Sustainable 3D Printed Traction Spikes for Enhanced Mobility in Winter Conditions

SME Digital Manufacturing Challenge

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Executive Summary

Winter weather conditions pose significant risks to pedestrian safety due to the low coefficient of friction between snow or ice and standard footwear, leading to frequent slips and falls. These incidents can result in severe injuries, particularly among vulnerable populations such as older adults with diminished balance and mobility. For these individuals, safety devices such as traction spikes are essential to preventing life-threatening falls.

Existing traction spike designs predominantly cater to avid hikers navigating rugged, snowy terrains, such as in the Rocky Mountains. These products, while effective in extreme conditions, are often bulky, heavy, and unsuitable for everyday use. This project seeks to develop a lightweight, user-friendly solution tailored for daily wear in urban and suburban settings, enhancing both safety and convenience.

To achieve this, the traction spikes utilize a lattice structure designed using nTopology software to reduce the weight of the plates while maintaining their structural rigidity. This approach ensures that the traction spikes are durable and effective under typical usage conditions. Additionally, the use of additive manufacturing (3D printing) enables a significant reduction in material waste and supports recyclability, making the design an environmentally sustainable alternative. By optimizing the geometry, the final 3D-printed spike plates weigh approximately 123 grams, which is 3.5 times lighter than popular alternatives such as Crampons, a widely used brand of winter hiking spikes that have a mass of 431 grams. This innovative traction spike solution combines functionality, sustainability, and accessibility to address a critical safety issue for individuals in snowy regions.

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Industry Overview

Winter conditions present significant safety risks worldwide. Studies from Canada, Sweden, and Nordic countries highlight the prevalence of fall-related injuries caused by snow and ice [1]. Approximately one-third of sports and winter-related injuries are attributed to slipping, with the highest incidence occurring between January and March [2]. Older adults, especially females aged 50–69, are at the greatest risk of falls requiring emergency treatment, though this excludes unreported cases. Individuals aged 80 and older may walk outside less frequently in snowy conditions, but their injuries, often involving the upper arms, hips, and shoulders, tend to be more severe and have greater health consequences [3].

The low coefficient of friction between standard footwear and icy surfaces is the primary cause of these falls. While traction spikes improve grip, most commercially available options, such as Crampons (Figure 1), are designed for hiking in snowy, mountainous regions. It appears that this product is not required to comply with ergonomic and safety standards for urban use, such as ASTM F2913 (traction performance testing) and ISO 20344 (PPE footwear requirements), limiting their suitability for daily wear [4]. These products are bulky, heavy, and challenging to use for everyday activities. The additional weight can also create a tripping hazard. For instance, Crampons weigh approximately 431 grams, which increases fatigue during use [5].

Figure 1. Crampon Commercially Available Traction Spikes [5].

Current manufacturing methods for traction spikes also have many disadvantages. Many products are made with subtractive processes, like machining or casting, which generate significant material waste in mass production. Metal parts require post-processing, adding further inefficiencies.

Additive manufacturing (AM) provides a sustainable and efficient alternative. By minimizing waste and utilizing lightweight materials, AM reduces the environmental impact of production. Modern 3D printing filaments offer greater design flexibility and lower manufacturing costs. Additionally, advanced techniques, such as lattice structures, optimize weight while maintaining structural integrity and allow for the creation of efficient and adaptable designs that adhere to ISO/ASTM 52900 principles for additive manufacturing terminology and processes [6].

The innovative spike plate design discussed in this report has the potential to improve safety and reduce injury risks for a wide range of users, particularly elderly individuals. By prioritizing safety, sustainability, and usability, this solution aligns with the ethical responsibilities of engineers to hold safety and well-being paramount.

Design, Functionality, and Durability

Requirements

This product needed to meet several goals to be considered successful. The considerations for this design included safety, loading, and material usage. The use of modelling software aided in the design analysis to ensure it reached the desired goals. The general dimensions for the drawings in this section can be found in Appendix A.

1. Functional Requirements
    a. The traction spike should reduce slipping when worn in winter conditions.
    b. The traction spike should be compatible with most shoes.
    c. The traction spike should be lightweight, easy to clean, and convenient to store.
    d. The connection to the shoe should be safe, sturdy, and easy to secure.
2. Performance Requirements
    a. The traction spike should not fail during loading of 300lbs.
    b. The design should not fail when walking or attaching/detaching the plate in temperatures above -10º F.

Design Process

The traction spike plate design process integrates advanced CAD and lattice optimization tools, as shown in the flowchart in Figure 2. The detailed steps of the lattice structure creation using nTopology will be described in the following sections. This streamlined workflow ensures that the spike plate is lightweight, structurally rigid, and optimized for 3D printing.

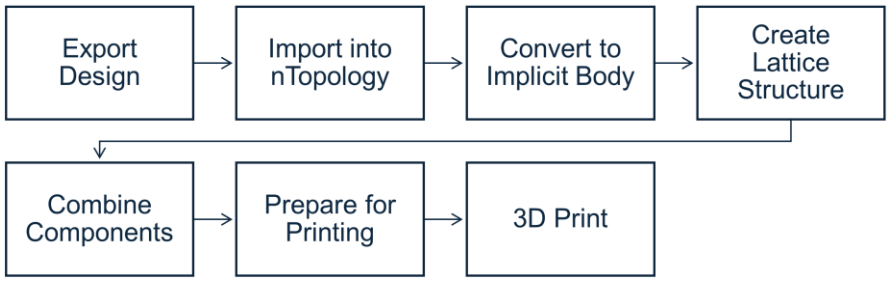

Figure 2. Design process for the traction spike plate, from initial modeling to 3D printing.

