Xiao LIU, 2026. Hierarchical algorithm for large-scale irregular packing problems. *ENGINEERING Information Technology & Electronic Engineering*, 27(3):250080. https://doi.org/10.1631/ENG.ITEE.2025.0080

ENGINEERING Inform Technol Electron Eng

Hierarchical algorithm for large-scale irregular packing problems

Key words: Large-scale packing; Hierarchical algorithm; Box stacking; Shape matching; Gravity packing; Principle of minimum potential energy

Corresponding author: Xiao LIU
E-mail: liuxiao@scut.edu.cn

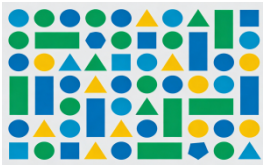
ORCID: http://orcid.org/0000-0003-2975-4749

Problem & Challenges

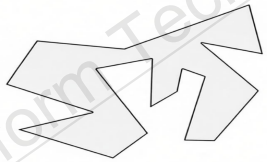
The Packing Problem:

Arrange parts on raw materials to maximize material utilization

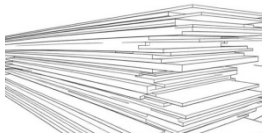
Industry Challenge: Large-scale manufacturing



Large Quantity of Parts



Complex geometries



Multiple Sheets

ENGINEERING Inform Technol Electron Eng

Research Gap:

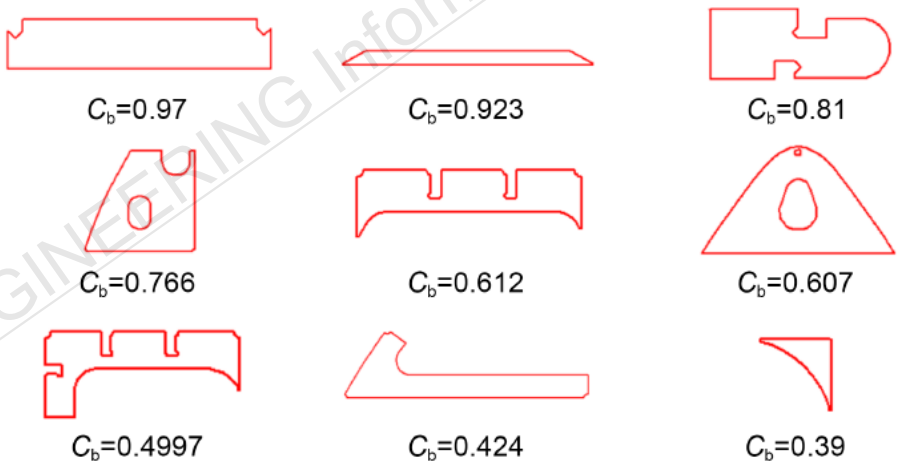
- Existing studies: ≤450 parts, single sheet
- No integrated solution for large-scale irregular packing

Core Innovation: Hierarchical Classification

Key Insight: Not all parts should be packed the same way!

Three-Level Classification:

Level	Part Type	Criteria	Primary Strategy
1	Large Rectangular	Area≥0.5 m², C_b>0.9	Box Stacking
2	Large Irregular + Medium	0.05 m²≤Area<0.5 m²	Shape Matching
3	Small + Failed	Area<0.05 m²	Shape Matching → Gravity



ENGINEERING Inform Technol Electron Eng

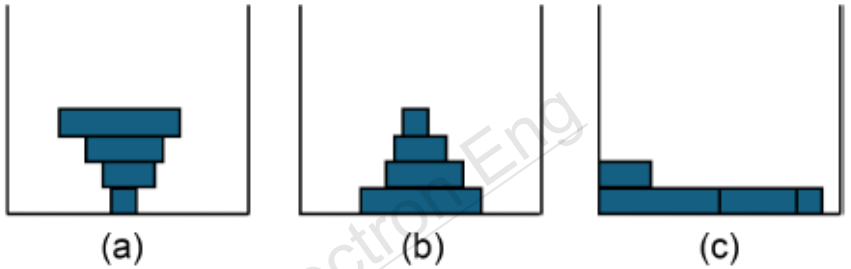
Block Coefficient C_b = Outer domain Area/Bounding Box Area
(measures "fullness")

