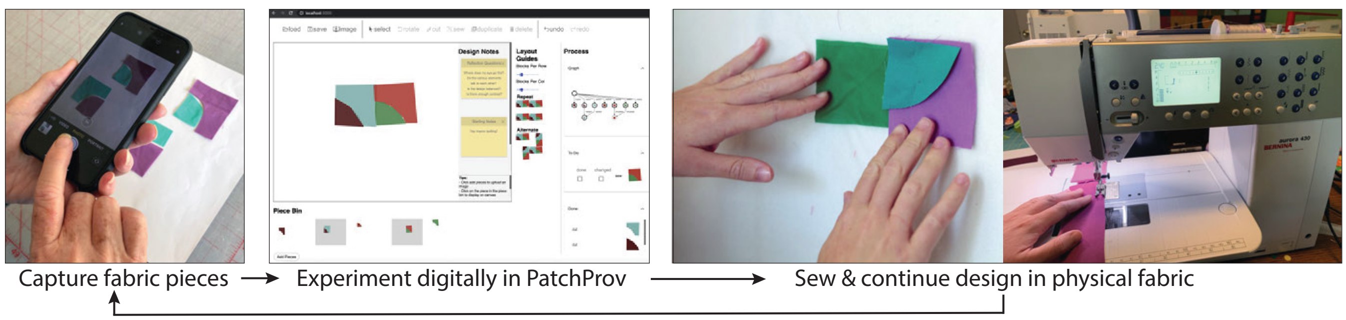

Figure 1: PatchProv fits into the common improvisational quilting workflow of interleaving design and sewing. The user can capture physical pieces of fabric, experiment with the design in PatchProv, and then continue to iterate in the physical fabric.

ABSTRACT

The craft of improvisational quilting involves working without the use of a predefined pattern. Design decisions are made "in the fabric," with design experimentation tightly interleaved with the creation of the final artifact. To investigate how this type of design process can be supported, and to address challenges faced by practitioners, this paper presents PatchProv, a system for supporting improvisational quilt design. Based on a review of popular books on improvisational quilting, a set of design principles and key challenges to improvisational quilt design were identified, and PatchProv was developed to support the unique aspects of this process. An evaluation with a small group of quilters showed enthusiasm for the approach and revealed further possibilities for how computational tools can support improvisational quilting and improvisational design practices more broadly.

CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**.

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KEYWORDS

improvisation, quilting, craft, textile arts, design tool

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1 INTRODUCTION

Quilting is a traditional craft with a rich history and a nuanced relationship with technology [28]. The practice of patchwork, in which small pieces of fabric are sewn together to create larger designs, has been found throughout history but gained popularity during the Great Depression as a way of upcycling fabric from worn clothing into warm quilts [3]. More recently, the low cost of the industrialized production of textiles has shifted the role of quilting to be more of an art form, albeit a functional one [23]. Large quilt shows around the world, from Paducah, Kentucky, to Tokyo, Japan, attract tens to hundreds of thousands of attendees to admire quilts and celebrate the craft [53, 58]. While modern quilts are celebrated for their craftsmanship, it would be reductive to position quilting as standing in opposition to technology. Computerized long-arm sewing machines have been widely adopted by practitioners to stitch the layers of quilts together, and it can be argued that the popularity of the modern quilting movement is in part due to the ease with which designs can now be shared on social media [23].

While the practice of quilting has been influenced by technological innovations and practitioners have shown a readiness to adopt technology into the process of *creating* quilts, the process of *designing* quilts remains largely manual [4, 28]. This is particularly the case for modern quilting techniques, such as *improvisational piecing*, which involve designing and creating quilt tops without reference to existing or pre-defined patterns. While digital tools, such as Quiltster [49] and Electric Quilt [48] do support quilt design, these tools require adherence to strict constraints, such as specific block libraries, patterns, and fabrics. These tools do not support improvisational design because in the process of improvisation, design decisions are made "in the fabric," without guidance from a pattern or strict plan. Fabric may be cut free-hand, without precise measurement, and design decisions are interleaved with the creation of the artifact itself, guided by rough frameworks or "scores" rather than precise instructions. Designs are often staged and experimented with on physical surfaces called design walls (Fig. 5). Design constraints emerge organically during the process of creation and take many forms, such as adhering to a limited color palette, abstract shapes, symmetric patterns, or visual balance [23].

The nuanced relationship between quilting and technology mirrors an ongoing shift in the problems and domains to which computing technology is applied. As the cost and availability of technology has dropped, the uses that are of interest to researchers, designers, and developers have broadened from large-scale endeavors that prioritize efficiency, to more subtle uses, such as supporting creativity or preserving traditional cultural practices [26, 32, 42]. Creativity support tools have been an area of focus in the HCI community in recent years [14], and while these tools do support creative freedom in many different domains, they are focused on workflows in which the designer has a plan for a finished artifact and are not designed to support improvisation. A compelling question is whether the unique practice of improvisational quilting might be supported through design tools to address challenges faced by practitioners and lower the barriers to novices. These challenges include the difficulty of getting started working improvisationally, becoming stuck part way through a design, experimenting with costly materials, and communicating the design process that leads to a completed artifact [15, 18, 41, 62]. Moreover, a tool to support this process must address these challenges without creating significant new work or challenges for practitioners or constraining their creative space or design process in undesirable ways.

Motivated by the broader goal of understanding how to support improvisational design practices, a collection of popular books on improvisational quilting was reviewed to identify common challenges in the practice and to distill a set of design principles to guide the development of a tool to support improvisational quilting. Based on these principles, *PatchProv*, a system for supporting improvisational quilt design (Fig. 1), was designed and developed. PatchProv is a lightweight tool designed to work alongside a quilter who is working in the fabric. A quilter can load photos of pieces of fabric into the system, engage in digital quilt design experimentation that would be difficult to do using physical fabric, and easily keep track of the process, e.g., the steps needed to sew the design in the physical fabric. The system also provides features to help users get started, such as design prompts, and to get unstuck, such as displaying layout suggestions based on the current design.

The rest of this paper is structured as follows. First, a review of the HCI literature on supporting improvisation, hybrid digital-physical design tools, computational textiles, and craft practices is presented. This is followed by a more detailed definition of the improvisational quilting design process and design principles distilled from popular books on the topic. Based on these design principles, we present the design of *PatchProv*. Finally, an evaluation with four quilters is presented, which indicates that PatchProv can be effectively integrated into improvisational quilting workflows and has clear benefits to quilters, particularly in lowering the cost of experimentation.

2 RELATED WORK

This work builds on prior HCI research on improvisation, creativity support tools, design and making in hybrid digital-physical scenarios, and crafts and textiles. Each area is reviewed below.

2.1 Improvisation

Improvisation is a technique common in many different performance domains, such as theatre, dance, and music [7, 29, 30]. It is characterized by its encouragement of spontaneity [7, 16, 30]. While it may seem that improvisational performances are free-form and lack structure, in fact, improvisation requires a high level of domain-based skill for success [7, 47]. Researchers in music and neuroscience have argued that jazz improvisation is similar to spoken speech, with predictable patterns that performers have learned and know to use in the appropriate settings [29, 46]. Some general planning of what to play occurs shortly before the performance, and there are rules, which some have viewed as having an algorithmic nature, that dictate when to use each pattern [29].

Due to its prevalence in the performing arts, much of the prior work in improvisation emphasizes the social nature of the practice [7]. Uses of improvisation in the HCI community have largely focused on applying the social properties of improvisation to support brainstorming and design work [16, 17, 19] or introducing computational systems or agents into music [6, 22, 44, 60] and dance performances [27]. While improvisation in the performing arts often emerges in social environments, improvisational quilting is typically an individual practice. Another distinguishing feature is the time scale of the activity. While music or dance performances often last minutes or hours, a quilt can take hundreds of hours to complete. Spontaneity is important, but quilting does not have the urgency created by a live performance. Overall, these differences mean that a system to support improvisational quilting does not necessarily require real-time input and responsiveness and must also account for longer-term reflection and planning.

