PRINTED PROSTHETICS

VUW School of Design + NZ Artificial Limb Service

R & D Report
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Executive Summary

Background

The New Zealand Artificial Limb Service (NZALS) in collaboration with Victoria University of Wellington’s School of Design have worked over the past 3 months to research the potential 3d printing can have on the Prosthetic Limb industry and whether there is potential the NZALS can adopt these findings into their business and manufacturing process.

This research has been structured into two time frames. The now and the future, not only does this allow the NZALS to see a gradual progression of implementing 3d printing into their system it also includes a degree of speculation that has the potential to bring people from other disciplines of research together.

The two design directions that were focused around the now time period, 12 - 18 months.

1. Functional Fairings - Creating Fairings that not only provide an aesthetically component but a functional factor too.

2. Socket design - Printing a full socket that can easily adjust to the patients limb swelling.

The final two design directions focused on the future, looking at the 7-10 years period.

3. Multi-Density Foot - Printing a foot with areas of multi density to tailor a better responsive foot for the patient.

4. Information Driven - Speculating that information will be gathered of the patients limb that in turn generated a 3d model fit for the patient.

Brief

“Printed Prosthetics” will explore new possibiities design can have on the making process of prosthetic limbs by exploring 3D Printing and CAD software and scanning.

Design Directions

NOW

12-18 months

This initial phase of concepts is focused around what can be done now, it will give a good direction the NZALS can feasibly achieve in a seeable future.

1. Functional Fairings
2. Adjustable Socket

Functional Fairings

Adjustable Socket

FUTURES

7-10 Years

The futures part of the project develops a speculative approach that considers new technology and technology that is yet to be released in the design of these two concepts. Yet still maintaining realitive to the service.

1. Multi-Density Foot
2. Information Driven

Multi-Density Foot

Information Driven

Printing

Fused Deposition Modelling (FDM) printing is the main type of 3d printing. The way these machines work is by thin filament feeding through a heated nozzle which is then extruded to build up layer by layer. (Refer to fig 1.1 for visual). This form of printing is used by both low end entry level printers and high end industrial level where precision and quality is necessary.

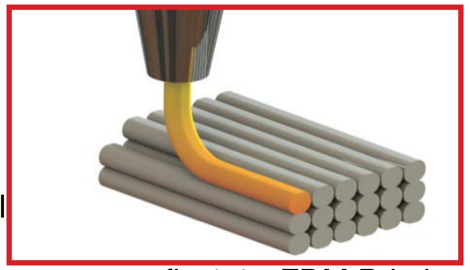


fig 1.1 - FDM Printing

Outsourcing

As 3d printing is still quite expensive and a quickly changing technology NZALS also have the option to use other services that will print your models for you, both saving the heavy start up costs, and investment while the service is still learning about the technology and discovering what the best solution is. Below is a few companies from around the world that provide such services.

shapeways — Netherlands

Shapeways is one of the largest 3d printing services and provide a great range of materials that can be printed with. Ranging from strong nylon, to metals and various plastics. However, the lead time for Shapeways takes around 6 weeks. Shapeways also have an online store where you can both upload your CAD models for other people to purchase,

i.materialise — Belgium

I.Materialise markets towards a similar target as Shapeways but also encourage people who can't 3D model to use their "Hire a designer" serve where you describe your ideas for a designer to model. Similar to Shapeways, it has a 5-6 week lead time and prints come in a range of materials.

Objective 3D (3D PRINTING SOLUTIONS) — Australia

Objective3D are a commercial printing service that provide both printing as a service as well as selling large high quality printers. They target towards business and organisations that rely on high quality prototypes and parts as suppose to the general public and hobbyists who print their own objects.

Printers

UpBox — RRP $3100 NZD

The UpBox is an entry level desktop printer and is the model that was used in this project.
Build Platform:
255 mm width, 205 mm depth, 205 mm height
Materials: ABS plastic, PLA or TPU Flexible Filament.

Pros:
- Easy set up and use.
- Cheap to run, $60 per role of ABS Filament

Cons:
- Can be temperamental and break
- Needs post manufacturing applied.

Stratasys Fortus — RRP $250,000 NZD

The Stratasys Fortus range is a high end FDM printer that is all about speed performance and accuracy for high quality prototypes and finished products that uses dissolvable support material for easy post manufacturing processing.
Build Platform :
Fortus 380mc: 355 x 305 x 305 mm
Fortus 450mc: 406 x 355 x 406 mm
Fortus 900mc: 914 x 610 x 914 mm
Materials : Large range of materials, primarily ABS plastic and Nylon for toughness.

Pros:
- Accurate and reliable high quality print
- Materials are tensile strength rated
- Dissolvable support material

Cons:
- Expensive to set up and run
- Large physical printer footprint
- Mono-material.

