

Material Selection Report

From Prototyping to Industrialization

1 Introduction

This report documents the material selection for the structural parts of the Domino Stacker Robot, with the explicit goal of transitioning from a functional prototype to a manufacturable and durable product.

The prototype validated the concept, but industrial constraints (repeatability, lifetime, assembly, and friction behavior in the slider) require a re-evaluation of the chosen materials. The selection was performed using the Ashby methodology with Granta EduPack.

2 Prototype vs. Industrial Constraints

The prototype relied on rapid-prototyping choices:

- MDF for the main chassis (cheap, easy to laser-cut, readily available).
- 3D-printed PLA for the motor brackets, slider and custom mechanical parts (fast iteration, complex geometries).

These choices were acceptable for prototype validation, but they are not ideal for an educational product meant to be handled repeatedly:

- MDF is moisture-sensitive and can swell or degrade over time.
- 3D printing is not suitable for series production (cycle time, variability, finishing).
- PLA parts can crack under impact or stress concentration, which is a risk in student use (drops, tipping).

To reduce manufacturing complexity, the industrial approach targets a mono-material solution for the chassis, tower walls, and the slider guidance surfaces. This aligns with DFMA (Design for Manufacturing and Assembly) principles and simplifies sourcing, assembly, and end-of-life recycling.

3 Ashby Selection

The primary structure is modeled as a stiff plate in bending. The footprint dimensions are fixed; thickness is treated as the free variable.

3.1 Requirements

The selection problem is defined as follows:

- Function: structural support (chassis) and guidance (tower/slider surfaces).
- Constraints:
 - stiffness adequate for a load capacity above 5 kg,
 - electrical insulation (safe mounting for PCB/Arduino),
 - non-brittle behavior (elongation at break above 2%),
 - density below 2000 kg/m³ (portability and motor efficiency).
- Objective: minimize material cost.
- Free variable: thickness t .

3.2 Performance index

The part cost is

$$C = V \cdot C_v = w t L C_v, \quad (1)$$

where C_v is the price per unit volume.

For bending stiffness,

$$S \propto E t^3 \quad \Rightarrow \quad t \propto \left(\frac{S}{E} \right)^{1/3}. \quad (2)$$

Substituting into cost gives

$$C \propto w L C_v \left(\frac{S}{E} \right)^{1/3}. \quad (3)$$

For fixed w , L , and target S ,

$$C \propto \frac{C_v}{E^{1/3}}. \quad (4)$$

Therefore, minimizing cost is equivalent to maximizing

$$M = \frac{E^{1/3}}{C_v}. \quad (5)$$

In log form,

$$\log(E) = 3 \log(C_v) + 3 \log(M), \quad (6)$$

which corresponds to a selection line of slope 3 on a $\log(E)$ vs. $\log(C_v)$ chart.

3.3 Screening and shortlisting

The performance index derived above was used as the main ranking criterion in Granta EduPack. Candidate polymers were compared on an Ashby chart plotting Young's modulus against price per unit volume, using the slope-3 selection line. To ensure feasibility for the robot, additional screening limits were applied (electrical insulation, elongation at break

above 2%, and density below 2000 kg/m³). The resulting chart and the corresponding shortlist are shown in Fig. 1 and Fig. 2.

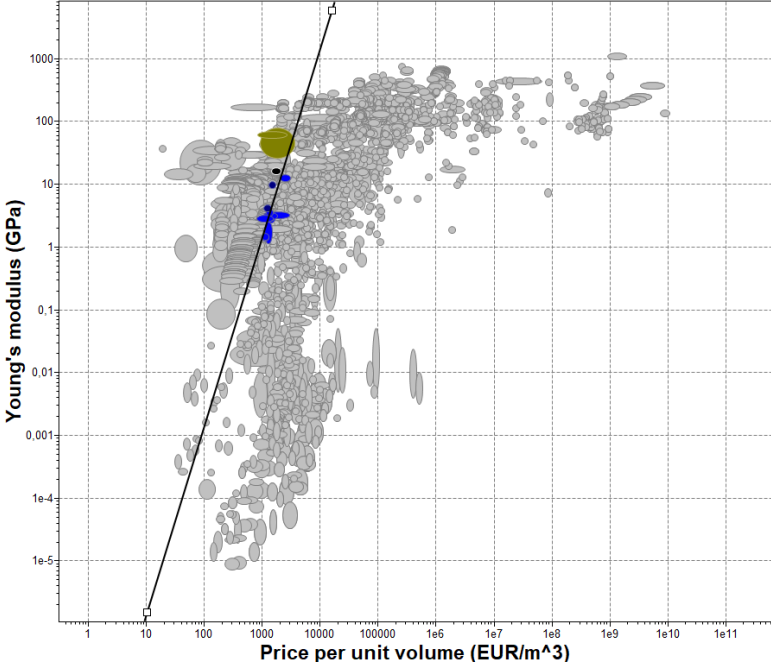


Figure 1: Ashby chart (Young’s modulus vs. price per unit volume) with a slope-3 selection line and screening limits.

















-  Flax fiber
-  Hemp fiber
-  PET (35-45% glass fiber and mica)
-  PET (unfilled, amorphous)
-  PET (unfilled, semi-crystalline)
-  Polypropylene fiber
-  PP (homopolymer, high flow)
-  PP (homopolymer, low flow)
-  PS (general purpose, 'crystal')
-  PS (heat resistant)
-  PS (high impact)
-  PUR(r) (casting resin, unsaturated)
-  PVC (rigid, molding and extrusion)
-  SAN (molding and extrusion)
-  SMMA (clarity, stiffness)
-  UF (woodflour filler)

Figure 2: Candidate materials after screening.

The shortlist was then reviewed using secondary considerations that are not captured by the stiffness/cost index, notably impact robustness in student use and friction behavior for the gravity-driven slider.

3.4 Selected Material

Based on these results, Polypropylene (PP) was selected as the unique structural material for the robot.

This strategic choice is justified by the following technical characteristics:

- **Density and Lightweighting:** PP is the lightest among rigid commodity polymers (significantly lighter than PVC or PMMA). This minimizes the robot's inertia, reducing the torque requirement for the stepper motors and extending the final product's battery autonomy.
- **Mechanical Stiffness Strategy:** Although PP has a lower Young's Modulus compared to MDF, the stiffness constraint is satisfied by adjusting the wall thickness (t). Since stiffness scales with t^3 , a marginal increase in thickness provides the required structural rigidity without a weight penalty, thanks to the low density.
- **Impact Resistance :** Unlike the PLA used in the prototype, which is brittle and prone to cracking, PP offers excellent ductility, providing superior toughness to withstand handling by students and accidental tip-overs.
- **Tribological Behavior:** The contact interface between the PP slider and the dominos benefits from the material's low surface energy. This minimizes the adhesive component of friction. This ensures smooth gravity-fed sliding, unlike PVC which possesses higher surface energy and stronger adhesion tendencies.
- **Industrial Rationalization (DFMA):** Adopting a Mono-Material strategy satisfies Design for Manufacturing and Assembly principles. It standardizes the raw material stock (single sheet reference), simplifies the cutting parameters (laser/CNC), and guarantees a simplified end-of-life scenario where the entire robot structure can be recycled in a single stream (Resin Identification Code 05).

4 Conclusion

The prototype materials (MDF and 3D-printed PLA) were appropriate for fast validation but do not match the durability and manufacturability constraints of an industrialized product. The Ashby-based selection supports polypropylene as the best compromise between stiffness-to-cost, weight, impact tolerance, and low-friction sliding behavior. A mono-material PP structure improves sourcing, assembly, and end-of-life handling.