The Problem with Gravity Packing

Gravity Packing (HAPE):

•Based on principle of minimum potential energy

•Parts seek the lowest center of gravity



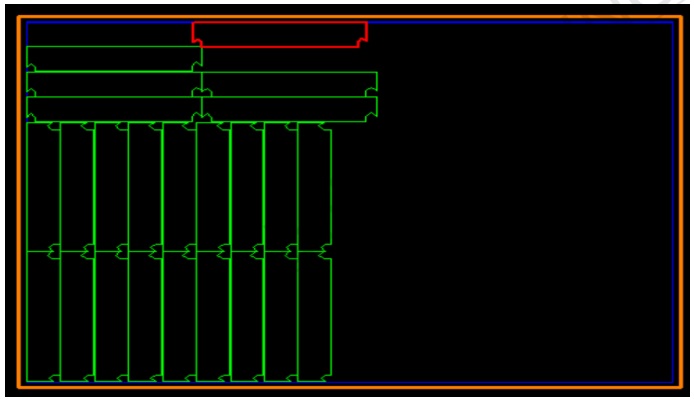
Gravity packing (gravity directed vertically downward): (a) unstable (high center of gravity); (b) relatively stable (lower center of gravity); (c) the most stable (the lowest center of gravity)

The Hooking Problem:

•Local interlocking between adjacent parts

•Disorderly layout

•Sacrifices global efficiency for local optimization



Hooking of box parts caused by gravity packing (assuming that gravity is directed horizontally leftward)

Traffic congestion from cutting in line

Box Stacking (Level-1)

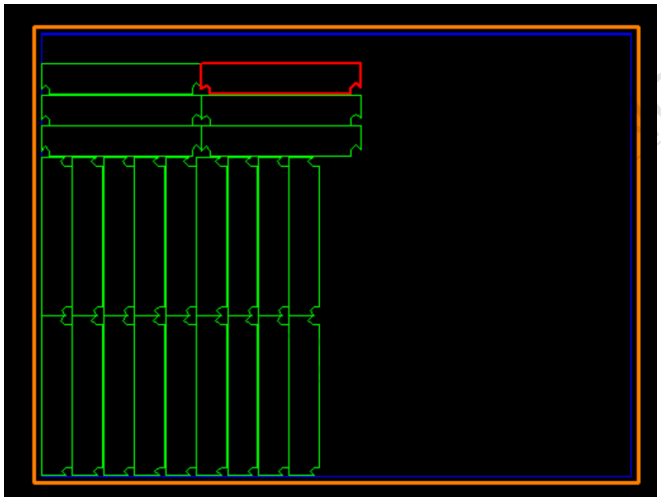
Purpose: Solve hooking for rectangular parts ($C_b > 0.9$)

Method: Align bounding box corners → essentially **rectangular packing**

Process:

1.Align corners (bottom-left with bottom-right, etc.)
2.Check conflicts
3.Try all rotations (0°, 90°, 180°, 270°)
4.Select attitude with the smallest x coordinate of centroid

Result: Clean, orderly arrangement without hooking



Box stacking can avoid mutual hooking of box parts

Compliance with traffic rules

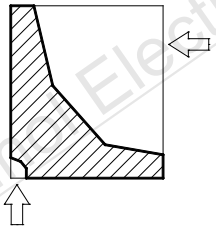
G Inform Technol Electron Eng

Shape Matching (Level-2&3)–the novel contribution

What it does: Two similar parts achieve **contour complementarity** through rotation and sliding

Why it matters:

- Creates tighter packing
- Frees space for additional parts
- Prioritizes utilization over pure physics

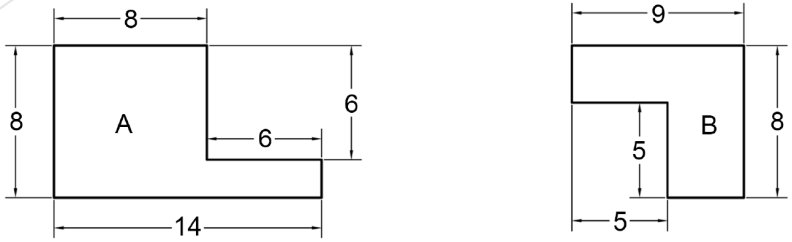


Part bounding box and its blank area

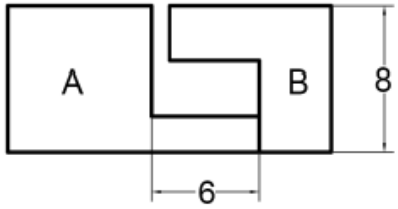
Shape Matching Coefficient (SMC):

$$SMC = detArea/blankArea \times 100\%$$

- **detArea:** Reduction in bounding box area
- **blankArea:** Total blank area = $A_b(1 - C_b)$