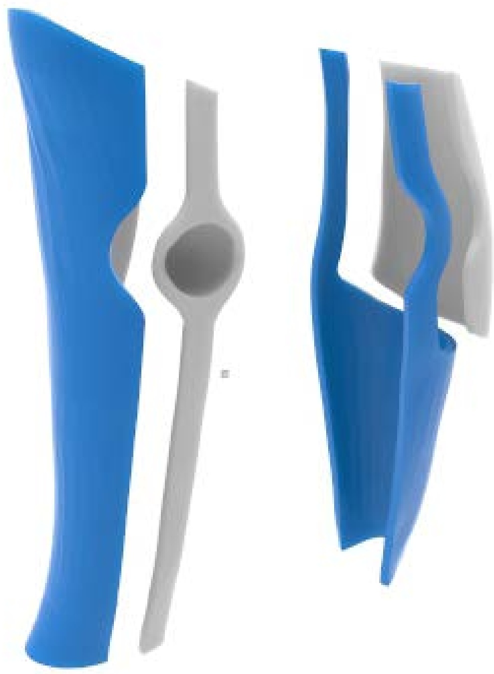
Functional Fairings

These attachable and functional fairings help to improve the lives and mindsets of people with prosthetic legs. Designed around specific hobbies and activities, these accessories can change what is commonly perceived as a loss, into the potential for something more. A space for creativity and practicality that is only possible for an amputee.

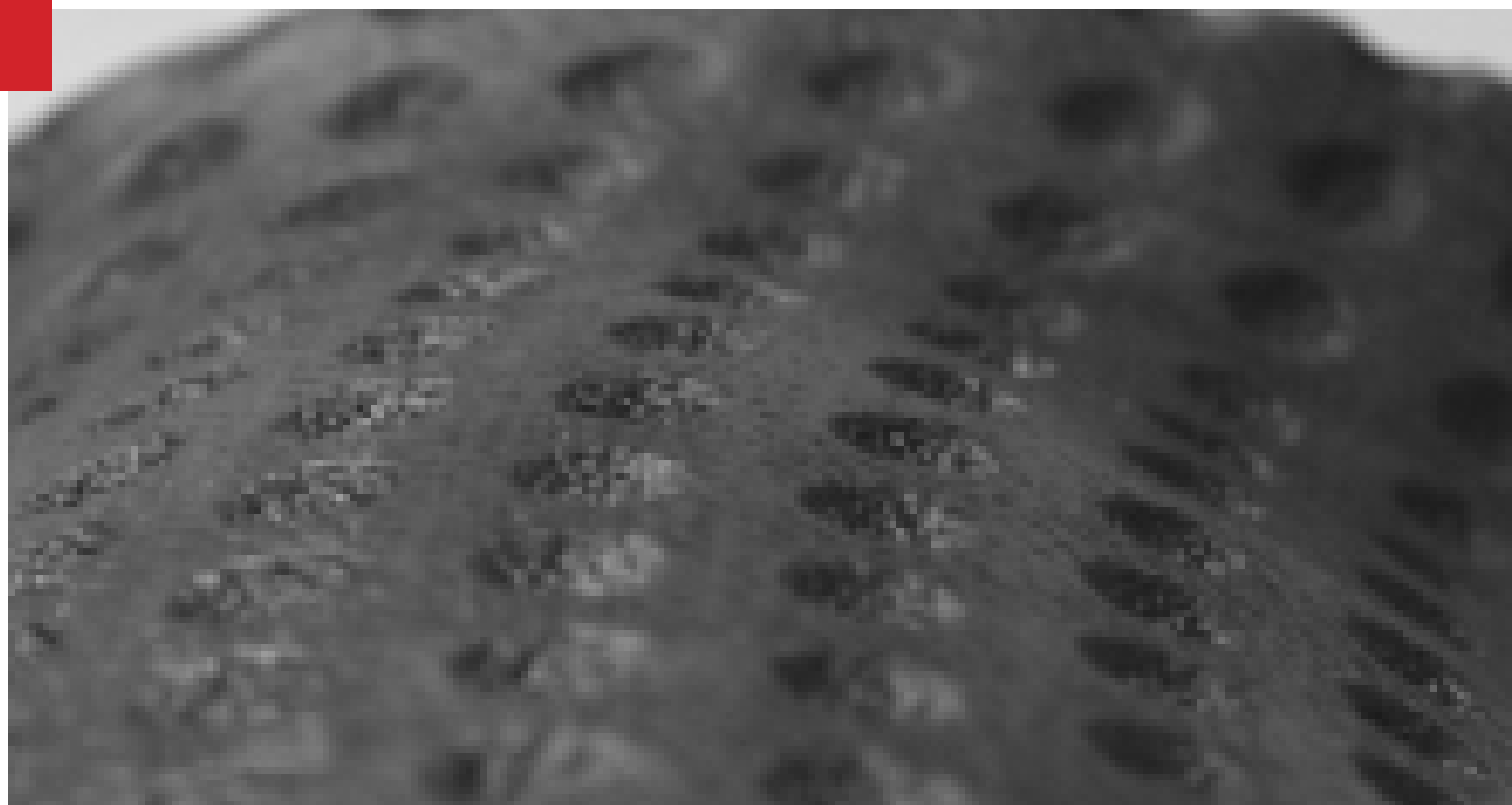
Sport Fairing

Throughout this project I has developed two distinct areas where fairings could help to improve the lives and experiences of getting a prosthetic limb made, and also living with one in the following years. Both are feasible projects that could very easily be accomplished by NZALS within months.

