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MEMS 411: Bamboo Clamping Device

Grace Chen
Washington University in St. Louis

Anya Gupta
Washington University in St. Louis

Yosef Weiss
Washington University in St. Louis

Washington University in St. Louis
James McKelvey School of Engineering

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Bamboo Clamping Device

The objective of this design project was to create an automatic clamping machine to keep bamboo bundles tight during lashing. Currently, manual clamping and lashing of bamboo require simultaneous user effort, posing challenges in terms of efficiency and safety. Our project introduces a mechanical and automatic clamping tool, designed to significantly alleviate the physical strain on users and enhance overall safety. This report details two primary designs of solutions to this problem. The first is a motor-tightened hose clamp controlled via a three-way switch. The second design is a claw clamp with an inflatable pouch used to pin the bamboo together. By automating the clamping process, this project aims to revolutionize the traditional method, offering a more user-friendly and secure approach. The report details the design, functionality, and potential impact of the automated clamping tool, highlighting its contribution to both the field of robotics and sustainable bamboo utilization practices. This design met the re-scoped project requirements, including tight clamping, a portable tool, and a time frame quicker than the manual method. Future design iterations include a more condensed inflation tool and a quicker and more powerful motor to tighten the hose clamp. To create this design, the total cost is $4008.16 including all parts, assembly, and labor hours.

CHEN, Grace
GUPTA, Anya
WEISS, Yosef

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1 Introduction

In the pursuit of advancing sustainable practices and enhancing the efficiency of bamboo utilization, this report presents the development of a mechanical and automatic clamping tool for bamboo clamping. The customer for this project is Professor Wyly Brown of Washington University in St. Louis, who currently works abroad in Bali. The current manual method poses challenges, requiring users to simultaneously clamp down on bamboo while engaging in the lashing process, resulting in inefficiency and potential safety concerns. Our project addresses these issues by introducing an innovative tool designed to automate the clamping process, alleviating physical strain and minimizing risks. Moreover, our focus on sustainability aligns with the intrinsic eco-friendly nature of bamboo as a renewable resource. This research report outlines the design, functionality, and potential impact of our automated clamping tool.

2 Problem Understanding

2.1 Existing Devices

Currently, the method for bamboo clamping and lashing has not evolved beyond manual labor using builders' hands. Some technology has been proposed, but no devices are widely used. In order to conceptualize functional designs for the prototype, products with similar functions were examined. Below are three examples of devices that wrap around and clamp onto materials.

2.1.1 Existing Device #1: ITECH Material Robot

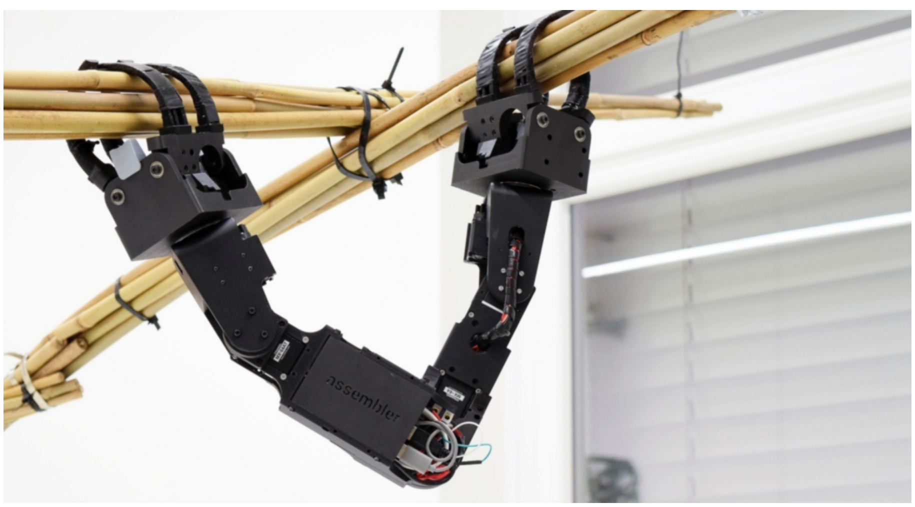


Figure 1: Proposed robot clamping onto bamboo clusters

Link: https://www.itech.uni-stuttgart.de/itech-thesis-projects/2020-co-designing-material-robot-behaviors/
Description: This design was developed as a thesis project by researchers at the University of Stuttgart and involves robots that can respond to the behavior of bamboo material to traverse various bamboo structures utilizing a neural network. The programming of the robots focused

mainly on their movement and adaptability across bamboo bundles, achieving impressive mobility and balance. The robots attach to the bamboo bundles using clamps at each end, which they were able to release and tighten. This clamping technology would work well for holding together bamboo bundles while lashing them together.

2.1.2 Existing Device #2: Rebar Tying Tool

Figure 2: Twintier RB611T Rebar Tying Tool around a rebar bundle

Link: https://www.maxusacorp.com/rebar_tying_tools/products/rebar-tie-gun-rb611t-twintier/
Description: Rebar (reinforced bar) tying tools are able to quickly dispense wire and tie it around bundles of rebar with minimal human effort. The device shown above is portable and ergonomic, and encompasses similar functions as the bamboo lashing device aims to cover. The user opens and closes the jaw around the rebar, and then triggers the wire mechanisms which rapidly feed the wire around, bend it, and tie it around the bundle.

2.1.3 Existing Device #3: Blood pressure cuff

Figure 3: Existing Blood Pressure Cuff

Link: https://santamedical.com/products/medvice-manual-blood-pressure-cuff-universal-size-aneroid-sphygmomanometer-nurses-bp-monitor-best-adult-bp-machine
Description: A blood pressure cuff is a vital medical tool used to measure blood pressure. Comprising a fabric cuff, inflatable bladder, closure mechanism, pressure bulb, pressure release valve, and a manometer, the device is typically wrapped around the upper arm. When the pressure bulb is squeezed, the cuff inflates, exerting pressure on an artery. The physician uses a stethoscope to listen for blood flow sounds as the cuff gradually deflates. The pressure at which these sounds begin and end is recorded, providing key indicators of a person's blood pressure. Whether manual or digital, blood pressure cuffs play a crucial role in monitoring cardiovascular health by facilitating accurate and essential blood pressure measurements.

2.2 Patents

2.2.1 Automatic Clamp (US 2466909A)

This patent was put out by Glenn W Periman for a c-clamp specifically with one fixed jaw and one spring-urged jaw. It is used to keep items in a working position.

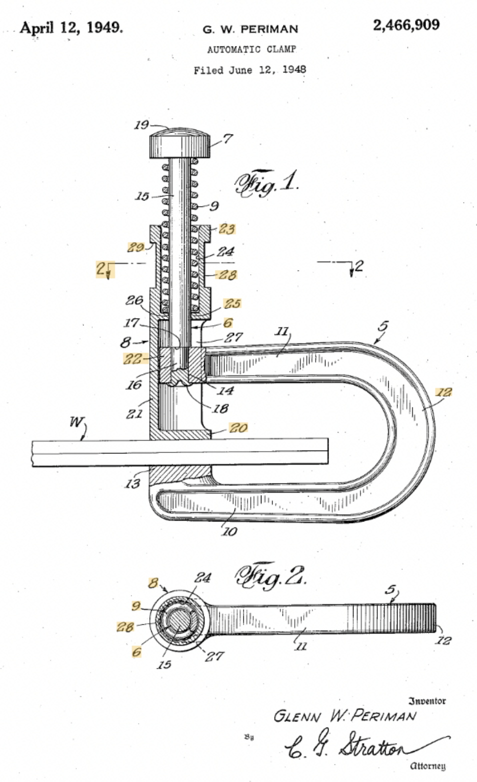


Figure 4: Patent Image: Diagram of C-clamp

2.2.2 Automatic clamp for paper cutting machines (US 1990392A)

Patented by John F Schroeter in 1935, this automatic clamp is geared towards improving the mechanism to provide even pressure to piles of sheets of different thicknesses. This is not influenced by temperature, humidity, or wear. Another goal was for it to minimize the power required to operate it. This is very similar to one of our goals of reducing the strain put on the user.

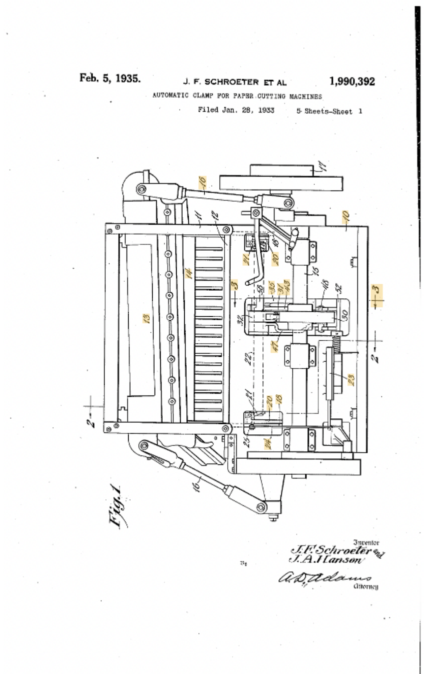


Figure 5: Front Elevation with Clamp Applied

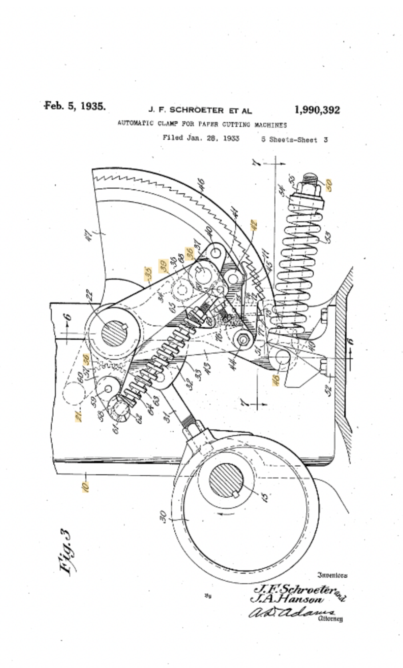


Figure 6: Sectional View on Enlarged Scale when Clamp is Released

2.3 Codes & Standards

2.3.1 Standard for Product Quality (ISO 9000)

ISO-9000 is the series of standards that governs the quality management and assurance of a product and/or process. This standard details the requirements for documenting the quality management system to ensure quality products. ISO-9000 is not specific to any industry; rather, it can be applied to any product. ISO-9000 can be applied to our project, the bamboo lasher, as a fundamental first step in the process. Establishing a quality management system is crucial to ensuring a quality final product. Without this standard, there is no way to conform to guarantee to our customers that they are getting the product they ordered.