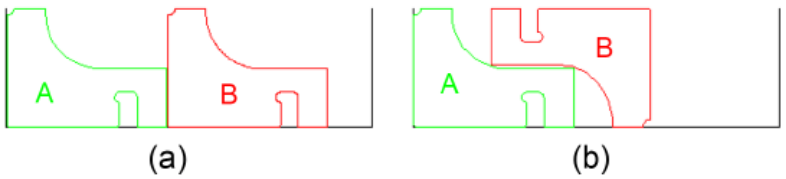
The blank areas of parts A and B are 36 mm² and 25 mm², respectively, and their sum blankArea = 61 mm². After shape matching, the reduction in the parts' bounding box area detArea = 6 × 8 = 48 mm². SMC = 48/61 = 78.7%.



Threshold: SMC_min = 0.25 (fallback to Gravity if below)

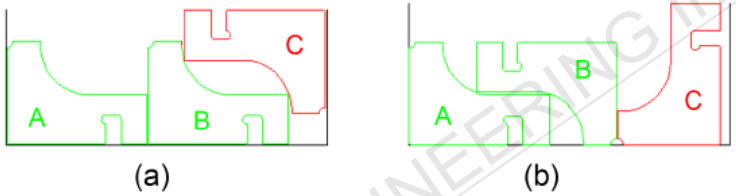
ENGINEERING Inform Technol Electron Eng

Shape Matching vs. Gravity–Demonstration 1



Two-part packing (gravity directed downward):
(a) gravity packing; (b) shape matching

Two Parts:
•Gravity: Lower center, less efficient
•Shape Matching: Higher center, **more space freed**

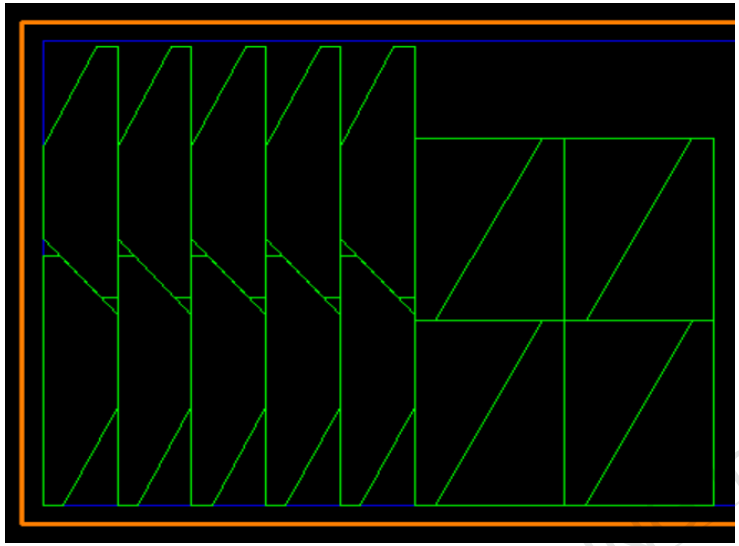


Three-part packing (gravity directed downward):
(a) gravity packing; (b) shape matching

