Rags2Riches: Computational Garment Reuse

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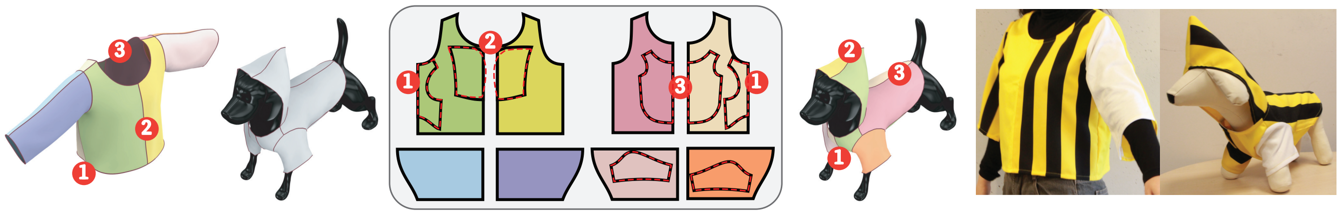

Fig. 1. We present a computational pipeline to convert an existing garment (a, source) into a new garment (b, target). Given the sewing patterns of both garments, our algorithm solves for placement of the target panels over the source garment (c) such that structural components of the existing garment are reused (seams, hems). In this example, the central seams of the front and back of the pullover are reused to form the body and hood of the dog's coat (1,2,3).

We present the first algorithm to automatically compute sewing patterns for upcycling existing garments into new designs. Our algorithm takes as input two garment designs along with their corresponding sewing patterns and determines how to cut one of them to match the other by following garment reuse principles. Specifically, our algorithm favors the reuse of seams and hems present in the existing garment, thereby preserving the embedded value of these structural components and simplifying the fabrication of the new garment. Finding optimal reused pattern is computationally challenging because it involves both discrete and continuous quantities. Discrete decisions include the choice of existing panels to cut from and the choice of seams and hems to reuse. Continuous variables include the precise placement of the new panels along seams and hems, and potential deformations of these panels to maximize reuse. Our key idea for making this optimization tractable is quantizing the shape of garment panels. This allows us to frame the search for an optimal reused pattern as a discrete assignment problem, which we solve efficiently with an ILP solver. We showcase our proposed pipeline on several reuse examples, including comparisons with reused patterns crafted by a professional garment designer. Additionally, we manufacture a physical reused garment to demonstrate the practical effectiveness of our approach.

CCS Concepts: • **Computing methodologies** → **Shape modeling**.

Additional Key Words and Phrases: Garment design, upcycling, reuse, sustainable design, circular design

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1 Introduction

The fashion industry is infamous for its mass production driven by mass consumption, resulting in high amounts of waste and pollution. Recent studies reveal that the industry is responsible for approximately 8% of global carbon emissions [Quantis 2018]. Moreover, an alarming 30% of produced garments remain unsold, ultimately ending up in landfills or incinerators [Koe 2020; Tonti 2024]. Despite this environmental impact, only 1% of used clothes are recycled into new garments, mainly because current technology is insufficient for recovering virgin fibers [Parliament 2024].

Garment reuse – also called garment *upcycling* – offers an alternative solution to recycling for reducing both resource consumption and waste. By creatively transforming existing clothing into new items, reuse is a low-cost, accessible form of personal fabrication that allows individuals to create custom garments and accessories, as documented in numerous online videos [bestdressed 2019; WellLoved 2022] and textbooks [Hilado 2023; Lawrie 2023; Scott 2020]. Reuse is also explored by textile retailers to achieve circularity [Berrens et al. 2025]. Despite its growing popularity, garment reuse poses unique challenges that hinder its widespread adoption on an industrial scale. In addition to the logistic challenge of sourcing and documenting existing clothing to be reused, modifying an existing garment to create a new one raises design challenges, as well as opportunities not present when creating a garment from scratch.

*The work for this paper was done while at ETH Zurich.

Specifically, garment reuse involves cutting panels from an existing garment – which we call *the source* – and sewing these panels together to recreate an envisioned garment – *the target* – as faithfully as possible. Planning this elaborate manual operation requires a careful assessment of various geometric and manufacturing constraints. For instance, the size of the panels is inherently limited by the dimensions and structure of the source garment. Another important factor to consider is the practical advantage of reusing structural components of the source garment, such as seams and hems, and mapping them to similar components in the target garment (see Figure 3). Strategic reuse of seams and hems reduces manufacturing costs and enhances the finish of the final product.

We present the first framework for automatically deriving a sewing pattern for garment reuse. While most existing works [Bartle et al. 2016; Brouet et al. 2012; Korosteleva and Sorkine-Hornung 2023; Meng et al. 2012; Pietroni et al. 2022; Qi and Igarashi 2024; Umetani et al. 2011; Wang et al. 2005; Wang 2018; Wolff et al. 2023] and industry tools [Fashion 2024a] focus on designing new garments from scratch, only a few studies have explored the functional modification of existing ones [Eggler et al. 2024], and none specifically tackle generation of target sewing patterns to convert existing garments into potentially very different items.

Our pipeline begins with two 3D digital garments and their 2D sewing patterns. We believe that this scenario aligns with the future of fashion design and fabrication pipelines, where garment patterns are created using digital design tools and representations [Korosteleva and Sorkine-Hornung 2023; Liu et al. 2024; Nakayama et al. 2024; Pietroni et al. 2022; Wang et al. 2018], reconstructed through reverse-engineering [Bian et al. 2024; Korosteleva and Lee 2022; Lim et al. 2023; Liu et al. 2023b; Yang et al. 2018; Zhou et al. 2024], and shared on online repositories [Etsy 2024; maaidesign 2024; moodfabrics 2024; mynextmake 2024; Sewist 2024]. Given this input, the core of our approach consists in finding the placement of the target pattern panels on the source garment. To provide sufficient flexibility, target panels can be slightly deformed. The main computational challenge then resides in deciding which source panels to cut, and where, to cover the target while achieving a balance between reuse of structural components (hems and seams) and preservation of the design intent (shape of the target panels). This optimization problem, which combines discrete and continuous variables, quickly becomes intractable as soon as the number of source and target panels grows. Our algorithm copes with this challenge by *quantizing* the panel shapes into *polyominoes*, which are geometric figures composed of unit squares that provide an efficient approximation for the relative complexity of 2D garment patches. Snapping freeform panels to such canonical shapes allows us to compare panels up to small deformations and to reduce the search space to a grid of panel placements, yielding the formulation of garment reuse as a discrete assignment problem that can be solved efficiently with ILP solvers.

