Additively Manufactured Personalized Golf Training Grip

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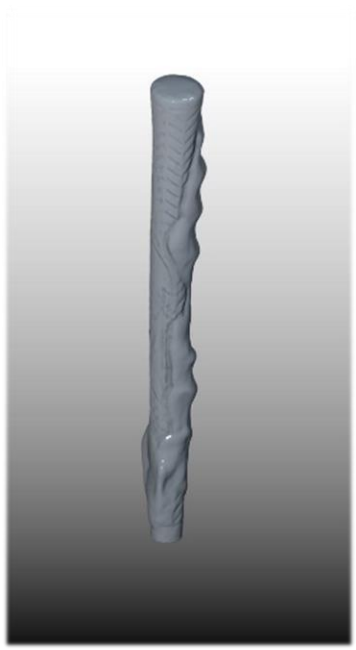

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Additive manufacturing (AM) is an emerging process within the field of direct digital manufacturing (DDM) as it offers exciting opportunities for designers to incorporate complex geometries and enable mass customization of products through manipulation of digital files. Although AM technologies have been previously used for rapid prototyping and rapid tooling, the field is now advanced enough to make end use parts. Our group presents a novel application of material extrusion AM to process our custom-made thermoplastic polyurethane filament feedstock into training grips for golf clubs customized to the user's hands and desired grip style. This document presents our identified problem, identified market, and unpacks the rationale supporting our proposed solution. Our solution is governed by the 7 key user needs of comfort, cost, turnaround time, durability, aesthetics, compatibility, and safety and the 17 engineering metrics which comprise the user needs. We present "mass customization" as our justification for selecting AM over a traditional method of fabrication and unpack this in Section III. The same metrics that govern the part design also guide the machine selection process. The metrics form the substantive base from which we present our machine selection rationale. We also present the engineering analysis validating our rationale with quantitative and qualitative results from a fully functioning prototype and from analysis of bulk material properties. Our economic analysis, shown in Figure 11 of the appendix, indicates a cost per set (3 grips in set) of $58.82 and price per set of $150, resulting in $91.17 profit per set. Our use of additive manufacturing and direct digital manufacturing facilitates a novel way to enhance the mobility of golfers around the world.

Introduction

Problem Statement

The golf grip is a critical aspect of golf - it is the only interface between the player and the golf ball. The proper grip significantly influences a player's performance. Additionally, new and emerging playing styles such as single plane golf swings require a unique grip to execute the swing properly. The single plane swing style is preferable for senior golfers because it reduces the amount of movement during the golf swing, allowing power to be generated from the club rather than twisting and flexing of the hips and wrists; this reduced movement is particularly appealing to golfers with limitations such as arthritis and weakened muscles. The single plane golf swing, though, relies heavily on proper gripping of the golf club, which has become a limiting factor for players looking to adopt this new swing style. Learning the proper grip is also particularly difficult and important for new players.

Proposed Solution

To address these issues, we developed a training golf grip that facilitates active lifestyles and aids players in adopting new swing styles. This grip will allow players to practice the proper grip even without a golf professional's constant supervision. These grips will be custom-fit by a golf professional using clay or another shape-forming material. This clay mold will then be sent to a centralized facility for scanning, further digital processing, and production. After scanning, the resulting point cloud model will be used to produce an editable 3D CAD model, which will be modified to include a cavity to interface with the existing golf club shaft. This CAD model will be directly manufactured via additive manufacturing systems into a set of grips. Following production, the mold may be mailed directly to the customer or back to a brick and mortar store.

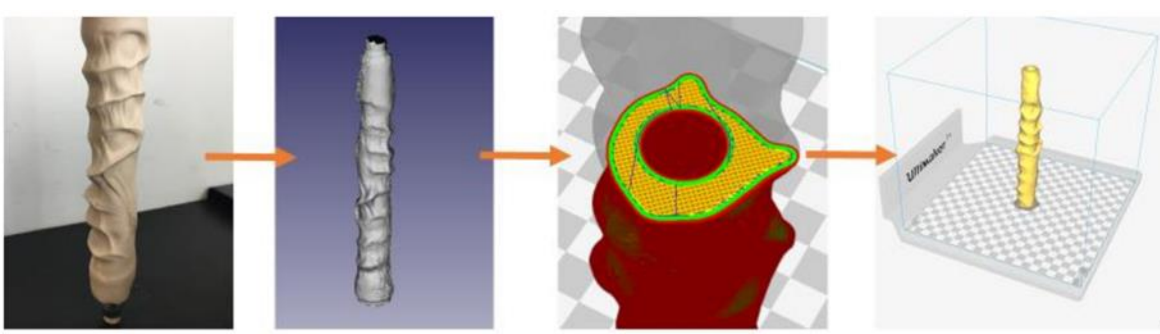

Figure 1: (From left to right) molded clay primitive, point cloud model, cross-section of part infill, STL file loaded onto build tray in slicing software