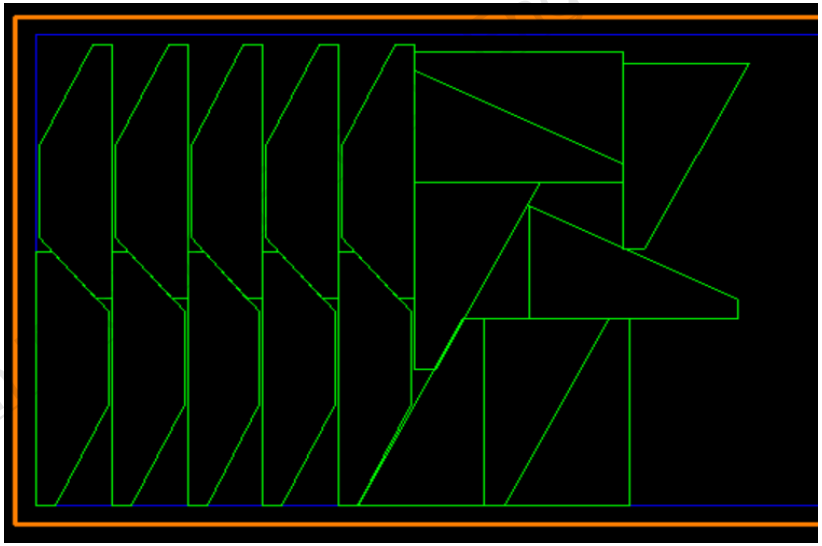
Three Parts:
Shape matching frees bottom-right corner for Part C → better overall density

ENGINEERING Inform Technol Electron Eng

Shape Matching vs. Gravity–Demonstration 2



Shape Matching
(Packing density = 80.89%)

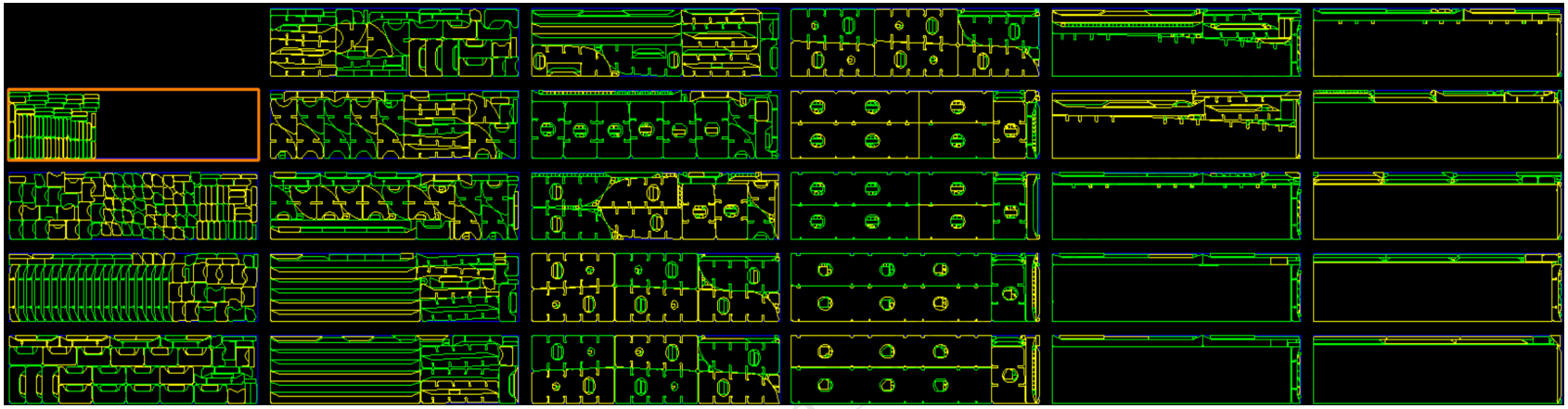


Gravity Packing
(Packing density = 74.16%)