We illustrate the potential of our approach on diverse source and target garments, and we demonstrate the practical effectiveness of our solutions by having one of the reuse designs manufactured by a professional tailor. We also compare the decisions taken by our algorithm with the ones taken by a professional garment designer on three garment reuse tasks.

2 Related work

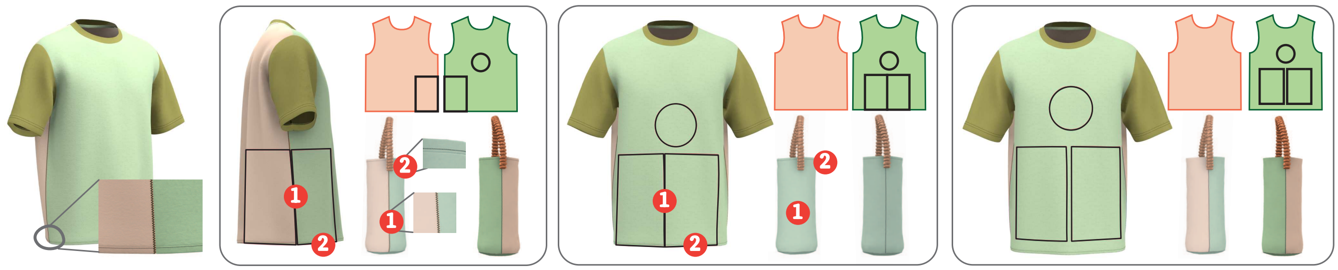
2.1 Garment and pattern design

The digitization of the fashion industry, especially in garment design, presents significant economic, ecological, and societal benefits while introducing intriguing research challenges. In response to market demands, the industry has developed various interactive CAD tools (such as Clo [Fashion 2024a,b] and Optitex [Optitex 2022]), which allow artists to create sewing patterns in 2D and then simulate their physical appearance and draping on a 3D avatar. Researchers have also proposed sketch-based [Chowdhury et al. 2022; Fondevilla et al. 2021; Liu et al. 2018; Robson et al. 2011; Turquin et al. 2007; Wang et al. 2003, 2018], image-based [Liu et al. 2023b], text-based [He et al. 2024], parametric [Korosteleva and Lee 2021; Korosteleva and Sorkine-Hornung 2023] and bi-directional [Umetani et al. 2011] user interfaces to ease the creation of 3D garments and the corresponding 2D patterns. Physical simulation can then serve to automatically optimize garment patterns for a specific body shape [Bartle et al. 2016; Brouet et al. 2012; Meng et al. 2012; Qi and Igarashi 2024; Wang et al. 2005; Wang 2018; Wolff et al. 2023], focusing on minimizing stress, pressure, or seam tension, or aligning with target design folds [Li et al. 2018]. While these approaches typically optimize the garment's shape while preserving the overall structure of the pattern layout, other methods allow for structural optimization from scratch [Pietroni et al. 2022] or perform strategic modification over existing layouts, such as adding darts to achieve a desired fit [de Malefette et al. 2023]. Closer to our goal of sustainable design, Zhang et al. [2024] describe an interactive system to create or edit so-called *zero-waste* garment designs, where a rectangular piece of fabric is shaped into a garment through cutting and sewing while removing as little fabric as possible.

The above methods focus on designing new garments from scratch. In contrast, digital garment alteration [Eggler et al. 2024] allows modification of existing garments to fit a target body shape, which represents a fundamentally different problem, as the practical operations and constraints involved in altering an existing garment are distinct from those in designing new garments. However, this method focuses on the local insertion or removal of small pieces of fabric while preserving the overall garment design, while we consider global changes of an existing garment to create another, possibly significantly different, garment. To the best of our knowledge, the only research focusing on reuse has been recently presented by Indrie et al. [2023]. However, this algorithm does not account for structural components like seams or hems, and creates patchworks of fabric pieces rather than panels with prescribed shapes.

2.2 Reuse

Unlike the fashion industry, architecture has long considered reuse to reduce fabrication costs, for which dedicated computational tools have been developed. In particular, *rationalization* seeks to minimize the number of geometrically distinct elements, such that these elements can be mass-produced. Various methods have been proposed to reduce the number of distinct beams [Bi et al. 2024; Brütting et al. 2021; Lu and Xie 2023], or nodes [Bi et al. 2024; Brütting et al. 2021; Liu et al. 2023a]. Other techniques focus on reducing the number of distinct panels [Eigensatz et al. 2010], approximating freeform



(a) Source (b) Reuse of seam and hem (c) Reuse of inside and hem (d) High fabrication cost

Fig. 2. Multiple solutions often exist to reuse a garment. When possible, designers seek to reuse seams and hems (b) to reduce fabrication cost and preserve high-quality finish (insets). A seam in the target can also be avoided if the two panels to be sewed can be cut as a single panel in the source (c). Ignoring these principles results in additional work (d), as each panel needs to be cut and sewed with the others. We created these examples by hand for illustration purpose.

surfaces using congruent groups of triangles [Bi et al. 2024; Liu et al. 2021; Singh and Schaefer 2010], quads [Fu et al. 2010; Pellis et al. 2021; Zhu et al. 2023], or general polygons [Chen et al. 2023], or designing reusable formwork [Scheder-Bieschin et al. 2024].