Shaping and Sizing of Plate

The spike plate was designed to fit a wide range of shoe sizes and types. The Brooks Adrenaline GTS 22 (women's size 9.5, EUR 41) was selected as the reference model (Figure 3a), as it represents a commercially available and widely used athletic shoe with a standard shape suitable for outdoor activities. Shoes with large heels were not considered due to their rarity in outdoor use

and significant variation in size and shape. Additionally, flat-soled shoes are often preferred by at-risk individuals for their stability, so these shoe types remained the focus for this design.

The spike plate can accommodate most shoe sizes, though it may not fully cover the soles of larger shoes. However, the adaptability of AM allows for easy size modifications to meet consumer needs. The design aims for adequate traction to reduce slipping across compatible shoes. Autodesk Fusion 360 was used to trace and extrude a scan of the shoe's sole to create the spike plate's shape, as shown in Figure 3b.

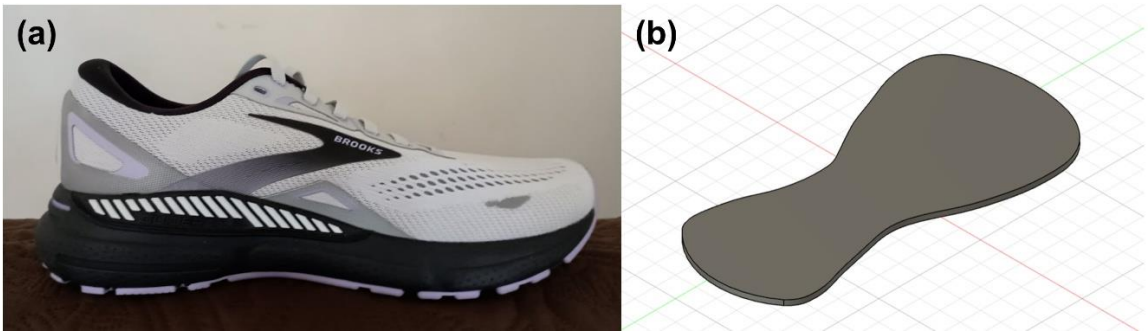

Figure 3. Reference shoe model and initial spike plate design (a) Reference shoe model (Brooks Adrenaline GTS 22) (b) Initial spike plate design in Fusion 360.

Lightweight Design Optimization

The spike plate was optimized for weight reduction while maintaining structural rigidity using nTopology software (Figure 4). The process began by converting both the inner and outer components of the spike plate into implicit bodies, which allowed for the creation of the lattice structure on the inner component. A hexagonal honeycomb pattern was selected for the lattice due to its excellent strength-to-weight ratio and ability to evenly distribute forces [7]. This pattern is widely recognized in engineering applications for its ability to minimize material usage without compromising durability, making it ideal for traction plates that endure dynamic loads. Additionally, the honeycomb structure enhances the surface grip and provides sufficient attachment points for the spikes. This ensures the design is both functional and durable.

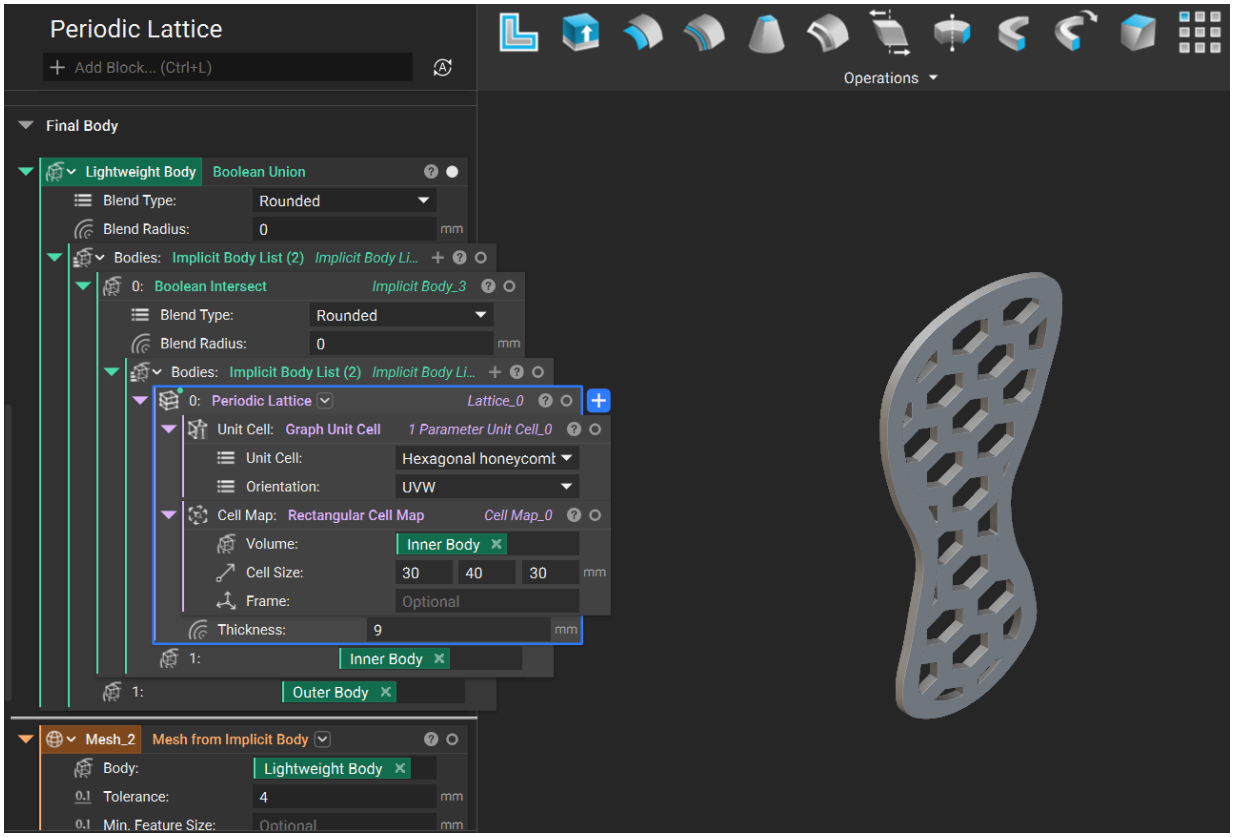

Figure 4. nTop lattice design structure.