The first example is the concept of using fairings like footwear. We wear different shoes for every aspect of our lives, whether it be work, going out, playing sport, or going to the beach. Why should amputee's not be allowed the same luxury at an affordable price? To be able to customize their leg based on their own lifestyle, and re-gain as much control over their day to day activities as possible. As a specific example of the 'Functional Fairing', I have provided and example of a Golf Leg. The modern design not only looks good, but it is equipped to hold a spare golf ball and a couple of extra tee's for the golfers convenience. This is a perfect example of not only bringing freedom and choice back to the customers, but even pushing their disadvantage, to an advantage.

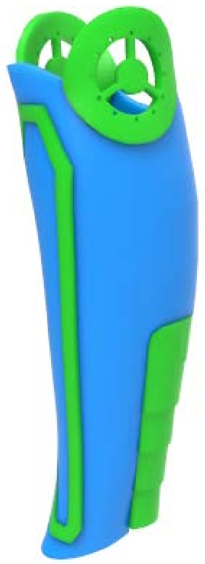


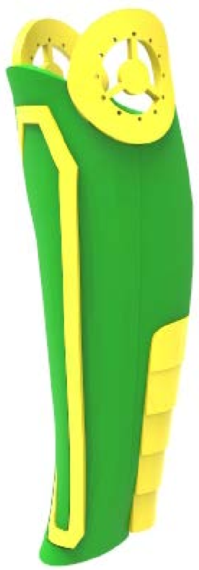
Whilst I understand every client has a different mind-set and will want different things from their fairings, by providing a vast range of options for different sports, hobbies, even day to day wear, everyone has the ability to customise their leg to their own life. By offering these fairings as a package set that the customer is able to pick out and order whilst their prosthesis is being made, it can easily fit into the current system and provide the customer with more options, as well as the workers an opportunity to increase their skill set. With pre-set 3D files and some training on a 3D printer, they will be able to run both businesses simultaneously.



Child Fairing

The second example is a similar concept, but targeted towards children. Beyond coloured and patterned sockets, there are no other options to really customise children's prosthetics. Kids are creative, and hugely imaginative. By offering them the freedom to design their own leg, they can use that imagination to make a leg that they really want to wear. Instead of simply having their favourite super hero or movie character printed onto their socket, you can give them a replica of their actual limb! I have provided an example of a 'Bionic Leg' to show one of the themes a child may enjoy. Not only is this concept something children will love, but it can also seriously improve their mindsets about their prosthesis when surrounded by peers who wish they could have a bionic leg too. Instead of seeing something different, show them that it can be something better.





For the distribution of this concept I believe the best method is to sell them through a website. This will allow children and their parents to enter some information about their prosthesis, then drag and drop different parts and themes and design their own leg. It then becomes a fun and interactive way to get everyone involved and make the experience an exciting one. With pre-set parts that fit together and change size depending on whether it is above or below knee, as well as some simple measurements, the parents can then order the leg when the design is complete and it will get shipped out to them. This process gives NZALS the choice to do the 3D printing themselves, or to simply outsource it to a company like Shapeways.

Conclusion

I believe that both of these concepts have potential to greatly improve the experiences of the clients, as well as giving the employee's at NZALS the perfect opportunity to combine 3D printing into their workplace and see the possibilities it has. Being such a low cost and flexible manufacturing method, fairings don't have to be as expensive and fragile as they are through other companies. They also don't have to stop at being simple and purely aesthetic. With someone skilled in working with CAD, and access to 3D printers, either of these examples could be fully functioning businesses within the year.