2.3.2 Standard for Bamboo Structures (ISO 22156)

This standard applies to the structural soundness of bamboo constructions whose primary load bearing structures is made of round bamboo, and concerns mechanical resistance and durability of such structures. As the connections between bamboo pieces are vital to the structure's durability, this standard should be considered during the testing of the bamboo lashing device to ensure that it can produce structurally sound connections.

2.4 User Needs

User needs for this project were determined based on an initial customer interview. These criteria were then interpreted in a user needs table to evaluate the importance of each need which will then inform the design specifications.

2.4.1 Customer Interview

Interviewee: Prof. Wyly Brown
Location: Zoom
Date: September 18th, 2023
Setting: The interview was conducted over Zoom, as the customer was on sabbatical in Bali.

Interview Notes:
What are the projected uses of the device?

- Hold bamboo pieces together
- Tie lashing rope around pieces to securely connect them

What are the current issues with the product?

- There is no current product, all work is done by hand
- Strength intensive manual labor
- Potential for injury

2.4.2 Interpreted User Needs

Based on the user interview, several needs were determined and listed below. Upon further consideration, these needs were assigned levels of importance to be considered in the design of the product.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	Clamp bamboo tightly	5
2	Quickly lash bamboo	4
3	Wrap lashing tightly	5
4	Automatic lashing	4
5	Portable and handheld	3

Overall, the most important needs were to clamp and wrap the lashings as tightly as possible. This makes sense as the fundamental part keeping the structure together is this lashing, which needs to be tight. Without a tight clamp, the lashing will slip out. The second needs is the timing and automation. Clearly, even if it takes more time, it is still worth getting a tighter clamp and lashing. The least important need is the portability as they are willing to have a bulkier product for a better quality result.

2.5 Design Metrics

Based on the interpreted customer needs in the table above, metrics were assigned to each need. These metrics will be used to characterize our prototypes and final product. For each metric, there is an acceptable value and an ideal value. At this point, the values are rough estimates but will be narrowed in as we progress.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Force of clamp	lb	100	200
2	2	Angular velocity	rad/s	0.1	0.5
3	2	Time to finish lashing	s	20	10
4	3	Tension in lashing cord	lb	200	350
5	4	Low force required from user	N	10	0
6	5	Compact size	kg	0.5	0.2

2.6 Project Management

The Gantt chart in Figure 7 gives an overview of the project schedule.

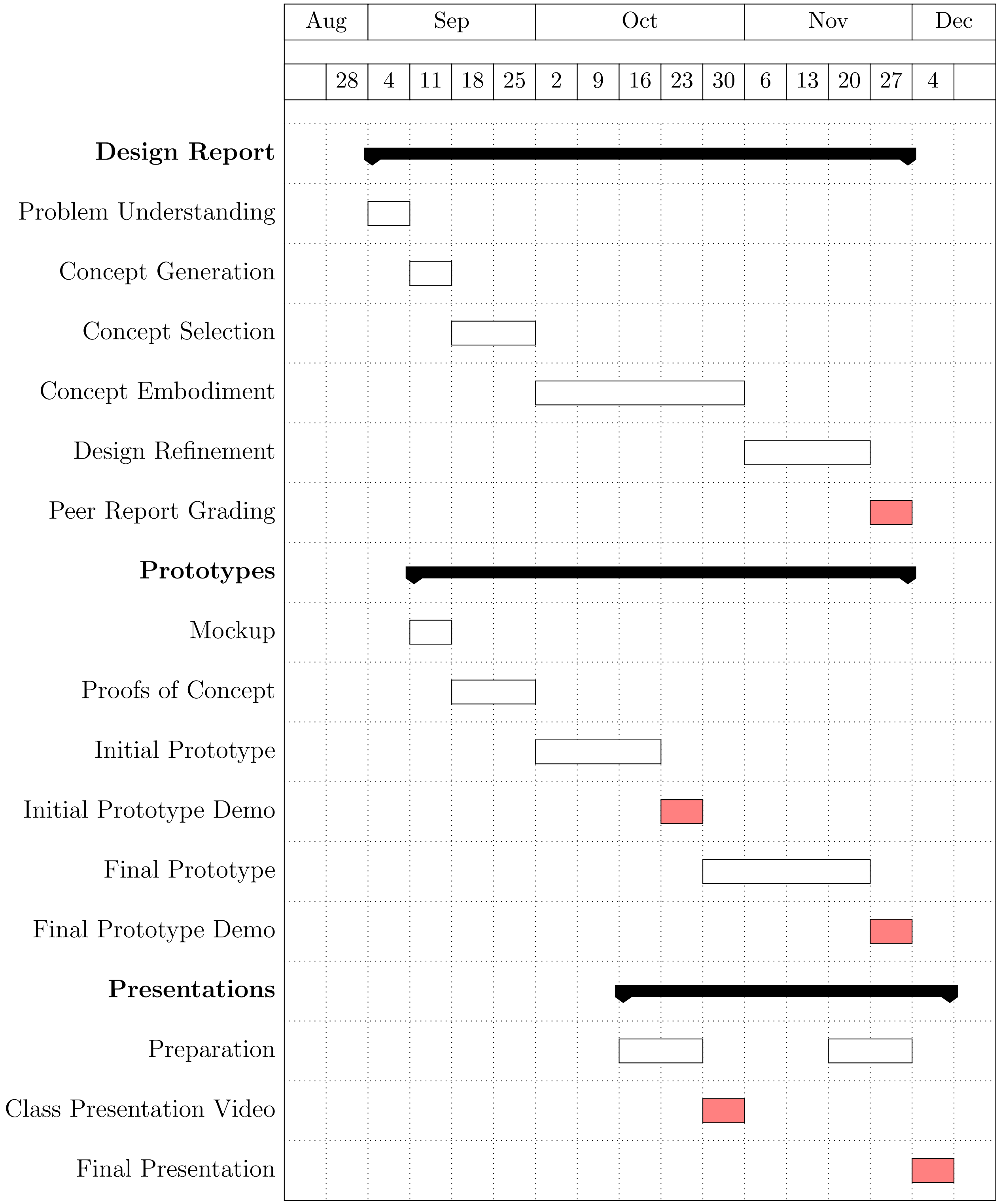


Figure 7: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

As we were building the mockup, we started to realize the general dimensions and function of the clamp. The mockup showed us the importance of visualizing a design before beginning construction. In the mockup, Figure 8, the skewers represent the bamboo, and the mechanism is attached around the bamboo. Figure 10 shows an exploded view of the mockup where the cardboard with rubber bands represents the clamping mechanism, the duct tape foam piece is the rotating armature, and the PVC pipe with twine is the spool of rope used for the lashing. This mockup showed us how difficult it would be to build a piece that can rotate but is also easily detachable. As explained later in the report, the results from this mockup suggested to us to rescope our project to focus on the clamp.

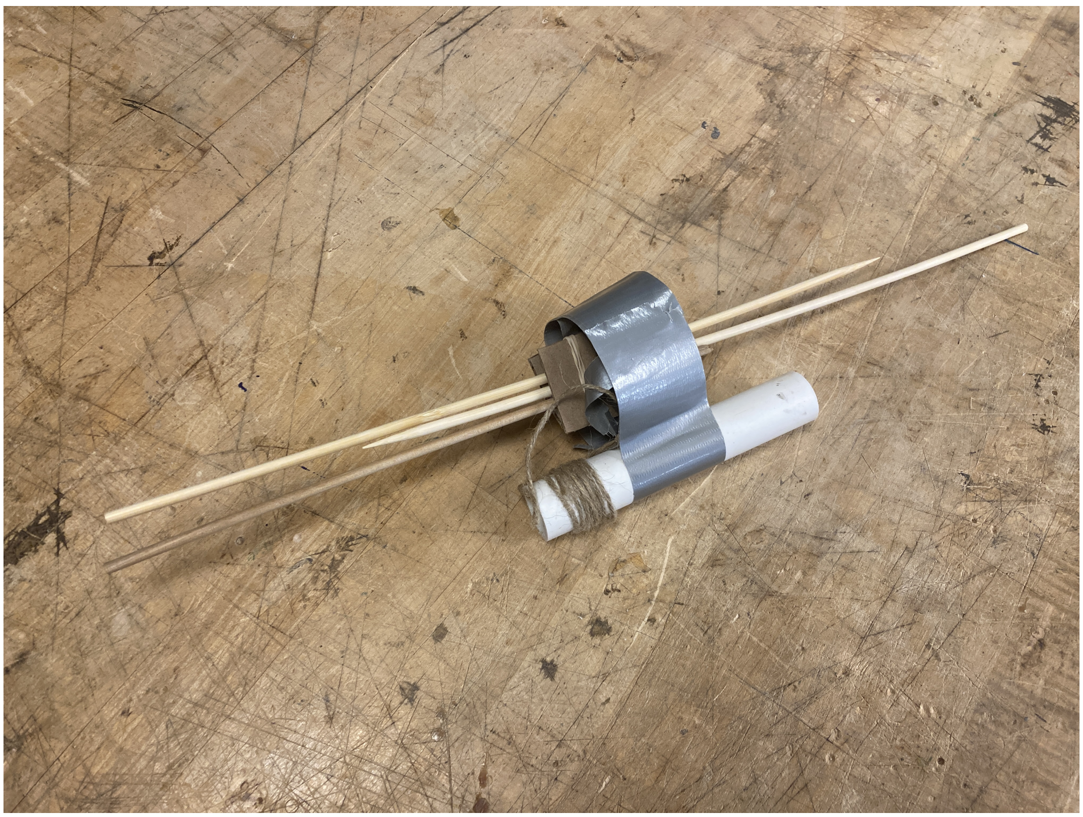


Figure 8: Mockup Picture

Figure 9: Mockup Second Angle

Figure 10: Mockup Exploded View

3.2 Functional Decomposition

The function tree below details the user needs for our product. .

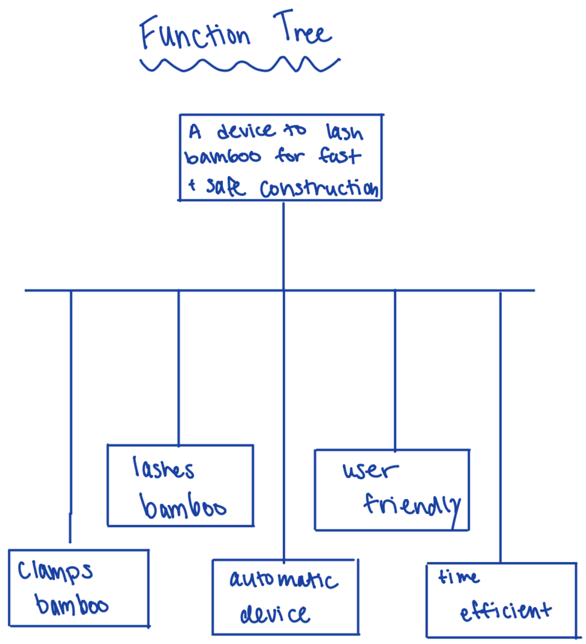


Figure 11: Function tree for bamboo lashing robot, hand-drawn and scanned

3.3 Morphological Chart

In the morphological chart, each identified function has three or four possible iterations of solutions.