Finite Element Analysis

Using nTopology, a simple static Finite Element Analysis (FEA) was performed to examine material deformation and determine the optimal placement and number of spikes. The spike plate was modeled as an isotropic material with a Young's Modulus of 1850 GPA and a Poisson's Ratio of 0.4 to simulate Nylon 12 [8, 9]. The static load was measured at 900N, which exceeds the average male weight of about 200 lbs in the United States [10]. In reality, the plate would experience dynamic loading that would require more advanced analysis techniques. The model used for the analysis was modified by incorporating the individual spikes as part of the plate to reduce complexity while maintaining appropriately accurate results.

The deformation distribution was tested with six spikes—three near the heel and three near the ball of the foot (Figure 5a). This configuration exhibited significant midfoot deformation (~1cm). This is area of deformation was concerning, as the midfoot carries a significant portion of the body weight during loading. By adding two central spikes (8 spike design), the midfoot deformation decreased to less than one millimeter (Figure 5b). The load was increased to 1335 N, or about 300 lbs and the midfoot loading was found to be about two millimeters. This approach showed that the 8-spike design is optimal for distributing the load without failure.

Figure 6 shows the spike plate with eight spikes, including the hole locations for the individual spikes as modeled in Fusion 360.

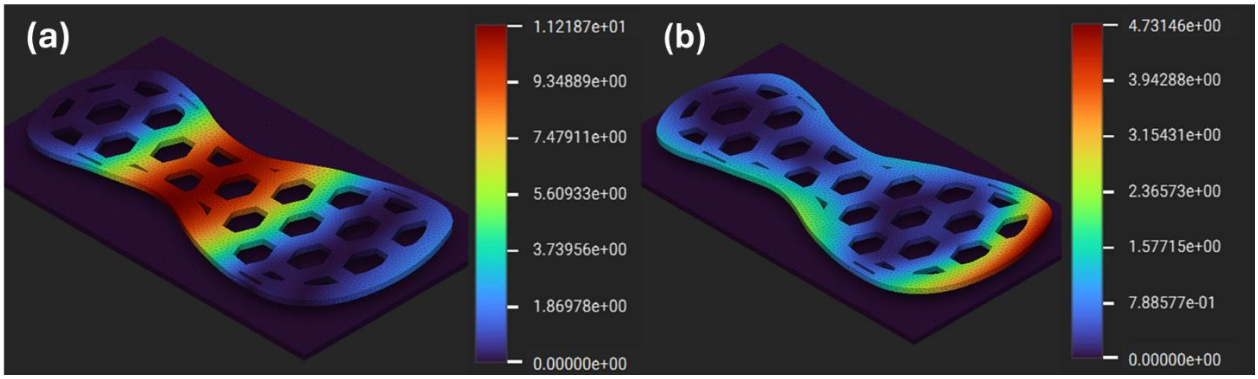

Figure 5. FEA deformation of spike plate, measured in millimeters, at 900N (a) with six individual spikes (b) with eight individual spikes.

Figure 6. Spike plate model with eight holes for individual spikes.

Individual Spike Considerations

To optimize the design, the individual spikes were made detachable from the traction plate. Directly 3D printing the spikes onto the plate would make the entire shoe plate unusable if a spike broke. Initially, the spikes were designed to screw into the plate, similar to traditional athletic track spikes (Figure 7a). However, fine threads and internal threading in the plate posed challenges, including the risk of thread damage under loading and the need for a tightening tool.

Instead of a threaded design, an annular snap fit joint was used (Figure 7b), which allows the spikes to be securely attached without the need for tools. The snap fit mechanism should endure minimal

stress since the spikes will only be inserted before the first use and removed once worn down. Holes were added to the plate design, with a rounded locking mechanism that ensures easy insertion and locking of the spikes into place. The spike tips were slightly flattened to reduce initial breakage (Figure 4c and 4d). Due to the flexibility of AM, the spike size can be easily adjusted in the design for use in more challenging conditions.

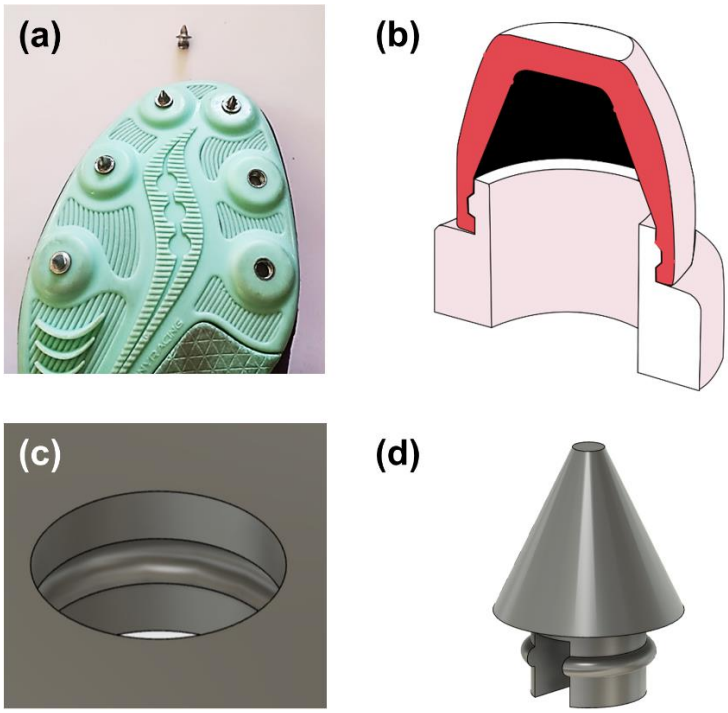

Figure 7. Track Spikes Design (a) Traditional Track spikes (b) Annular snap fit joint [11] (c) Hole design for spike plate (d) Individual spike design with flattened tip

Shoe Attachment

Attaching the traction spikes to the shoe presented several challenges, primarily concerning material flexibility and cold temperature performance. While a rubber-like consistency was desired for the straps, rubber tends to become brittle in low temperatures, and producing rubber parts for testing would be difficult. PLA, although readily available and widely used, lacks the required flexibility. After exploring alternative materials, TPU (Thermoplastic Polyurethane) was selected due to its excellent balance of flexibility, durability, and performance in cold temperatures. TPU is

a relatively inexpensive filament choice that remains flexible and resistant to degradation in freezing conditions. It is well-suited for winter applications like snow and ice traction devices [13].