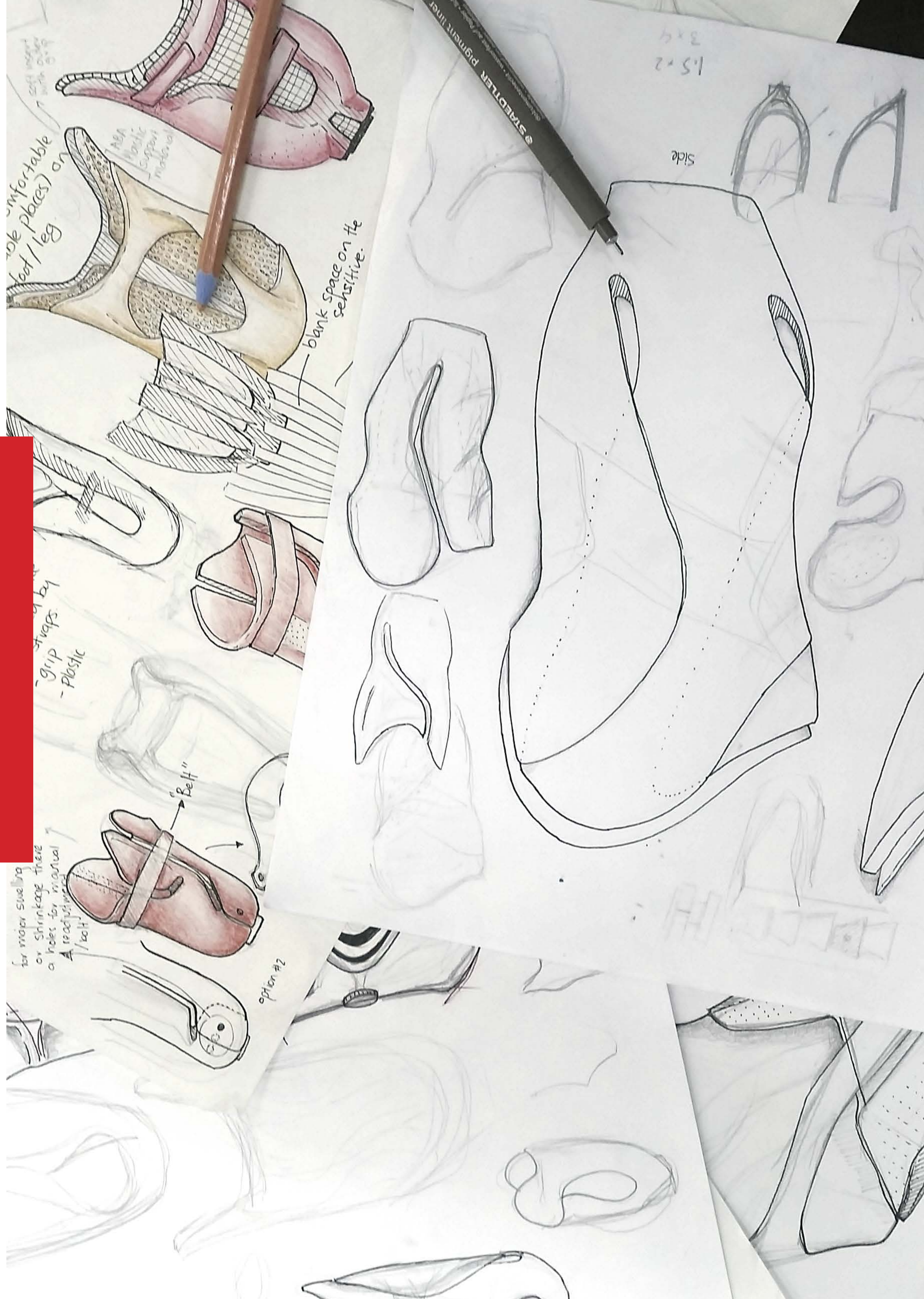
Adjustable Socket

Brief

During the past six weeks we have been researching the possibilities around 3D printed prosthetics, in particular the socket design. With the latest in 3D printing and 4D scanning we have the opportunity to develop a system that can simplify difficult processes and provide clients with a socket that is comfortable, aesthetic and functional. We hope to have explored different ways the sockets physiological fit could be changed that makes the doffing and donning process easier for the client, reducing the amount of times it needs to be replaced, as well as using 3d printing as our point of difference to other existing models.

Why create an adjustable socket?

The main reason to experiment and design an adjustable socket was to create an experience for the patient that required no more effort than putting on or removing a shoe. It would mean the socket would be more comfortable because you could easily change the fit throughout the day due to the fluctuation in the size. It would also bring the aspect of convenience. There would be no more having to remove the socket with multiple layers of socks or using excessive force to remove it. This type of adjustable system could also potentially be used in other sporting activities.



Adjustable Socket

Scanning

With the help from Auckland Bioengineering Institute we have a better understanding of what the latest scanning technology can provide for the current systems as well as how it could be used in the future. Soft tissue scanning generates an accurate volumetric mesh of a patient's limb which allows technicians to visualise what areas of the stump are tolerant or sensitive, or what is hard and what is soft, meaning they have a better representation of how the socket design should be sculpted. Using this scanning then provides an easily editable model for the overall socket design and will allow for the development of multi-density materials to be used.

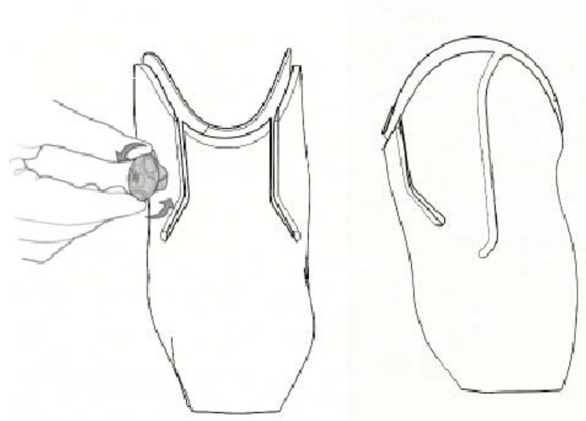
Modelling and Materials

ABS (Acrylonitrile Butadiene Styrene) plastic was used for a large amount of the 3D modelling due to its hard and rigid properties. The material reflects that of the current prosthesis with its impact resistance and stability under pressure, but unlike carbon fibre, it can easily be edited to the desired form. Prototyping with this material gave us accurate complex models with little to no post processing needed. Unfortunately, what we did find with ABS is that because of its lack of flexibility, parts that needed to allow movement became fragile when flexed. If studied more in depth we think this material has potential to create a socket that is durable, flexible and able to withstand the pressure produced everyday on the patients' limb. An additional material we looked at was TPU (thermoplastic polyurethane). It provides properties that ABS struggles to provide, it is flexible, extremely durable and abrasion resistant. Working with TPU gave us the advantage of creating models that could not be broken and allowed us to edit the fill to create areas that are flexible or stiff where it was needed. Because of the materials flexible nature we found TPU was difficult to work with when it came to more complex models and had a longer post-processing time to allow for application on patients'. This material would be a great advantage for the prosthetics sector but it still needs work to perfect the processing and final model outcome.