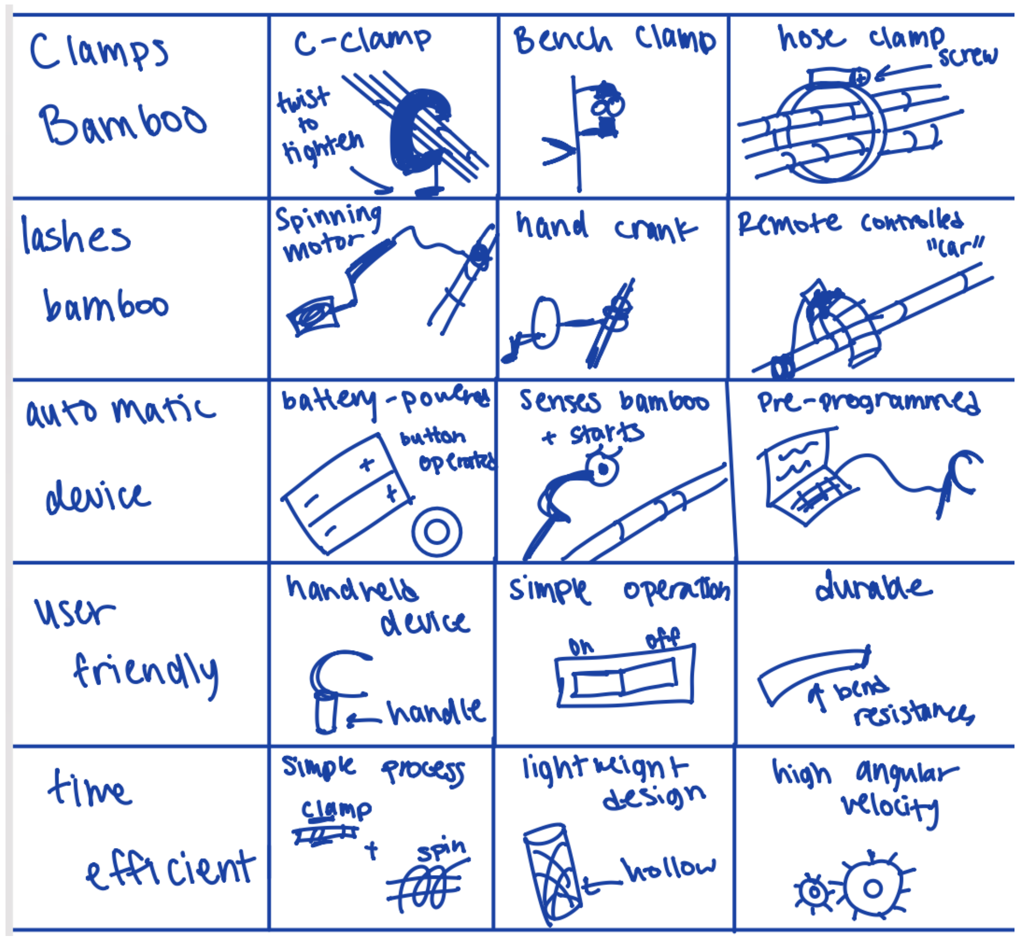


Figure 12: Morphological Chart for Bamboo Lashing Robot

3.4 Alternative Design Concepts

3.4.1 Concept #1: Oh-So-Tense

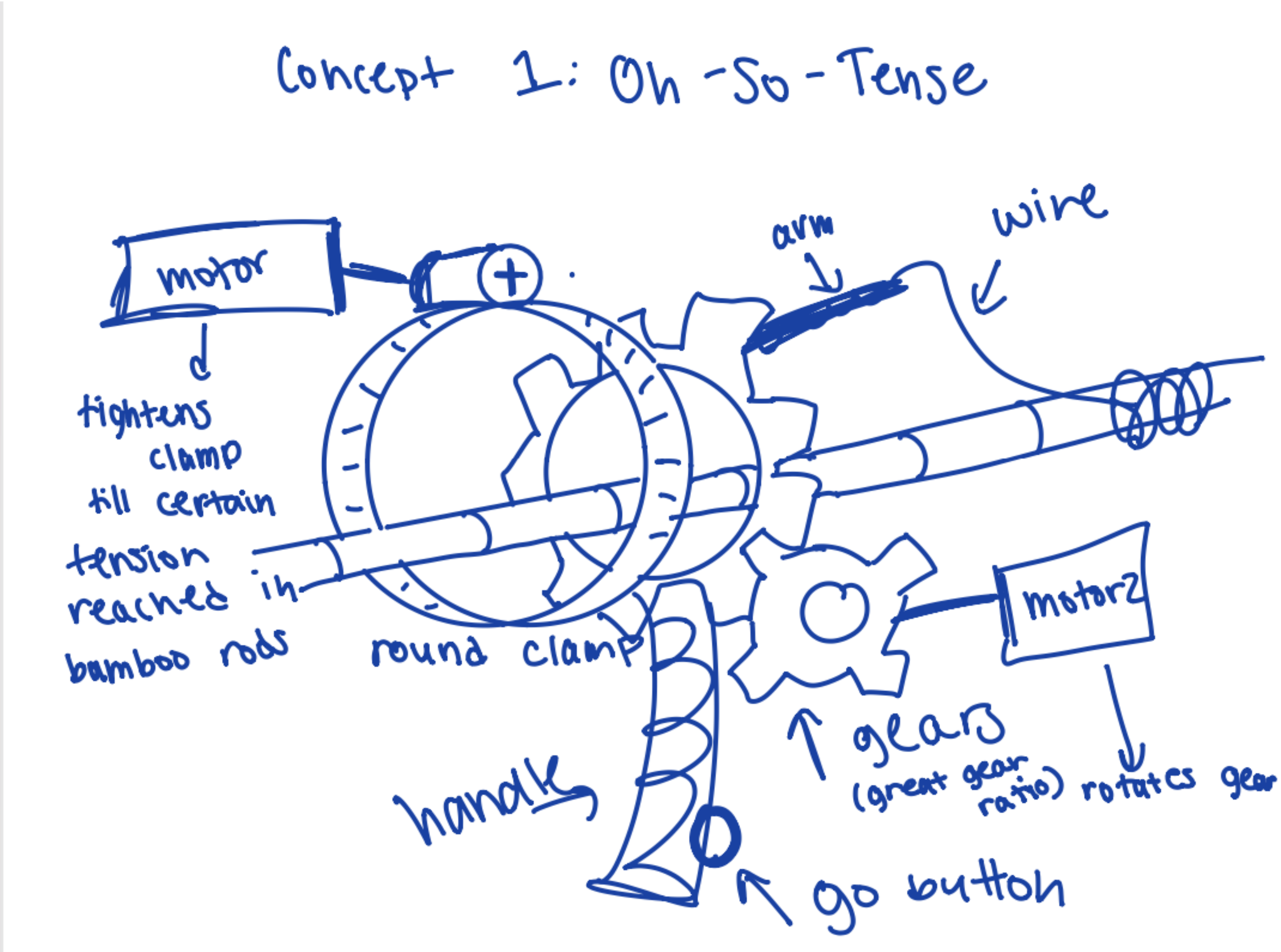


Figure 13: Sketches of Oh-So-Tense concept

Description: This is a handheld tool that can be slotted into a belt loop. On the handle is a motor that tightens a hose clamp until a certain tension is reached in the bamboo rods. For the second iteration of the design, the clamp is connected to a large gear that can open and close around the bamboo bundle. This larger gear is connected to an arm and spool that winds the rope around the bamboo bundle. The hose clamp can be completely opened and put around the bundle. The end is fed into the opening until the worm screw catches it.

3.4.2 Concept #2: Motor-cycler

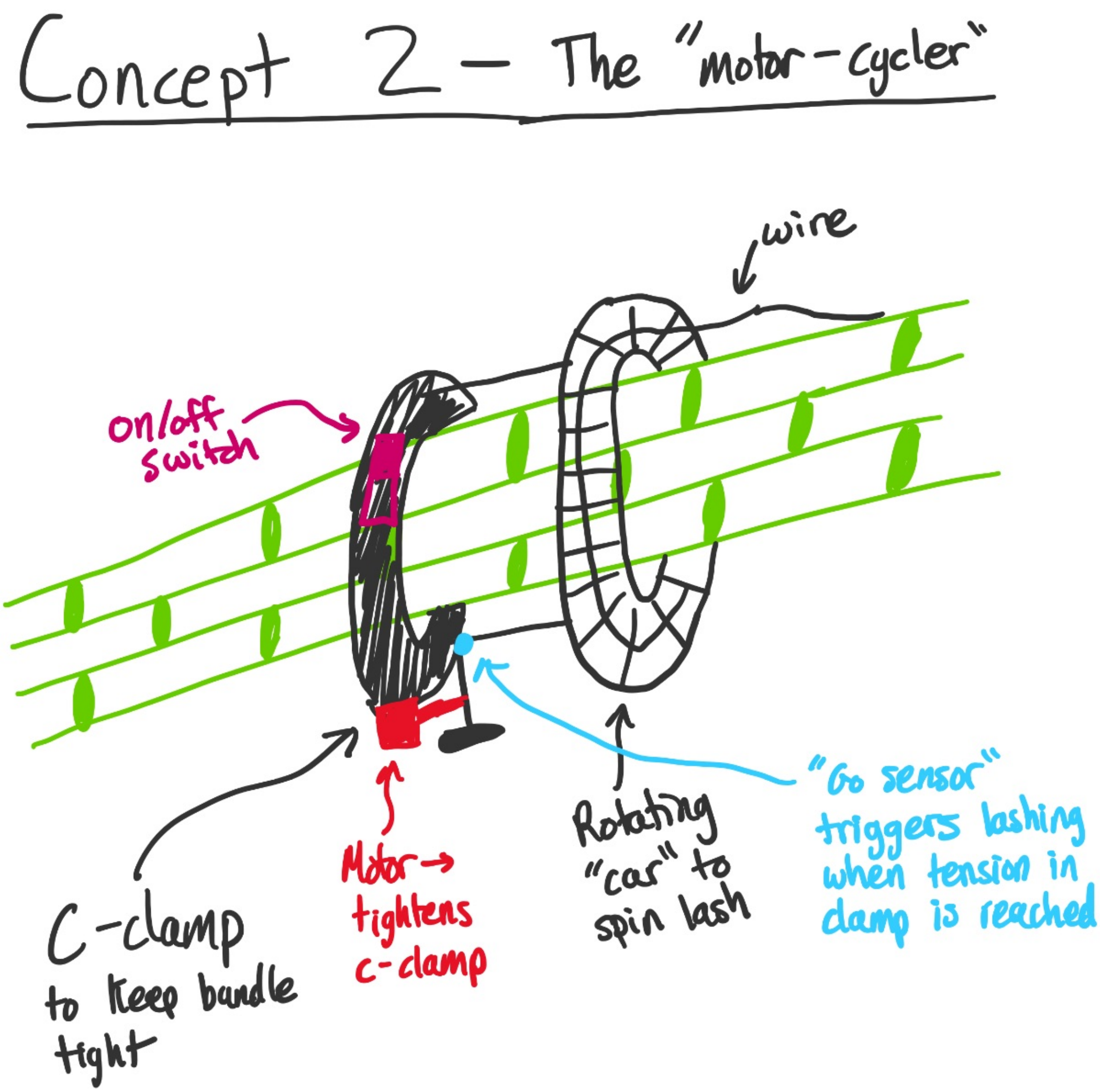


Figure 14: Sketches of Motor-cycler concept

<u>Description</u>: The motor-cycler is an independent mechanism that can be slotted onto the bamboo bundle. The fundamental clamping mechanism is a c-clamp with a motor that tightens the clamp. For the lashing iteration of this project, a rotating "car" is connected to the c-clamp that spins around the bundle. There is a "go sensor" on the clamp that measures force and only begins the lashing rotations once a proper clamping force is reached.