2.2 Creativity Support Tools

Creativity support tools support the open-ended creation of new artifacts [9]. Shneiderman distinguished *productivity* support tools, whose development was rooted in economic objectives (e.g., increasing productivity, reducing manufacturing costs, and so on), from the emerging class of *creativity* support tools, whose focus was to extend users' capabilities to make discoveries, innovate, and engage in creative activities [55]. He also distinguished the means used to evaluate these systems – productivity tools are typically evaluated using well-defined objective measures, but measures of success for creativity support tools are typically subjective and less clearly defined.

Creativity support tools can minimize challenges or barriers to creative expression in a domain. These tools seek to provide features, support, or new abstractions that help lower the barriers for novices or amplify the capabilities of experts. Motif, for example, guided users through the editing of narrative videos by providing templates based on common storytelling patterns [33]. PortraitSketch, on the other hand, supported novice sketch artists in learning to draw through an interactive tool that provided automatic, real-time adjustments to a sketch [64].

Tools targeting advanced users can offer new or modified ways of working that extend existing practices. Animation software, such as Draco, has enabled the creation of novel animation-authoring interfaces with advanced features [32]. Work by Jacobs et al. supported the creation of generative art pieces by developing new programming languages and environments for visual artists [26]. These types of systems often require users to learn new skills or ways of working but provide advantages, such as enabling users to work more quickly on tedious tasks, such as rotoscoping visual effects [38], editing rough cuts of videos [37], or designing industrial knitting patterns [35]. When designing such systems, it is important that these tools preserve the creative decision making process so that users can follow well-established workflows or use alternatives that are just as expressive.

PatchProv brings creativity support tools to the novel context of improvisational quilting by lowering the barrier to entry and extending existing practices. The iterative design and execution phases and lack of pre-planning in improvisational quilting pose special challenges to designing creativity support tools. PatchProv is designed to work within existing improvisational quilting workflows, capturing aspects of the quilter's process in a digital tool and supporting more fluid experimentation than is possible in physical sewing materials alone.

2.3 Hybrid Digital-Physical World Tools

There has been extensive prior work in the HCI community on tools that bridge physical and digital domains [34, 56, 65]. In this work we emphasize one common challenge that arises in these types of tools: keeping the digital and physical environments synchronized. Because the software contains a model of the physical world, it is important that this model remains updated whenever changes occur in the physical world. In the domain of simulating and debugging circuits, for example, several systems have been proposed that use sensing and signal processing to track the state of the physical world [13, 63] or cameras coupled with optics in augmented 3D objects [54]. The ElectroTutor tutorial system uses a semi-automatic approach, with the user placing sensing probes and providing input about which tutorial steps have been completed [61]. Likewise, DemoCut [10] and Spyn [52] use a combination of visual input and user annotations to connect the physical world with a software system. PatchProv uses a similar technique, relying on the user to take and upload photos of the quilt pieces being created, which are then processed using lightweight computer vision techniques. The goal of keeping the physical and digital environments synchronized also differs from prior work in that the objective is to enable design exploration during a long iterative design and execution process, rather than debugging incorrect behavior or sensing when particular goals have been met. For an improvisational tool the goal of supporting design exploration can still be met with imperfect or incomplete synchronization between the physical and digital domains.

2.4 Craft & Textiles

The relationship between craft and technology has long been explored within the HCI community, from using technical tools to communicate craft practices [20, 42, 51] to developing systems to enhance specific craft processes [52]. Prior work on weaving has explored the potential for master weavers and technical collaborators to come together to learn from each other [12]. This work places emphasis on the value of using deep knowledge from creative domains to develop technical tools alongside domain experts. HCI researchers have also emphasized the role that technology can play in preserving cultural practices, for example by documenting traditional crafts and sharing them with wide audiences [42, 50, 52]. In line with this, PatchProv has been designed with careful attention to how a computational tool could aid a modern quilting process. This work takes inspiration from prior work on the value of preserving elements of craft that often go unseen, such as intention and process [52]. One of the features of PatchProv is its ability to capture the non-linear process of improvisational quilt design, which often goes unseen.

A number of HCI research projects have introduced novel forms of input and interaction with textiles, primarily through augmenting threads with sensors and electronics [1, 21]. Additional work in computational textiles has introduced creative ways to use craft tools, such as sewing machines [2] and looms [57], as input devices for games. PatchProv instead focuses on using conventional fabrics and augments the improvisational quilting process through a software tool.

Recently there have been several tools to address the domain-specific challenges in textiles that have emerged with new fabrication technologies [24, 43]. Prior work in knitting has emphasized connections between computation and knitting and enabled new computational workflows with knitting machines [25, 31, 43, 45]. Prior work has also created algorithms to help quilters sew layers of fabric together using pictorial [40] or geometric fill patterns [39]. In contrast to this work, PatchProv focuses on an earlier phase of the quilting process – designing the quilt top – and requires no specific machinery. As a result, PatchProv can be incorporated into any quilting design process.

3 IMPROVISATIONAL QUILTING

To gain a deeper understanding of the practice of improvisational quilting and to inform the design of PatchProv, we reviewed four popular books on the topic. This section begins with quilting basics and an overview of modern and improvisational quilting and then presents key themes that emerged from the review.

Figure 2: Three improvisational quilts selected to be displayed at QuiltCon 2020. These quilts embody the principles of improvisational quilting, which is one category of modern quilting.

3.1 Quilting Basics

A quilt typically comprises three layers: a fabric top, a layer of soft batting that is not visible, and a fabric backing (Fig. 3). The term "quilting" specifically refers to the act of sewing together the layers, though it is also used to refer to the overall practice of creating a quilt. The design of a quilt top is achieved by sewing together different patches of fabric. Traditional designs often follow a block-based approach, in which geometric patterns are repeated on each block, and the blocks are arranged in a grid pattern. When working from a pattern (i.e., not improvisationally), a quilter will typically start by selecting fabrics for the design, cut them according to the pattern, and then sew them together. Advanced quilting designs can have thousands of pieces and utilize complex geometric arrangements, so many quilt patterns comprise both the geometric layout of the quilt design as well as step-by-step instructions for how to sew the design. It is a widespread practice for quilters to use patterns and designs created by others. Many experienced quilters have extensive skill at executing complex and intricate designs, but little or no experience with creating original designs [41].

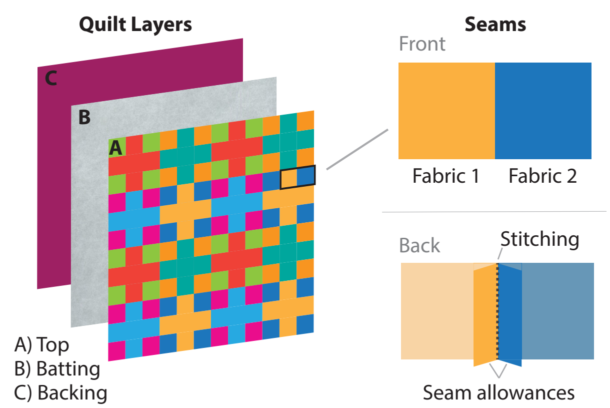

Figure 3: (left) A quilt comprises three layers: the top, the batting, and the backing. (right) The regions between the edges of the fabrics and the line of stitching are called seam allowances, which are hidden between the top and batting.

3.2 Modern and Improvisational Quilting

The history of modern quilting is a subject of ongoing debate and discussion, but the term is often used to refer to quilts that have an aesthetic similar to modern art (Fig. 2), achieved through various patchwork techniques [11, 23, 36]. One such technique, *improvisational piecing*, often leads to abstract and free-form designs. In this technique, a quilt is designed without a pre-defined pattern, with design decisions made throughout the process of creating the quilt top by interleaving the design, execution, and documentation of the design.

Below we summarize key themes from four popular books on improvisational quilting [15, 18, 41, 62], selected from the top 20 Amazon.com results for improvisational quilting and advice from an experienced local quilting teacher. We also introduce design principles for PatchProv, based on what each theme reveals about potential barriers for novice quilters, or ways that the practice of improvisational quilting might be supported.

