Engineering & Computing

MECHANICAL AND MATERIALS ENGINEERING DEPARTMENT

Fall 2025 Senior Design Project

3D Printed Four-Bar Linkage Knee Prosthetic

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MOTIVATION

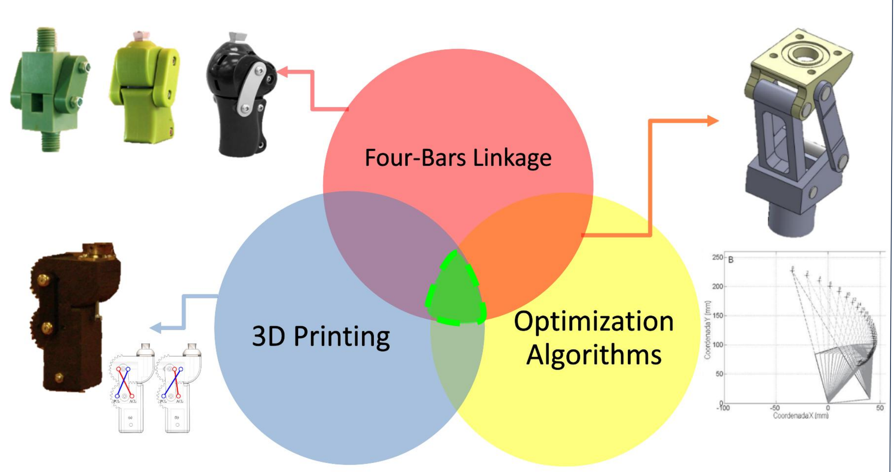
Over one billion people in low- and middle-income countries live with disabilities, and access to prosthetic services is severely limited according to data from the World Health Organization (WHO). Among them, there are more than **four million lower-limb amputees who rely on prostheses for everyday mobility but lack functional and affordable options**. With the rapid expansion of 3D printing worldwide, accessible manufacturing offers a promising way to deliver low-cost prosthetic solutions to this underserved population.

PROBLEM STATEMENT

Access to knee joints in developing countries is extremely limited in terms of cost and availability.

Existing 3D-printed designs rely on simple gear mechanisms, but these do not replicate natural knee motion.

Four-bar linkage systems better emulates the translation and rotation of the knee, yet their dimensions are usually chosen through empirical methods.



