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# 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

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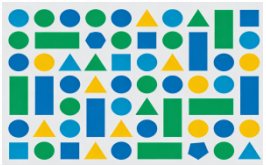
# Problem & Challenges

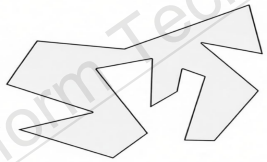
**The Packing Problem:**

Arrange parts on raw materials to maximize material utilization

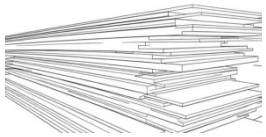
**Industry Challenge: Large-scale manufacturing**



Large Quantity of Parts



Complex geometries



Multiple Sheets

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**Research Gap:**

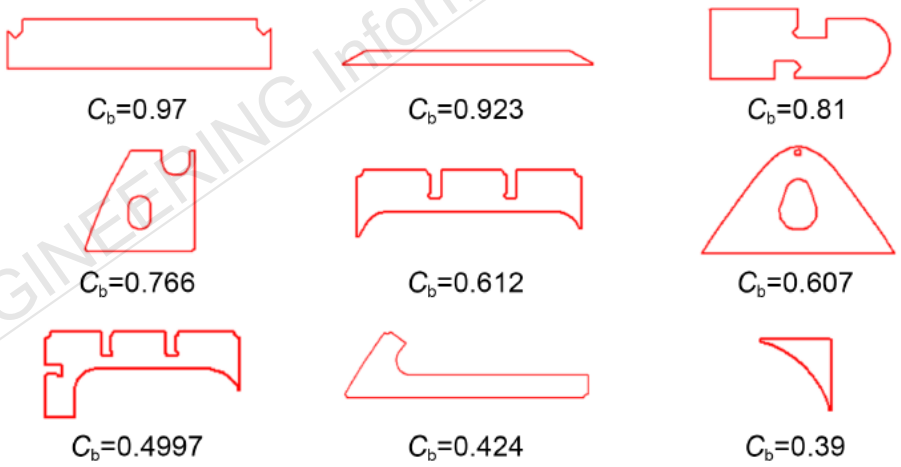
- Existing studies: ≤450 parts, single sheet
- No integrated solution for large-scale irregular packing

# 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 |

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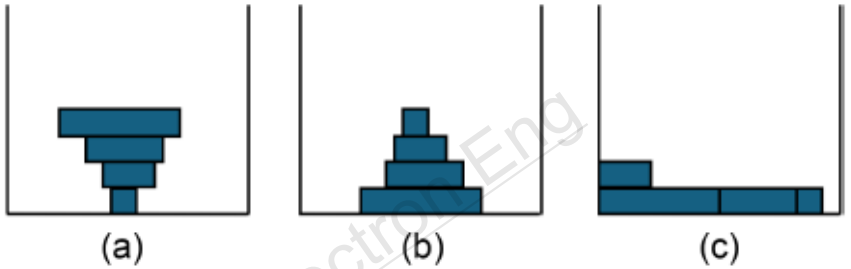
**Block Coefficient $C_b$ = Outer domain Area/Bounding Box Area**
(measures "fullness")

# The Problem with Gravity Packing

**Gravity Packing (HAPE):**

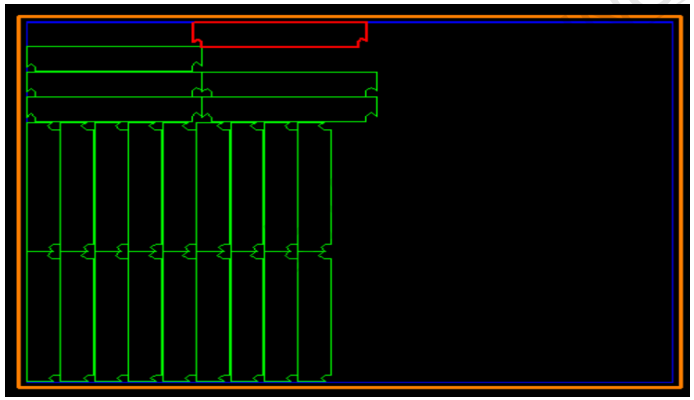
- Based on principle of minimum potential energy
- Parts seek the lowest center of gravity