The straps were designed to attach to the spike plate using tabs that insert into slots on the spike plate. Similar to the spike plates, the straps are designed without the need for support structures during printing. Figure 8 shows the left and right straps attached to the spike plate.

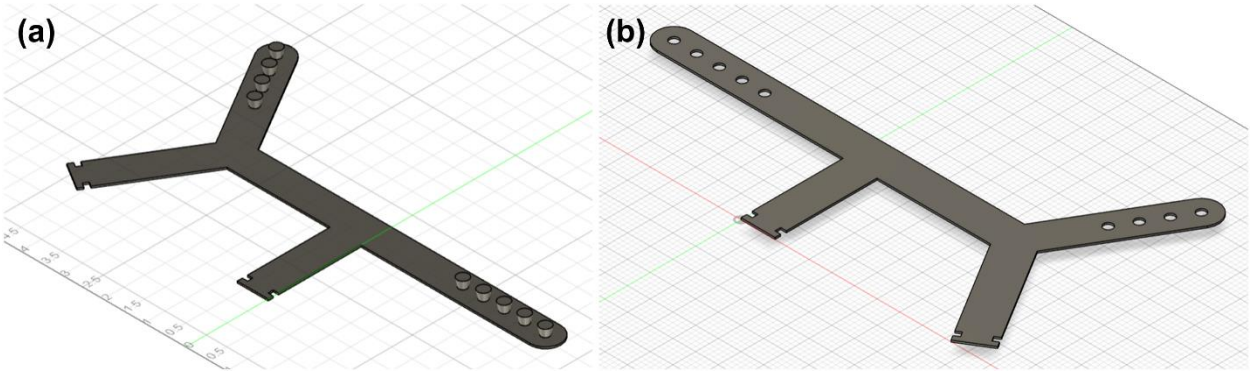

Figure 8. Straps attached to the spike plate (a) Left strap (b) Right strap.

Final Product Design

Figure 9 shows the final spike plate design, printed with PLA and including the attached TPU straps. The spike plate is completely reversible, meaning the spikes and straps can be inserted into either side. This feature simplifies the design and helps avoid errors in product distribution.

As seen in Figure 9a, the TPU straps are easily inserted into the slots by folding and inserting the tabs. Based on testing observations, the straps can withstand significant tensile forces before breaking or loosening from the spike plate.

The process of securing the plate to the shoe is straightforward. First, the shoe is placed on top of the plate, followed by the attachment of the back straps and then the front straps. The straps should be tightened snugly to ensure the plate stays in place. Figures 9b and 9c show the design secured on the shoe, with 9b showing the side view and 9c showing the bottom view. For simplicity and testing purposes, the individual spikes are not shown in these images.

The spike plate design is relatively safe. While the spikes could cause injury if improperly handled or if incompatible shoes are worn with the design, the overall design is focused on improving user safety by providing better traction in snowy conditions.

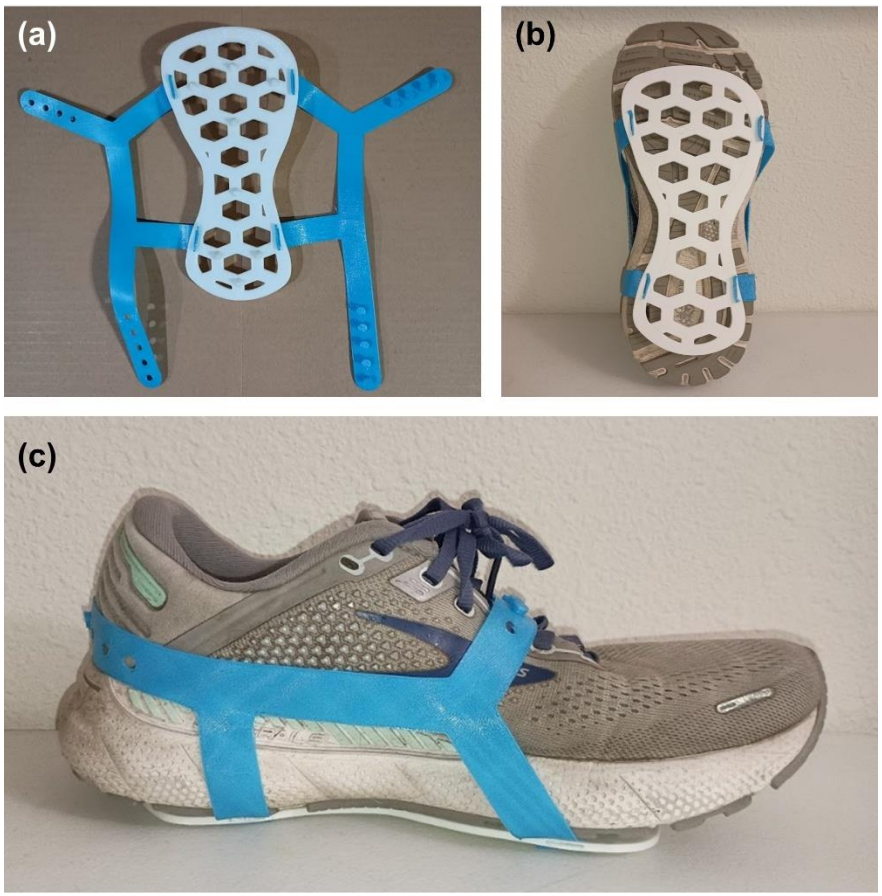

Figure 9. Finalized spike plate with TPU straps attached. (a) Insertion of TPU straps into the spike plate (b) Spike plate secured on the shoe (side view) (c) Spike plate secured on the shoe (bottom view)

Materials and Testing

An in-depth discussion of materials will be covered later in the report, but SLS methods and Nylon 12 were heavily explored. For the prototype, PLA was used for both the spike plate and the individual spikes. This is not the desired material, but it provides a relatively inexpensive manufacturing process on a small scale.