OBJECTIVES

Cost
< $80

Safety Factor
≥ 1.25

Stability & Control
RMSE <10.78

Flexion Range
90°-100°

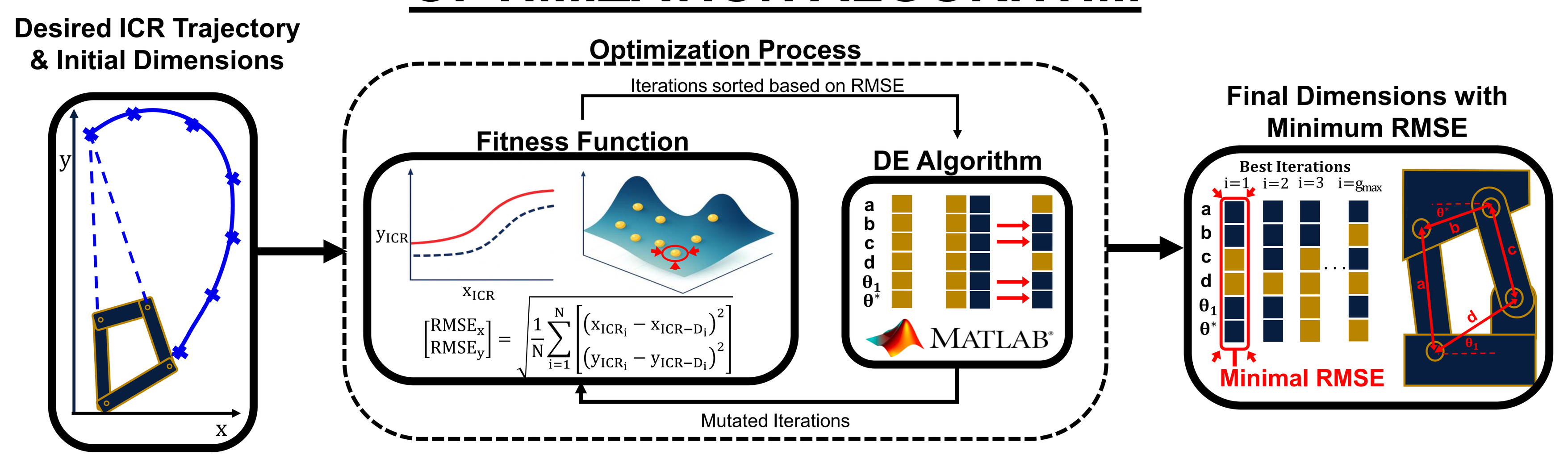
Weight
≤ 680 g

GLOBAL DESIGN

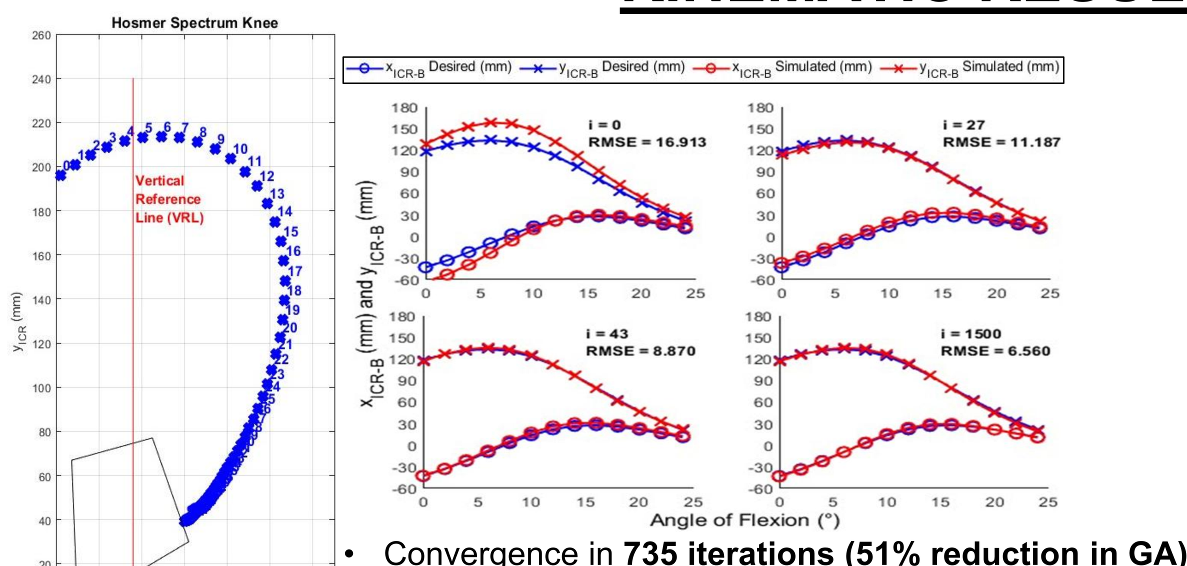
To develop affordable, durable prosthetic solutions that enhance mobility, promote accessibility, and improve lives across global underserved communities.