While the above approaches reduce cost through the reuse of molds and other manufacturing processes, we aim to reduce waste and resource consumption by repurposing elements from an existing structure to play a similar role in a different context. Existing works on structural reuse in architecture focus on reusing linear [Brütting et al. 2018; Bukauskas et al. 2017; Larsson et al. 2019] or quadrilateral elements [Pekuss and Popescu 2024], or employing tree fork connectors [Allner et al. 2020; Amtsberg et al. 2020] to model complex shapes. Typically, the problem is formulated as a two-step process: first, processing source materials into an inventory, and second, performing inventory matching using greedy search, mixed-integer linear programming, or the Hungarian algorithm [Huang et al. 2021]. Joustra et al. [2021] study how wind turbine blades can be segmented into flat rectangular panels that follow timber standards for reuse in construction or furniture design. While these studies are inspiring, we face the significantly different challenge of searching for reuse opportunities over surface elements of irregular shapes, i.e., freeform fabric panels.

A broader category of related work involves transformable objects, focusing on fabricating assemblies that can be reconfigured into different forms. This concept has been explored in domains such as furniture [Song et al. 2017], puzzles [Tang et al. 2019], and dissections [Duncan et al. 2017]. Each domain introduces unique challenges, and we refer the reader to the survey [Wang et al. 2021] for further details. Importantly, existing studies focus on application scenarios where the different forms are designed jointly to be transformable. In contrast, in our scenario, the existing garment is fixed and only the new garment can be adjusted to achieve a balance between reuse and design intent.

2.3 Irregular 2D shape packing

Rearranging a set of 2D garment panels into another set is closely related to the classical problem of shape packing, which consists of arranging a set of shapes within a container to minimize unused space while avoiding overlap. Packing algorithms are widely used in various industries for efficient manufacturing and transport [Cui et al. 2023], as well as in computer graphics to best arrange texture atlases [Limper et al. 2018]. We refer to the surveys by Leao et al. [2020] and Guo et al. [2022] for discussion of traditional optimization algorithms to cope with this combinatorial problem. Recently, learning-based methods use reinforcement learning or diffusion models to predict the placement of each element [Xue et al. 2024, 2023; Yang et al. 2023]. In the context of wood furniture design, Koo et al. [2016] and Wu et al. [2019] jointly optimize part design and packing layout to minimize material usage.

Fig. 3. Converting jeans into tops, from [Shani 2019] (left, ©Orly Shani) and [BlueprintDIY 2020] (right, ©@BlueprintDIY). Left: The designer reused the inseam of the jeans to imitate *princess seams* on the top (1,2). Right: The designer reused the hems of the legs to form the bottom hem of the top (3).

A key distinction of our setup is that we treat panels as structural elements, considering boundary features such as seams and hems and the resulting interdependency between panels as integral parts of the optimization. We make this problem tractable by taking inspiration from the work of Liu et al. [2019], which converts the irregular packing problem to a rectangle packing problem. Instead of rectangles, we approximate garment panels as polyominoes [Livesu et al. 2013] to better capture shape details, and we embed a vector field within each polyomino to keep track of panel deformations.

3 Design principles

Garment reuse is a creative activity for which practitioners have developed diverse strategies. By studying examples from books [Lawrie 2023; Scott 2020] and online tutorials (full list as supplemental materials), we identify three key principles that guide the development of our algorithm. In what follows, we refer to the existing garment as the *source*, and to the new garment to be created

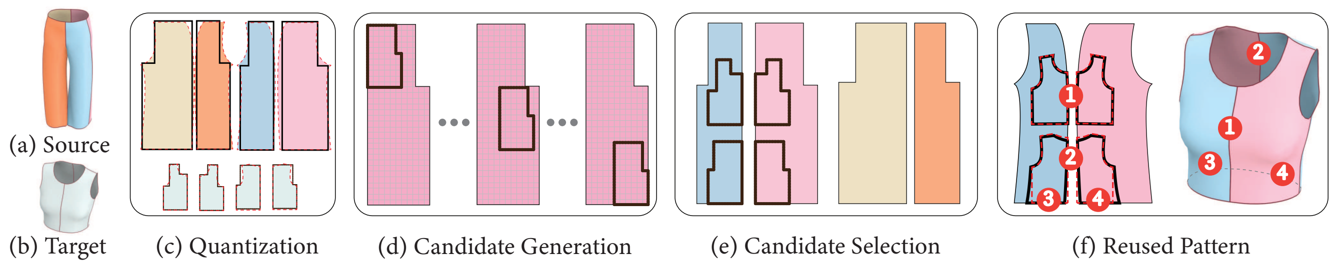


Fig. 4. Our method takes as input the sewing patterns of source (a) and target (b) garments. We first quantize all panels of the two garments into polyominoes (c). This approximation allows us to generate candidate placements of target panels by sliding them over the source in discrete steps (d, only a few candidates are shown). We then select one candidate for each target panel by solving an assignment problem that balances panel deformation with the reuse of seams and hems (e). In this example, our algorithm finds a configuration where the outer seam of the pants is reused to form the central seams of the top (f - 1,2), and the bottom hem is reused to form the hem of the back (f - 3,4).

as the *target*. Each of these garments is composed of fabric *panels* connected by *seams* or bounded by *hems*.

Reuse of garment components. Compared to virgin fabric, existing garments contain seams and hems that are tedious to deconstruct [Lawrie 2023]. Yet, seams and hems are precisely the parts that are costly to manufacture on garments, and sometimes contribute to their unique aesthetic. Designers preserve the embedded value of these structural components by reusing them in the new garments (Figure 3). For example, Orli Shani stresses in her tutorial on jeans reuse that *"This really cool inseam is such a sort of classic denim look, you want to apply that inseam down the princess line [of the new garment], that's what will create this really cool design effect"* [Shani 2019]. Figure 2 illustrates several common strategies, either to reuse seams and hems, or to avoid seams by cutting neighboring panels of the target as a single piece in the source.