Because the proper materials were not easily accessible, strength testing was not heavily explored. Testing the PLA until failure would likely provide rather undesirable results that would not enhance the design. The PLA was successful, however, under a static loading of 175 lbs. Running on the cement did damage the PLA spikes, so again, PLA is not recommended for the spike materials themselves. The primary test was to explore the traction spike's ability to reduce slippage. The spike plate did not shift position or loosen during a one mile walk in the snow. There was no damage to the plate or the straps and increased traction was apparent, especially on sloped surfaces.

Design Integration and Utilization of DDM Materials and Processes

Additive manufacturing offers distinct advantages over traditional manufacturing methods, particularly in terms of material efficiency and the ability to produce complex geometries. Unlike subtractive manufacturing, where material is cut away from a solid block, 3D printing builds objects layer by layer, minimizing waste and allowing for the creation of complex, customized parts. FDM (Fused Deposition Modeling) is a highly accessible and cost-effective printing technology that is suitable for both hobbyists and small-scale production. In contrast, SLS (Selective Laser Sintering), a more advanced form of 3D printing, is ideal for mass production and offering higher efficiency and more precise results for industry needs.

For hobbyists, FDM provides an affordable method to print customized traction spikes and plates. Materials such as PLA, Nylon, PC (Polycarbonate), PETG, and ASA are commonly used in FDM [12]. Among these, Nylon is particularly effective for outdoor applications due to its strength, durability, and resistance to cold [13]. For parts requiring flexibility, TPU is ideal for the straps, offering flexibility and tear resistance [14]. However, FDM has limitations, particularly in production speed and efficiency. For instance, printing two spike plates at 100% infill on a Creality Ender 3 Pro takes about 8 hours and 25 minutes, according to Ultimaker Cura's slicer software (Figure 10a). This slower pace, combined with the need for constant removal and resetting of parts, makes FDM less efficient for mass production.

For industrial-scale production, SLS technology provides a more efficient solution. Nylon 12, the most widely used material in SLS, is ideal for this project due to its strength, flexibility, and cold resistance. It is also stable against chemicals, water, UV light, and dirt, which makes it perfect for outdoor conditions [13]. Using Formlabs PreForm slicing software, it is clear that 31 spike plates can fit vertically on the Fuse 1+ 30W SLS printer, with an estimated print time of just under 23 hours. This is over five times faster than the FDM process because the SLS printer can produce multiple plates simultaneously. Additionally, SLS requires minimal observation during the print cycle. This reduces the need for manual labor until the full cycle is completed. Since SLS doesn't require support structures, it further reduces material waste and post-processing time. Figure 10b illustrates the printing orientation and estimations in PreForm. Overall, SLS has superior efficiency compared to FDM processes.