3.2.1 Interleaving Planning & Execution. In improvisational quilting, designs emerge incrementally, with planning and execution interleaved over the course of creating the quilt. A quilter may start with some ideas about a design but no complete plan. The goals may solidify or change over the course of the project. Loomis emphasizes the importance of making design decisions "in the fabric" as she goes along, rather than pre-planning her design:

> Remember, sew first, plan later... By contrast, let's contemplate the opposite approach of "plan first, sew

> second." That's how people make quilts from patterns. They might sit down with some graph paper and sketch out what the quilt is going to look like. Then they figure out how many squares or triangles of each size will be required. They add seam allowances and figure out exactly how big the pieces need to be. Then they cut the needed pieces according to the plan. Finally they sew everything together. I don't like this approach because it seems that all the fun–the creative decisions about how the quilt will look–is over before you sew your first stitch... I like to make my creative decisions on the cloth, not on paper. I like to sew some things together and see what happens. [41]

While some improvisational quilters stick to standard geometric shapes created with the assistance of rulers or cutting grids, others use improvised, freehand cuts to create irregular shapes that often have more interesting angles [15]. A benefit of working without a fixed pattern is that it "lets you make decisions as you go along, without overthinking" [18]. If a quilter is accustomed to working from patterns, however, it can be difficult to determine where to start and how to develop a design. In particular, cutting fabric without a pattern or guide can be intimidating because mistakes are irreversible.

Considering the above, our first design principle for PatchProv is that it should ***support low-cost experimentation*** to lower the barrier to working without patterns or guides and promote making design decisions incrementally throughout the project.

3.2.2 Encouraging Experimentation, Reflection, & Self-Critiques. Each of the books on improvisational quilting suggests approaches for quilters to create opportunities for experimentation in the fabric. Several of the authors suggest starting with prompts and challenging oneself to do quick exercises or block studies (e.g., create one block) because this removes the pressure of committing to a full design. Some example design exercises suggested from [18] are: constrain one's time (e.g., 2 hours for a block study), limit material amounts (e.g., pre-cut fabrics and try to use everything), and play with a single shape (e.g., only squares or triangles).

Loomis suggests that improvisational quilters write out some guidelines for themselves and then adjust them as they work:

> I suggest you write your preliminary plan down on an index card and post it someplace where you can see it as you cut and sew. For instance, your plan might say, '42 square blocks, three to five rectangular rails of varying width per block, most blocks dark, some blocks medium with white accents.' Of course you can modify this plan after you start sewing the fabrics together and putting them up on the wall; and, in fact, I'd be surprised if you didn't have some modifications. That's the joy of the sew first, plan second approach; you have the chance to fine tune your design as it progresses. [41]

The fact that most of these exercises take the form of placing constraints on aspects of a design suggests that the vast space of potential designs may be overwhelming and may contribute to the challenge facing quilters starting with this practice. Also, the recommendation of quick exercises and block studies suggests that it takes practice to overcome the design roadblocks that prevent forward progress. To address these potential challenges, PatchProv should ***assist users with starting a design and help them avoid decision paralysis in the face of a large space of potential design directions***.

In contrast to these challenges, another theme that emerges from the review of the books relates to promoting reflection and critiquing design decisions throughout the process. Gilman cautions that "improvisational piecing doesn't automatically yield good design" [18]. While quilting improvisationally is open-ended and personal, there are some strategies quilters must develop to critique their designs. Friend notes, "Most successful improvisational works have some guidelines established by the maker"[15]. Rather than give firm instructions or guides, teachers tend to give questions to encourage students to reflect and examine their work. Teachers often tell their students to look at their compositions and consider elements, such as focal points, balance, unity, repetition, rhythm, and variety [18]. Considering the above points, PatchProv should ***promote reflection on the design as it is being created***.

3.2.3 The Process is More Valuable than Reproducible Patterns. While improvisational quilters seek inspiration from many sources, including books, blogs, and meeting other quilters, they are often reluctant to share reproducible patterns. For some quilters, designing patterns or even conveying how to achieve a particular aesthetic in improvisational quilting is seen as being in opposition to the technique itself. Wood explains:

> The Improv Handbook offers a unique approach to patchwork that doesn't rely on step-by-step instructions for replicating fixed patterns. Instead it provides frameworks, or scores, for flexible patterning that support improvisatory exploration... If you picked up this handbook to learn how to make quilts that look like mine, I'm sorry to disappoint. I can't teach you how to do that. I can't even replicate my own quilts, because each one is unique to the moment it was made. [62]

Despite the lack of step-by-step instructions, quilters are often eager to learn about each other's processes. While quilt shows allow quilters to show off their finished designs, it can be difficult to learn in any detail about the process used to construct the quilts. While some quilters do share snapshots of progress on social media, the full process used to create a design is difficult to capture, as the process does not naturally produce a trail of artifacts. In particular, it is difficult to capture the many, and often spontaneous, design decisions made throughout the process.

Considering the above challenges, PatchProv should ***capture the process by which a design is produced***, with a focus on the overall approach rather than exact replication.

The next section describes the PatchProv user interface that was developed based on insights from the above review and the four guiding design principles presented above.

4 PATCHPROV

The PatchProv user interface was designed around the virtual representations of two areas that are commonly found in physical sewing

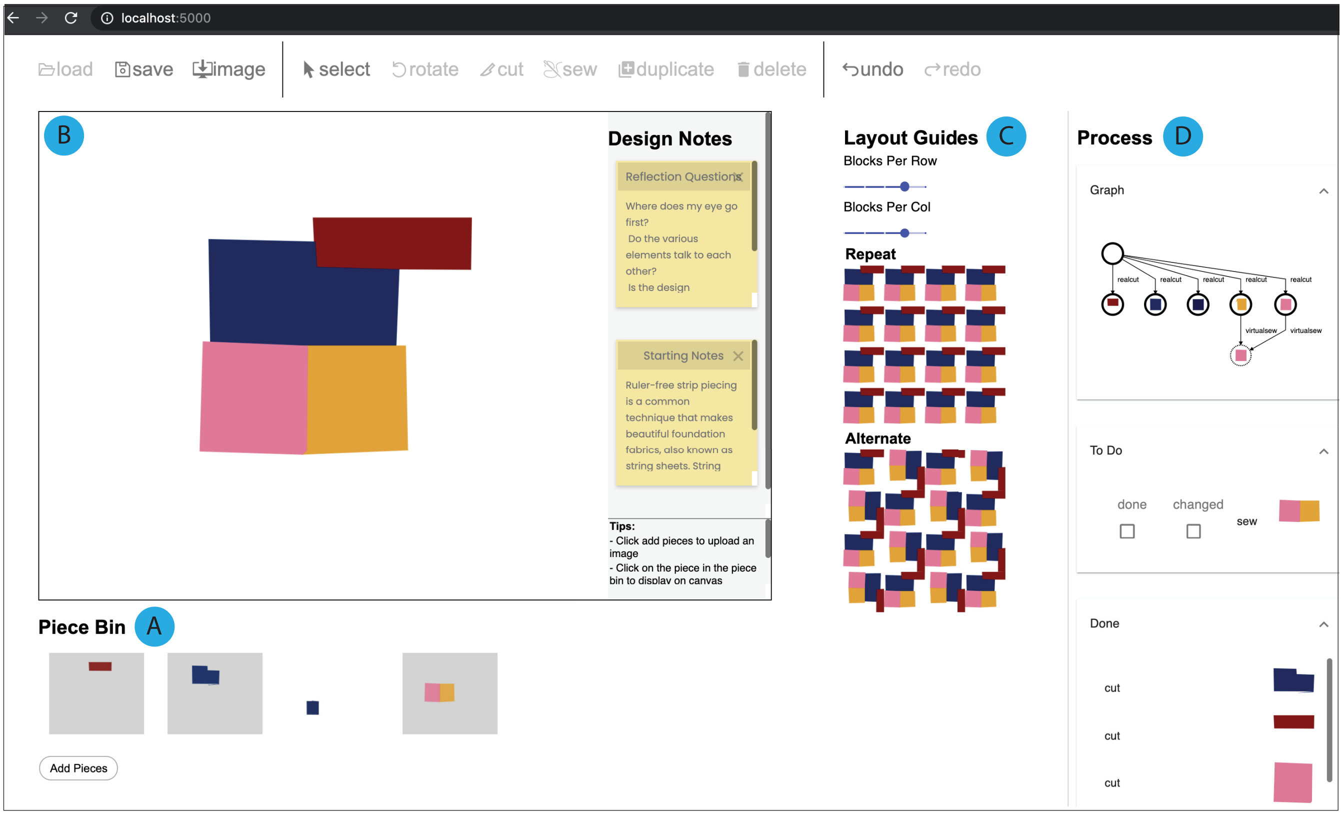

Figure 4: The PatchProv interface comprises: (a) a Piece Bin for storing available pieces and works in progress, (b) a Design Wall for design experimentation, (c) Layout Guides to imagine sewn components within a larger composition, and (d) Process Visualizations to capture and present design progressions.

rooms, i.e., a *Design Wall* (Fig. 4, B), which serves as an area for prototyping and experimenting with designs, and a *Piece Bin* (Fig. 4, A), which stores available materials and partially-built elements of a design that is being created. The interface also includes areas not present in physical sewing rooms, including *Layout Guides* (Fig. 4, C), which show potential layouts as a user works, and a *Process Panel* (Fig. 4, D), which displays two representations of the work completed to highlight 1) how the virtual design has diverged from the physical representation and 2) which physical steps must be performed to synchronize the physical and digital representations.