Marketing

Our design is well suited for golfers looking to develop their swing mechanics without constant, costly supervision of paid professionals as well as senior golfers interested in adapting their swing style to one less physically demanding. Our ideal client is driven by the love of the game, and has an emotional connection to the game that represents relaxation, socialization, and personal freedom. The product enables the client to retain these aspects by adjusting their swing after the realities of aging would prevent the full extent of their enjoyment. The personal customization of each grip is ideal for demo day and other promotional events. Having your grip fitted by professional golfers carrying significant star power or representatives from big name club manufacturers add a novelty experience aspect to the product increasing its value - a value only captured through the mass customization afforded by additive manufacturing.

The market for personalized golf grips is large and both willing and able to purchase luxury recreational items. According to National Golf Census reports, 32 million Americans played golf in 2015, and 53% of them intended to purchase new golf equipment in the next year. In addition, 10.7 million American golfers over the age of 60 who may be interested in adjusting their swing to continue enjoying golf. Using a professionally fitted, personalized golf grip for training in lieu of professional lessons lowers some of the barriers to game entry for new players. This paves the way for sales beyond the currently captured market for non-personalized golf clubs.

Functionality and Durability

Description of Design & Functional Analysis

Our team has analyzed the market and determined specific needs that must be met for the product to be both functional and marketable. The primary needs include durability to wear and tear, compatibility with any club, comfort, reduced cost, and safe to use. Both cost and compatibility needs are easily met because low quantity production is efficient for additive manufacturing when compared to other processes, and the design can be modified as needed to fit a specific club. Safety, comfort, and durability depend primarily on the material used. Our team also specified that the material be safe to use and should be FDA approved for long-term skin contact. This prevented the use of any UV-curable material and processes. The team finally decided upon using a thermoplastic polyurethane (TPU) material, Texin RxT70A. This material has been FDA approved for skin contact up to 30 continuous days.

As previously stated, comfort must also be considered when designing this product. Golfers heavily rely on comfort when making equipment-related purchases. If the golf grip is not comfortable for long-term use, golfers will simply not use the product. Therefore, our team tested the TPU golf grip both qualitatively and quantitatively. The team performed compression tests using a modified version of ASTM 395-B, “Standard Test Methods for Rubber Property – Compression Set.” The team printed small cylinders using varying infill densities. The cylinders were compressed in both the axial direction and the radial direction. The results are shown in Figure 1-4 in the Appendix. These tests showed that the higher infills required a larger force to reach the same compression. This suggests that the lower infills would be softer to grip, but would provide less support during the actual swing. We tested this qualitatively: we printed prototypes of the golf club with the TPU material using various infill densities, which did indeed impart varying stiffness to the grips. We then attached the grips to clubs and our resident expert golfer swung them multiple times. He claimed that the 80% infill provided the best support and comfort to his swing.

The final need, durability, was also tested using various methods. These tests include water vapor transmission rate testing and water absorption. The water vapor transmission test, shown in Figure 5 and 6 in the Appendix, suggested that water could easily pass through the TPU material. This will be a useful property for golf grips to prevent water or sweat from becoming stuck in the grip. A water absorption test was also used to determine the durability of the material. This test, results shown in Figure 7 and 8 in the Appendix, indicate that TexinRxT70A absorbs about 1% by weight of water. This result indicates that the material is moderately hydrophilic and will have very similar mechanical function in both wet and dry conditions.

Utilization of Direct Digital Manufacturing (DDM)

DDM material selection & DDM process selection

In keeping with the identified user needs and metrics, our team has identified Texin RxT70A as a suitable material for producing personalized training golf grips. This is a thermoplastic polyurethane (TPU) which has been FDA approved for tissue contact for no more than 30 continuous days. TPU's are known for being soft yet extremely durable, making this an ideal material for our application. Texin TPU is easily purchased as pellets and converted into filament for extrusion based 3D printers. The manufacturer specification sheet claims this is a low shrinkage material (0.008 in/in) which will be beneficial for final part fidelity with the CAD model. Our team was able to convert TPU pellets into 1.75 mm filament using a Filabot EX2 extruder and successfully printed with the filament using a Monoprice Maker Select 3D printer.