Adaptation to available components. In some cases, the seams and hems present in an existing garment might not exactly correspond to those needed to form a chosen target. Designers comply with this constraint by adapting their design to leverage what is available in the source rather than strictly adhering to an envisioned target.

Preservation of grain orientation. In garments, the fabric grain is typically aligned with the vertical direction, or along specific axes such as the arm, to ensure predictable and symmetric behavior when the garment is subjected to gravity or shaped by the pressure of the body. As a consequence, designers seek to preserve the orientation of the target panels with respect to the orientation of the grain when cutting these panels in the source.

Our algorithm offers a trade-off between these principles. Given a source garment and an intended target, we formulate an optimization that seeks to reuse as much of the existing seams and hems as possible to minimize fabrication cost, while deviating as little as possible from the target shape to best preserve design intent. To do so, we search over translations of the target panels over the source panels, such that the orientation of the grain is preserved.

4 Method

Figure 4 illustrates the main steps of our method for garment reuse. The input to our algorithm is the patterns of the source and target garments. Each pattern describes the panels that compose the garment and the seams that connect some of the panel sides.

Our goal is to cut the target panels within the source panels, while reusing as much as possible of the valuable hems and seams present in the source. Our key idea is to quantize the panels into *polyominoes* to efficiently enumerate possible placements, and select the configuration that offers the best trade-off between structural reuse and reproduction of the target shape, while respecting fabrication constraints: the target should be fully covered, no part of the source should be reused more than once. We first describe this discrete optimization (Sec. 4.1), before explaining how we convert garment panels into polyominoes (Sec. 4.2).

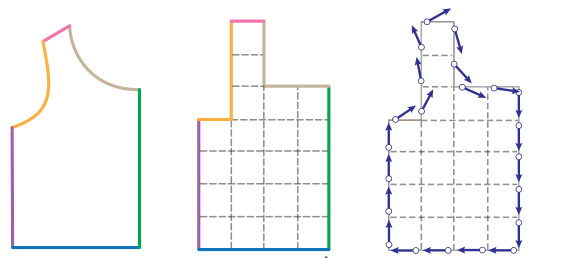
4.1 Discrete optimization

Inspired by rectangle-based packing algorithms [Liu et al. 2019], we reduce the complexity of the original discrete-continuous problem by approximating the source and target panels as *polyominoes*, i.e., geometric figures formed by joining unit squares edge-to-edge. Figure 5 illustrates such an approximation on a typical panel.

We denote $\{s_{k\in[1,S]}\}$ and $\{t_{i\in[1,T]}\}$ the sets of panels of the source and target, respectively, and $\{\hat{s}_{k\in[1,S]}\}$ and $\{\hat{t}_{i\in[1,T]}\}$ their polyomino approximations, where S and T are the number of panels in the source and target, respectively. Furthermore, we denote $D_{\hat{p}}$ the deformation field that maps the boundary of a polyomino approximation $\hat{p}$ to the boundary of the original panel p. We express this deformation field at each edge of the polyomino boundary as a vector whose magnitude encodes changes of length and whose angle encodes changes of orientation (Figure 5c).

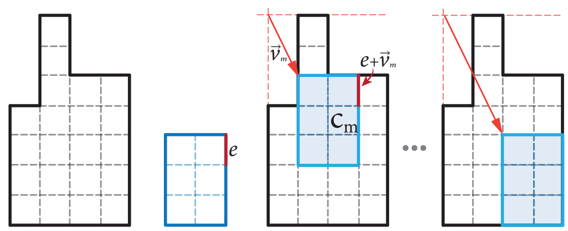
This approximation offers several advantages. First, it transforms each source panel into a grid, enabling the discrete sliding of each target panel and yielding a finite set of *candidate positions*. Second, by approximating the panels as polyominoes, we can identify positions where source and target panels align *with minimal deformations*, as determined by their respective deformation fields.

4.1.1 Candidate generation. Equipped with the polyominoes of the source and target panels, the first step of our algorithm consists in



(a) Panel p (b) Polyomino $\hat{p}$ (c) Deformation field $D_{\hat{p}}$

Fig. 5. We quantize each panel (a) into a polyomino (b) composed of unit squares. Each edge is labeled as a seam, a hem, or an internal cut. Each boundary edge of the polyomino stores the orientation and length of the corresponding edge in the original panel (c), effectively encoding the deformation induced by the quantization.

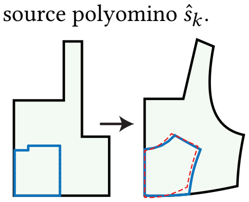


(a) Source $\hat{s}_k$ (b) Target $\hat{t}_i$ (c) Candidates $\mathrm{c_m}$

Fig. 6. We generate candidate placements of a target panel t_i by sliding its polyomino $\hat{t}_i$ over each source polyomino $\hat{s}_k$. We denote as $\vec{v}_m$ the shift applied to form candidate c_m (c, red arrow). For each edge e of $\hat{t}_i$, we denote as $e + \vec{v}_m$ the corresponding edge of candidate c_m.

sliding each target polyomino $\hat{t}_i$ over each source polyomino $\hat{s}_k$ to obtain a set of candidate positions where to cut the target panels in the source (Figure 6). Note that we intentionally restrict the search to translations of $\hat{t}_i$ to preserve the original grain orientation. Although the search space could be expanded by including 180° rotations of $\hat{t}_i$, this would increase computational complexity by a factor of 2^T. All results in this paper were obtained without considering these additional rotations.

We denote C_{ik} the set of candidates obtained by sliding $\hat{t}_i$ over $\hat{s}_k$, and $\vec{v}_m$ the 2D shift vector applied to $\hat{t}_i$ to form a given candidate $c_m \in C_{ik}$. Furthermore, we denote as e an edge of the target polyomino $\hat{t}_i$ and as $e + \vec{v}_m$ the corresponding edge of the candidate c_m, which coincides with an edge of the source polyomino $\hat{s}_k$.