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)

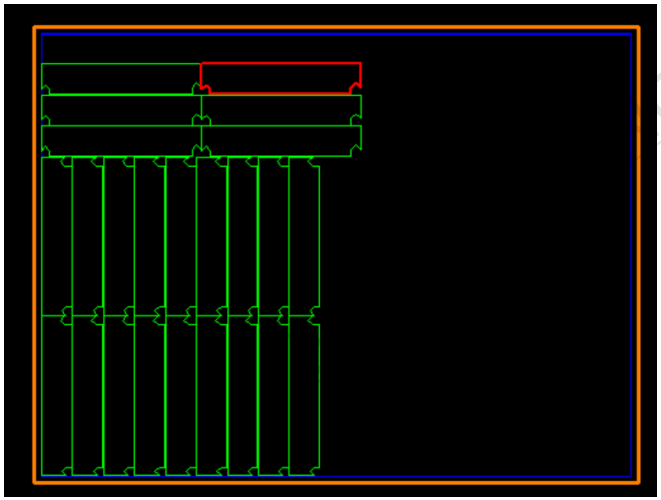
**Purpose:** Solve hooking for rectangular parts ($C_b > 0.9$)

**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

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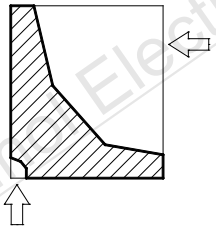
# Shape Matching (Level-2&3)–the novel contribution

**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

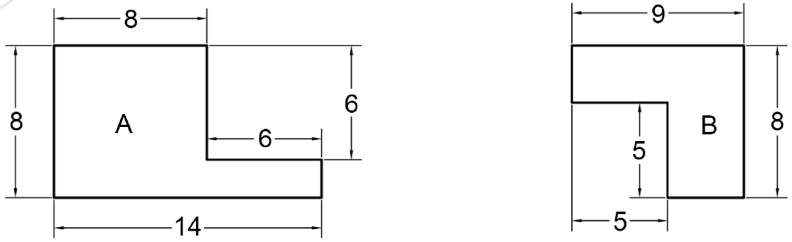


Part bounding box and its blank area

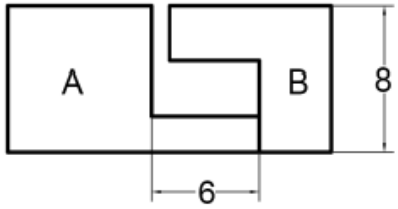
**Shape Matching Coefficient (SMC):**

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

- **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)

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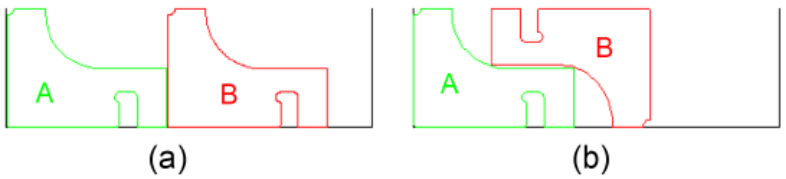
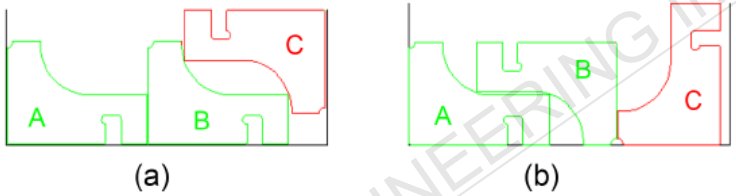
# Shape Matching vs. Gravity–Demonstration 1