4.1 Piece Bin

The Piece Bin (Fig. 4, A) acts as a repository for single pieces of fabric cut into shapes or multiple pieces sewn together. Pieces in the list are represented as thumbnails, which can be clicked to toggle whether the piece is on the Design Wall. The thumbnails for pieces currently on the Design Wall are displayed with a grey background.

Physical pieces of fabric can be loaded into PatchProv through the 'Add Pieces' button below the Piece Bin. The system prompts the user for a photo of the pieces, which is then automatically processed to identify contours around individual pieces of fabric in the photo. A contour editing interface is then displayed in a modal dialog (Fig. 7) to enable the user to adjust the automatically-identified contours or replace them by drawing new contours directly on the photo. When users are satisfied with the contours, they can select 'Save' to load the pieces identified in the photo into the Piece Bin.

Pieces loaded into the system using this process are considered *real*, meaning that they correspond to the state of pieces in the physical world. When editing operations are performed on these pieces in PatchProv, they become marked as *virtual* instead to indicate that they include operations that have not yet been performed in the physical world.

4.2 Design Wall

In a physical sewing studio, a Design Wall provides an area for experimenting with potential designs and laying out pieces before they are sewn together (Fig. 5). PatchProv's virtual Design Wall (Fig. 4, B) has a similar purpose. The main area in the interface can be used for supporting quick design experimentation without wasting physical materials. Pieces can be dragged and rotated. They can be cut into smaller pieces by selecting the 'Cut' tool and then drawing a line across the piece. They can also be sewn together by selecting another piece and then selecting the 'Sew' tool. When "sewn" together, the two pieces are replaced by a single combined piece in the Piece Bin so that they will be treated as a unit during all future operations. As mentioned above, when editing operations

Figure 5: A Design Wall is a tacky surface that quilters use to experiment with fabric layouts and quilt designs. PatchProv provides a virtual version of a physical design wall.

are performed on pieces, they are marked as virtual. Virtual pieces are displayed as semi-opaque on the Design Wall.

The Design Wall also displays design prompts and reflection questions for users to reference if they get stuck (Fig. 6). The prompts are selected by the user at the start of the design session and are drawn from popular improvisational quilting books [15, 18, 41, 62][1]. Selecting a prompt is optional, and users can continue to the main area of the tool with or without taking preliminary notes.

4.3 Layout Guides

One of the ways in which quilters can get stuck in their designs is not knowing how a particular design decision in one part of the quilt may affect other parts of the overall design and layout. To overcome this challenge, a common strategy is to take photos of the quilt and view them at a smaller scale and in different orientations [18]. Particularly for quilts with repeated blocks, it is common to place different pieces of the quilt in a grid pattern [41]. PatchProv automatically makes a copy of all of the pieces on the Design Wall, creates an image cropped to the exterior boundary of the pieces, and repeats the design in two common grid configurations in the Layout Guides (Fig. 4, C). The Repeat Grid simply repeats the blocks, and the Alternate Grid alternates blocks oriented in the direction on the Design Wall with those rotated 90 degrees. Using the two sliders, users can select the number of rows and columns in the grid to view. The Layout Guides allow users to see how their blocks will look when repeated, which provides quilters with a preview of potential design steps without requiring users to cut and sew physical fabric.

4.4 Process Panel

PatchProv provides two different visualizations of the improvisational quilting process based on an underlying process graph (more details provided in Sec. 5). The graph serves two purposes: 1) keeping track of the steps the quilter needs to perform to synchronize the digital and physical designs and 2) providing a record of the creation process (Fig. 4, D). In the graph visualization, nodes with solid borders reflect steps that have been taken with the physical fabric. Nodes with dashed borders indicate the next steps that the user could take to make progress in the real world to match the virtual representation. Nodes with gray borders represent digital steps that cannot be completed with the physical fabric because there are additional operations that need to be completed using the physical fabric first. At the end of the improvisational design and sewing process, the graph shows all of the steps that were taken to achieve the finished design. Branches and leaves show the various design explorations taken and choices made.

In addition to the graph-based visualization, PatchProv provides a sequential list of steps that can be used for tracking progress while working and reflecting on the process used to reach the end result. The system maintains two lists: a *To Do* list, and a *Done* list (please see Sec. 5 for a further discussion on synchronizing the physical and virtual representations). The To Do list presents two options: 'Done' and 'Done with Changes'. Checking the done box moves an item from the To Do list to the Done list and converts the operation from virtual to real. The 'Done with Changes' option enables users to deviate from the virtual design by making design decisions in the fabric. Checking the 'Done with Changes' option prompts users to upload a new image to reflect the changes that were made in the fabric.

To encourage the user to keep the virtual representation synchronized with the physical, the system displays a warning indicator at the bottom of the process graph when the To Do list is more than 10 steps long. The warning is meant to ensure that the two environments do not get too far out of sync, but users can ignore the warning and proceed adding more virtual steps. To encourage users not to get too far ahead in the physical world, the system also displays a warning when the To Do list is empty, reminding them to upload a new photo if they have taken several steps forward in the physical world.

5 IMPLEMENTATION

This section describes the methods that were implemented in PatchProv, including how images are parsed, and the underlying abstractions, data structures, and operations that enable for the manipulation and experimentation with pieces in the tool.

5.1 Parsing Input Images

In order to support experimentation in both the digital and physical environments, PatchProv must present faithful digital representations of physical fabric pieces without requiring significant effort on the part of the user. Therefore, PatchProv uses a photo as input and automatically identifies and creates virtual representations of the pieces shown in the photo. The system accepts JPEG images that display solid color pieces placed on a uniform background as input. In an initial pre-processing step, each image is resized to a maximum width of 300 pixels and flattened to no more than 10 colors using k-means clustering on pixel color values [8]. The

[1]Example prompts are available on our website: http://web.stanford.edu/~mleake/projects/patchprov/

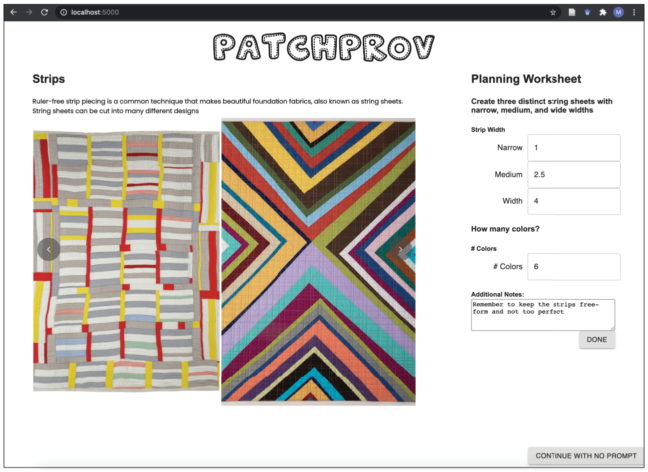

Figure 6: The welcome screen shows users "design scores" from improvisational quilting books and blogs and allows them to make notes about the designs they plan to create.