3.4.3 Concept #3: Crank It

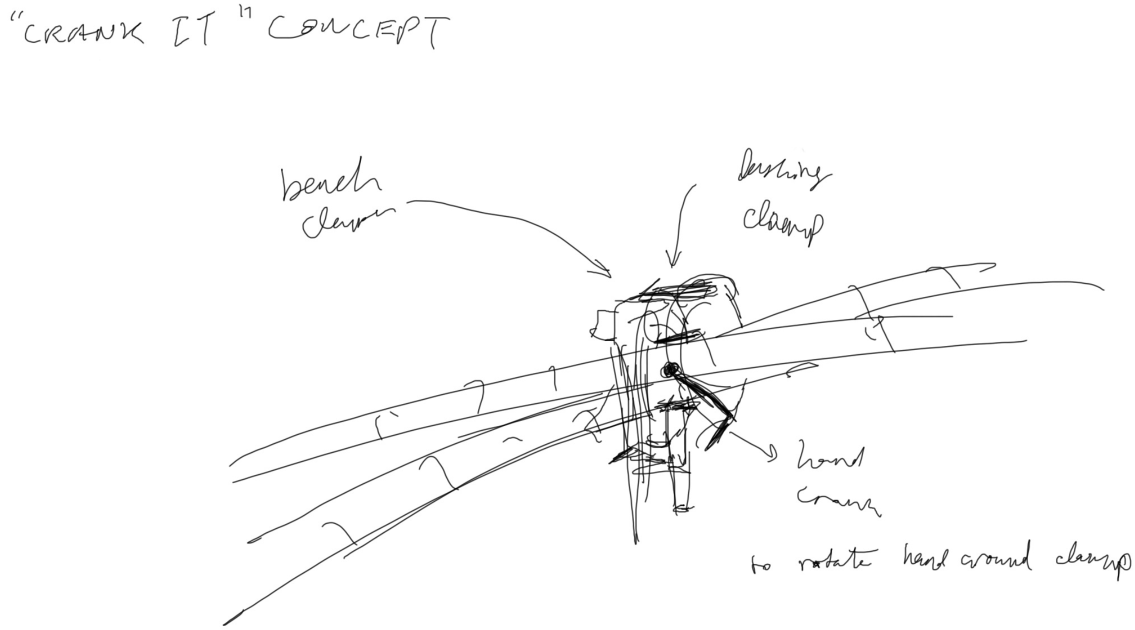


Figure 15: Sketches of Crank It concept

Description: The "crank it" mechanism is a hand tool that utilizes a bench clamp as the fundamental clamping mechanism. It then operates via a hand crank that rotates an armature around the clamped bamboo bundle. This mechanical tool allows the user to be in control of the tightness of the bundle.

3.4.4 Concept #4: Self-attached

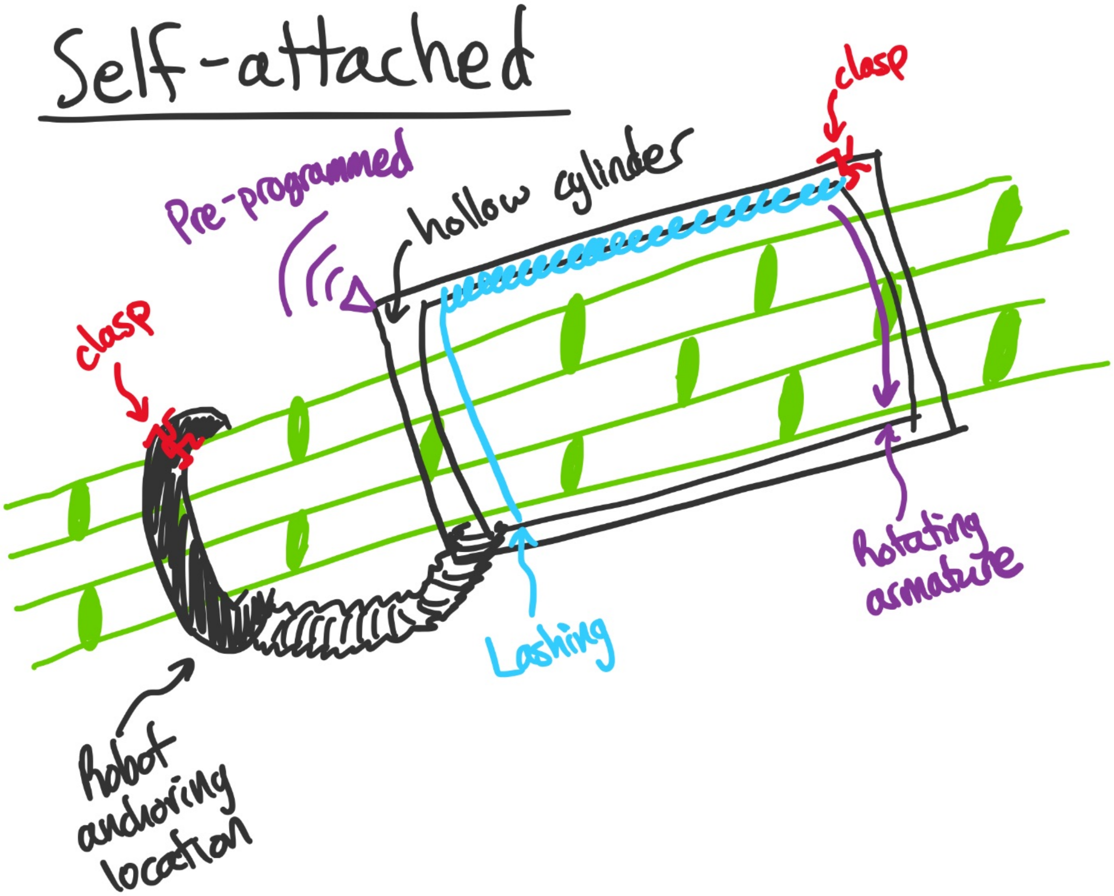


Figure 16: Sketch of Self-attached concept

Description: The self-attached concept has a nested cylinder. The outside cylinder is connected to the robot anchoring clamp. The inner cylinder carries the lashing twine and spings around inside the outer cylinder. Due to the flexible connection between the two components, this design would have to be placed on the bundle with two hands.

4 Concept Selection

4.1 Selection Criteria

As displayed below in Figure 17, the five selection criteria were determined to be portability, ease of use, the ability to clamp, quick lashings, and the manufacturability of our product. Each criterion was weighted against each other and the Excel formula determined the overall weights for each criterion.

	Portability	Ease of Use	Ability to Clamp	Quickly Lashes	Manufacturability		Row Total	Weight Value	Weight (%)
Portability	**1.00**	0.20	0.11	1.00	0.33		2.64	0.04	3.91
Ease of Use	5.00	**1.00**	0.20	5.00	9.00		20.20	0.30	29.89
Ability to Clamp	9.00	5.00	**1.00**	5.00	9.00		29.00	0.43	42.91
Quickly lashes	1.00	0.20	0.20	**1.00**	9.00		11.40	0.17	16.87
Manufacturability	3.00	0.11	0.11	0.11	**1.00**		4.33	0.06	6.41
						Column Total:	**67.58**	**1.00**	**100.00**

Figure 17: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

In order to evaluate each concept, the criteria were listed and each concept was rated with respect to each criterion. The Excel sheet determined the optimal concept based on weights and ratings.

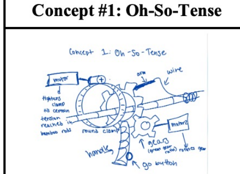
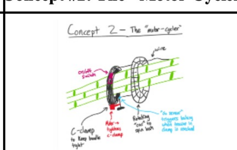
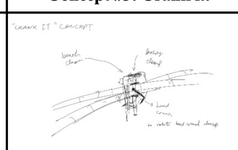
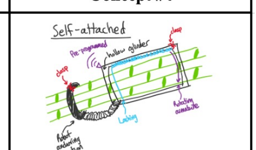
Alternative Design Concepts		**Concept #1: Oh-So-Tense**		**Concept #2: The "Motor-Cycler"**		**Concept #3: Crank it!**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Portability	4.15	3	0.12	3	0.12	2	0.08	2	0.08
Ease of Use	31.73	5	1.59	4	1.27	1	0.32	3	0.95
Ability to Clamp	45.55	4	1.82	3	1.37	3	1.37	2	0.91
Quickly lashes	11.62	4	0.46	4	0.46	1	0.12	5	0.58
Manufacturability	6.95	3	0.21	4	0.28	3	0.21	1	0.07
	Total score	**4.206**		**3.503**		**2.092**		**2.596**	
	Rank	**1**		**2**		**4**		**3**	

Figure 18: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

As seen in Figure 18, the best concept was "Oh-So-Tense." This concept consists of a circular "hose" clamp that is used to clamp the bamboo bundle together for the lashing. A motor connected to a set of gears spins an arm that lashes the rope around the bundle. This concept scored average in the portability and manufacturability criteria. It is relatively portable as it is lightweight and doesn't consist of many parts. The handle also makes it more portable. Due to the gears, this concept did not score so high on manufacturability as that requires higher degrees of precision. This concept scored very well on lashing quickly, the ability to clamp, and ease of use. Since these were the criteria with the highest weights, this concept won as the best concept. This concept is easy to use as it comes with a handle and has convenient buttons to start the clamping process. It has a strong ability to clamp as this "hose" clamp mechanism works well for a circular clamping motion. "Oh-So-Tense" also scored highly in the quickly lashing category as the rotating arm can spin quickly without fear of tangling.

