Extended Abstract - Optimizing 2D Cutting: A Bin Packing Approach to Minimize Scraps and Maximize their Reusability

Manuel Chastenay
Lab-Usine - Joint Research Unit for Advanced Manufacturing, Université Laval, Québec, Canada
SOKÏO Industrie, Saint-Augustin-de-Desmaures, Canada

Xavier Zwingmann
Lab-Usine - Joint Research Unit for Advanced Manufacturing, Université Laval, Québec, Canada
SOKÏO Industrie, Saint-Augustin-de-Desmaures, Canada

Claude-Guy Quimper
Lab-Usine - Joint Research Unit for Advanced Manufacturing, Université Laval, Québec, Canada

Jonathan Gaudreault
Lab-Usine - Joint Research Unit for Advanced Manufacturing, Université Laval, Québec, Canada

Abstract

In industrial settings, cutting predefined pieces from one or multiple sheets of material is a common optimization challenge. This problem can be formulated as a variant of the 2D bin packing problem, where the edges of the pieces define the cut lines. This paper presents a constraint programming model developed in collaboration with an industrial partner in construction to minimize scrap waste generated when cutting insulation pieces. The model introduces an objective function designed to maximize the reusability of leftover material. To fully leverage the model's efficiency, an initial process transforms irregular insulation pieces into rectangles using one of four processing methods. A comparative analysis is conducted to evaluate the impact of these methods, as well as to benchmark the model's results against the partner's manual approach.

1 Introduction

Efficient material utilization is a critical concern in modern manufacturing. Minimizing waste directly translates into environmental benefits and helps industries reduce costs. In the construction industry, cutting insulation pieces from material sheets presents a complex but common challenge. In practice, these pieces are often made up not only of rectangles, but also of triangles and trapezoids. In addition, they can be rotated or flipped to fit better on the sheet, which increases the complexity of the problem. This increased complexity, coupled with the heterogeneous nature of the available sheets, makes the already NP-Hard problem [4, 5] even harder.

We present two novel constraint programming models that integrate distinct objectives. First, the total area of the sheets that are used to nest the pieces is minimized. This reduces the number of sheets used and prioritizes the use of scraps over new sheets. Second, using the sheets found using the first model, the placement of all pieces is optimized to enhance the reusability of any resultant scrap. This second objective function is inspired by the work of Lodi et al. (1999) [6] that maximizes the total perimeter of the pieces that touch the edge of the sheet or another piece. These models each use a DiffN constraint [2] that ensures that no pieces overlap, as well as a cumulative constraint [1] that greatly reduces the time needed to obtain optimality. To manage the inherent computational difficulty, irregular insulation pieces are transformed into rectangles by a preprocessing phase that occurs before the optimization phase. The preprocessing uses one of the four new algorithms that we introduce. Figure 1 represents an instance that is sent to the four different preprocessing

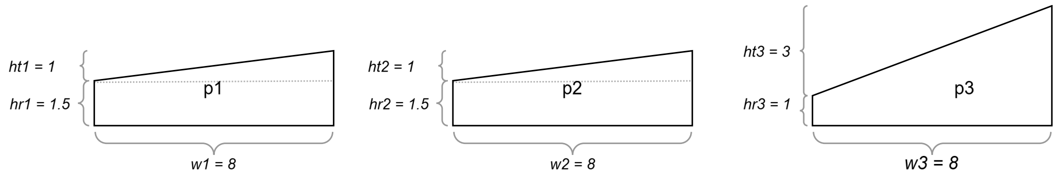
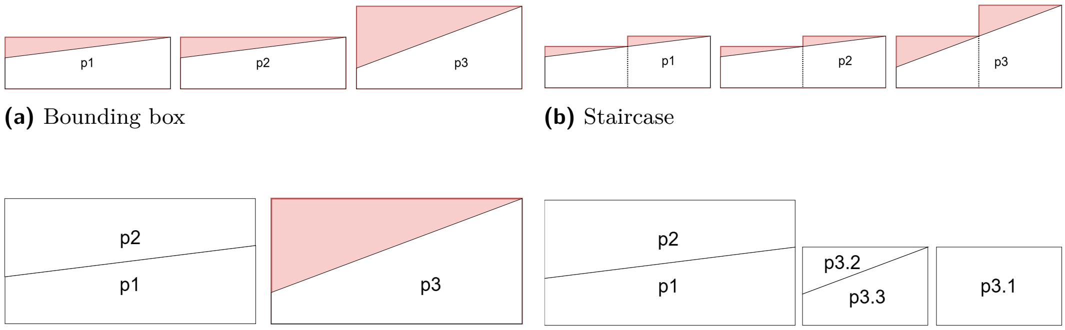


Figure 1 Instance being passed to the different preprocessing algorithms



(a) Bounding box **(b)** Staircase

(c) Slope mapping **(d)** Slope mapping +

Figure 2 Preprocessing algorithms examples

methods. The treatment performed by these preprocessings is shown in the subfigures of Figure 2. These methods aim to reduce the search space of the optimization process, thus improving computational efficiency. As can be seen in figure 2d, insulation pieces that are not rectangles can be further subdivided and reassembled as one, nullifying the induced material losses.

2 Main results

Our results show a definitive improvement compared to those of the industrial partner. Using the only instance they benchmarked, while manually calculating a packing that results in 21.58% waste material in a week, we managed to optimize it to 6.71% waste in under 3 seconds using the Slope mapping + preprocessing. In comparison, the Bounding box preprocessing optimized the same instance for 17.31% waste in 2 seconds, the Staircase one, 15.38% in 6 seconds, and the Slope mapping one, 13.37% in 2 seconds as well. We also managed to generate scraps that are more easily reusable compared to those they manually generated, further reducing the amount of waste.

3 Conclusion

We introduced four different preprocessing methods that work with trapezoidal and triangular shapes in a bin packing problem implementation, using solvers that typically only work with rectangular shapes. We also introduced a new objective function that optimizes scrap reusability. Directions for future work include the implementation of a constraint described by Beldiceanu et al. [3] that directly supports trapezoidal shapes.

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