Finally, we also need to compute, for each candidate, the shape of the corresponding panel placed on the source. However, the original shape of the target panel might not align perfectly with the hems and seams to be reused. Our solution consists in fixing the boundary vertices of the target panel to the position of the corresponding vertices of the source hems and seams, and solving for the position of the remaining boundary vertices using as-rigid-as-possible deformation [Igarashi et al. 2005], as illustrated in the inset where the red dashed curves outline the original panel and the blue curves outline its deformed version placed on the source.

Importantly, we only consider candidates that entirely fit within a source panel to ensure complete coverage of the target. We do not attempt to place a target panel across multiple source panels since this would introduce unintended seams in the result.

4.1.2 Candidate selection. Next, we associate each candidate $c_m \in C_{ik}$ with a binary variable $\mathbf{c_m}$ that takes a value of 1 when the candidate is selected, 0 otherwise (we use bold typeface to represent binary variables throughout the paper). We ensure coverage of the target by enforcing that one and only one candidate is selected for each target polyomino $\hat{t}_i$:

$$\sum_k \sum_{c_m \in C_{ik}} \mathbf{c_m} = 1. \tag{1}$$

Our goal is to optimize the values of $\mathbf{c_m}$ to select the candidates that yield the best trade-off between deformation and reuse. We next define custom costs for deformation, cutting, and sewing, along with a term that favors the reuse of seams between panels.

Deformation cost. For each candidate $c_m \in C_{ik}$, we compute the difference between the deformation of the target panel and the deformation of the portion of the source it overlaps. We only compute this difference along the boundary edges that correspond to hems or seams of the source, since other edges can be cut freely to follow the shape of the target panel. We express the resulting deformation cost as:

$$F_{\mathrm{Deform}}(c_m \in C_{ik}) = \frac{1}{|\partial \hat{t}_i|} \sum_{e \in \partial \hat{t}_i} \delta^k_{\mathrm{HS}}(e+\vec{v}_m) \| D_{\hat{t}_i}(e) - D_{\hat{s}_k}(e+\vec{v}_m) \|, \tag{2}$$

where $\partial \hat{t}_i$ denotes the boundary edges of polyomino $\hat{t}_i$, $\vec{v}_m$ denotes the shift applied to this polyomino to form candidate c_m over the source, and $\delta^k_{\mathrm{HS}}(e)$ is an indicator function that equals 1 when edge e is a hem or seam in the source polyomino $\hat{s}_k$, 0 otherwise.

Cutting cost. The table in inset details the costs F^k_{Cut} we define for cutting an edge in a source polyomino $\hat{s}_k$, depending on the type of that edge. Cutting a seam edge is the most costly as seams are difficult to cut cleanly. In contrast, hems do not require any cutting, making them free to be reused. We set the cost of creating new cuts inside the source panel to an intermediate value between these two extremes. The cutting cost of a candidate c_m is then obtained by summing the cutting cost of its boundary edges:

Seam	2
Internal	1
Hem	0

$$F_{\mathrm{Cut}}(c_m \in C_{ik}) = \frac{1}{|\partial \hat{t}_i|} \sum_{e \in \partial \hat{t}_i} F^k_{\mathrm{Cut}}(e + \vec{v}_m). \tag{3}$$

Sewing cost. Sewing only occurs for seam edges in the target panel, and the cost F^k_{Sew} depends on the type of the source edge that needs to be sewed (inset). Sewing an edge that corresponds to a seam or a hem in the source is more costly because it requires deconstructing these elements, which often degrades the fabric. In contrast, sewing an edge that corresponds to an internal cut of the source panel is less difficult, which we express with a lower cost. We obtain

Seam	2
Internal	1
Hem	2

the cost of sewing a candidate c_m by summing the sewing cost of its seam edges:

$$F_{\text{Sew}}(c_m \in C_{ik}) = \frac{1}{|\partial \hat{t}_i|} \sum_{e \in \partial \hat{t}_i} \delta^i_{\text{S}}(e) F^k_{\text{Sew}}(e + \vec{v}_m), \tag{4}$$

where $\delta^i_{\text{S}}(e)$ is an indicator function that equals 1 when e is a seam edge in the target polyomino $\hat{t}_i$, 0 otherwise.

Seam reuse. The costs above are defined for each candidate independently. However, seam reuse requires considering interdependency between candidates of different panels. Specifically, we want to favor configurations where two panels that share a seam in the target get assigned to panels that also share a seam in the source. Alternatively, we also favor configurations where seams in the target get assigned to internal edges in the source, as this corresponds to cases where the two neighboring target panels can be merged and cut as a single panel in the source, avoiding the need for a seam in the target (Figure 2c).

We incorporate such pairwise terms into our optimization via an auxiliary binary variable $\mathbf{b_{mn}}$ that indicates for two panels t_i and t_j whether their candidates $c_m \in C_{ik}$ and $c_n \in C_{jl}$ are selected concurrently. We constrain this variable to equal 1 if the two candidates are selected, 0 otherwise: $\mathbf{b_{mn}} = \mathbf{c_m} \wedge \mathbf{c_n}$.