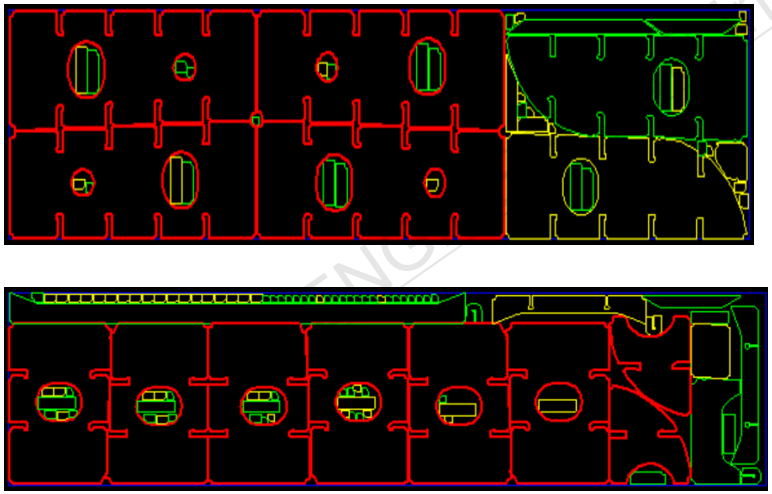
ENGINEERING Inform

Experimental Results

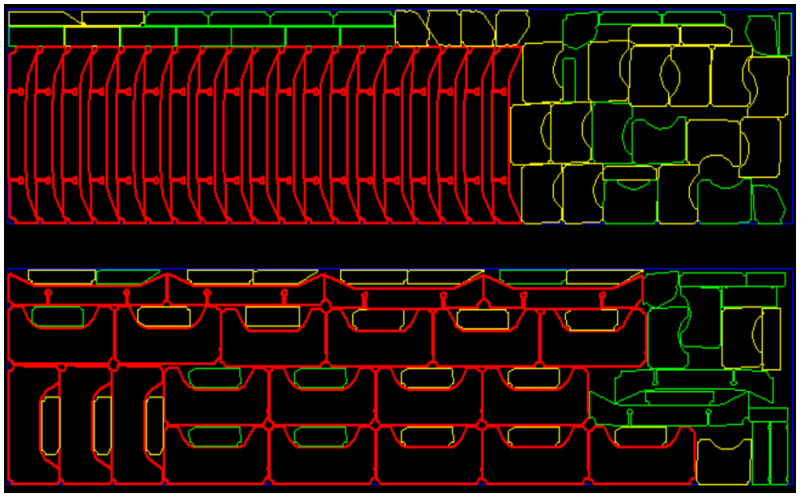
Experiment 1: Shipbuilding (1400 parts, 29 sheets, Computation time = 157.39 s)



Multi-plate hierarchical packing (global view)



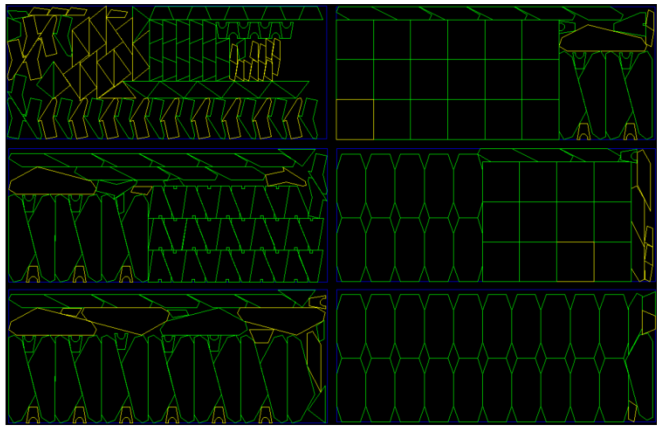
(a) Shape Matching (local view)



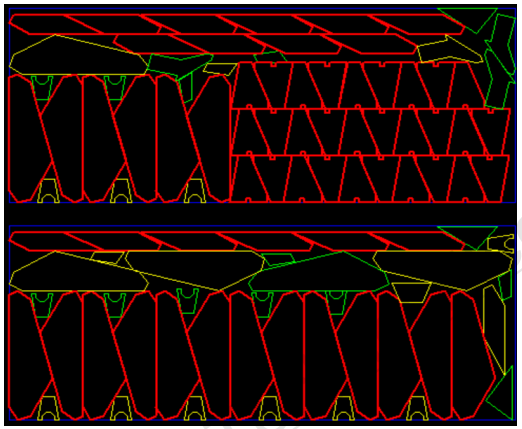
(b) Box Stacking (local view)

Experimental Results

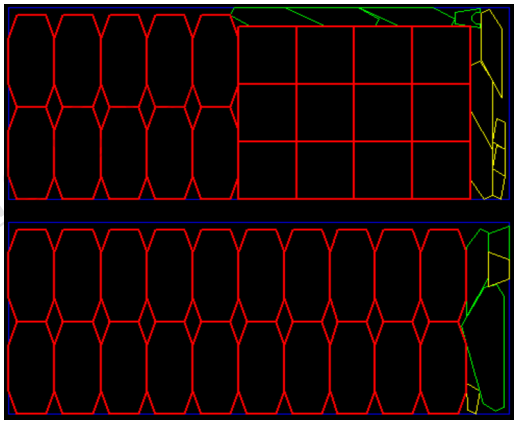
Experiment 2: Benchmarks (DAGLIx10, Marquesx10)