The team used preliminary concept screening matrices with several AM processes to determine which AM process is best suited for producing customized golf grips. Extrusion based additive manufacturing was determined to be the optimal AM process for our product for several reasons (see figure 9 for process screening matrix results). Extrusion based AM allows for a wide range of commercial and customized materials to be extruded, has sufficient surface finish, resolution and can print at relatively fast rates. In addition, extrusion based machines and consumables are very inexpensive when compared to other AM technologies. In addition, the Monoprice Maker Select is the optimum extrusion based AM machine due primarily to its low initial cost, superior layer thickness and its ability to process customized filament (see figure 10 for machine screening matrix results). To overcome the small build space of the Monoprice, the team has split the golf grip design vertically into two sections.

Figure 2: Prototype of golf grips with various infill densities

Design Integration and Innovation

Additive manufacturing has created a cost-effective platform that can efficiently print personalized grips. The process of creating these fully personalized grips can now be completed in just a few steps. This process starts with a golf professional that can aid in correctly placing a trainee's grip on a molded golf grip. This mold is then scanned using a 3D scanning device and printed using any 3D printer. Additive manufacturing will allow that exact grip to be printed relatively quickly and cheaply. Other manufacturing processes such as milling or machining would require several days of machining and extremely skilled machinists to complete the job. Additionally, technologies such as injection molding or blow molding require a mold, making them excellent for mass production applications. However, these processes become extremely inefficient at small production volumes, as each new product would require a new mold. With additive manufacturing, however, complexity is free. Once a scan is taken, and an STL file generated, it costs nothing extra to produce a highly personalized, complex geometry with direct digital manufacturing. In addition, the speed of production offered by additive manufacturing also allows for a short turnaround time; the print can be started as soon as the part is scanned and the STL file is received.

Social and Environmental Impact

The advent of 20th century medicine has created a top-heavy population pyramid for many industrialized countries for the first time in history. Although modern medicine allows humans to live longer, society now faces new issues stemming from an aging population. As bone density and muscle mass naturally decrease with age, finding physical activities that our senior population is willing and able to perform is a challenge. This personalized golf grip allows veteran golfers to adopt a less strenuous single plane swing, enabling more seniors to get outside and stay active. From an environmental perspective, the snug fit of the grip onto the club shaft eliminates the need for adhesives and enables fabrication from a single, thermoplastic material. This allows our grips to be recycled, and reduces the overall carbon footprint through the elimination of the adhesive supply chain.

Appendix

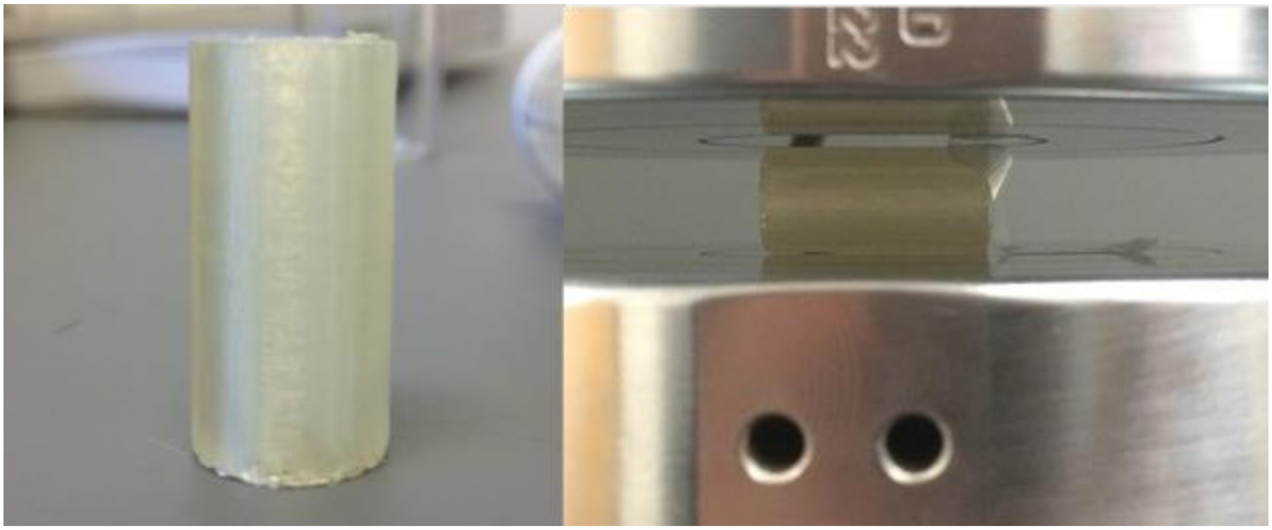

Figure 3: (Left) Sample cylinder used for modified compression testing. (Right) Set up for modified compression testing.