Adjustability

To make the socket adjustable we needed to look at different mechanisms to provide the appropriate function in the socket. We took inspiration off ski/snow boots using the buckles which would allow a stable and strong support around the stump as well as the durability of the clip. However, we also found a system called BOA (BOA, n.d.). This closure system provides a dial that can adjust the tightness by millimetres at a time by simply turning the dial for the perfect fit without the need to remove the prosthetic. Making use of these systems would create an opportunity to join with other companies and work together to produce the most effective design solution.
Adjustable sockets have already been designed using the latest Boa Closure System by a company called Click Medical creating a limb by the name of Revo-Limb. We plan to push the adjust-ability and breath-ability further and make it a common place product in prosthetics. These designs can be found at: https://www.clickmedical.co/revo-welcome/

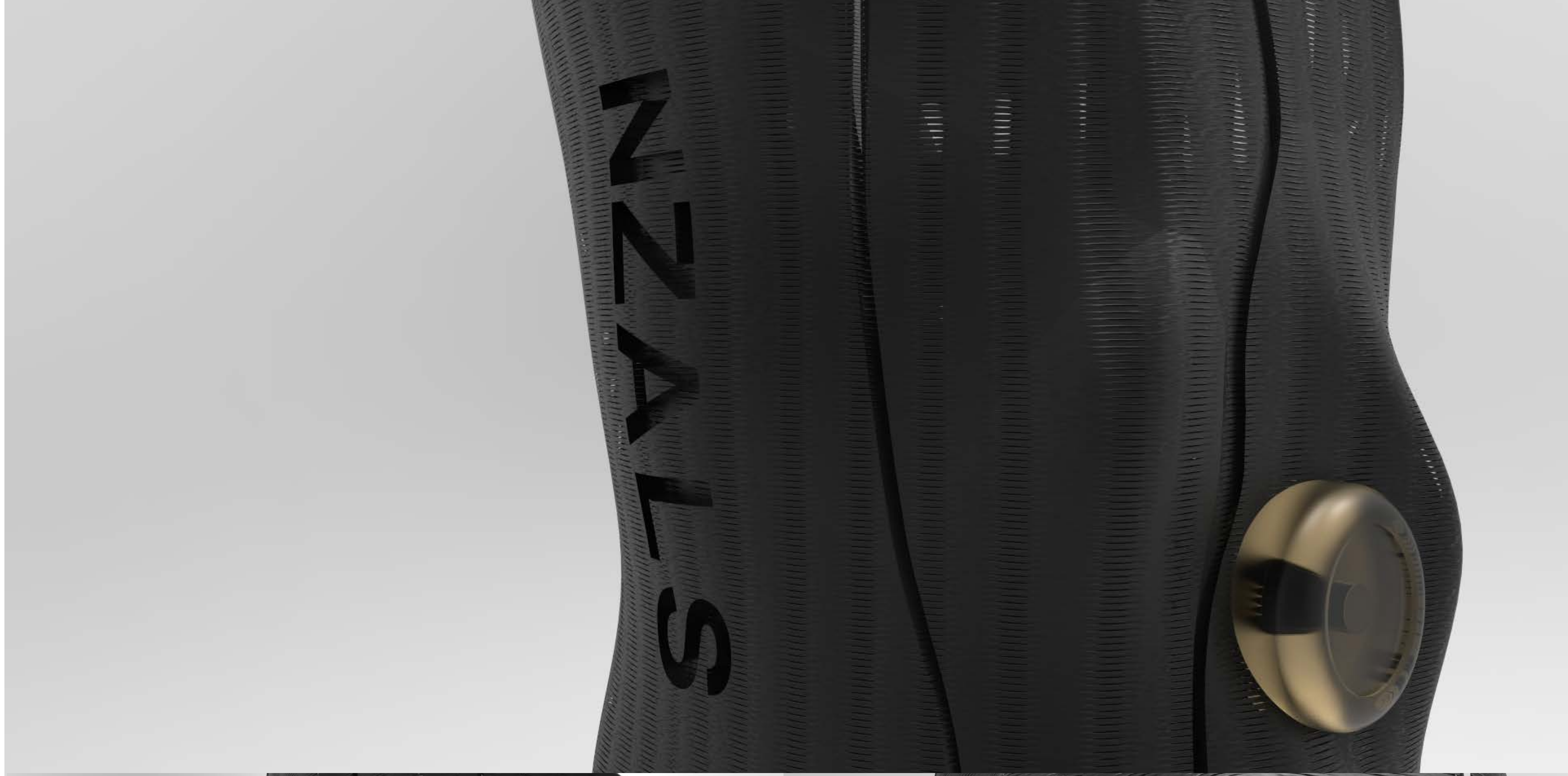
boa®
Boa® Closure System

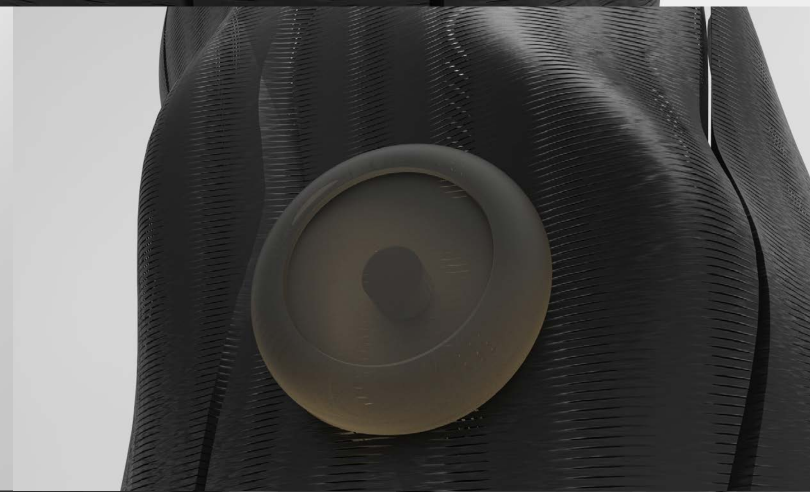


Adjustable Socket

Conclusion

In conclusion, we believe that because of the constant development of 3D printing, the opportunities are out there to create an adjustable socket that can be used by patients' today. This could be done by:
- Teaming up with Auckland Bioengineering Institute, who provide inundated knowledge of 3D scanning soft tissue and will advance the current systems dramatically.
- Continuing experimenting with ABS and TPU materials on specific designs that benefit from their properties.
- Working with companies that are already in the market for adjustable systems and work together to create the most effective method of use.
- Work with the current NZALS technicians who know the ins and outs of making prosthetics for the best fit and socket design.





MULTI-DENSITY FOOT

High end prosthetic feet are expensive and can be costly to frequently replace for clients. It was mentioned some clients are even encouraged to opt to a more basic prosthetic foot and to reduce costs due to constant wear and tear of high end prosthetic feet.