4.4 Engineering Models/Relationships

As the prototyping continues in development, it is helpful to determine some engineering models that can be used to help predict situations and possible issues. The first engineering model, as seen below in Figure 19, is a torque-speed curve for a DC brushed motor.

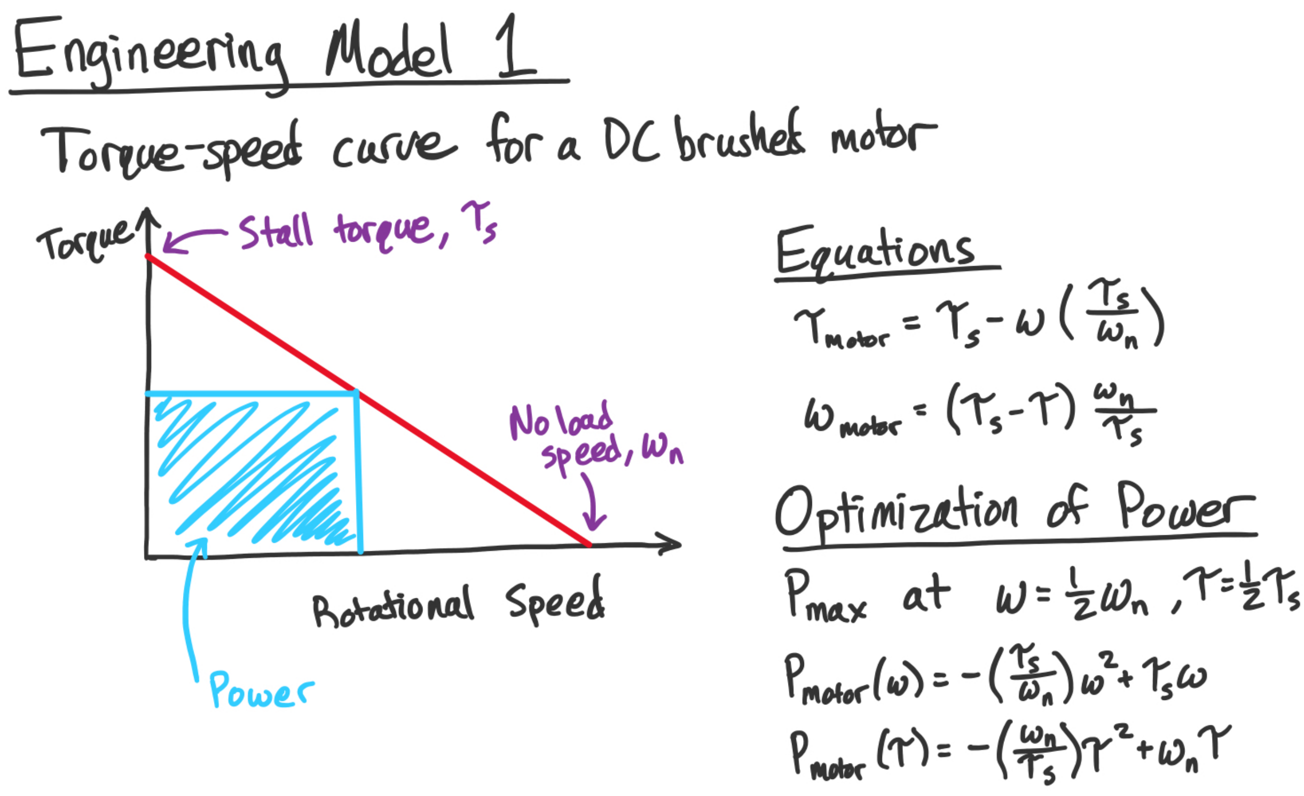


Figure 19: Engineering Model 1

The second engineering model, as seen below in Figure 20, is a torque simulation for a rope in tension pulling on the bundle. It was determined that due to this one-sided torquing, the bundle might twist. In order to counteract that, a possible solution was developed where there are two ropes crossing behind each other in opposite directions.

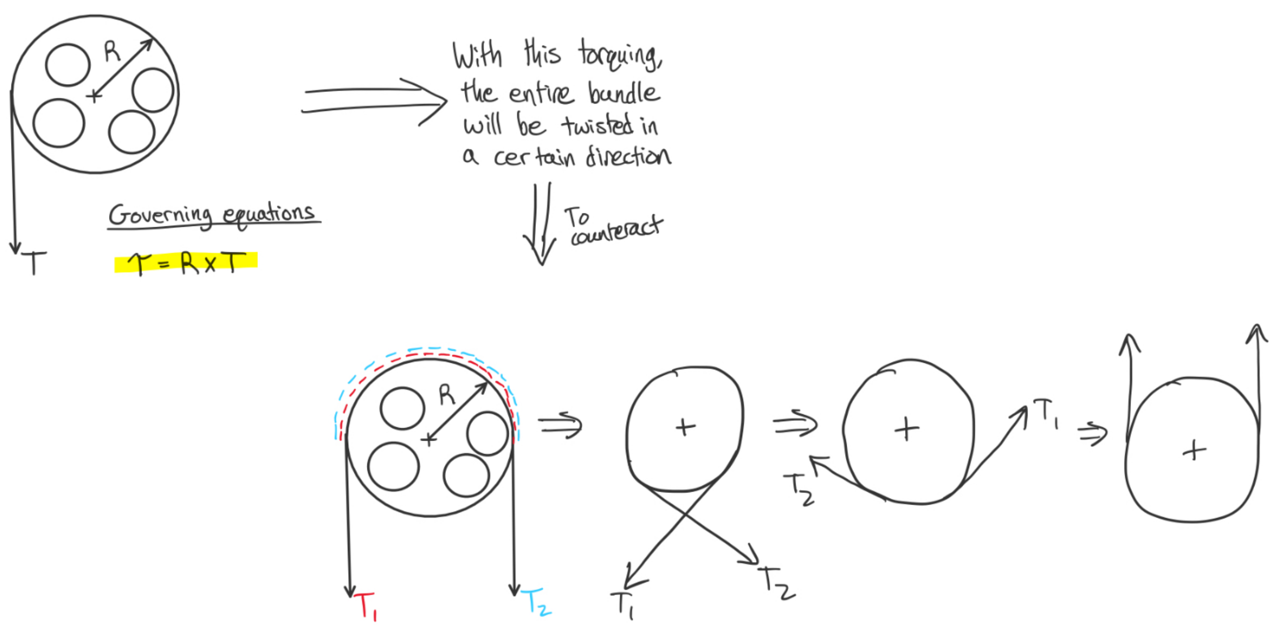


Figure 20: Engineering Model 2

The third engineering model, as seen below in Figure 21, is the model of Hooke's law associated with the clamping of the bamboo. The bamboo pieces need to be clamped together with enough force to hold them firmly, but not too much which will deform the bamboo.

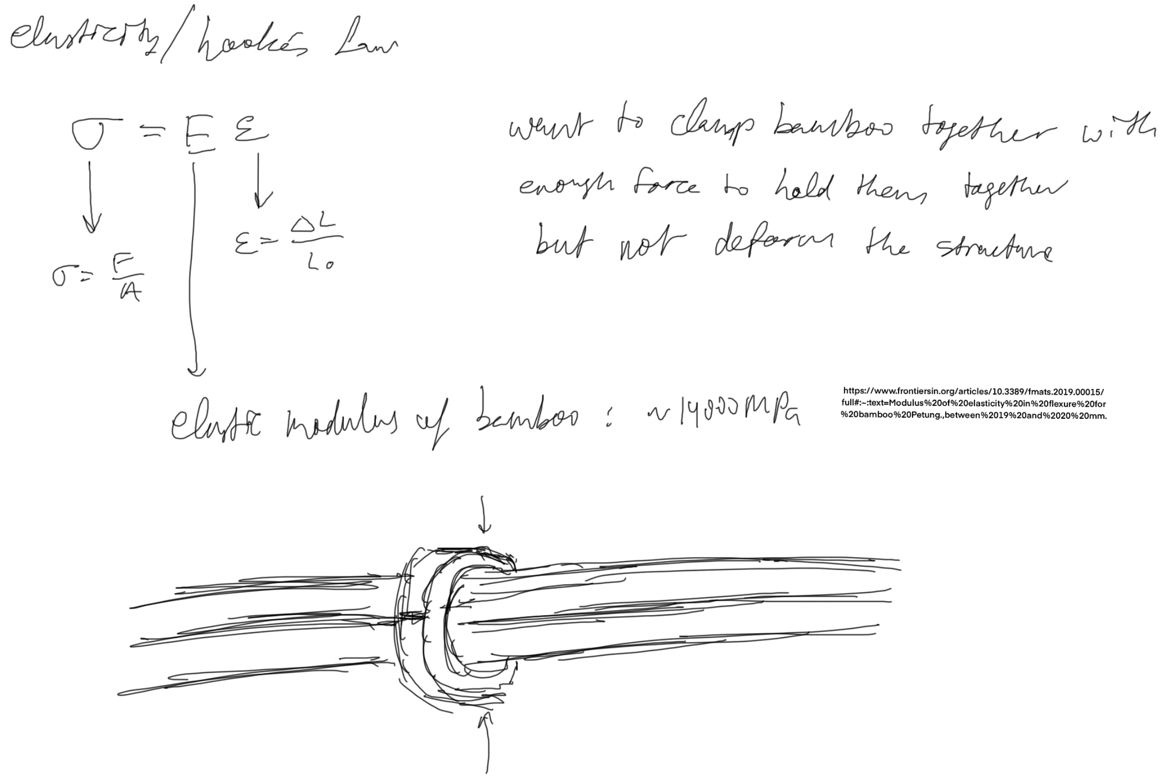


Figure 21: Engineering Model 3

5 Concept Embodiment

5.1 Initial Embodiment

For the first prototype, we tried to match our proof of concept as best as possible. We looked into creating both a clamping feature and a lashing feature separately with the hopes of combining them in a future prototype. Our performance goals were to clamp onto bamboo with enough force so that a person could not pull it out of the clamp, to lash bamboo with less time and no required force from the user, to create a durable and tight connection around the bamboo which does not move more than 1mm, and to make the device portable and convenient to carry, weighing less than 5lbs. However, we determined that the lashing mechanism we had designed wasn't feasible, so we focused our efforts on the clamping mechanism. The following drawings detail the prototype for the clamping device.