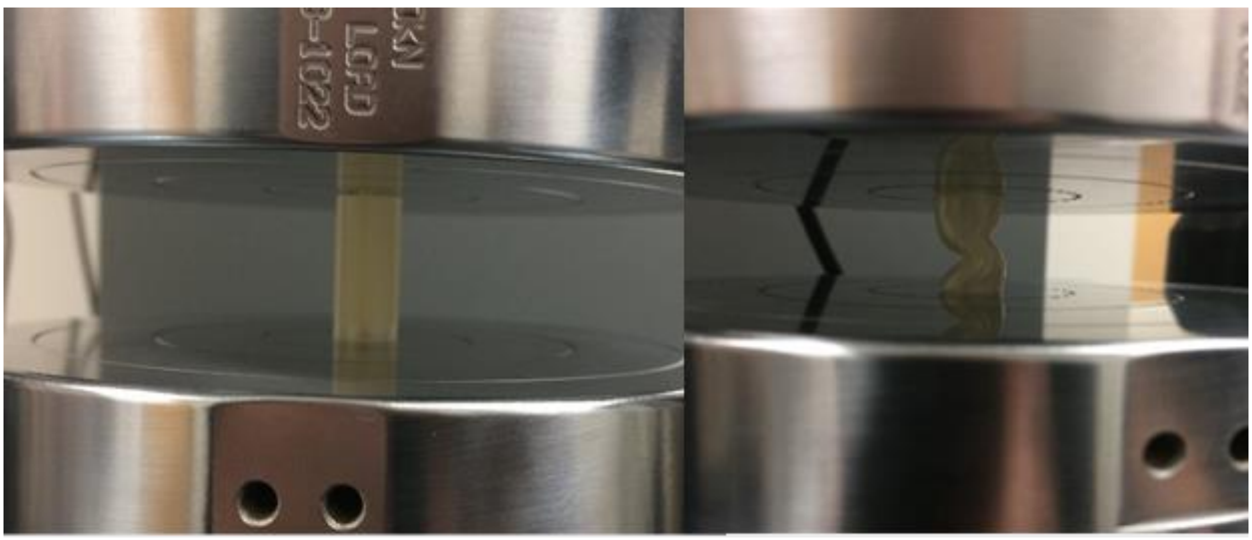

Figure 4: (Left) Compression test with force being applied in the direction of the Z-axis. (Right) Image of buckling failure during axial compression loading of sample

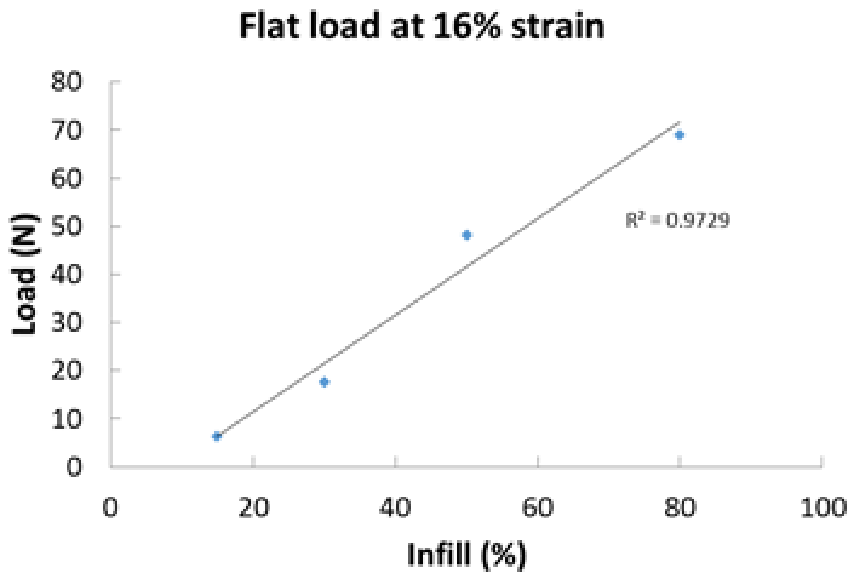

Figure 5: Results of compression tests with the force applied perpendicular to the Z-axis

