

Beyond the Kit: A Quantitative Comparison of 3D Printed and Traditional Components in Botball Robotics

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Abstract—With the allowance of 3D printing in 2025[7], many Botball teams have increasingly used 3D printed parts and integrated them into their robots. However, there is little quantitative analysis on when 3D printing is actually beneficial. This paper aims to compare the effectiveness of 3D printed parts to traditional kit parts like LEGO and metal kit components. Additionally, it will evaluate multiple factors connected to these parts, including strength, weight, design flexibility, and development cycles. Using this, appropriate guidelines are proposed that will allow Botball teams to select the optimal construction method under different cases.

I. INTRODUCTION

Educational robotics and Botball both require a need for mechanical design, as students must learn how to integrate mechanical, electrical, and software systems into their robots[1]. More specifically, these robotics teams build from three main components: LEGO, aluminium kit parts, and custom 3D printed parts[8]. However, there is no clear framework for deciding:

- When should a team use kit parts?
- When should a team print a custom part instead?

For example, during the 2025-2026 season, our team, Los Altos Community Team 399, frequently debated whether we should use aluminum components or design 3D printed parts for our mechanisms. While custom parts often improved overall functionality, print failures, durability concerns, and longer design cycles were some problems that it brought up[2]. Because of this, several key research questions were formulated that will help us determine a solution:

- Which method/material produces the strongest mechanism?
- Which method/material produces the lightest mechanism?
- Which is the fastest to build and prototype?
- Which gives the higher competitive advantage?
- Under what conditions should each be used?

In the subsequent sections of this paper, these questions are evaluated on certain mechanisms and designs to answer the ultimate question: when should a team use what method to improve a robot's reliability and functionality? As LEGO and aluminum components (along with others, like foam) both fit under traditional kit parts, primarily two different methods will

be tested, 3D printed parts versus kit parts, which include both LEGO and aluminum parts.

II. BACKGROUND

To start, some basic advantages and disadvantages of LEGO, metal, and 3D printed parts are to be explained. This is represented by the table below:

TABLE I
COMPARING DIFFERENT METHODS

Method	LEGO	Metal	3D Print
Advantages	Fast assembly Beginner friendly Highly reusable	Strong Durable Precise	Precise replication Customization
Disadvantages	Limited geometry Flexing	Heavy Hard to modify	Print time Requires CAD skills

As you can see from the table, LEGO parts generally are very fast to assemble and simple to use. However, they lack strength and structure. In contrast, metal parts are very strong, but are very heavy consequently. 3D print takes characteristics from both methods, being precise and having rapid iteration[3], but requires skill in CAD and is limited to 6 parts across both robots. These advantages and disadvantages are consistent with findings from additive manufacturing literature, which show that 3D printing is better with customization and design flexibility[2].

III. EXPERIMENTAL DESIGN

To specifically and accurately observe individual characteristics, two functionally identical claw mechanisms were constructed that performed the same task. One (Fig. 1) was made out of kit parts, while the other (Fig. 2) was mainly made from 3D printed parts, with a sparse infill density of 15% and a slicing profile of 0.2 mm Standard @BBL X1C. Both mechanisms aimed at grabbing a drum.

A. Testing for weight

First, the weight of each claw was measured in grams. This includes all components that are connected to the claw, not including the servo responsible for moving the claw.