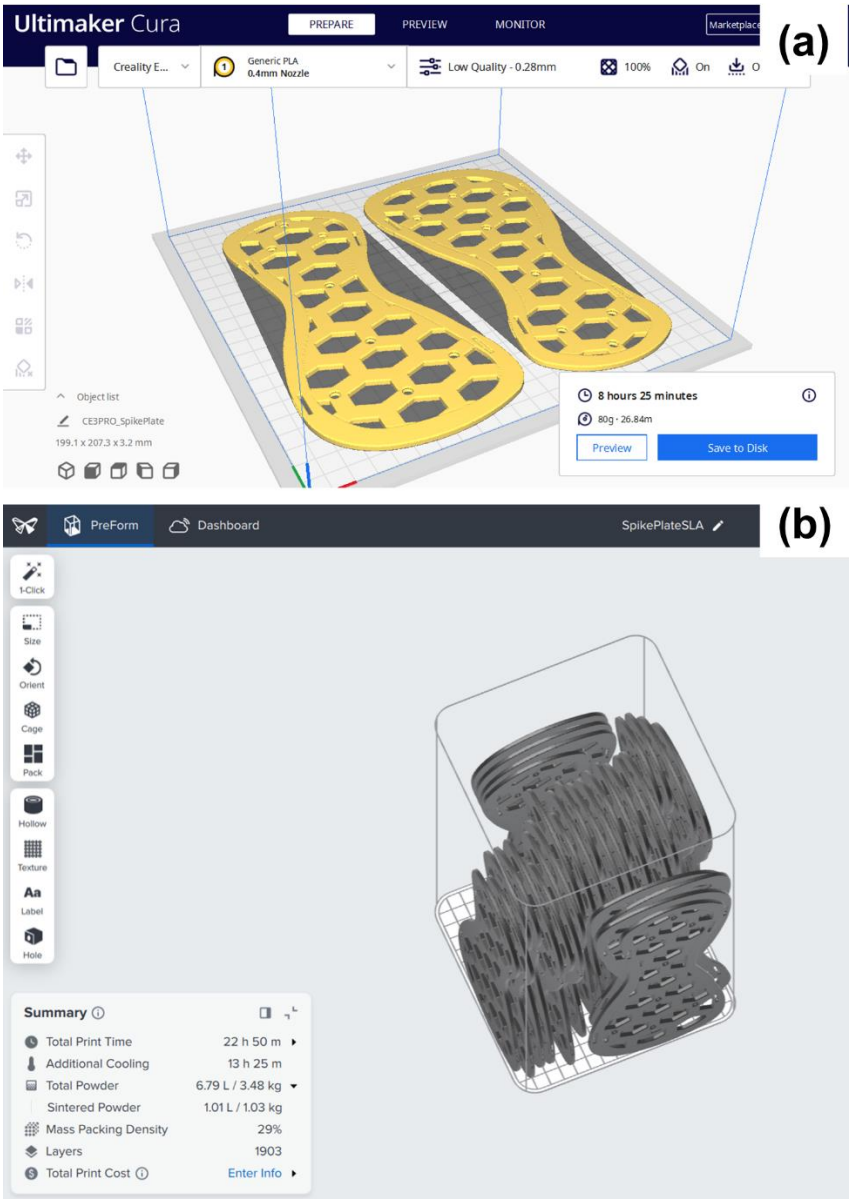

Figure 19. FDM vs. SLS printing summary (a) FDM printing on Creality Ender 3 Pro for two spike plates (b) SLS printing on Formlabs Fuse 1+ 30W for maximum spike plate volume (31 plates).

The design of the spike plate requires relatively minimal post-processing, making it easy to maintain. After printing, parts only need light polishing or cleaning. The standardization of the design and the ability for individual spikes to be removed and replaced ensures that the spike plate remains functional for an extended period and reduces overall waste. Moreover, 3D printing offers the flexibility to make continuous improvements to the design based on performance or advancements in materials. This aids in the goal of continuous optimization and long-term usability.

Digital and physical infrastructure: Systems integration, utilization, value chain leverage, agility, lean and continuous improvement

The manufacturing of these traction spikes can be executed by either large businesses or by hobbyist makers. Since the design can utilize traditional FDM processes or the higher recommended SLS processes, it is simple for both individuals and companies to produce the parts. In terms of value chain leverage and utilization, the final design of the product is valuable to consumers, especially those who do not have access to 3D printers. It also reduces waste and automates the manufacturing process.

The use of design software significantly increases the agility of the product. Each part can be adjusted to fit larger or smaller shoe sizes if necessary. Additive manufacturing enhances the ability to continuously improve a product. The process to convert the model to G-Code for the printer is all calculated by the design software, and the tooling does not have to be altered. Subtractive manufacturing process often require significant changes during a redesign. This is one reason as to why AM is most used for prototyping 67% of the time, followed by end-use parts at 21% [15].

Supply chain resilience is important to consider since there may be unexpected events that cause material sourcing, shipping issues, and manufacturing problems. The materials used for prototyping and at home printing are mainly PLA, PETG, and TPU, and all are typically readily available. There have been reported PLA shortages in the past few years. Specifically in 2019, many companies, like Spool3D, had to notify consumers of the shortage and that there may be price increases [16]. Since this time, efforts to reduce the use of harmful, single use plastics have been made on both a local and global level. PLA and TPU are recyclable materials [17].

For the final product design, it is recommended that an SLS printer is used with Nylon 12 powder. There have been some shortages due to its high popularity. Specifically, a plant in Germany melted down in 2012 that caused major supply chain issues, specifically for car manufacturers [18]. There have not been major issues recently, however, it is important to consider changing market conditions and alternative options. In terms of environmental impact, Nylon 12 is also recyclable. Since it is a thermoplastic, it can be made into new parts. In fact, one study conducted by the UNSW SMaRT Centre found that Nylon 12 could be recycled at least four times before changes to its material properties were notable [19].

Since this 3D printed spike plate has limited post-processing, there is no need to ship the part to other plants. All manufacturing can be completed efficiently in one location. This is one advantage of AM, and it can greatly reduce supply chain and overflow issues.

Cost Benefit/Value Analysis

Traditional traction spikes, called Crampons, cost around $27 [5]. The cost to manufacture 3D printed traction spikes depends on the material used, the amount used, the test methods, and the machine costs. This will also change depending on the scale of the factory.

Importantly, the printing method, FDM or SLS, will affect the production cost. Table 1 shows the approximated cost for the PETG printed spike plate with FDM processes. The PETG and PLA are relatively similar in cost. Table 2 shows the approximated cost for the Nylon printed spike plate with SLS processes.

Table 1. Cost breakdown for FDM process [20, 21]

Material	Cost per Mass ($/1kg)	Weight of Parts (g)	Cost per Pair ($/pair)
PETG (2 Plates + 16 Spikes)	$16.00	83	$1.33
TPU (4 Straps)	$32.29	40	$1.29
Total	-	123	$2.62

Table 2. Cost breakdown for SLS process [21, 22]

Material	Cost per Mass ($/1kg)	Weight of Parts (g)	Cost per Pair ($/pair)
Nylon 12 (2 Plates + 16 Spikes)	$99.90	83	$8.29
TPU (4 Straps)	$32.29	40	$1.29
Total	-	123	$9.58

SLS printing is a more expensive process than traditional FDM printing. Not only is the material more expensive, but the printers themselves are more costly. However, over the process of mass production, the benefits of SLS printing outweigh its negatives. The SLS printer is more time efficient. Overall, the printer type and material depends heavily on the desired productions parameters.

Additionally, material testing would add expenses to the production. Tensile, compression, and flexural testing machines can be expensive. The prices widely vary based on the quality and type of testing. The cost of the product would have to offset the cost of this initial machine purchase, possible repairs, and labor. It may be beneficial to outsource testing to a qualified plant.