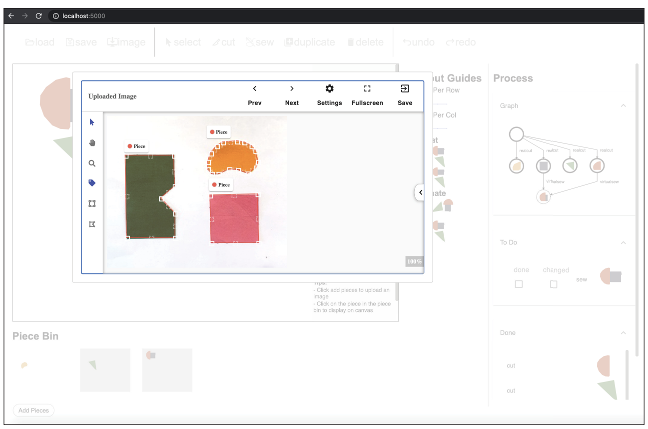

Figure 7: PatchProv provides a contour editing tool for editing the automatically detected piece boundaries, if needed.

image is then converted to grayscale, and OpenCV contour detection is used to identify the boundaries of each piece [5]. Based on the identified contour for each piece, a SVG polygon is created and colored based on the average color of a 5x5 pixel window in the center of the shape in the downsampled image. This limits the system to supporting only solid colored pieces, which are common choices for modern quilts [23]. This simple image processing pipeline has some limitations (e.g., it does not properly identify pieces that occupy less than one percent or more than 95 percent of the image frame or those in photos with uneven lighting conditions that affect the appearance of the boundaries). To address these limitations, PatchProv provides an additional interface for adjusting the automatically detected boundaries or drawing new polygonal boundaries for pieces that were not caught by the system during the image upload process (Fig. 7).

5.2 Real & Virtual Operations

To enable low-cost experimentation in the PatchProv interface while keeping track of how pieces in the system have deviated from their physical-world counterparts, PatchProv maintains a *Process Graph* data structure that keeps track of operations performed on pieces in the system. Operations are considered "virtual" when performed in the system, and the virtual operations in the graph are displayed to the user as a To Do list of operations that must be completed and checked off to bring the physical artifact in-line with the representation in the system.

The primary operations supported by PatchProv are *cut*, which subdivides a piece or group of pieces; and *sew*, which joins pieces or groups of pieces. While this may seem overly simple, it is worth noting that even the most elaborate improvisational quilt designs are realized through these two basic operations. PatchProv also supports three additional operations – *duplicate*, *undo*, and *redo*. The duplicate operation creates a clone of the original piece and replicates the history of cut and sew operations for that piece, marking all steps as virtual so that they will be added to the To Do list. The undo and redo operations enable users to roll back operations selectively.

When taken together, the above operations enable experimentation at a lower cost than is possible with physical fabric. Virtual cut and sew operations are performed nearly instantly, whereas their physical world counterparts take significantly more time and effort. Duplicate, undo, and redo together enable experimentation that is not possible outside the system because physical fabric cannot be "uncut," and "unsewing" would require ripping out stitches, which can leave permanent holes in the fabric.

Divergence between the digital and physical representations can occur either 1) when the user takes too many steps forward in the digital tool without cutting and sewing physical fabric pieces or 2) when the user makes changes to physical fabric pieces that are not represented in PatchProv, causing the digital representation to become out of sync. To handle the first case, the user can simply follow the To Do list items in the digital tool to cut and sew the necessary fabric pieces. In the second case, a user can simply take a new photo of the current state of the physical pieces that have changed and use it to replace the out-of date pieces represented in the system.

In the next section, we describe the underlying data structure that supports the operations described above.

5.3 Process Graph and To Do List Generation

Capturing the complex process of improvisational quilt design can be challenging to do in the physical world, but the combination of the physical and digital representations provided by PatchProv enables new ways of recording this information. The purpose of capturing this information is to allow users to know which steps to take next in the design while they are working (i.e., generating the To Do list), and to communicate this process with others when the quilt is complete by sharing the resulting graph, list, and finished design. This is supported through the Process Graph data structure (Fig. 8). Nodes in the graph correspond to states of the construction process, and edges correspond to the operations used to transform one state to the next (e.g., Cut or Sew). Each edge has a start and end

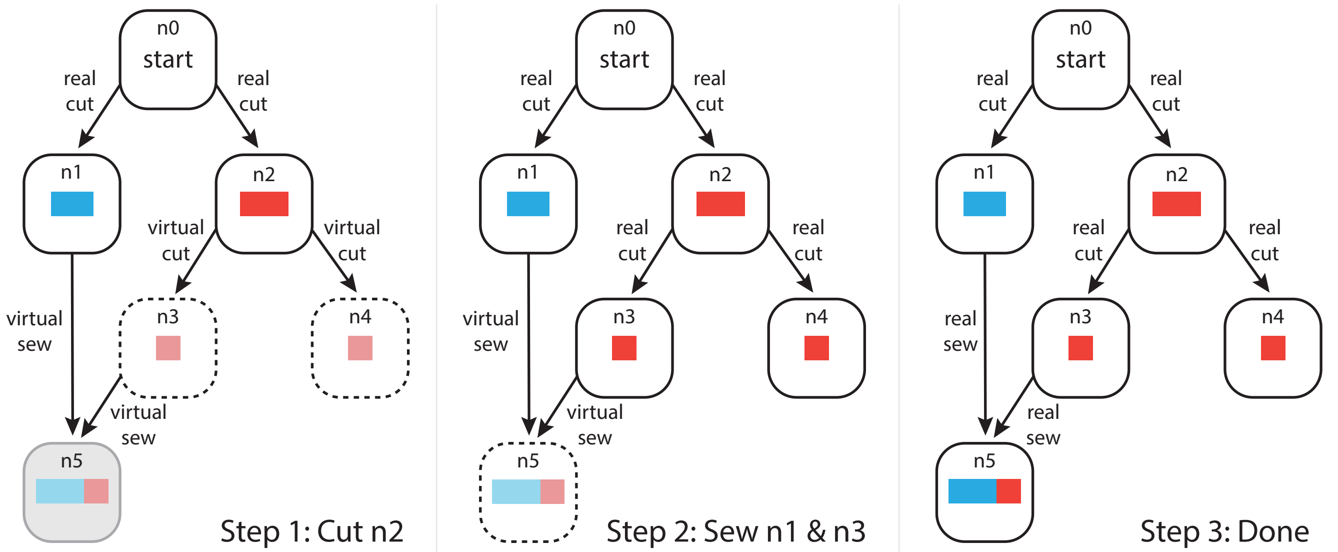

Figure 8: The Process Graph keeps track of the next real world operations that are feasible. Nodes for completed steps have solid black outlines, nodes for available steps have dashed black outlines, and nodes for steps not yet possible have grey outlines. In this example, the Cut operation on *n2*, resulting in *n3* and *n4*, is available to do in Step 1, the Sew operation at *n5* is available in Step 2, and the virtual and real representations are in sync in Step 3.

node, an operation, and a real or virtual flag indicating whether the operation has been performed using the physical fabric. Duplicating a node with the Duplicate tool copies the sub-graph consisting of all ancestors of that node and sets the virtual flag on all operations in the duplicated sub-graph.

The Process Graph keeps track of the operations performed in PatchProv, initially marking each as virtual, and using them to generate the To Do list. To produce the To Do list, the system uses the graph to determine which operations the user can perform next, given any dependencies that exist between operations. For example, before sewing two pieces of fabric, these component pieces must have been cut first.

To determine the ordering dependencies between tasks and generate the To Do list automatically, the system first performs a topological sort of the nodes in the graph such that all nodes precede their successors. The nodes are iterated through in this order, and considered as 'done' if all incoming edges to the node have the 'real' flag, and as 'not done' otherwise. Edges with a 'virtual' flag between a 'done' node and a 'not done' node are added to the To Do list as steps that can be performed immediately (e.g., in Fig. 8 Step 1, the virtual cuts *n3* and *n4* can be performed by the user). Edges between 'not done' nodes are also added to the To Do list, but are shown as unavailable, as they cannot be completed until operations on which they depend are completed (e.g., in Fig. 8 Step 1, the virtual Sew *n5* cannot be performed because it depends on *n3* being completed first). In some cases there are multiple items available to be done on the To Do list, and these steps can be completed in any order in the physical world.