KINEMATIC STUDY

OPTIMIZATION ALGORITHM

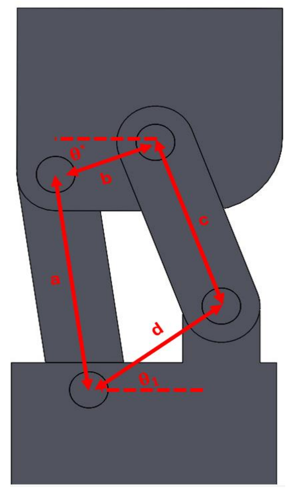


KINEMATIC RESULTS



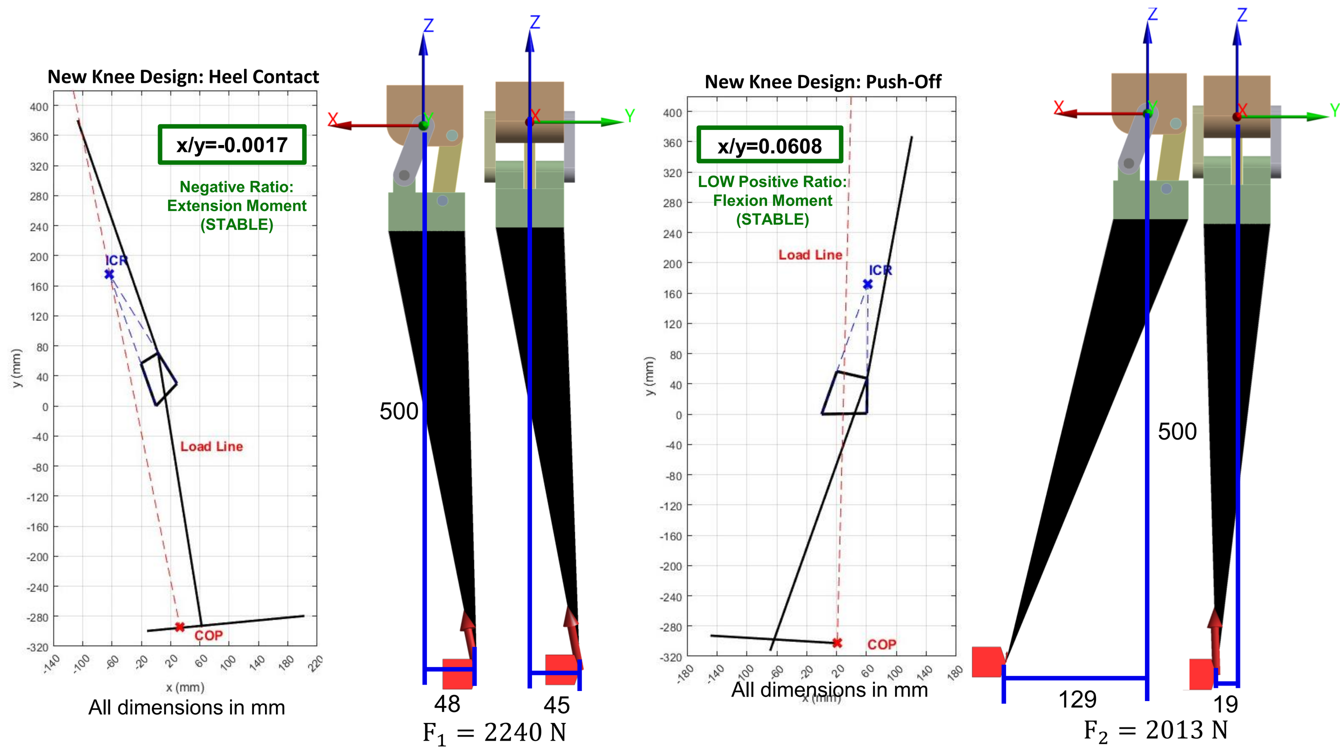
- Convergence in **735 iterations (51% reduction in GA)**.
- **39% RMSE reduction** compared to GA.

Compared to the GA configuration, the DE design achieved a **44.5% improvement in geometric compactness**.



$a = 60.00\ \mathrm{mm}$
$b = 27.24\ \mathrm{mm}$
$c = 48.24\ \mathrm{mm}$
$d = 41.26\ \mathrm{mm}$
$\theta_1 = 34.04°$
$\theta^* = 19.06°$

- **Negative ratio (ICR posterior):** produces an extension moment, allowing self-stability at heel contact and eliminating the required hip moment from the user.
- **Positive ratio (ICR anterior):** produces a flexion moment, but the design minimizes this value, thereby reducing hip effort during push-off.