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

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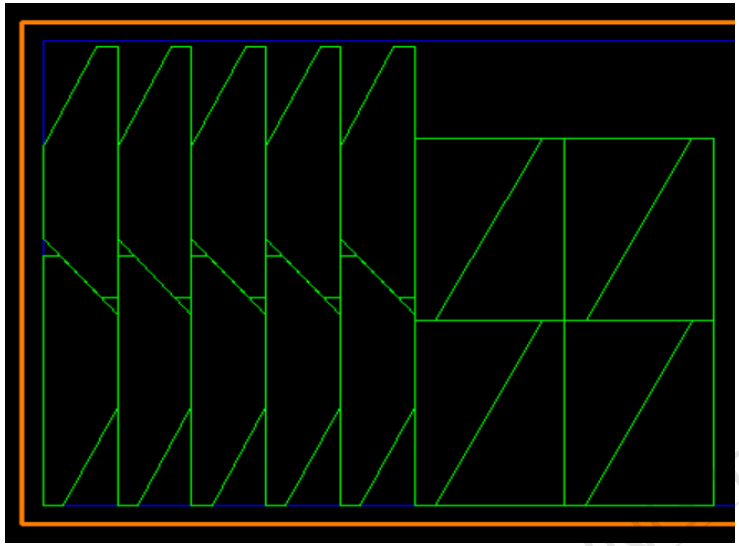
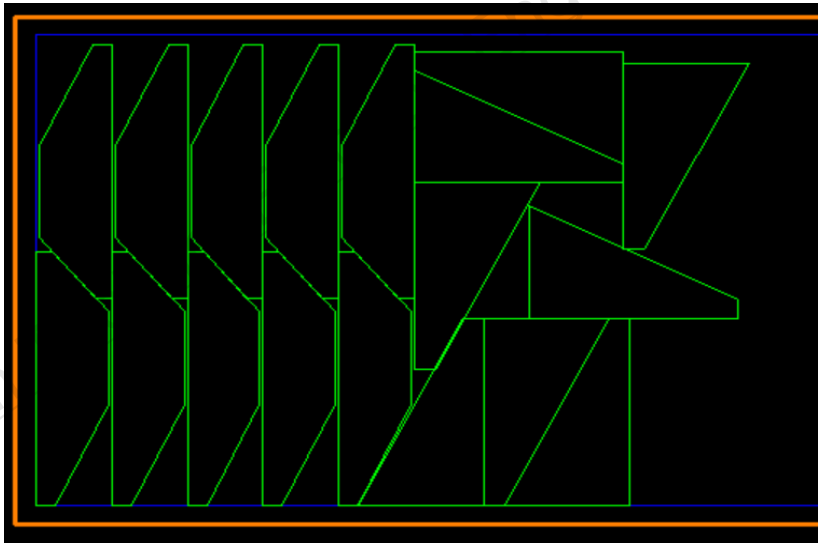
# Shape Matching vs. Gravity–Demonstration 2



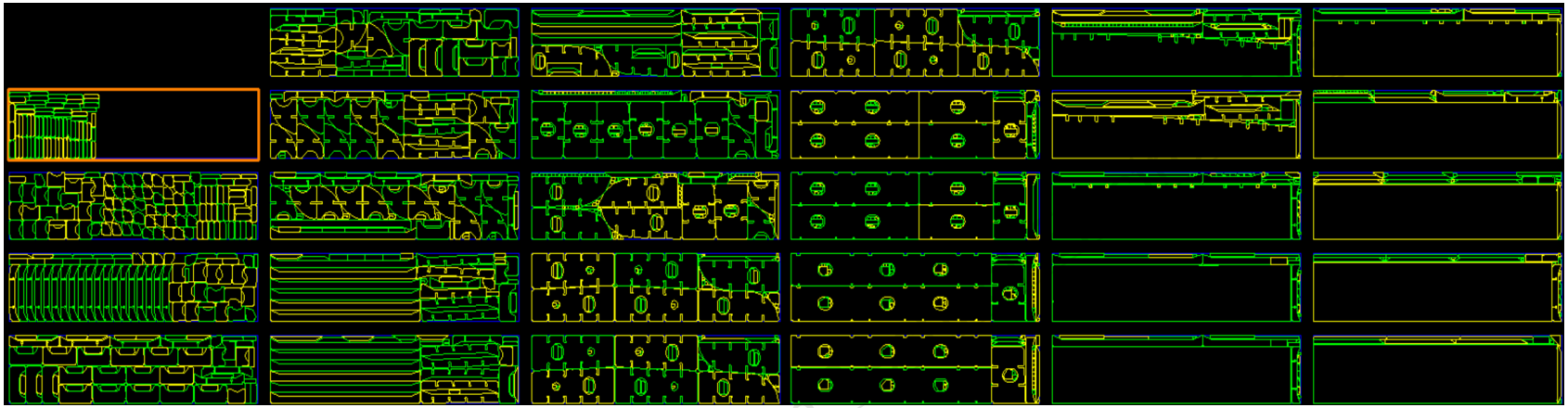
Shape Matching
(Packing density = 80.89%)