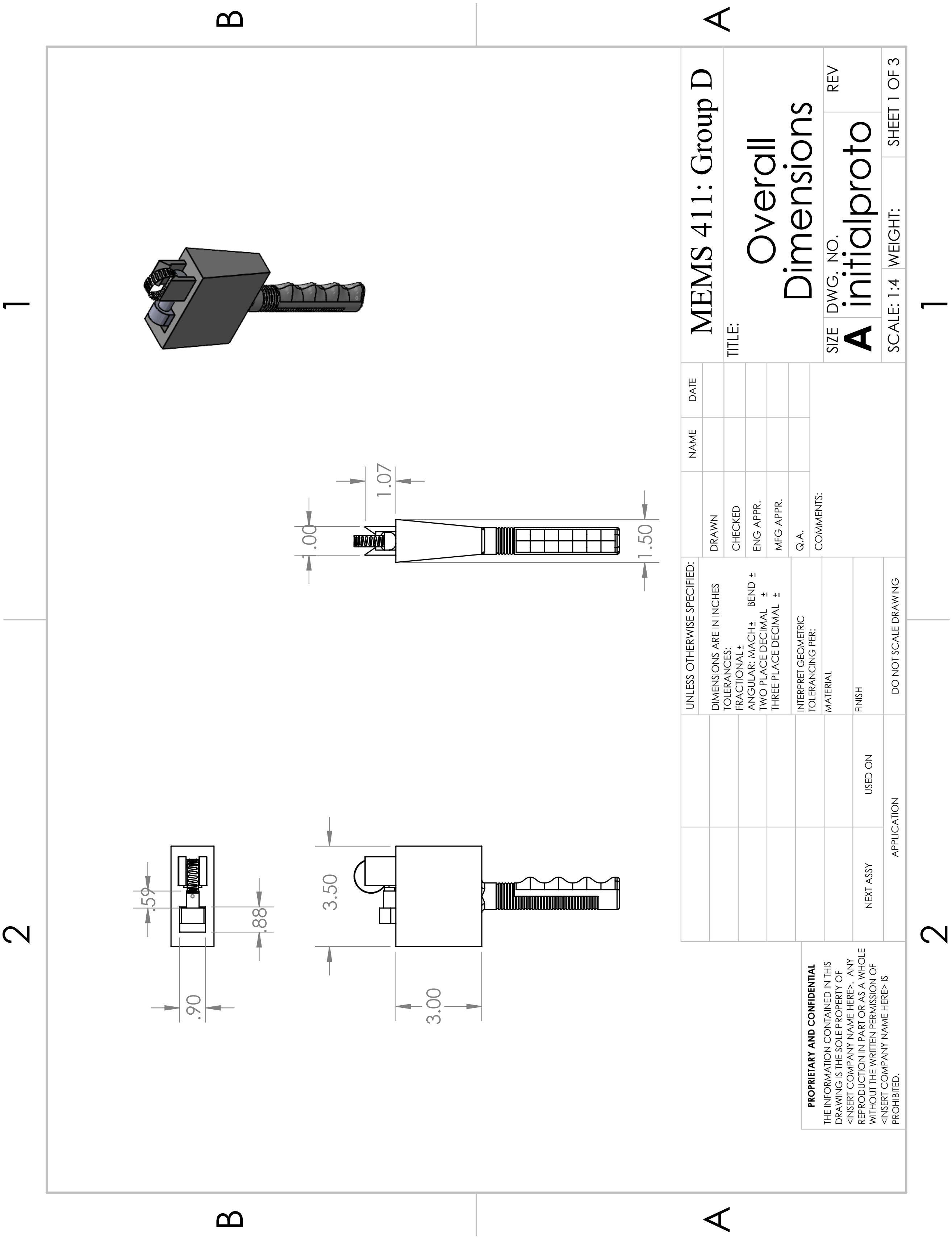


Figure 22: Assembled projected views with overall dimensions

Figure 23: Assembled isometric view with bill of materials (BOM)

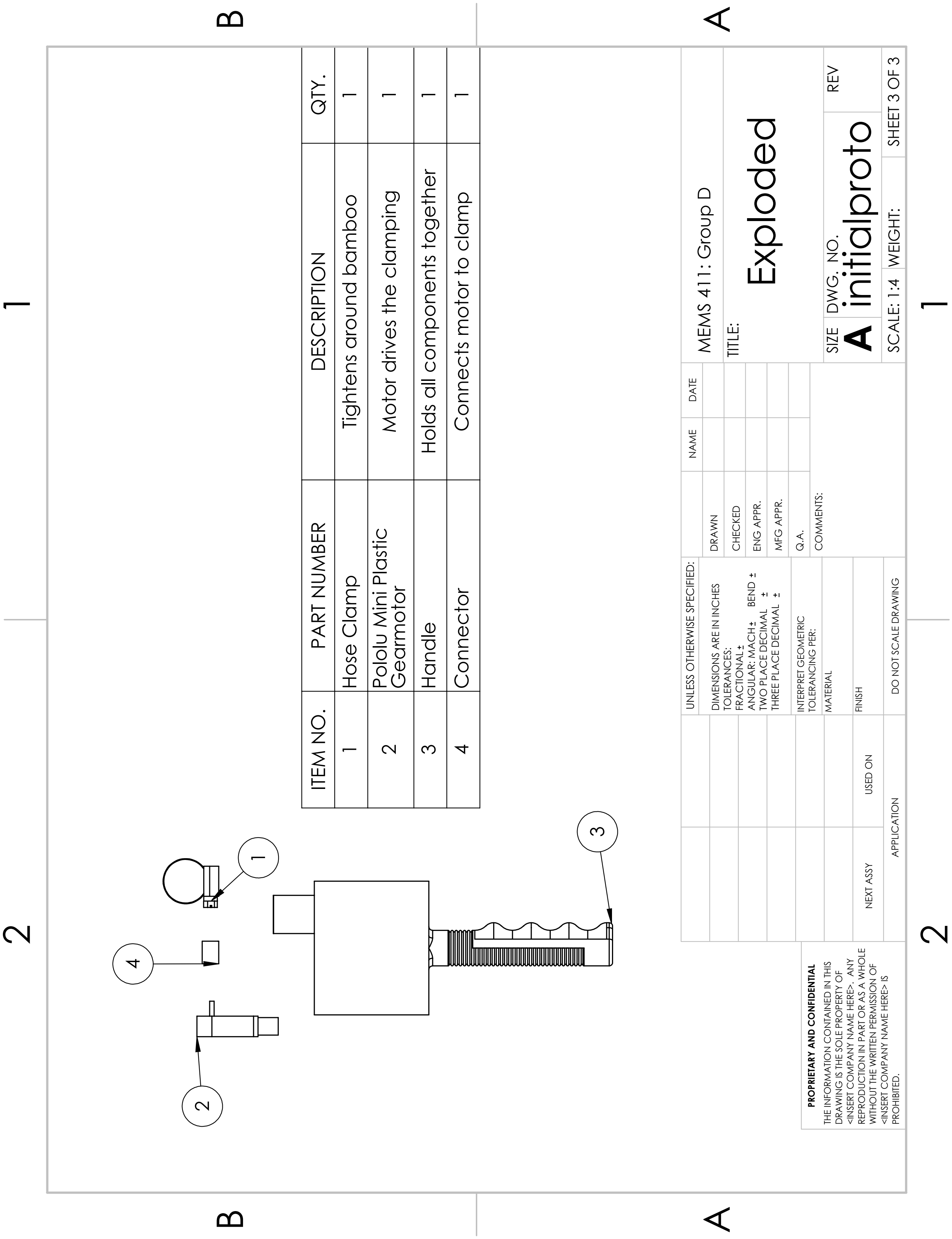


Figure 24: Exploded view with callout to BOM

Our second prototype was inspired by a blood pressure cuff, which uses air pressure to inflate a soft material and clamp around an arm. The use of a soft flexible material allows the cuff to adapt to irregular shapes as it is inflated. Since not all bamboo bundles will have the same geometry, a similarly adaptable design was conceived. This design involves a hard outer clip, inspired by a hair clip, which can open and close via tension springs. Inside the clip, a blood pressure cuff connected to two pumps inflates around the bamboo. The drawing below shows the outer clamp.