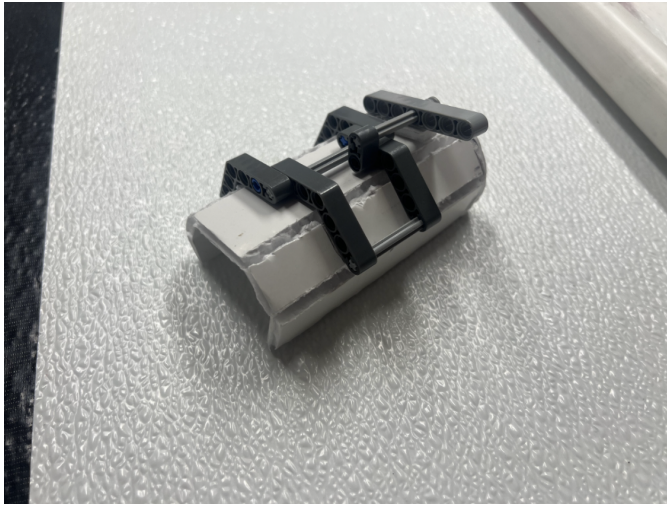


Fig. 1. Claw from kit parts

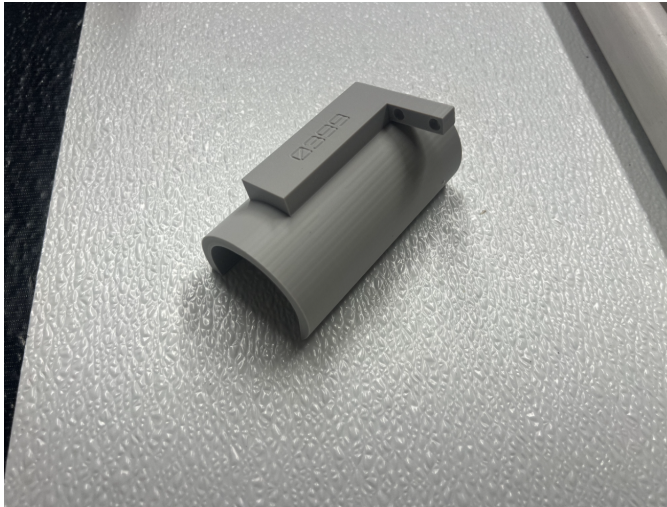


Fig. 2. 3D printed claw

B. Testing for strength

Next, both claws were dropped from an increasing altitude until it broke, measuring the highest altitude it was able to keep its function. In this study, a claw becomes broken when there are obvious signs of damage on the part and it cannot perform its task properly (in this case, picking up a drum).

C. Testing for precision

To test for precision and accuracy, The same drive path was executed for each mechanism, as follows. Both robots aimed at

- 1) grabbing a drum
- 2) moving it into the drum holder

After testing, the success rate of each method was calculated. The success rate was calculated with this formula:

$$successrate = (successfulattempts/totaltrials)*100 \quad (1)$$

D. Build time

Before starting all the other tests, the time required to design and assemble a working version of each mechanism was recorded.

E. Repair Time

Finally, damage was simulated to each claw by removing the main body of the claw, essentially simulating destruction to the claw's body. Then, the time it took to restore the claw to its former state, ensuring full functionality was measured. For the 3D printed version, it is assumed a spare part is ready to model the competition environment.

F. Results

The below table shows all the cumulative data after all 5 tests:

TABLE II
CUMULATIVE DATA FROM TESTS

Method	Kit Parts	3D Print
Weight (g)	22	34
Strength (in)	70	81
Precision (%)	87.5	97.5
Build Time (min)	65	102
Repair Time (min)	25	5

DETAILED ANALYSIS

G. Build time

After the experiments, the 3D printed claw turned out to be around 55% heavier than the claw constructed from kit parts. A lighter claw can have significant implications, like a faster acceleration when grabbing objects and a lower risk of motor/servo strain.

H. Structural Analysis

Kit parts were found to be approximately 13.6% less stronger than 3D printed parts. Although 3D printed parts were found to be stronger, the difference is not as large as expected. Previous research has shown that the strength of PLA components is heavily influenced by factors like print settings, layer adhesion, and print orientation[4]. Ultimately, 3D printed parts should be used for strength if there is enough resources, although using kit parts is also acceptable to an extent.

I. Maintenance Analysis

When building from scratch, 3D printing took almost twice the time compared to building with kit parts. However, it took five times faster to repair compared to kit parts. This can be due to the long periods of time needed to print the object[3], although when the piece is manufactured it takes very little time to reassemble it onto the robot.



Fig. 3. 3D printed drum storage

J. Competition Performance

From the data above, the 3D printed claw had a clear reliability boost of 10%, from 87.5% to 97.5%. This improvement may be attributed to the ability of additive manufacturing to create highly customized geometries that would be difficult to recreate using standard kit components [2].

CASE STUDIES FROM 2026 SEASON

Using these findings, several mechanisms from the 2026 season were analyzed. In Fig. 4, 3D printing was used to model and print the piece that holds drums via two tubes. This was because it was determined that the shape needed for this part required a specific geometry that could not be easily replicated with kit parts[2]. Additionally, it also needed to be lightweight, as it would be controlled by a servo. These two criteria both fit under 3D printing, which helped determine the final construction method.

In Fig. 5, a claw was designed for grabbing poms on the game table. As this mechanism would be fairly simple to construct and wouldn't require a heavy load, it was ultimately decided to use kit parts to construct this mechanism.

DECISION FRAMEWORK

Using all the data gathered, A decision framework was developed based on the experimental results. See Fig. 6 to