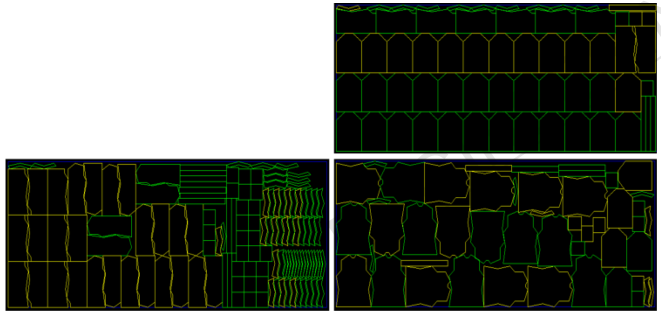
Hierarchical Packing (global view, DAGLIx10), where the number of parts=300 and computation time=1.23 s



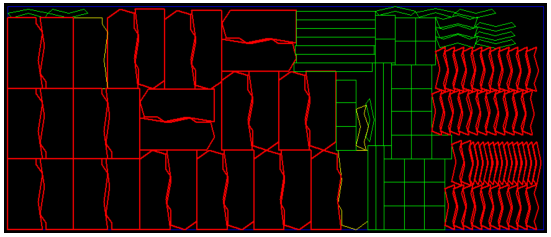
(a) Shape Matching (local view)



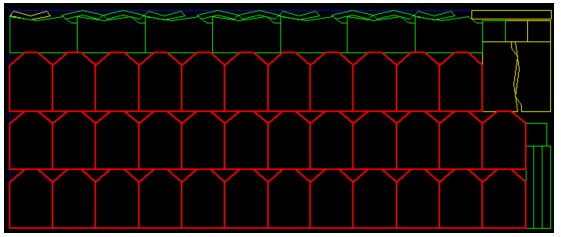
(b) Box Stacking (local view)



Hierarchical Packing (global view, Marquesx10), where the number of parts=240 and computation time=0.81 s



(a) Shape Matching (local view)



(b) Box Stacking (local view)

Conclusions

Key Contributions:

1. Hierarchical algorithm: handling 1400+ irregular parts across multiple sheets

2. Shape Matching (novel): Achieves contour complementarity for higher utilization

3. Box Stacking: Eliminates hooking for rectangular parts

4. Systematic enhancement: Gravity packing as fallback, not replacement

Benefits:

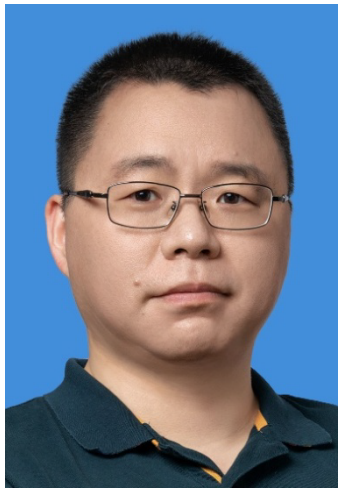
•Higher material utilization

•Faster computation (Box Stacking = rectangle packing speed)

•Practical for real engineering (5.43 s/plate)

ENGINEERING Inform Technol Electron Eng

The program and experiment data can be downloaded from the following website:
http://www.huagongchuanhai.cn/packing/HierarchicalPacking.rar



Name: Xiao LIU

Position: Associate Professor, School of Civil Engineering & Transportation, South China University of Technology

Email: liuxiao@scut.edu.cn

Personal Website: www.huagongchuanhai.cn

Research Interests: Naval Architecture and Ocean Engineering, Structural Mechanics, Finite Element Software Development, Optimization Packing Algorithms, Novel Algorithms for Floating Condition

Educational and Professional Background: He received his Bachelor's and Master's degrees from Wuhan University of Technology, and his Ph.D. from South China University of Technology. He has been an Associate Professor at South China University of Technology since 2015.

ENGINEERING Inform Technol Electron Eng