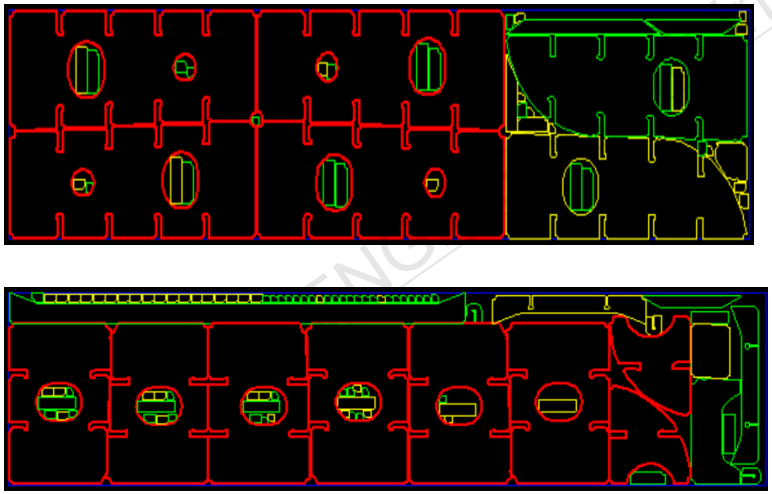
Gravity Packing
(Packing density = 74.16%)

# Experimental Results

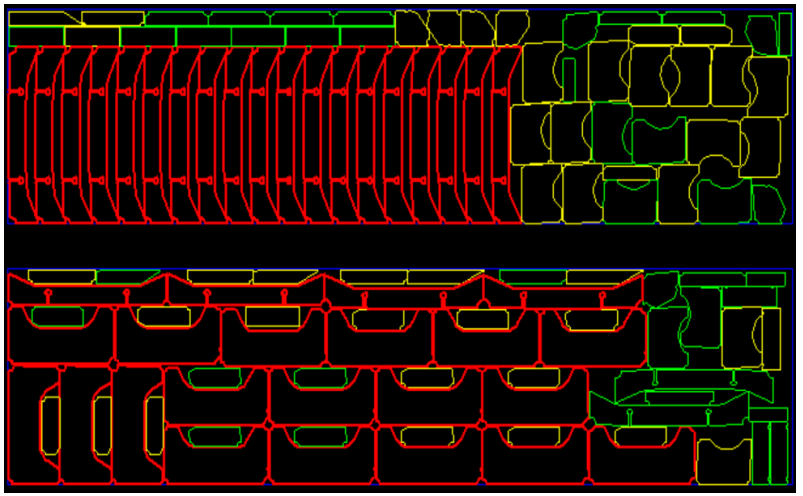
**Experiment 1: Shipbuilding (1400 parts, 29 sheets, Computation time = 157.39 s)**



**Multi-plate hierarchical packing (global view)**



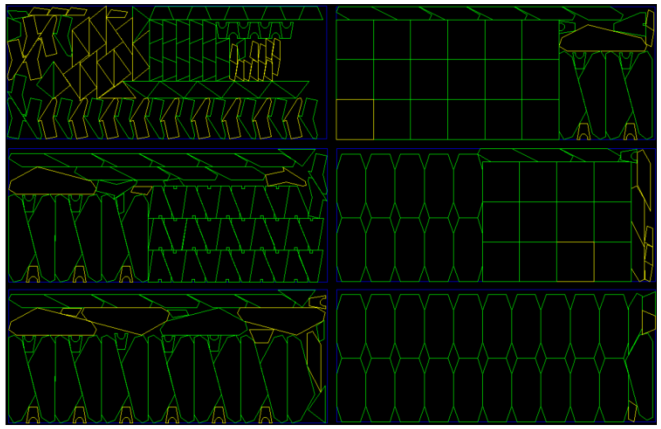
(a) Shape Matching (local view)