The goal of this section of the project is to explore the potential of 3D printing's unique fabrication benefits in the application of TPU and variable density printing to achieve an everyday performing prosthetic foot which is economical in cost and easily replaceable for the client.
In terms of performance, the K3 level is the goal - the client should be able to carry out everyday activities by means of walking, climbing stairs and traversing the streets, the home and the office.
The following report is a pitstop in the research and development of this concept and is meant to provide a platform for a masters student to continue on from.
It contains details of fabrication methods, example projects, crucial software for variable dense printing and the initial beginnings of exploring and designing concept and form.

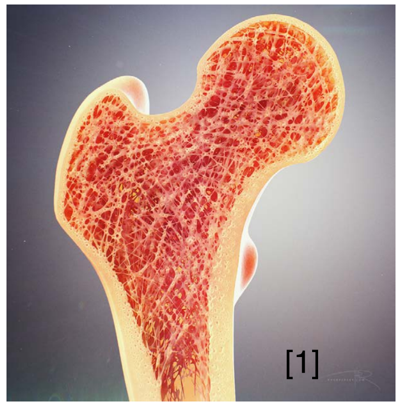
Variable Density Printing

A strong benefit of 3D printing and FDM is the high level of fidelity of internal construction. By the pure nature of layer by layer construction, objects, with consideration to the material properties being applied, can be designed and produced in a way which the fill/density of a material can be varied to match and achieve desired object performance.

A parallel of this important benefit of this technology and construction process must be drawn to the natural construction of organic matter. A popular and appropriate example are bones - they have a dense outer rim while the centre is porous and spongy. By exploring variable density printing, future prosthetics may be able to be made through a means of achieving high object performance with low weight to strength ratios. Another further benefit of variable density printing is the ability to customise sections which are either hard, soft or a range in between in the one print. This allows intentional flex and strength to be inserted into a model with consideration to how it moves and supports weight bearing loads.

"Nature always uses graded materials. Bone, for example, consists of a hard, dense outer shell, and an interior of spongy material. It gives you a high strength-to-weight ratio."