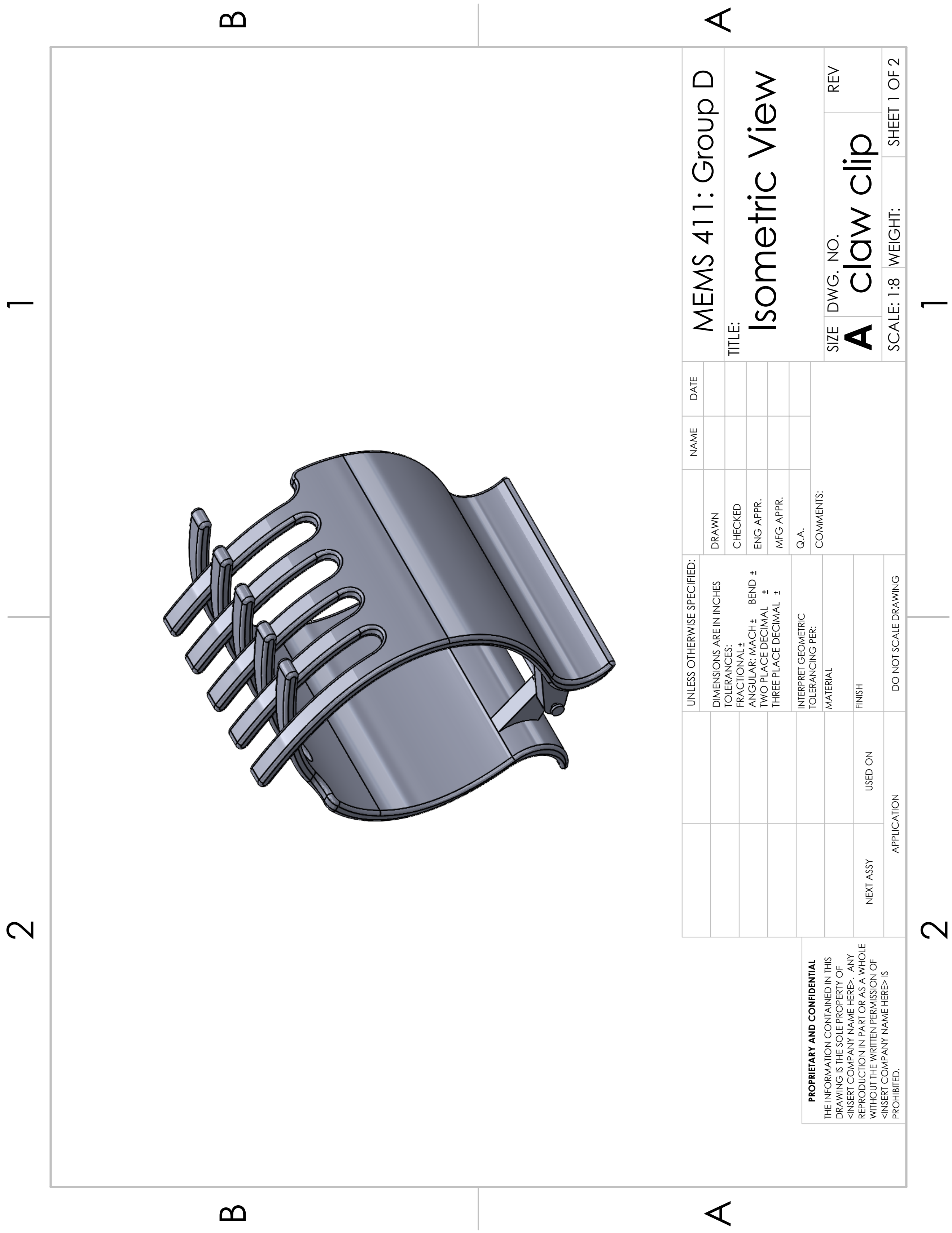


Figure 25: Isometric view of clip

5.2 Proofs-of-Concept

The proof-of-concept testing and prototypes greatly influenced the design of the initial prototype as it had two main components, a lashing component and a clamping component. For the clamping mechanism, we envisioned having a round clamp that could squeeze the bamboo inwards from all sides, so as to make the bundle as tight as it could be. For the lashing mechanism, the plan was to have a rotating arm that could latch onto the bamboo. This led us to start our initial prototype by making the two mechanisms separately in order to figure out the best way to accomplish these different goals.

5.3 Design Changes

While prototyping, we found that it was extremely difficult to create a rotating body about a bamboo bundle. This came from the design feature that allows the lashing mechanism to open and close about an arbitrary spot on the bamboo, rather than sliding it on the end of some bamboo rods. Having decided that this was beyond the scope of this project, we shifted gears to focus on further developing the clamping mechanism, thus narrowing our design scope. First, we want to modify our existing prototype. Our next goals are to implement a button to trigger the clamping/tightening of the hose clamp and electrical speed control unit to allow the motor to spin in both directions. Additionally, we plan on modifying our handle to better hold onto the hose clamp and to make space for the new electrical components. On another note, we plan to develop two other design concepts – one that mimics a hand grip clamp and uses straps to wrap around the bamboo, the other which would mimic a blood pressure cuff, where a bag would inflate around the bamboo to hold the bundle in place.

6 Design Refinement

6.1 Model-Based Design Decisions

Figure 26 shows theoretical calculations for the clamping force the hose clamp would exert on the bamboo rods and the time it would take for clamp to fully tighten. Using data from the motor specifications and an estimated efficiency of 0.5 to represent high amounts of friction in the system, we used the leadscrew model to determine force along the hose clamp and a free body diagram to determine the clamping force. Finally, we used the gear ratio between the worm screw in the mounting point of the clamp to the main round body to determine the rate it would take the clamp to fully tighten around a bamboo bundle.

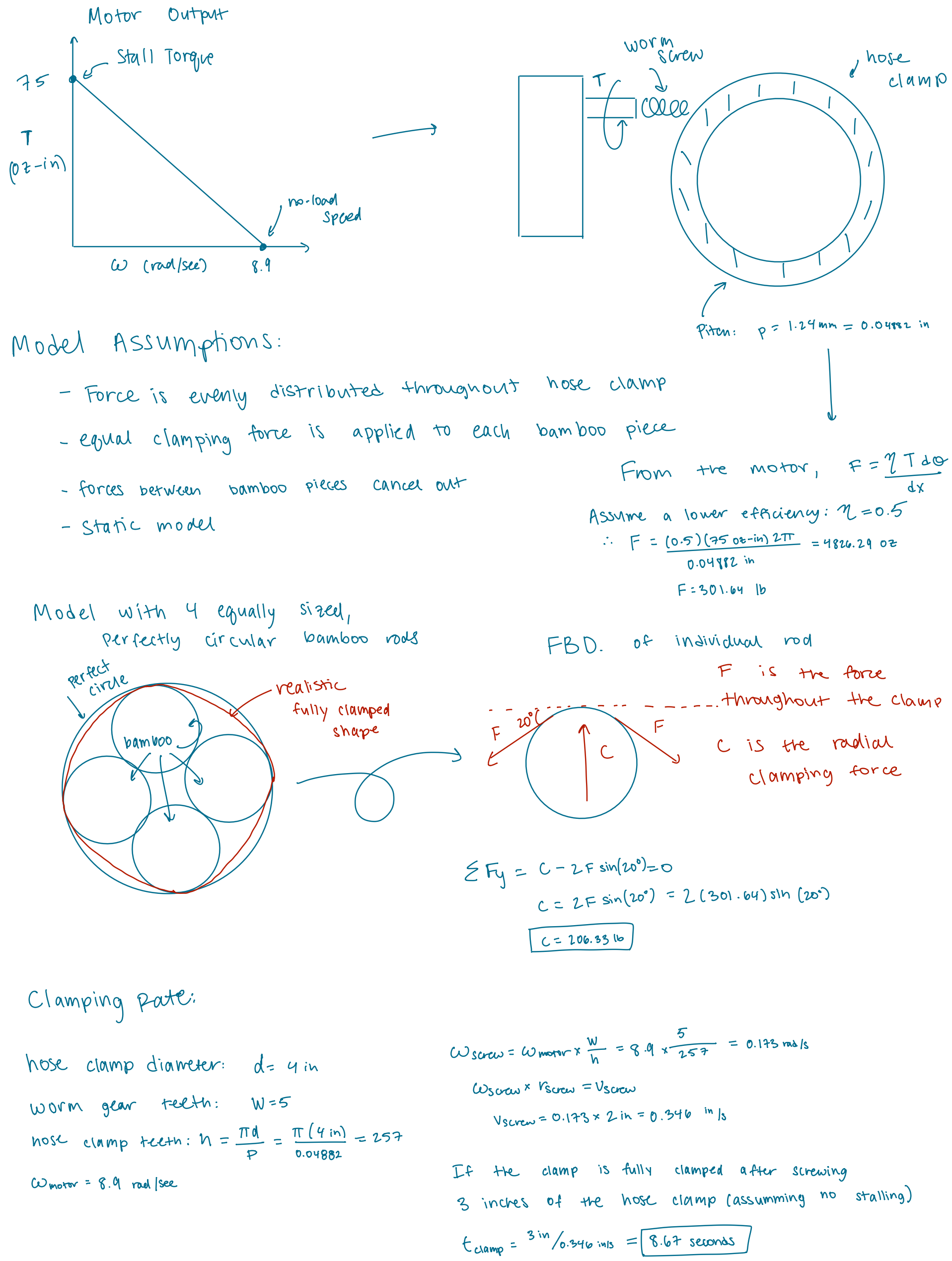


Figure 26: Theoretical calculations

6.2 Design for Saftey

Our product is expected to be used on the construction scene, a highly dangerous profession. Even though there are highly trained professionals on-site, there are also many dangerous construction locations and tools on-site.

6.2.1 Risk #1: Clamping on Hand

Description: When operating the clamp, it might clamp down on the user's fingers. This would happen if the user is not paying attention to the position of their hand during the clamping. Also, if the user is unaware of the strength of the torsional springs, they might catch their hand with the bamboo. Especially if the weather is cold and wet, hands might slip into the claw and get caught.

Severity: Marginal, because it would be slight discomfort in the hand with a possible cut. The device itself would be totally fine and able to be used again.

Probability: Occasional, because we have to expect the users, especially new ones to be unfamiliar with the device.

Mitigating Steps: Include a safety latch that must be undone before using, so the user is aware of the clamp.

6.2.2 Risk #2: Clamp Release

Description: The clamp clasp releases prematurely, releasing the bamboo bundle, possibly causing it to fall down. This could be caused due to fatigue failure in the clamp.

Severity: Catastrophic, because if this happens a structure could collapse or a person could be crushed. Without proper warning, the user might not be in a safe area or expecting the release.

Probability: Seldom, because this clamp has to be manually reversed to release the clamp. The only way that it could be released is if the converter slips off the motor shaft or if a component breaks.

Mitigating Steps: To mitigate this risk, we could build in a failsafe that would emergency clamp if it detects slippage or a too-quick release. We would also include in the written instructions that the user should not stand directly under the tool during use.

6.2.3 Risk #3: Overtighten

Description: This occurs when the clamp doesn't stop at proper tension. Due to the three-way switch in the current prototype, this could only happen if the user isn't paying attention and allows the motor to tighten for too long.

Severity: Marginal, because the main issue would be that the motor stalls for too long and slightly damages the motor. This would be inconvenient as you would have to replace the motor more frequently than expected, but no severe damage would occur.

Probability: Seldom, because we expect the user to be able to stay engaged with the project for the time it takes for the clamp to tighten. If this does happen, however, the user would hear the slowing of the motor and realize their mistake.

Mitigating Steps: To mitigate this risk, we would add a visual and audio cue that the tool is getting close to the optimal tightening point. This solution would alert the user to stop the clamp.

6.2.4 Risk #4: Battery Fire

Description: This risk is due to excessive use where the battery starts a fire. This is much more likely to happen in high-heat areas. This would be due to frequent uses without allowing breaks for the machinery to cool down.

Severity: Catastrophic, because it would render the tool useless. It could also be highly dangerous as it could injure the user and could even start a larger fire surrounded by dry bamboo.

Probability: Unlikely, because there has to be enough time between uses to do the actual lashing. This would force enough time for the cooldown.

Mitigating Steps: To prevent this risk, we would include warnings in the instructions to not use this product constantly. We would also warn the user that if they felt the product getting warm, they should stop to prevent a battery fire.

6.2.5 Risk #5: Stripping Converter

Description: This risk includes the inside of the converter stripping due the motor slipping out of place.

Severity: Critical, because it would completely ruin the converter. Without the converter, the rotation of the shaft cannot be converted into a linear force tightening the clamp.

Probability: Unlikely, because there is a lot of friction keeping the converter in place. Additionally, when the motor slips out, it slips out completely as opposed to partially. Therefore, there is not enough time to actually strip the inside.

Mitigating Steps: To mitigate this risk, we would include a wall at the other end to pin the hose clamp to the motor shaft.

		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
Severity of risk	**Catastrophic**				Clamp Release	Battery fire
	Critical				Stripping Converter	
	Marginal			Clamping on hand	Overtighten	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 27: Risk Heat Map

Based on this heat map, the most important risk is the clamp release risk in the orange section. Despite the "seldom" nature of this risk, it is labeled as catastrophic and therefore extremely important to consider. It is also important to develop a consistent and safe way to mitigate this risk. The battery fire, stripping converter, and clamping on hand are all tied as the next highest priority in the yellow section. They all have different probabilities and risk severities but those combine to fairly even priorities. The least important risk is the overtightening issue. This concern is not so likely to happen and will not cause much damage, so it has the lowest priority.