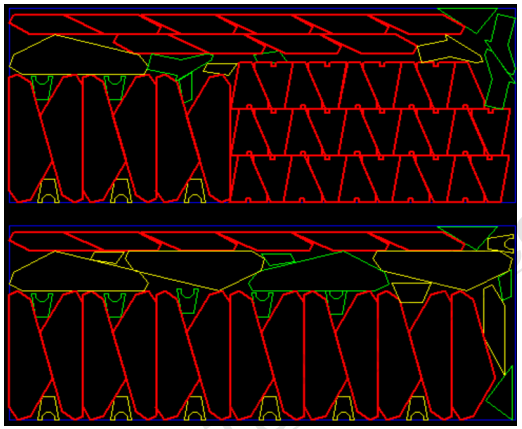
(b) Box Stacking (local view)

# Experimental Results

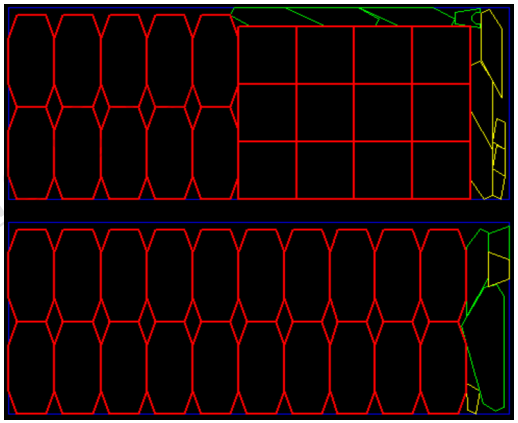
## Experiment 2: Benchmarks (DAGLIx10, Marquesx10)



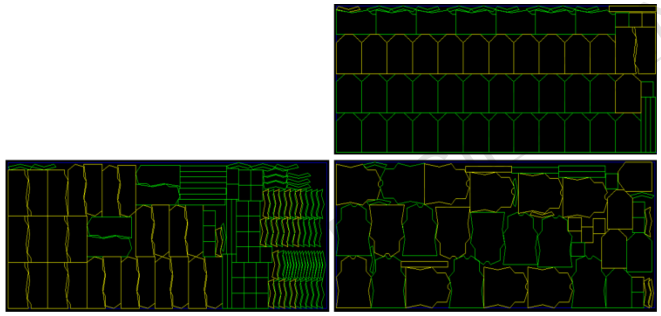
Hierarchical Packing (global view, DAGLIx10), where the number of parts=300 and computation time=1.23 s



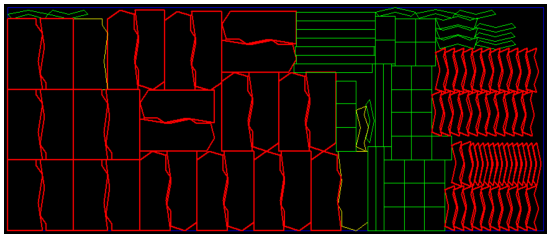
(a) Shape Matching (local view)



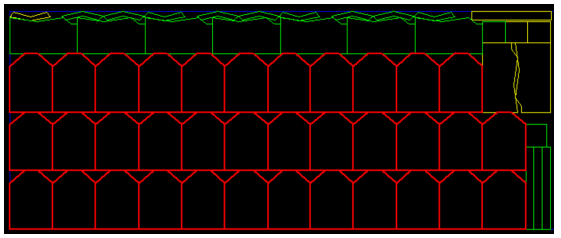
(b) Box Stacking (local view)



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)

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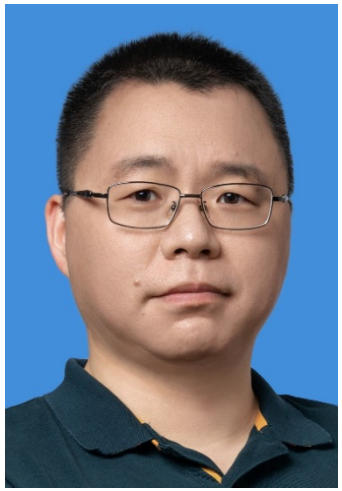
The program and experiment data can be downloaded from the following website:
http://www.huagongchuanhai.cn/packing/HierarchicalPacking.rar



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