In addition to guiding the user about how to create a design in the physical fabric, the Process Graph records the sequence of steps the user took to create an improvisational design. Steps are displayed in a Done list in the order that they were marked as completed by the user, creating a design snapshot and a record of which operations were completed.

Using the Process Graph to reflect the process captures some elements of the design process at a different granularity than others. For example, a user might use PatchProv to experiment with the design of a block, capturing the process of how to create that block in the graph, and then go on to create several variations of that block in the physical fabric, only loading in the end results of those blocks once they have been completed (perhaps to experiment with the final layout). This is not necessarily a problem, as the goal of the system is not to produce a pattern for reproducing a design, but rather to capture the approach taken to create a quilt. This interest in representing process rather than an exact recipe is not unique to improvisational quilting – members of DIY crafting communities have also indicated a preference for this type of process-oriented information [59].

6 USER EVALUATION

We conducted a user evaluation with quilters with varying levels of experience and familiarity with improvisational quilting to gain insights about how PatchProv could be used within a quilter's design process. We sought to learn which features support improvisation and gain feedback on how to improve the tool to better aid this practice.

6.1 Participants

Four female participants were recruited with at least three years of experience in making quilts. Participants' quilting experience ranged from three to forty years and five to two hundred quilts completed (Table 1). Two participants listed quilting as a full-time job,

Table 1: Participant demographics and quilting experience

ID	Age	Quilting Experience		
		Years	# Quilts	Notes
P1	50-59	40	40	Familiarity but no improv experience
P2	30-39	3	5	No familiarity with improv
P3	50-59	25	200	Improv experience; works as quilt artist's assistant
P4	30-39	4	40	Familiarity but no improv experience; owns a quilt business

one as a quilt artist's assistant (P3), and the other as the owner of a custom quilting business (P4). One participant commonly works improvisationally (P3), two were familiar with improvisational quilting but had never worked this way before (P1, P4), and one was unfamiliar with the process (P2). Two of the four participants had prior experience using Electric Quilt 8 software [48] to aid in the planning of a traditional quilt design (P1, P3), and three regularly use social media to communicate with other quilters (P2, P3, P4).

6.2 Study Protocol

The study consisted of one-on-one sessions between the experimenter and a participant, conducted over video conferencing software[2]. Each participant provided her own fabric, sewing supplies, camera, and computer. Study sessions lasted approximately two hours in total. The first 15 minutes of the study were devoted to a background interview in which the participant discussed her current quilting practice and views on improvisational quilting. Next, the facilitator provided the participant with a 15 minute demo of PatchProv. Participants then used PatchProv while sharing their screens with the experimenter. They were instructed to design one quilt block 4-12 inches in size using solid fabrics and were encouraged to think aloud and discuss their designs while working. Participants were required to upload at least one input image of fabric pieces into the system but were otherwise free to use whichever features of the system or tools available in their physical sewing studio to design their quilt blocks. After 75 minutes to complete their designs, the study sessions concluded with a 15 minute interview, focusing on experiences with the system and reflections on the improvisation process. Following the session, participants were given the opportunity to continue using PatchProv for additional compensation at the rate of $25/hr. Two participants (P1 & P3) continued to work on their designs after the initial session, one adding to her block, and the other completing a full mini-quilt with four blocks (Fig. 10).

6.3 Results

We begin by presenting observations and feedback relating to the design principles for PatchProv and then discuss some high-level observations of how PatchProv was used by the participants. Finally, we present suggestions made by participants on PatchProv features, which provide further insights into how they viewed the system.

6.3.1 Getting started. Although three of the four participants did not have direct prior experience with improvisational quilting, all participants were successful at designing blocks during the study. From the available design scores on the Welcome Page, P3 chose to work from the "ruler free strips" prompt, and her resulting design embodies this technique (Fig. 9, top). P4 told us that she referenced the "log cabin" prompt from the Welcome Page while working on her block, and she noted that having the prompts was helpful in getting started:

> [The prompts] get your brain thinking of the different shapes and stuff that you could do, and obviously subconsciously, the square in the square block was stuck in my head because I was trying to replicate that. So I think it's nice. It gets you thinking what's possible to do in different shapes and stuff that can be put together (P4).

The other two participants looked through the prompts on the Welcome Page but did not choose to work from any of them explicitly. None of the participants noted having trouble getting started, and all were designing original blocks within minutes of beginning to use PatchProv.

6.3.2 Avoiding indecision and getting stuck. Throughout the course of designing blocks, none of the participants said they had reached a point where they felt stuck in their designs. When asked about getting stuck, P3 said that she has experienced this problem in the past and noted that she could see PatchProv helping to overcome this challenge:

> I didn't get stuck in this one, but I have gotten stuck with the pieces that I've made in the past and just not quite knowing how to proceed and kind of being scared to try anything because I only have this much fabric. I don't want to cut it up first. So being able to take a picture of that fabric and bring it in here and cut it up and see how it looks, would definitely help bridge that artist's block – when I'm not quite sure how to proceed and your materials are limited – so this is a really nice solution to that because you could do it virtually and then decide whether that's really the avenue you want to take with it or not (P3).

This suggests that the ability to make changes virtually in a way that does not require making irreversible changes does lower the bar to experimentation and helps prevent users from getting stuck.

6.3.3 Promoting experimentation. Building upon P3's comment about not getting stuck, we observed that all participants used PatchProv to experiment with potential designs. Even the participants with less quilting experience noted the benefits of being able to experiment in the digital representation:

> I guess, to me, I'm not instinctively brave enough to try that [improvisation], but seeing it in front of me with the computer generated version, it helps me have a little more freedom to say okay, I'll need this triangle or that piece to fill in here instead of cutting all of that first, and it's the wrong size and shape for what you need (P1).

Participants also noted the ability to save materials by experimenting digitally:

> I think what's brilliant about this is that it's cutting [virtually]... [In the real world] it's so time-consuming and laborious, and you could use up a lot of material,

[2] The study was carried out with IRB approval for a remote lab study. An in-person study would have had some advantages, but was not possible due to COVID-19.