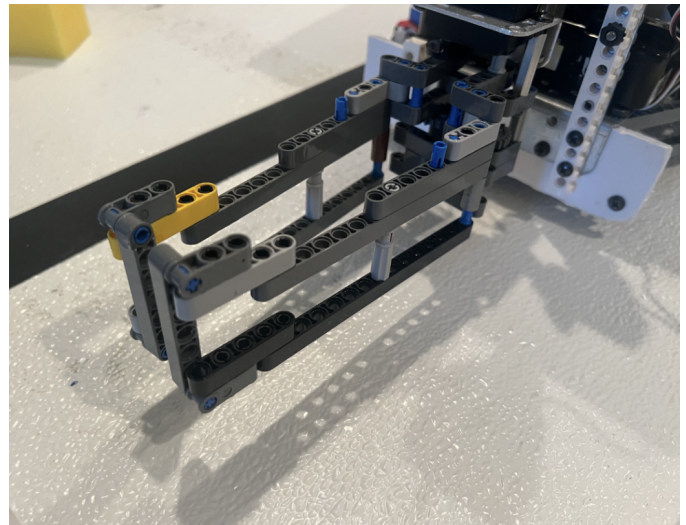


Fig. 4. Lego claw for poms

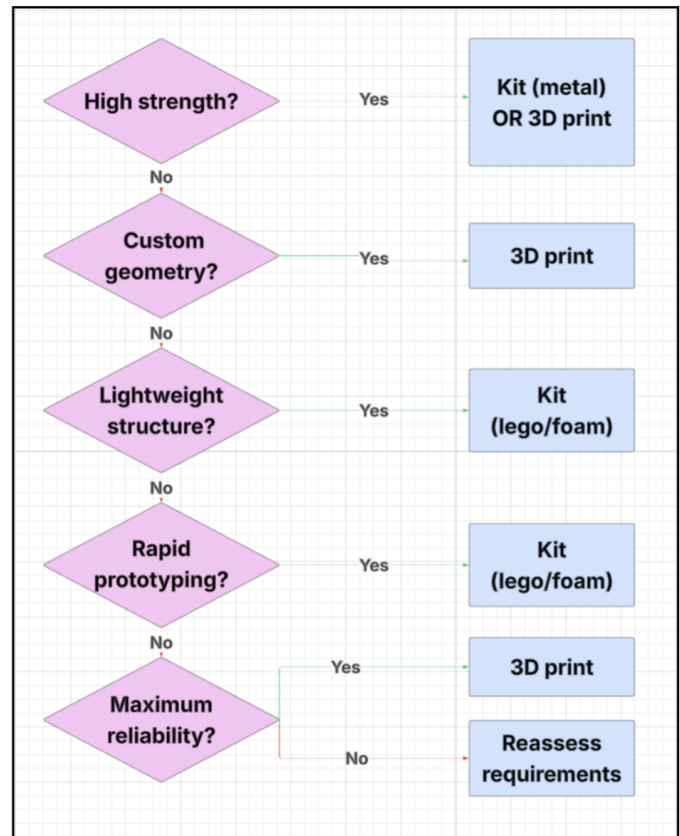


Fig. 5. Decision Flowchart

access which method to use under certain circumstances.

LIMITATIONS

Despite getting clear and helpful results from the research, various limitations still existed that would require further experimentation. First, only Botball kits components were tested, so these findings may not be able to be applied to

other robotics programs, like FRC where materials and scale are massively different. Additionally, only PLA filament was tested[4] as the 3D print material as Botball only allows this print type to be legally used on robots. Because of this, there could be differing results if other materials, like PETG and ABS were used[5].

Different printers could also produce different results. The printer used for the experimentation was a Bambu Lab X1 Carbon printer, which excels in accuracy and speed. However, other printers differ in functionality. For example, the Creality Ender 3 V3 SE printer, the 3D printer included in Botball's official kit, could result in a slower and less accurate print.

FUTURE WORK

This research also raises future areas of study. As explained in the previous section, future experiments should compare 3D printing materials[4], such as PLA, PETG, ABS, TPU, nylon, and carbon-fiber-reinforced filament. This shifts the issue to a broader lens, and would help determine whether certain materials are better for certain tasks.

Secondly, print settings must be considered in future studies, as variables such as infill percentage, layer height, wall thickness, print orientation, and infill pattern may significantly change a part's strength and weight[5]. To address this, more research could be done to determine the best print settings for Botball components like servo mounts and brackets, claws, and structural supports.

Third, future work could explore the usage of generative design[6]. This would allow software to construct the optimal design of parts without wasting material. This could allow lighter parts to be created that are still the same strength as its metal counterparts.

Fourth, this study could be expanded to test hybrid mechanisms that combine both kit parts and 3D printed parts. For example, an elevator mechanism could combine both metal beams and 3D printed parts to ensure strength and facilitate iteration.

Finally, the durability of different components is a crucial factor that should be considered. A useful follow-up experiment should aim at testing how each method performs under hundreds of repeated cycles. This is important as Botball robots often undergo long periods of impacts through transportation, testing, and competition collisions.

CONCLUSION

This paper investigated one of the most common engineering decisions that Botball teams face: whether to use traditional kit parts or 3D printed parts instead for building robot mechanisms. While 3D printing has become a popular and useful technique in robotics, there has been little analysis regarding when it becomes the better choice over LEGO or metal components. This was addressed by comparing different construction methods over different criteria, among those being weight, strength, precision, design flexibility, manufacturing time, repairability, and overall competition performance.

The results show that no construction method by itself is superior. While metal components consistently improved overall strength and reliability, LEGO components allowed for faster prototype cycles, and 3D printed parts offered the highest design flexibility, which allowed for lightweight parts that kit parts could not produce alone.

Ultimately, it is determined that 3D printing should not be a replacement for metal or LEGO parts, but as a powerful tool that needs to be used appropriately. The most effective Botball teams understand not to mindlessly design parts, but know how to effectively use these different methods to build mechanisms under different conditions.

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