Conclusion

The development of 3D-printed traction spikes presents a unique opportunity to address the limitations of current commercial traction spike designs. The goal is to enhance safety, functionality, and sustainability in traction spikes for everyday use in snowy conditions rather than for hiking or other specialty use. By utilizing additive manufacturing, the 3D-printed traction spikes offer major advantages such as reduced weight, recyclability, and minimized waste during and after production. This innovation benefits all age groups but particularly benefits the elderly or people with mobility issues. The flexibility and scalability of 3D-printing enables continuous improvement and cost-effective production for individual and large-scale manufacturers. This design ultimately aligns with engineering ethics by prioritizing safety and sustainability while also demonstrating the transformative potential of manufacturing techniques.

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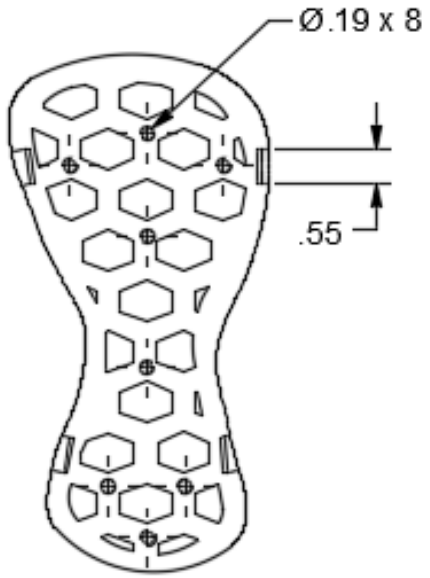
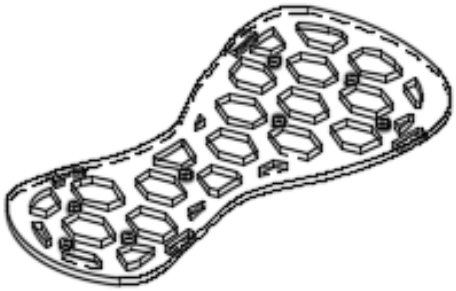
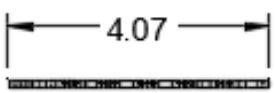
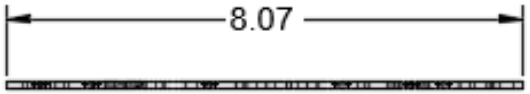
Appendix A

General Dimensioning on following pages. See part file for all dimensions.

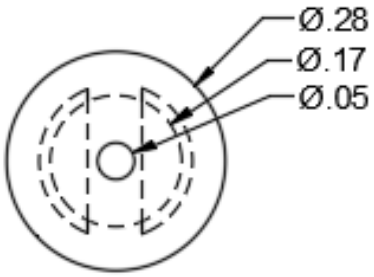


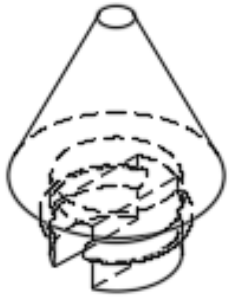


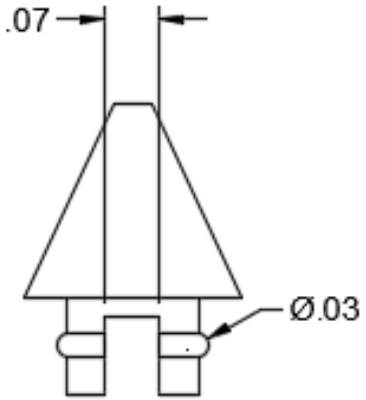


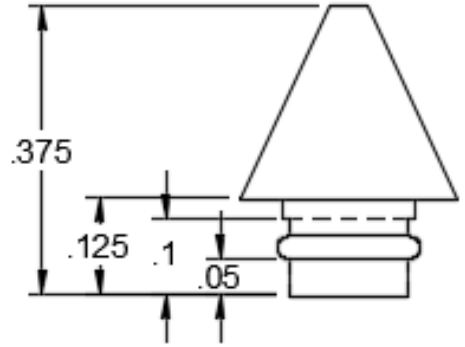


Slippery Rock University Mechanical Engineering Material: Nylon 12 Tolerance: -0.00/+0.001in Dimensions in inches Overall Dimensions, see part file for manufacturing	PROJECT SME Digital Manufacturing			
	TITLE Spike Plate Traction Spike Design Project			
APPROVED - -	SIZE A	CODE	DWG NO 01	REV 9
CHECKED - -				
DRAWN Jennifer Cichra 1/11/2025	SCALE 1:3	WEIGHT 34 g (1.197 oz)	SHEET 1/1	