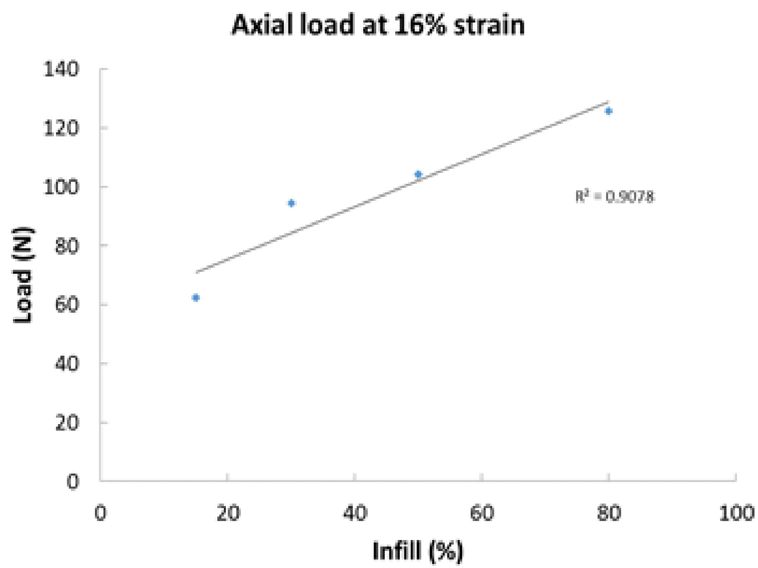

Figure 6: Results of compression test with the force applied in the direction of the Z-axis

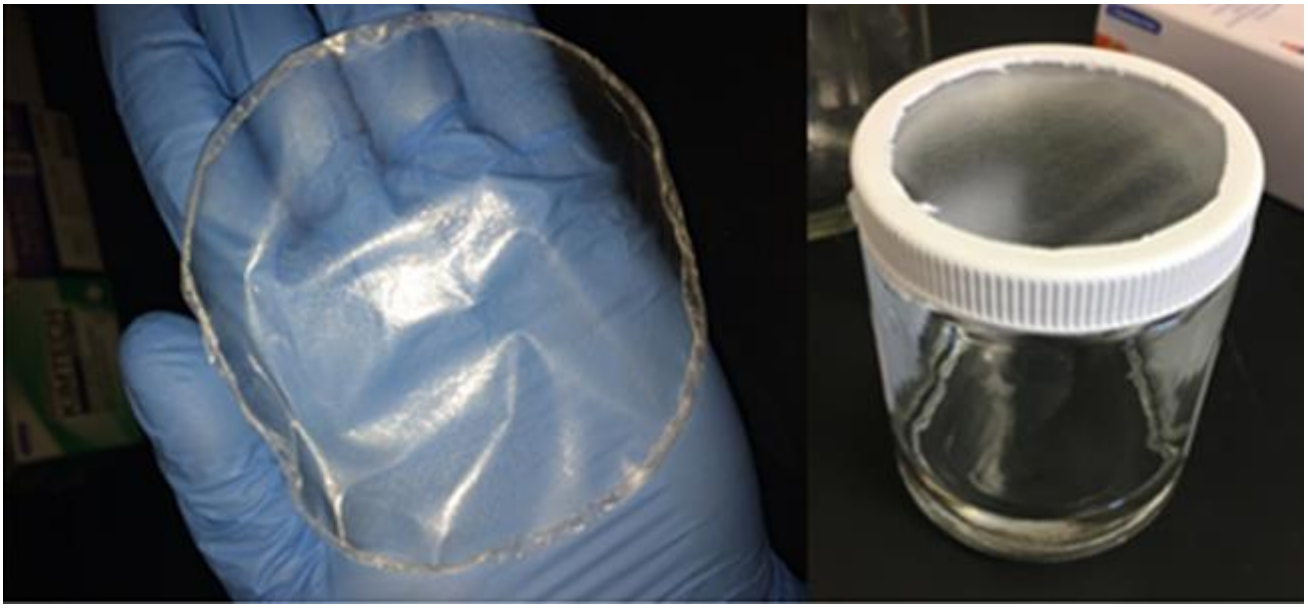

Figure 7: (Left) Solvent cast film for water vapor transmission test (Right) Water vapor transmission test fixture