-Steven Keating Graduate Student from Mediated Matter Group at the MIT Media lab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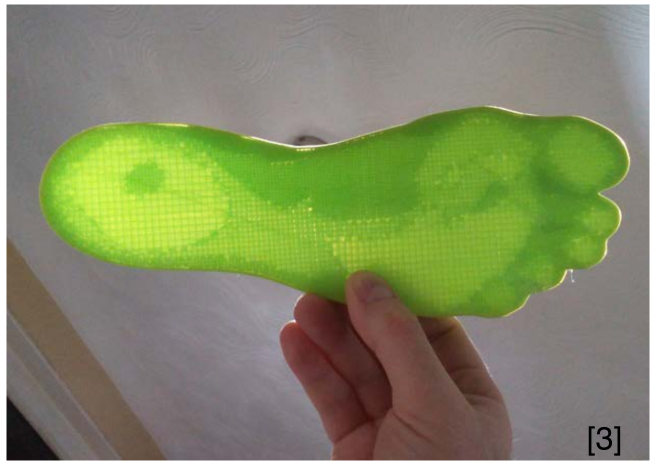
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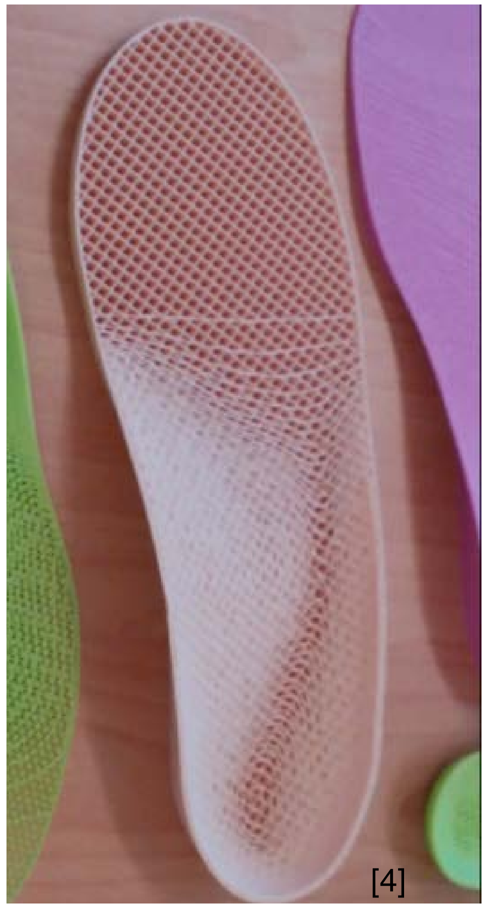
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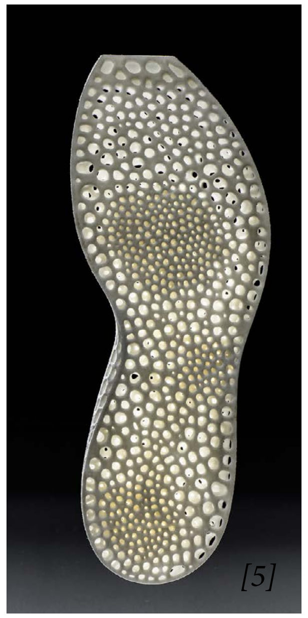
New Balance have worked alongside Nervous Systems to produce a 3D printed running midsole with the technological expertise of 3D Systems SLS 3D printer.

"We have created proprietary systems to generate midsole designs from pressure data from runners, making it possible to create variable density cushioning that is customized to how a person runs."
- Nervous Systems co-founder Jessica Rosenkrantz.

"While man-made foams are rather uniform, the foams we see in nature like wood and bone are highly variable in scale and direction, enabling specific material properties in different zones."
- Nervous Systems co-founder Jessica Rosenkrantz.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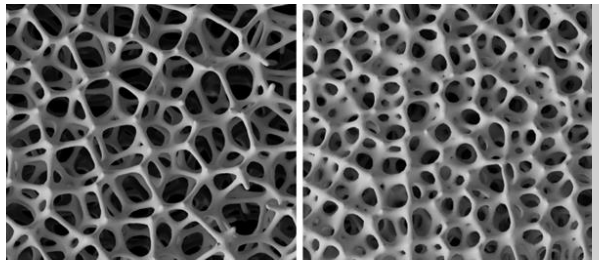
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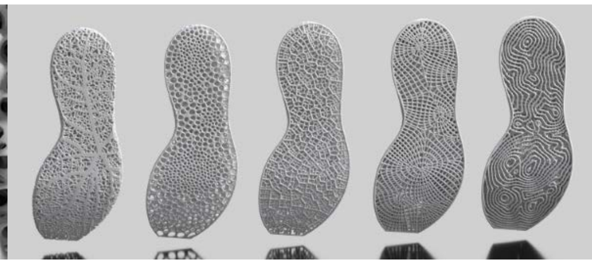
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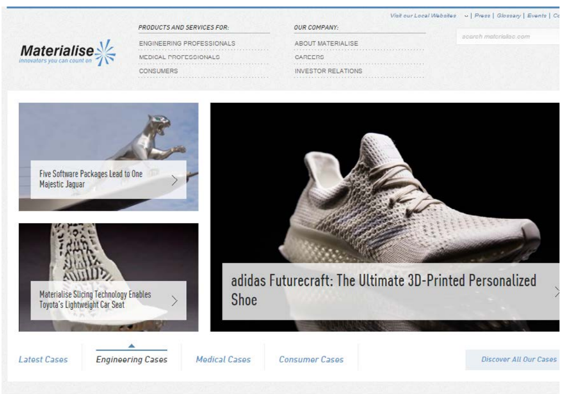
Materialise (mentioned in the following section) aided adidas in the creation of the complex and lightweight structure in the 3D-printed midsole. Using Materialise's own software, 3-maticSTL, adidas was able to design the porous structure which was then laser sintered in TPU.