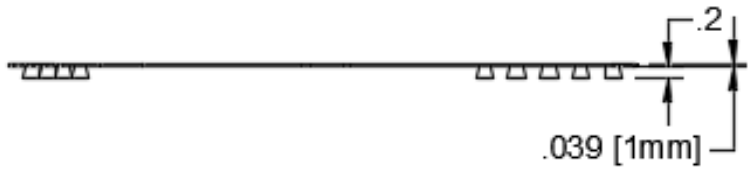


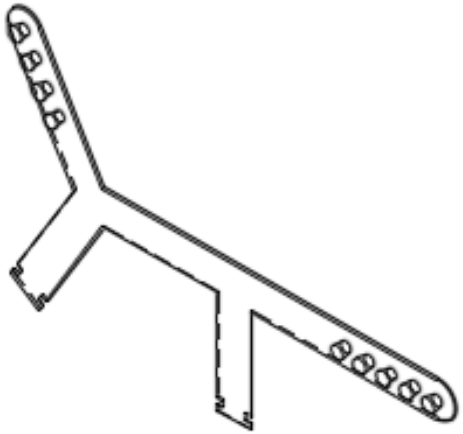


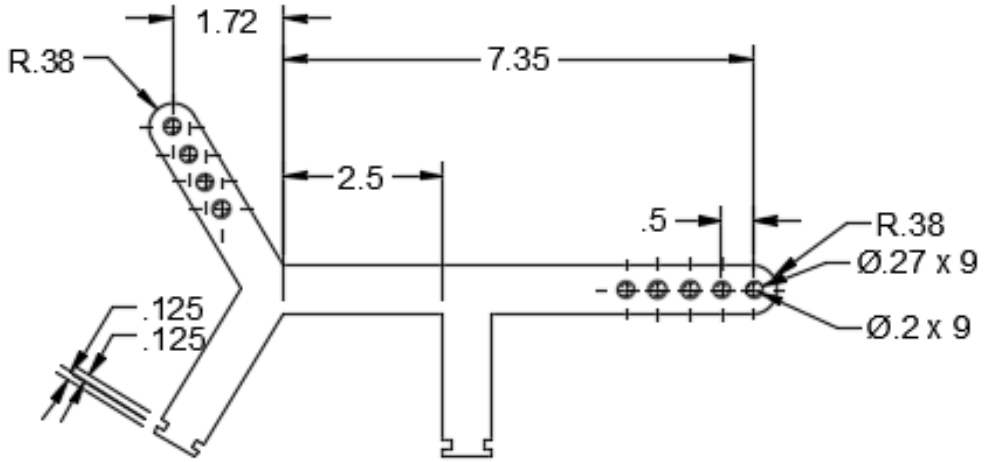


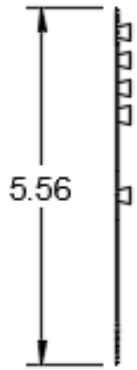


Slippery Rock University Mechanical Engineering Material: Nylon 12 Print infill 100% Tolerance: +/-0.001in Snap fit - general dimension 8 Spikes needed per plate	PROJECT SME Digital Manufacturing			
	TITLE Individual Spike - Grooved Traction Spike Design Project			
APPROVED -	SIZE A	CODE	DWG NO 02	REV 5
CHECKED -				
DRAWN Jennifer Cichra 1/11/2025	SCALE 4:1	WEIGHT 0.005oz (0.142g)	SHEET 1/1	

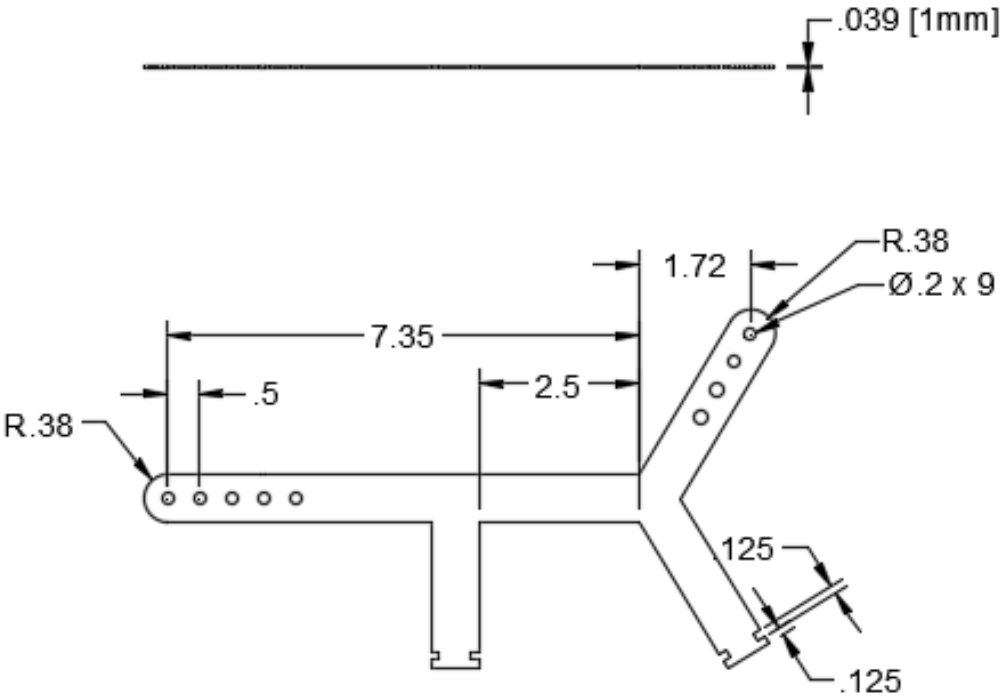


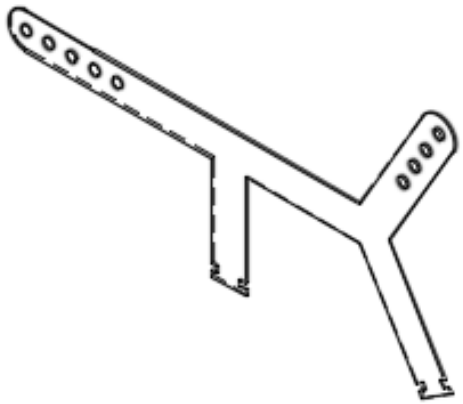


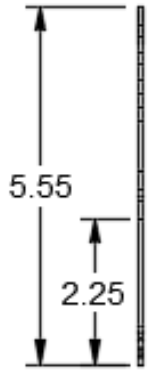




Slippery Rock University Mechanical Engineering Material TPU Print Infill: 100% No Support Necessary General Dimensions Only	PROJECT SME Digital Manufacturing TITLE Left Snow Strap Traction Spike Design Project			
APPROVED - -	SIZE A	CODE	DWG NO 03	REV
CHECKED - -				
DRAWN Jennifer Cichra 1/12/2025	SCALE 1:3	WEIGHT 0.247 oz (7g)	SHEET 1/1	







Slippery Rock University Mechanical Engineering Material TPU Print Infill: 100% No Support Necessary General Dimensions Only	PROJECT SME Digital Manufacturing TITLE Right Snow Strap Traction Spike Design Project			
APPROVED - -	SIZE A	CODE	DWG NO 04	REV 4
CHECKED - -				
DRAWN Jennifer Cichra 1/12/2025	SCALE 1:3	WEIGHT 0.176oz (5g)	SHEET 1/1	