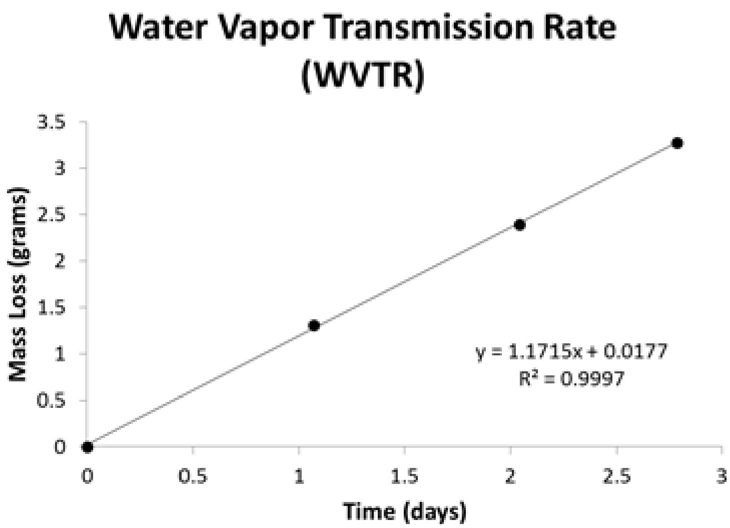

Figure 8: Results of the water vapor transmission rate (WVTR) test

Figure 9: (Left) Sample filament used in water absorptivity test (Right) Set up for water absorptivity test