Seam	-4
Internal	-2

This auxiliary variable then serves to activate a term $F^k_{\text{Reuse}}(e)$ for edges that lie along a seam in the target and map to a seam or an internal edge in the source (values as inset). Intuitively, this term cancels the cost of cutting c_m along that edge (cutting cost of 2 for a seam, 1 for an internal edge), and reduces the cost further to favor these configurations. However, we only apply this term for pairs of panels t_i and t_j when the seam they share maps to a shared seam or shared internal cut between their respective candidates c_m and c_n. We model this condition mathematically with the indicator function $\delta^{i,j,m,n}_{\text{IS}}(e)$, that equals 1 when edge e of $\hat{t}_i$ forms a seam with edge f of $\hat{t}_j$ and edge $e + \vec{v}_m$ of c_m forms a seam with or coincide with edge $f + \vec{v}_n$ of c_n, 0 otherwise. Summing this cost function over all boundary edges of a candidate gives:

$$F_{\text{Reuse}}(c_m \in C_{ik}, c_n \in C_{jl}) = \frac{1}{|\partial \hat{t}_i|} \sum_{e \in \partial \hat{t}_i} \delta^{i,j,m,n}_{\text{IS}}(e) F^k_{\text{Reuse}}(e + \vec{v}_m). \tag{5}$$

Finally, we also constrain $\mathbf{b_{mn}}$ to equal 0 whenever candidates c_m and c_n overlap on the source, effectively preventing these candidates to be selected concurrently. This constraint is necessary to ensure that no part of the source is reused more than once.

The final cost combines the terms introduced above:

$$\begin{aligned} F \quad = \quad & \sum_{\hat{t}_i} \sum_{\hat{s}_k} \sum_{c_m \in C_{ik}} \mathbf{c_m} \Big[\lambda_{\text{Deform}} F_{\text{Deform}}(c_m) \\ + \quad & \lambda_{\text{Fabrication}} \Big(F_{\text{Cut}}(c_m) + F_{\text{Sew}}(c_m) \\ + \quad & \sum_{\hat{t}_{j \neq i}} \sum_{\hat{s}_l} \sum_{c_n \in C_{jl}} \mathbf{b_{mn}} F_{\text{Reuse}}(c_m, c_n) \Big) \Big]. \end{aligned} \tag{6}$$

We set $\lambda_{\text{Fabrication}}$ to a default value of 75 for all our results, while we let users adjust λ_{Deform} to balance deformation with reuse (see Figure 8 and supplemental materials for the value used for each result). We use an ILP solver [Google 2024] to find the selection of candidates $\{c_m\}$ that minimizes this cost function subject to the constraint defined by Equation 1. As a last step, we offset the boundary of the selected panels to provide *seam allowance* for fabrication.

4.1.3 Two-scale algorithm. Due to the pairwise variables $\mathbf{b_{mn}}$, the number of variables in the optimization is proportional to the square of the number of candidates, and the number of candidates to consider depends on the number of panels, their size, and the resolution of their polyomino approximation. We cope with this quadratic complexity by adopting a two-scale strategy, where we first solve our optimization problem using low-resolution polyominoes, and then solve the same problem on high-resolution polyominoes but restricted to candidates that lie around the solution found at low resolution. We adjust the cell size at low resolution to obtain roughly the same number of candidates for all results, and then use a cell size of 1×1cm at high resolution (see supplemental materials for details on each result). While we use the polyomino approximations to quickly test for overlap between panels at low resolution, we use the shapes of the panels placed on the source for a more precise test at high resolution to ensure they can be fabricated.

4.2 Quantization to polyominoes

We now describe our algorithm to convert source and target panels into polyominoes. This algorithm is inspired by related work on polycubes [Livesu et al. 2013], which we adapt to our 2D setting.

Our algorithm takes as input freeform panels, which we represent as regularly sampled polylines. The first step consists in assigning each edge of the polyline to one of four orientations, expressed as a label $l \in \{-X, +Y, +X, -Y\}$. Similarly to [Livesu et al. 2013], we perform a multi-label graphcut optimization to balance a unary cost (which measures the angle $|\text{rad}(l) - \text{rad}(e)|$ between the orientation of the label and the orientation of the edge) and a pairwise cost (which measures the label difference $|l_i - l_j|$ between adjacent edges to favor the emergence of long, straight segments made of a single label rather than jaggy outlines made of alternating labels). We give equal weight to the two terms.

The second step consists in solving for the position of polyline vertices that satisfy the orientation labels, using integer coordinates to quantize these positions onto a coarse grid. In practice, we only optimize the position of *turning points*, i.e., vertices where the orientation label changes, since all other vertices lie on vertical or horizontal lines connecting these turning points. The optimization includes equality constraints to impose that adjacent turning points are aligned vertically (resp. horizontally) if they are connected by edges with a vertical (resp. horizontal) label. The objective function seeks to minimize the difference in length between the edges of the original polyline and the edges of the quantized polyline. Furthermore, we also include a term to minimize the difference in length between edges corresponding to the two sides of a seam between two panels. This last term requires solving the quantization for all panels jointly. We provide the polyomino approximations for all our results in supplemental materials.

5 Evaluation

Results on diverse garments. We illustrate our method on diverse source and target garments in Figure 1, 7, 8 and 10. We obtained these garments from the dataset by Korosteleva and Lee [2021] or we created them ourselves using Clo3D [Fashion 2024a]. We selected garments that resemble real-world examples from tutorials (pullover to dog coat, pants to top, large skirt to tight skirt) as well as garments that exhibit similar seams to offer opportunities for reuse (straight seams in pants to bag, curved seam in top to skirt). We provide detailed timings for all results in supplemental materials. The most expensive steps of our algorithm are the computation of the term F_{Reuse} for all pairs of candidates, and solving the optimization. Total computation time varies from a few minutes for simple cases (Figure 8) to 30 minutes for the most complex one (Case 1 in Figure 7), measured on an Apple M2 Pro with 16GB of memory. While this computational cost might be prohibitive for one-shot reuse of a single garment, it would be quickly amortized at industrial scale where retailers seek to reuse garments from previous collections to design new collections [Berrens et al. 2025]. We also provide as supplemental materials a study of the relationship between the computational cost and the ratio of area between source and target.

Effect of parameters. Figure 8 shows how our formulation offers users control on the balance between reuse of structural elements and deviation from the target garment. In this example, a low value of λ_{Deform} yields a solution where 4 seams are reused and part of a seam is avoided, but the resulting hat does not open as much as the target. Increasing λ_{Deform} makes the hat nearly identical to the target by reusing fewer seams. While we used the same default cost values for all results, Figure 9 shows that different reuse strategies can be favored by adjusting these values. In this example, setting the cutting cost F^k_{Cut} to -5 for hems encourages their reuse further, yielding a different solution than the one shown in Figure 1. Our formulation can easily support additional user preferences, for instance to indicate parts that should not be reused, or to impose that a given part of the source is reused (see supplemental materials).