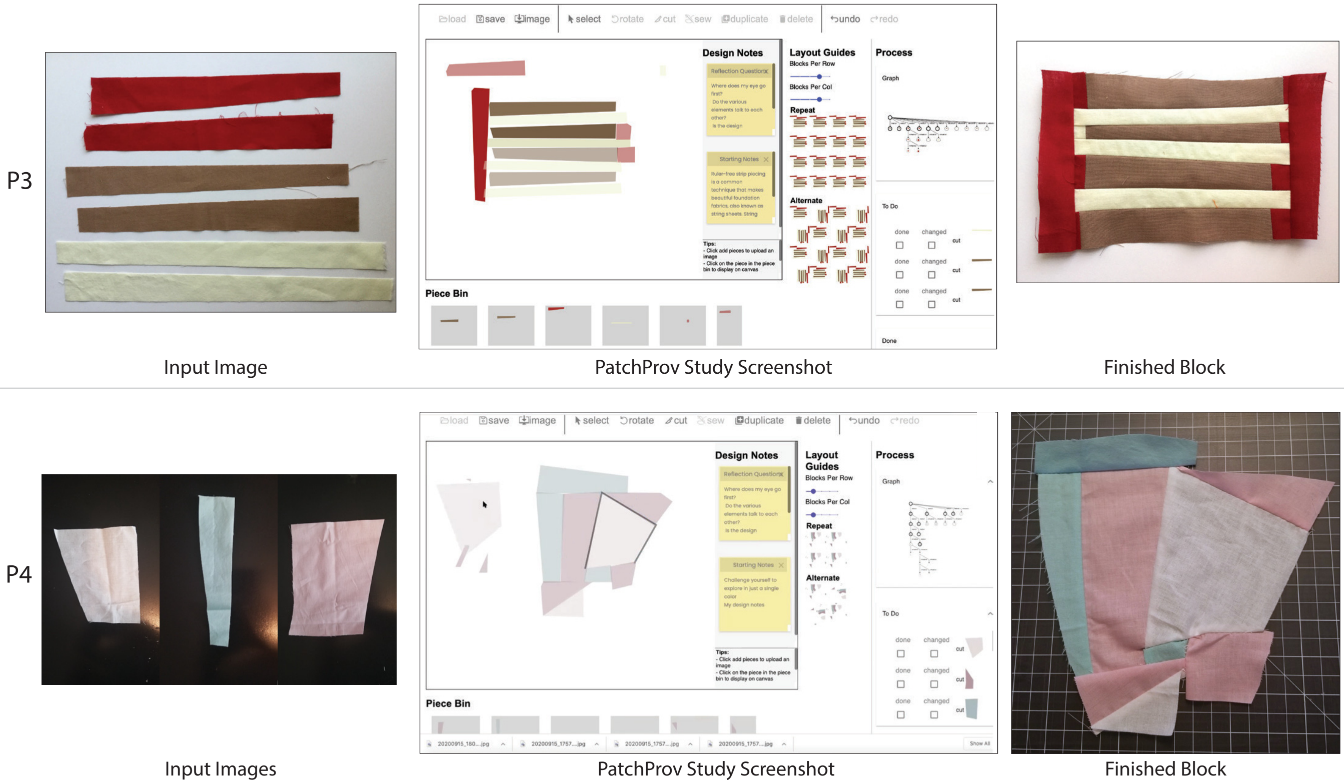

Figure 9: P3 improvised in the fabric based on her digital design, adding additional red fabric on both sides for balance and connecting the beige strips to create a stronger diagonal design. P4 did most of her design exploration in PatchProv and sewed a block very similar to her digital design.

> just trying things out in this way. Here you can do all of that trial and error virtually and using real-time images, which I think is fabulous. And the fact that you can upload this photo and use the actual pieces that you're working with is just cool. You can also see what the possibilities are before you cut up too much fabric, before you spend too much time with it (P3).

The above feedback provides further evidence that the features of PatchProv promote experimentation and suggests that a key way they do so is by enabling experimentation without requiring fabric to be cut physically, and thus potentially wasted if a design exploration does not yield a design the quilter likes.

6.3.4 Capturing process and enabling syncing. All participants noted the benefits of PatchProv capturing the process they had taken when working on the virtual pieces, and the two professional quilters expressed particular interest in these features. P3, who had worked for several years as an assistant drafting patterns for a well-known quilt artist, found both the Process Graph and the To Do list to be particularly helpful:

> [The To Do list] would really come in handy because then you don't have to remember what you did first and then second, because this will show you what you did. And I think just you could kind of disconnect a little bit and have more fun with the designing of it, knowing that the hard and fast steps were being recorded as I worked, and then it would just be a matter of reviewing it (P3).

Two of the participants (P3 & P4) spent some time examining the Process Graph at the end of the study, and discussed their interest in this visualization of their process. P3 noted the benefit of seeing both the Process Graph and the To Do list together:

> I think it's really interesting to see that to-do list next to the graph because the graph gives you the big picture of all that you've done, but then the To Do list breaks it down into all the tiny steps – so it's kind of cool to see that forest and trees comparison (P3).

It is interesting to note that P3 expressed appreciation for the Process Graph and To Do list and cited them as providing a helpful record of her design process that could be used to make additional blocks or write instructions for other quilters, even though she was one of the participants who made some alterations to her design in the process of creating it in the physical fabric.

6.3.5 Workflow Observations. Participants varied in the amount of time they chose to spend working in the fabric versus in the software tool. The two participants working as professional quilters

(P3 & P4) made more exchanges between PatchProv and the physical cutting and sewing steps. In the 75 minute design session, P3 made three round trips between designing in the tool and sewing seams, and P4 alternated between design steps and cutting steps frequently, making five trips between the digital and physical steps. This suggests that PatchProv was able to fit within a sewing workflow and became a part of the iterative process of designing, cutting, and sewing that is characteristic of improvisational quilting.

Two participants produced designs that were closely aligned with their digital designs created in PatchProv (P1 & P4) (Fig. 12, top & Fig. 9, bottom), while the other two made decisions in the physical fabric that deviated from the design produced in the system (P2 & P3) (Fig. 12, bottom & Fig. 9, top). P4, who alternated frequently between PatchProv design steps and sewing, kept her digital and sewn designs similar (Fig. 9, bottom). She stated that her original intention was to create a butterfly design, but the design evolved to be more abstract through the course of designing and constructing it. P3 worked on her design in PatchProv, and then changed several design elements to balance the red fabric on both sides of her block and draw attention to the zig zag motif in the center when working with the physical fabric (Fig. 9, top).

6.3.6 Suggested features. Participants suggested a number of additional features for the system, and several of these centered on improving the connection between the digital representations and the physical pieces that they represent. P1 and P3 suggested that the tool provide estimates of materials needed:

> You don't want to use a bunch of reds, blues, and whites and then find you've run out and don't have enough to finish up your quilt. Being able to estimate the amount of fabric needed would be a huge factor (P1).

P1 and P3 called this out as a feature that would be particularly useful for professional pattern designers. P3 also suggested that the tool could take into account additional physical constraints of sewing, such as seam allowances, which are the regions along each edges of fabric pieces that get folded under when they are sewn together (Fig. 3, right). The current PatchProv system could easily be extended to estimate and track material usage.

Participants also suggested further ways that the system could provide design guidance or encourage serendipitous discoveries. P1 suggested a 'shuffle' button that randomly scatters all of the pieces on the design wall, for inspiration, and P3 suggested that the Layout Guides could provide more tune-able attributes for the suggested grid layouts. P1, P2, and P3 suggested adding the option to print a document with the elements shown in the interface to keep a record in case they wanted to refer to the design in their sewing room at a later time.

6.3.7 Physical Sewing Constraints. Overall, we observed few challenges with using the system, but there were some situations in which the system did not capture the fabrics in a way the participants wanted. First, as mentioned, the system does not account for seam allowances when virtual sew operations are applied to pieces. This was generally not a problem, but one participant created a design with a set of thin fabric strips, which became unexpectedly thinner when sewn together, due to the fabric hidden by the seam allowances. This could be addressed by providing visual guides showing seam allowances for pieces on the Design Wall, or automatically hiding the fabric that would end up in the seam.

Second, because the image processing pipeline does not currently have a way of calibrating piece sizes between photos, it was sometimes the case that the scale of pieces loaded in separate photos was inconsistent. This led to a situation for P4 in which two pieces that lined up well in PatchProv were off when she tried to assemble them in the physical fabric. This could be addressed by correcting for differences in camera distance in the image processing pipeline (e.g., using a reference object or fiducial markers).

It should be noted that these challenges do not arise from errors in contour detection, but rather as a result of physical constraints specific to the sewing domain, e.g., fabric taken up by seams, or through scale calibration across photos. In both of the above cases, participants took these challenges in stride, in the spirit of improvisation. For example, when discussing the differences in scale between pieces, P4 said:

> [That is] just kind of the idea of the improvisational quilts though, it is go with the flow type design, so I don't think it's necessarily a bad thing that it's not the same length as it was on the computer, 'cause then it just makes you have to think of something else to do.

6.3.8 Impressions of improvisational quilting. Finally, we asked participants about their views of improvisational quilting after having completed the study. All four participants indicated their interest in pursuing further work in improvisational quilting. P2, despite being unfamiliar with this type of quilting, stated that she "found new inspiration for quilt designs" and "is planning a few improvisational quilt blocks right now." P4 reflected on the improvisational quilting experience in PatchProv, and characterized it as relaxing because it removes the stress that comes with cutting precise pieces:

> It's kind of relaxing 'cause you're not being as stressed about cutting the pieces perfectly square and the perfect length because you can just trim it, and I think that's really fun. And it was a lot more relaxing, doing that than cutting things perfectly (P4).

This feedback echoes some of the prior feedback that PatchProv lowers the bar to experimentation, and also suggests that the system was enjoyable to use. This is encouraging, because a potential concern about introducing technological solutions into craft processes is that they could increase stress or detract from the intrinsic enjoyment of a handmade process.