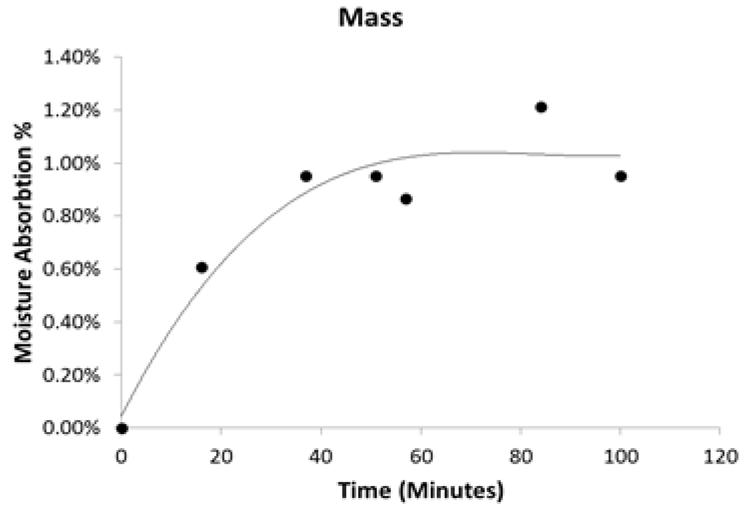

Figure 10: Results of water absorption test of the TPU material

	Datum – Binder Jetting						Datum – Powder Bed Fusion						Datum – Extrusion					
	Weighting Factor	Binder Jetting	Vat Photo	Powder Bed Fusion	Extrusion	Material Jetting	Weighting Factor	Binder Jetting	Vat Photo	Powder Bed Fusion	Extrusion	Material Jetting	Weighting Factor	Binder Jetting	Vat Photo	Powder Bed Fusion	Extrusion	Material Jetting
Surface Finish	8.92%	0	1	0	-1	1	8.92%	0	1	0	-1	1	8.92%	1	1	1	0	1
Elongation at Yield	9.71%	0	-1	0	1	1	9.71%	0	-1	0	1	1	9.71%	-1	-1	-1	0	-1
Yield Strength	7.76%	0	-1	1	1	-1	7.76%	-1	-1	0	1	-1	7.76%	-1	-1	-1	0	-1
Modulus	5.59%	0	-1	0	0	-1	5.59%	0	-1	0	0	-1	5.59%	0	-1	0	0	-1
HDT	4.39%	0	-1	0	1	-1	4.39%	0	-1	0	0	-1	4.39%	-1	-1	0	0	-1
Throughput	6.22%	0	-1	0	-1	-1	6.22%	0	-1	0	-1	-1	6.22%	1	-1	1	0	-1
Cost (machine)	2.88%	0	1	-1	1	1	2.88%	1	1	0	1	1	2.88%	-1	-1	-1	0	-1
Cost (consumable)	2.88%	0	1	0	1	0	2.88%	0	1	0	1	1	2.88%	-1	0	-1	0	-1
Cost (post production)	2.88%	0	1	1	1	1	2.88%	-1	1	0	1	1	2.88%	-1	0	-1	0	-1
FDA (external contact)	8.73%	0	-1	0	0	-1	8.73%	0	-1	0	0	-1	8.73%	0	-1	0	0	-1
Resolution (XY)	8.00%	0	1	-1	-1	1	8.00%	1	1	0	-1	1	8.00%	1	1	1	0	1
Layer Thickness	5.60%	0	1	0	-1	1	5.60%	0	1	0	-1	1	5.60%	1	1	1	0	1
Post processing time	5.06%	0	1	1	1	1	5.06%	-1	1	0	1	1	5.06%	-1	-1	-1	0	-1
Utilities	1.73%	0	0	0	0	0	1.73%	0	0	0	0	0	1.73%	0	0	0	0	0
Print speed	3.33%	0	-1	1	-1	1	3.33%	-1	-1	0	-1	-1	3.33%	1	-1	1	0	-1
UV resistant	9.49%	0	-1	0	0	-1	9.49%	0	-1	0	1	-1	9.49%	0	-1	-1	0	-1
Water permeability	6.82%	0	1	-1	0	1	6.82%	1	1	0	1	1	6.82%	0	1	-1	0	1
	Score	0.000	-0.122	0.013	0.035	0.110	**Score**	-0.013	-0.122	0.000	0.154	0.073	**Score**	-0.035	-0.338	-0.154	0.000	-0.396

Figure 11: Preliminary screening using three datum's for evaluation the most suitable AM technology for the golf grip fabrication

	Units	Weights	Direction of Improvement	Ultimaker 2+ extended			MakerBot Replicator Z18			RepRap x1000		
CONSTRAINTS				Yes/No			Yes/No			Yes/No		
Build volume (greater than 12x2x2")	mm^3		Y	Y			Y			Y		
CRITERIA				Score	Norm Score	Weighted Norm Score	Score	Norm Score	Weighted Norm Score	Score	Norm Score	Weighted Norm Score
Throughput	parts/print	6.22%	+	9	0.05	0.00	16	0.09	0.01	180	1	0.06
Cost (machine)	Dollars	2.88%	-	3000	0.94	0.03	6500	0.87	0.03	50000	0	0.00
Cost (consumable)	$/kg	2.88%	-	12.5	0.00	0.00	12.5	0.00	0.00	12.5	0	0.00
Resolution (XY)	µm	8.00%	-	12.5	0.17	0.01	11	0.27	0.02	15	0	0.00
Layer Thickness	µm	5.60%	-	20	0.80	0.04	100	0.00	0.00	100	0	0.00
Utilities (Electric) cost	$/year	1.73%	-	183.91	0.91	0.02	291.7	0.86	0.01	2080.5	0	0.00
Feed rate (@ .4 nozzle dia)	mm^3/s	3.33%	+	16	1.00	0.03	16	1.00	0.03	16	1	0.03
Sum						0.14			0.10			0.10

Figure 12: AM extrusion based machine selection matrix

	# items	Capital cost/Item	Capital cost	Capital/set	Cost/variabl	Variable/set	Cost/set
TPU Pellets (M_bar)					$ 2.70	1.8612	**$ 5.03**
Labor cost (L_bar)					$ 35.00	0.83	**$ 29.17**
Filabot extruder	1	$ 2,500.00	$ 2,500.00				
Filabot spooler	1	$ 1,200.00	$ 1,200.00				
Maker Select Plus	12	$ 400.00	$ 4,800.00				
Single Flexion head (i3)	12	$ 150.00	$ 1,800.00				
NextEngine Scanner	1	$ 3,000.00	$ 3,000.00				
Purchase cost (P_bar)			$ 13,300.00	**$ 10.93**			
Operating cost (O_bar)				**$ 3.64**			
Shipping							$ 8.00
Netfabb subscription				$ 2.05			
Other costs (K_bar)				**$ 10.05**			
Total cost/set (C_bar)				**$ 58.82**			
Price/set				**$ 149.99**			
Profit /set (P)				**$ 91.17**			

Figure 13: Economic analysis for production of a personalized training golf grip set (three grips)