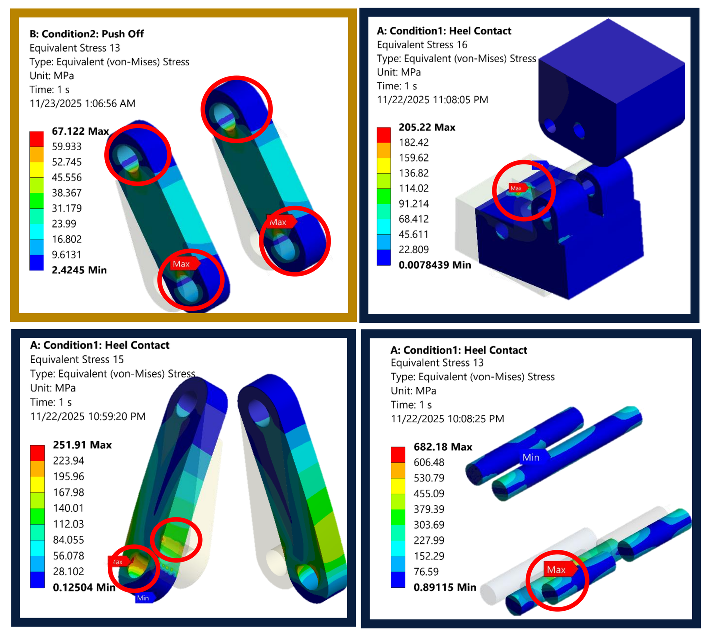


STRUCTURAL STUDY

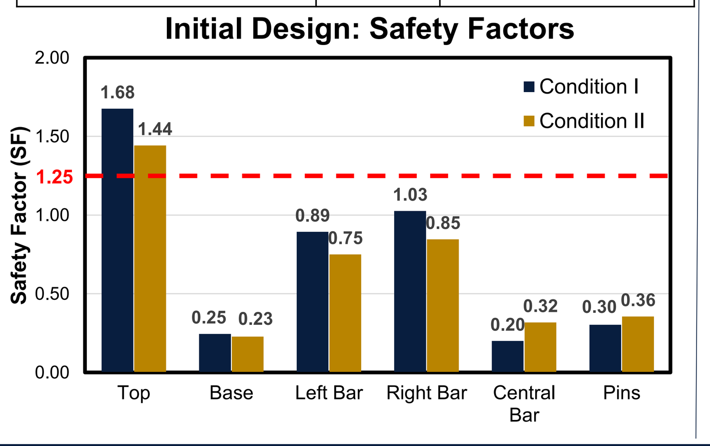
The **side bars** were critical under **Condition 2**, while the **central bar**, **top plate**, **base**, and **pins** were more critical under **Condition 1**.

Major stress concentrations at holes and the contact between central bar and base.

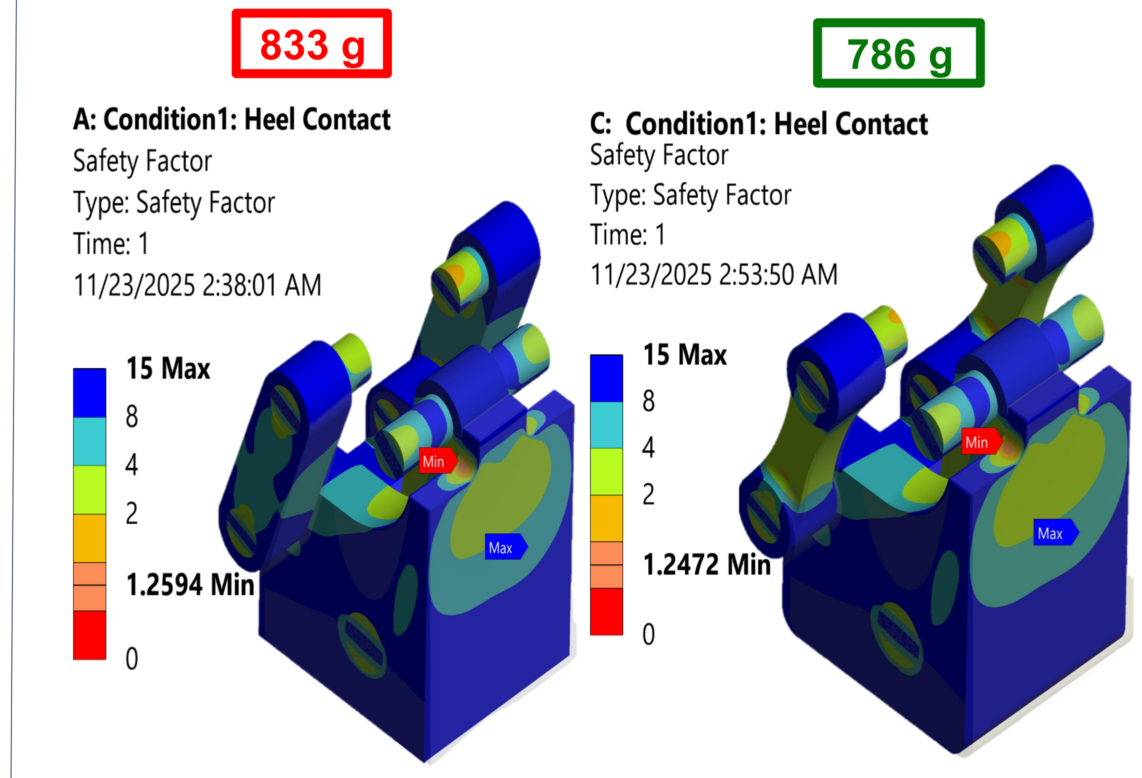
Improvements: increasing pin/hole diameter, bars thicknesses, and stopper height.