6.3 Design for Manufacturing

Number of parts in current design: 5
Theoretically necessary components:

- **Hose clamp** - The part that clamps around the bamboo. This is composed of a steel band and a screw which feeds one end of the band into a space between the band and the screw, tightening the loop formed by the band, when the screw is tightened.
- **Adaptor** - a 3D printed adaptor which connects the motor to the hose clamp screw, so that the motion of the motor turns the screw.
- **Motor** - A Pololu plastic gearmotor which provides the spinning motion that drives the spinning of the screw which makes the hose clamp tighten and loosen.
- **Switch** - Turns the motor on and off and toggles the direction to either tighten or loosen the clamp.
- **Housing** - A 3D printed base houses all the components in a compact and portable form and includes a handle for ergonomic ease of use.

The design is already comprised of a small number of parts which each have distinct functions and materials. Hypothetically, the number of parts could be further reduced if the adaptor was built directly onto the screw by printing these as one part. However, 3D printed threads are often unreliable. It may be beneficial to decouple the housing and the handle into two different components to reduce the need for supports while printing, which result in surface irregularities. A soft rubbery material could also be added over the handle to make it more comfortable to grip.

6.4 Design for Usability

Vision impairment Farsighted individuals would have trouble operating our device as it is comprised of multiple small, moving parts. For people that are color blind, we would want to choose colors that are easier to distinguish, like red or blue. Additionally, our device must alert the individual when the proper tension has been reached when clamping the bamboo. In addition to using a light, we could also use a noise to ensure they know when it is finished clamping. Our client is currently in Bali, which means that it would be beneficial to have any instructions or labels in both English and Balinese.

Hearing impairment Individuals with a hearing impediment would generally not have any issues with our device. It is a vision and control focused device that is expected to be used in loud construction environments. For the maximum clamping alert, we would design our product with the sound in the optimal audible frequency range. Optionally, we would also include a light in addition to a noise in case the operator was wearing ear plugs.

Physical impairment Our device requires a certain degree of strength to operate. However, the types of people using our device are construction workers who would have that strength. The physical part of our device is unclamping and clamping our product to the bamboo bundle. In order to require less force, we can ensure the clamp is easy to operate. Ergonomically, our product will be used up in the air in an awkward position. Therefore, it would be beneficial to try to design our product with a rotating handle that could move into the optimal location for a neutral user wrist position.

Control impairment Our device requires control and coordination to achieve proper clamping force and accurate lashings. Especially as this device will be used in the construction setting, we would ensure that no users are intoxicated, medicated, or otherwise distracted. However, a good design modification would be to build in a failsafe in case of emergency. This design would be similar to an emergency shutoff for any sensing of human limbs or overtightening.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	Applicable	Not Applicable
Public Health		X
Safety	X	
Welfare	X	
Global		X
Cultural		X
Societal		X
Environmental	X	
Economic	X	

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context	X	
Economic context	X	
Environmental context	X	
Societal context		X

7 Final Prototype

7.1 Automatic Hose Clamp

Figure 28 shows the final prototype of our device. In this updated version, there is a housing for the battery and a more ergonomic handle. The motor and battery are wired to a three-way switch that sticks out of a hole at the bottom of the device towards the user's hand. The switch naturally remains in the off position but can be flipped left to tighten the clamp or right to loosen the clamp. Additionally, ridges were added on the top of the device to hold the hose clamp down tightly to the base of the device.

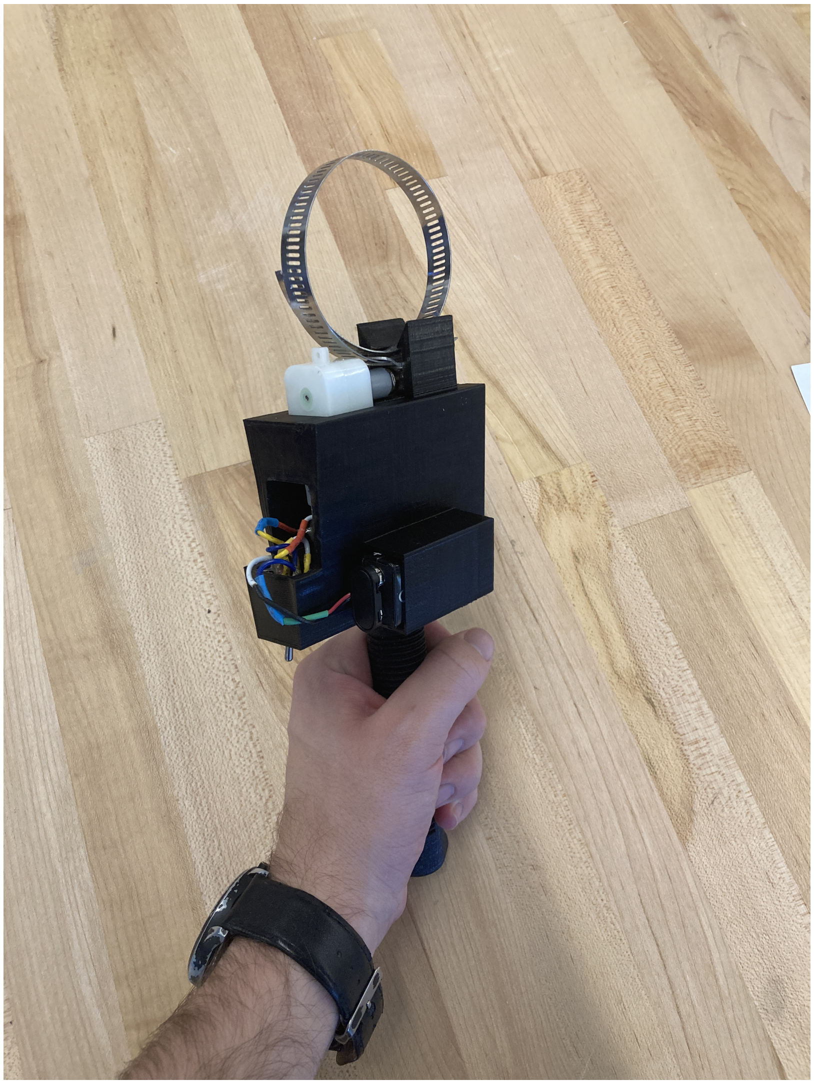


Figure 28: Final Prototype

7.2 Claw Clamp

The final prototype of the claw clamp concept is shown in Figure 29 below. The outer shell, modeled based on a hair claw clip, can be opened and closed with one hand. Inside the shell, a blood pressure cuff is attached to two pumps, which will cause it to expand and deflate. After closing the claw around a bamboo bundle, pressing the red button inflates the blood pressure cuff to clamp around the bamboo. Using a soft material and air pressure allows the clamp to adaptively fit to various bundle shapes.

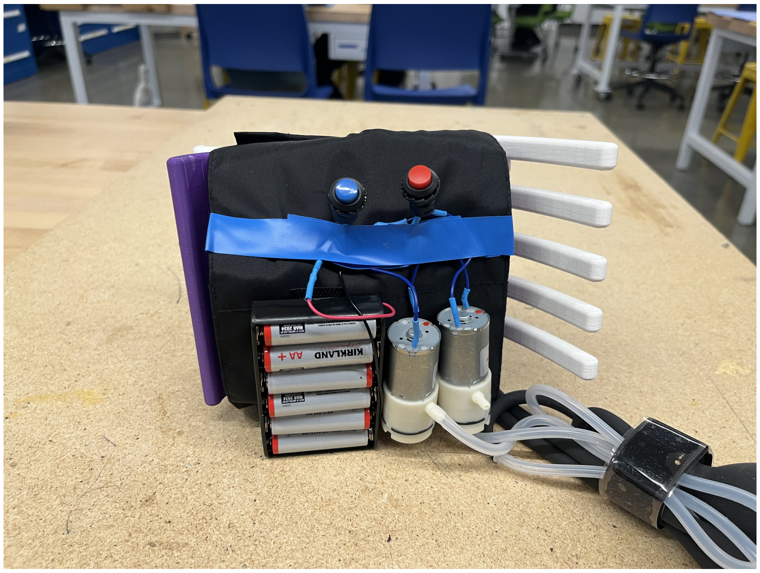


Figure 29: Claw Clamp Final Prototype

7.3 Adapted Trigger Clamp

The third final prototype is an adapted trigger clamp, shown in Figure 30 below. This prototype was made by attaching two 3D printed extensions onto the jaw, which allowed the clamp to wrap around a larger radius. A belt sits inside the clamp, and is fed through a buckle attached to the jaw extension. When the clamp is closed and the end of the jaws touch, the jaws press down on the buckle and allow the belt strap to be pulled tight around the bamboo bundle.

Figure 30: Adapted Trigger Clamp Final Prototype

7.4 Results

This final prototype definitely met the performance goals of the rescoped project. The only effort from the user is wrapping the hose clamp around the bundle and slotting it into the worm screw.

The user also has to flip the actual switch. Therefore, this prototype achieves the performance goal of being easier than manually clamping. The overall device weighs 7.7 oz, which is light enough to be easily portable and not stressful on the arms when being raised up to the structure. Additionally, the ergonomic handle and narrow base allow it to be easily used and kept on a belt loop. Therefore, this prototype achieved a portable and easy design. After clamping a bundle, a test user was not able to slide the clamp up or down the bundle, proving that this prototype also achieved the goal of tight clamping.

A Parts and Cost List

Item	Sub-item	Qty	Unit Rate	Labor	Mark-Up	Line Total	Total
Physical Components	3D Printed Handle	1	$2.44		$1.22	$3.66	
	Blood Pressure Cuff	1	$16.95		$8.48	$25.43	
	Hose Clamp	1	$9.99		$5.00	$14.99	
	Tie-down straps	4	$2.50		$5.00	$15.00	
	Air pump	1	$7.95		$3.98	$11.93	
	CAD for 3D printed parts	0	$75.00	3		$225.00	
	Dimensioned drawing	0	$75.00	3		$225.00	
	Assembly	0	$75.00	40		$3,000.00	
		0	$0.00	0			
		0	$0.00	0		$0.00	
							$3,521.00
Electronics	ESC Quicrun 1060	1	$17.08		$8.54	$25.62	
	Pololu mini plastic gear motor	2	$7.49		$7.49	$22.47	
	Push buttons	3	$3.00		$4.50	$13.50	
	Arudino Teensy	2	$32.39		$32.39	$97.17	
							$122.79
							Total
							$4,008.16