Comparison to designs by an expert. We validated our approach by asking a professional fashion designer to perform 3 reuse tasks, for which we provided the source and target patterns in vector format, and the 3D models (see instructions in supplemental materials). While we mentioned our preference for reusing seams and hems, we told them that they can disregard this objective if they prefer other strategies. The designer spent around 20 minutes per task, and Figure 10 compares the resulting patterns to ours. Case 4 (pant and skirt to top) is the one for which the designer achieved the most reuse (2 seams and 6 hems). With our default parameters, our algorithm reuses 3 seams and 2 hems on the same case. The designer reused fewer structural components for the two other cases (skirt to top and skirt, top to dog coat). We then showed our solutions to the designer and asked them to comment on the differences. The designer acknowledged that they approached the task as if the garment was deconstructed and flattened, as this corresponds better to their habits, which is why they did not reuse any seam for Case 5. They also commented that they had difficulty envisioning how panels could be deformed to improve reuse, which is a key feature of our approach. While they were surprised and pleased by the solutions found by our algorithm, they also suggested introducing darts to compensate for induced distortions (see Section 5.1).

Fabrication. Finally, we hired a tailor to fabricate one of our results (Figure 1e). To do so, we first asked the tailor to fabricate two copies of the source garment from its pattern. We then instructed them to fabricate the target garment by cutting one of the copies according to the reused pattern given by our algorithm. In addition to demonstrating the feasibility of our solution, this experiment provided us with feedback on the practical aspects of such a fabrication task. In particular, the tailor noticed that symmetric panels that share a seam can be cut precisely by folding the source garment along that seam, as is the case for the two panels sharing a seam (1) in Figure 1. In contrast, cutting different panels from the front and back, as is the case for the panels centered on seams (2) and (3), requires extra manipulation of the garment.

5.1 Limitations and future work

While our method performs well in several complex scenarios, we believe there is significant room for improvement before it can be fully embraced by the fashion community.

Real-world sewing requires keeping an extra margin around panels, so-called *seam allowance*. But such a margin is not necessary when seams are reused. Since we do not know in advance which seams will need extra margin, we ignore seam allowance in our optimization and add the margin where necessary as a post-processing step, which might not be possible if two panels nearly touch.

We assume that the new garment is smaller than the existing one and that each target panel can entirely fit into one of the source panels. As a workaround to this limitation, users can split the target panels by including optional seams, which the term F_{Reuse} will seek to remove by mapping them to the internal edges of the source.

Extensive reuse often comes at the cost of significant deviation from the target, as illustrated in Figure 8, which can yield to curvature mismatch along seams as highlighted in Figure 10, Case 5. Designers sometimes compensate for such deviation by introducing darts for better fit, as is the case for the tank top in Figure 3. Combining our approach with automatic dart placement [de Malefette et al. 2023] represents a challenging direction for future work.

Finally, by placing target panels along existing hems and seams, our optimization might produce cutting patterns where the unused fabric has a highly irregular shape, hindering further reuse. An exciting direction for future work would be to include a measure of layout efficiency to minimize waste [Koo et al. 2016]. As a first step in that direction, we show in supplemental materials how to implement an additional cost to penalize the use of multiple panels.

6 Conclusion

In this paper, we explored the use of geometry processing and discrete optimization to support the design of new garments through reuse of existing ones. Based on principles distilled from garment reuse tutorials and textbooks, we have formulated an algorithm that places target fabric panels over an existing garment to maximize reuse of structural components (hems and seams) while minimizing deviation from the design intent.

While our solution is specific to fashion design, we believe that our overall methodology could apply to other domains, such as furniture design [Rosner and Bean 2009] where practitioners seek to reuse entire parts of a furniture rather than disassembling it into individual components, as this strategy better preserves the structural strength of the assembly. Going further, we hope that our work will inspire research in rethinking the foundations of Computer-Aided-Design to support circular production models that are more sustainable than the "take-make-use-dispose" linear model for which most existing tools have been developed.

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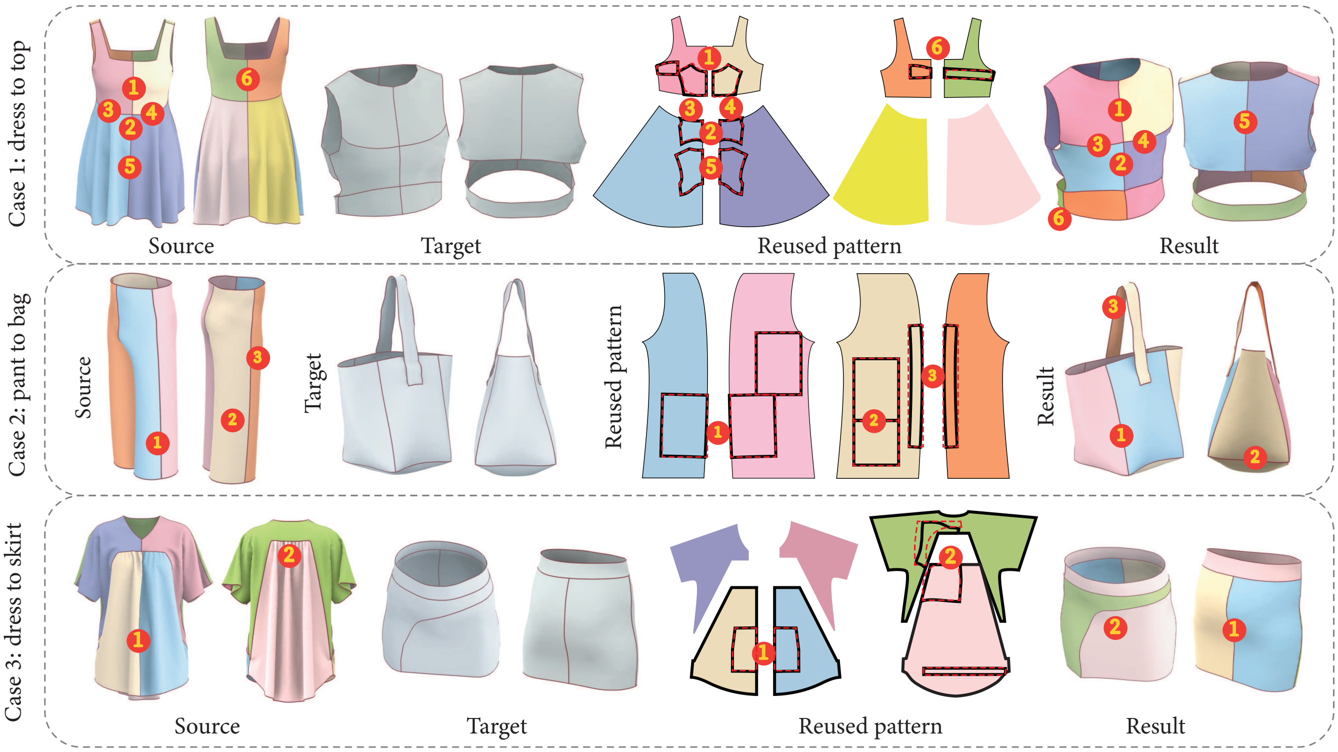