Property	PLA	18-8 Stainless Steel
Young's Modulus [GPa]	2.94	193
Poisson's Ratio	0.33	0.29
Yield Strength [MPa]	50.35	207



TOPOLOGY OPTIMIZATION

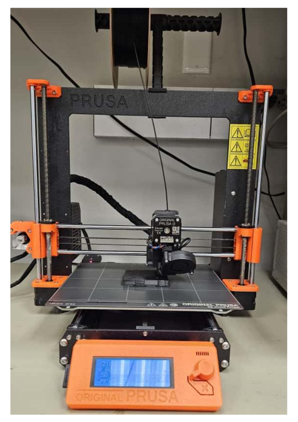


Material was added in regions with SF below 1.25 and removed where there were high SFs, optimizing both weight and strength.

The optimized design **reduced weight by 5.64%.**

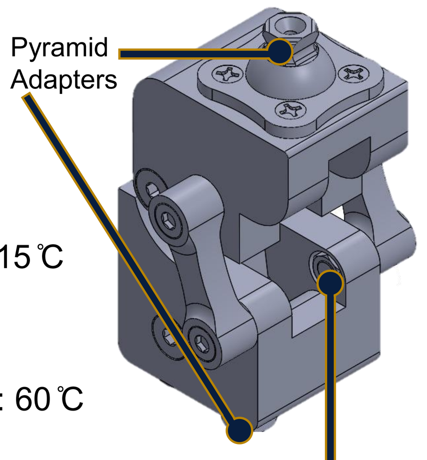
It remains 106 g heavier than the Remotion Knee. But a $\mathbf{SF_{min}} \geq \mathbf{1.25}$ was maintained still using 3D-printed PLA components, and the design is still **12.2% lighter than other joints** on the market.

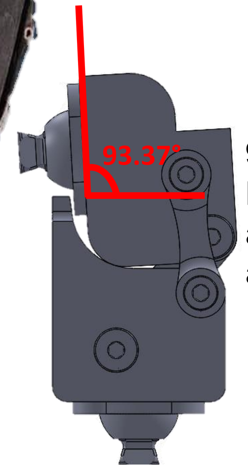
MANUFACTURING PROCESS



Printing Parameters for Prusa i3 MK4:

- Infill density: 100%
- Infill pattern: Rectilinear
- Extruder Temperature: 215℃
- Layer height: 0.20 mm
- Print speed: 100 mm/s
- Heated Bed temperature: 60℃





93.37° Maximum Flexion for daily activities: sitting and squatting.

Part Name	Quantity	Price
PLA+ Filament (1kg)	1	$15.33
Customized Stainless Steel Shoulder Screws	6	$11.94
Stainless Steel Hex Nut	Pack of 50	$5.97
Male Pyramids Adaptor	2	$64.85
	Total	**$98.09**

$18.09 more expensive, but Pyramids can be reused.

CONCLUSIONS

Cost of $98.09 with adapters	**22.6% more expensive, but still acceptable if adapters are re-used.**
RMSE of 6.560 using DE	**39% reduction compared with GA**
Lowest Safety Factor of 1.2472	**Meets ISO 10328 for heel contact & push-off**
93.37° maximum flexion motion	**Within 90°–100° sitting range**
Joint weight equal to 786 g	**12.2% lighter (but +106 g more than Remotion)**

Acknowledgement

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