7 DISCUSSION

The results of our evaluation indicate that participants had no trouble integrating PatchProv into an improvisational quilting workflow and that the system had clear benefits in terms of lowering the cost of experimentation. Participants also appreciated the tools that the system provides for capturing and representing their design activities and demonstrated they were able to create physical quilt blocks based on the designs they had produced in the system.

In this section, we further discuss the study findings. We also discuss potential extensions of PatchProv and how the approach taken in this work might be applied to improvisational design activities in domains beyond quilting.

7.1 Handling physical constraints in hybrid digital-physical tools

The process of developing PatchProv, and the feedback from participants, revealed an interesting tension in how physical constraints should be handled in hybrid digital-physical design tools. In particular, many of the benefits of PatchProv in terms of enabling experimentation come from the system enabling low-cost actions in the digital representation that are more costly or constrained in the physical material. But care must be taken in how these features are implemented because ultimately the actions in the system must be applied back to the physical world, with all of its attendant constraints. In PatchProv this led us to develop the Process Graph data representation and mechanisms for keeping track of 'real' versus 'virtual' pieces. This tension also came up in participants' suggestions that the tool do more to account for constraints intrinsic to the domain, such as tracking material usage. Ultimately, we believe design tools for hybrid digital-physical domains must balance representing the physical constraints in the tool with providing capabilities that enable greater creativity or other types of design support that are not available when working with the physical materials alone.

7.2 Generalizing beyond quilting

In terms of the implications of this work for supporting improvisational design more generally, our results indicate that improvisational design tools may have some advantages – or at least tolerances – in navigating the tension between physical constraints and digital support. In particular, we observed that some of the limitations of PatchProv in precisely capturing the constraints of the materials and construction process were accepted by participants because they were engaging in an improvisational design activity. This is not to suggest that tools for supporting improvisational design should not address functional or usability issues, but simply that there may be a tolerance in improvisational domains to some 'noise' when translating between the digital and real worlds.

Conversely, participants cited some existing quilt design software as being too rigid to support improvisational quilting (e.g., requiring precise dimensions and selecting from a fixed library of quilt block patterns). This further illustrates the tension between supporting improvisation and accurately representing the constraints of the physical world to help designers create designs they will be able to fabricate. This tension, as well as the opportunity to support low-cost experimentation, is likely to apply beyond the domain of quilting and may suggest that a process for developing improvisational design support tools for hybrid digital-physical domains should start with identifying relevant physical constraints, characterize these constraints based on how they might inhibit or help improvisation, and then ensure that experimentation in the software yields results that can be fabricated in the physical medium.

An important area for future work is to investigate other improvisational design domains, such as mosaic art, painting, or sculpture. This would provide insights into which of our findings generalize and which result from norms tied to quilting specifically.

7.3 Limitations

While PatchProv has a set of built-in tools for synchronizing a digital representation with physical fabric pieces, it relies on the user to capture and upload images of changes made in the physical world before they will be reflected in the system. Investigating continuous capture methods is an interesting area for future work. The image processing pipeline is also limited to solid-color fabrics and does not calibrate for scale or orientation across images. These limitations could be addressed through additional sensing or calibration mechanisms in the input pipeline. The system also does not take into account certain physical constraints, such as the amount of fabric available to a user or fabric hidden by seam allowances. While these constraints are not relevant for some types of designs, it can become more of an issue with repeated blocks, which require enough materials to replicate a design several times, or small pieces, in which the common 0.25-0.5in seam allowance takes up a large percentage of the area of pieces.

Among the four participants in our study, we had a great deal of variety in terms of quilting experience and familiarity with improvisational quilting. We also observed several different workflows for cutting, sewing, and working digitally. Improvisation is a very personal technique, and it would be valuable to test the system with a larger number of quilters. It would also be interesting to examine how the system is used over the course of much longer projects, on the scale of a full-sized quilt constructed over weeks.

8 CONCLUSION

The work presented in this paper was undertaken to understand how the practice of improvisational quilt design might be supported by technology, and whether a system designed with this purpose could be effectively integrated into existing improvisational design workflows. Through the design of PatchProv and the results of an initial study, we have demonstrated that this is possible, and that support tools of this type can effectively encourage experimentation and improvisation. We hope that this work will encourage further work on tools and reusable approaches for supporting improvisational design in quilting and broader domains.

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A APPENDIX

Figure 10: P3 asked for additional time to continue working with PatchProv after the study. She spent an additional 4 hours adding to her block from the study session to complete a mini art quilt (15x12in). Her study block is in the bottom right of the completed quilt.

Figure 11: One of our early pilot participants participated in three two-hour sessions using PatchProv and extended her designs into a full 36x42in quilt.

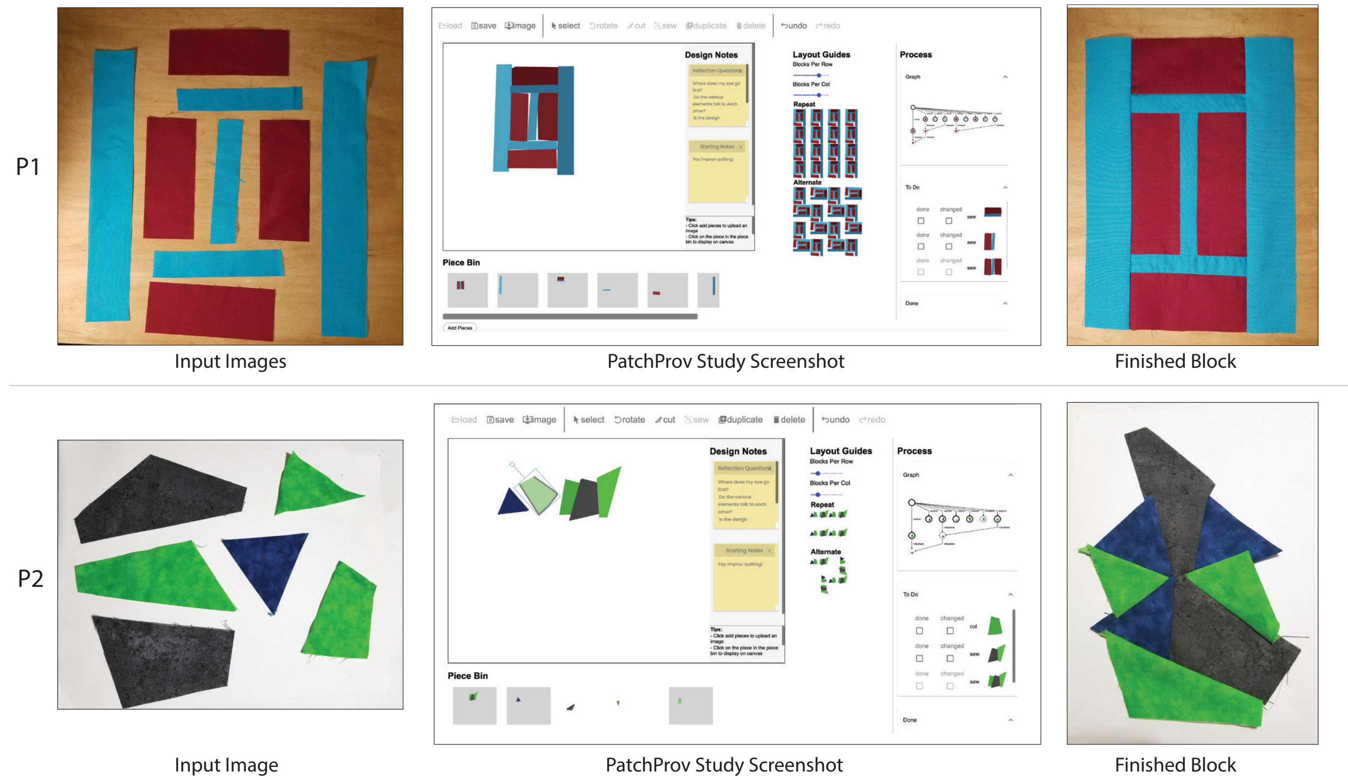

Figure 12: P1, who is accustomed to working with traditional quilt patterns, created much of her design in the fabric first, even before taking a photo to load into PatchProv (top). P2 shaped much of her design in the fabric after doing some initial exploration in PatchProv.