Fig. 7. Results on diverse garments. In each case, we show the 3D models of the source and target, the reused pattern produced by our method (red dashed curves delimit the target panels, black curves delimit our optimized panels), and the resulting 3D garment. We highlight reused seams and hems with numbers.

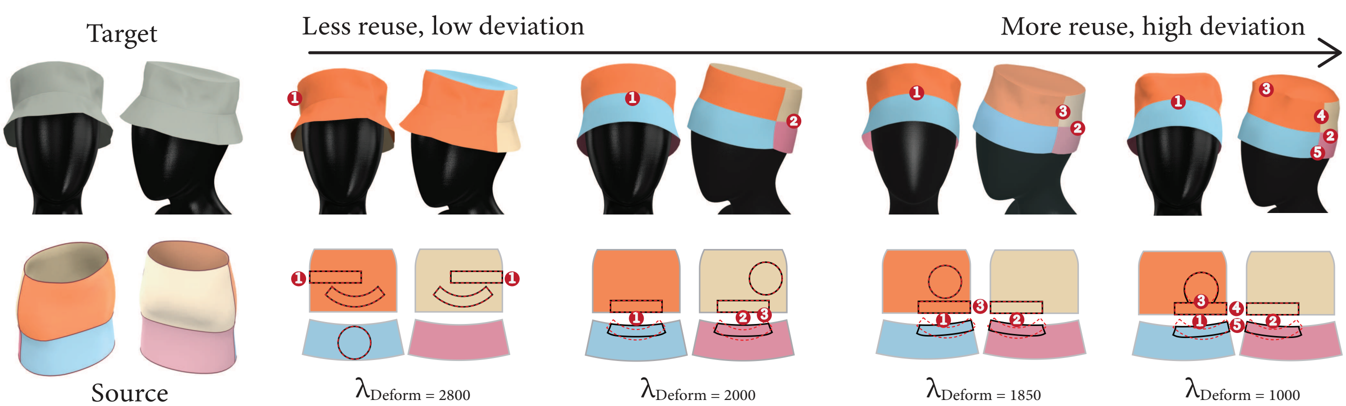

Fig. 8. By adjusting λ_{Deform}, users can control the trade-off between reuse of structural elements and deviation from the target.

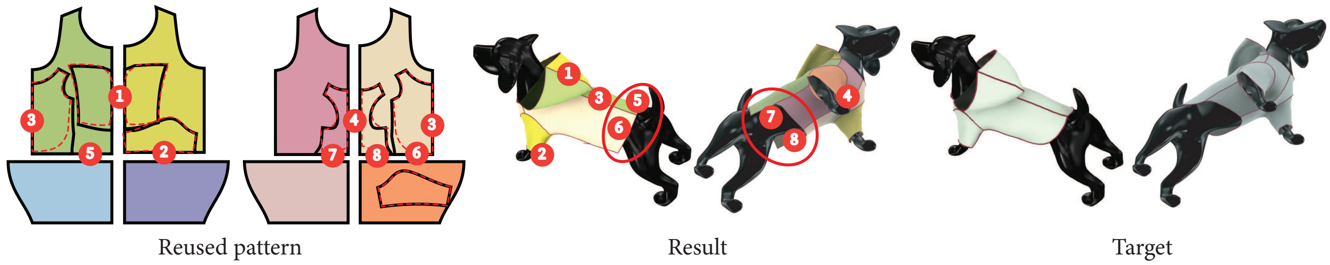

Fig. 9. Setting $F^k_{\text{Cut}} = -5$ for hems and $\lambda_{\text{Deform}} = 0$ yields additional reuse of hems compared to Figure 1, at the price of increased deformation.

Fig. 10. Results and comparison to manual designs. In Case 4, two sources are combined into one target, while in Case 5, a single source is used to form two targets. Note how Case 5 demonstrates significant reuse of seams thanks to deformation of the target panels. While these deformations change the shape of the top a little, we highlight a stronger deformation along the waist of the skirt. Case 4 also introduces deformations for the panels cut on the pants, yet these deformations are difficult to notice in the final 3D garment. We also provide the reused patterns produced by a professional fashion designer on these cases, as well as on the case shown in Figure 1. In particular, the designer took similar decisions to ours in Case 4, while they did not reuse any seam or hem in Case 5. Note that while reusing seam (1) of Case 4 would require deforming the panels, the designer did not depict that deformation.