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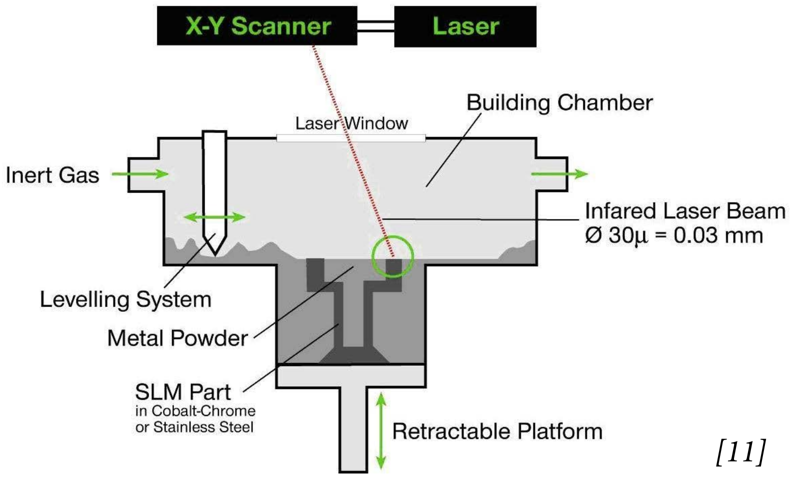
3D Printing Technology, Material and Materialise

Materialise offer a 3D printing service in the TPU material with Selective Laser Sintering (SLS) being the specific technology used.

SLS works by fusing powdered plastic layer by layer using a high powered laser.



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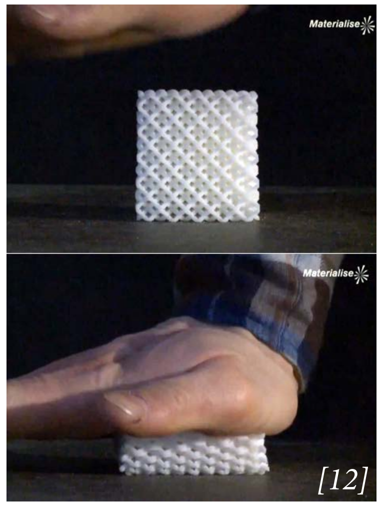
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TPU is hybrid material which consists of hard plastic and soft silicone.

Materialise offer a flexible TPU which is printed by the additive manufacturing technique of selective laser sintering.

Flexible TPU 92A-1

TPU 92A-1 is the only 3D Printing material that combines:

- Durable elasticity
- High tear resistance
- High resistance to dynamic loading
- High abrasive resistance
- Snappy response
- Good temperature range (-20°C to 80°C)

Taken direclty from the materialise website

Because of the material properties listed above, TPU 92A-1 is ideal for highly-flexible and abrasive-resistant parts in a wide range of applications such as:

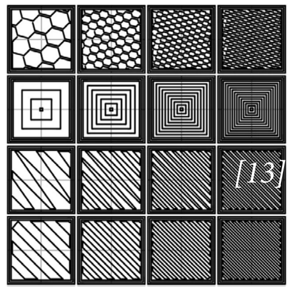
- Small series of seals and gaskets
- Complex tubes, hoses and manifolds
- Elastic lightweight structures
- Components for the shoe, fashion and leisure industry
- Cushioning and shock absorption
- Rapid Prototypes of elastic components

Software

Slicer software is software which allows the 3D printing of a 3D model file. The software fundamentally works by translating (slicing) a 3D model (commonly .STL format) into individual print layers. The print layers are transcribed into machine code (G-Code) which can then be read by the actual printer itself.

There are a range of different slicer software available, some free while others cost.
One example is Slic3r, which for the purpose of variable density prints seems to be the most appropriate.

Slic3r is a free slicer program which outputs the G-code to 3D printers.
Along with being free, Slic3r has a beneficial function which allows modifiers to be introduced into the parent model. The internal fill and fill density can then be changed for these modifiers which in turn produces multi variable dense prints.
This software, currently, seems to provide the most efficient and effective way of producing a multi-dense print.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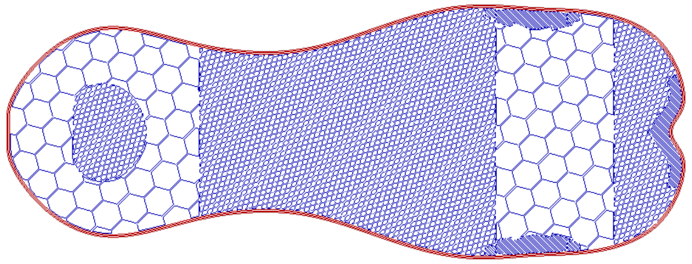
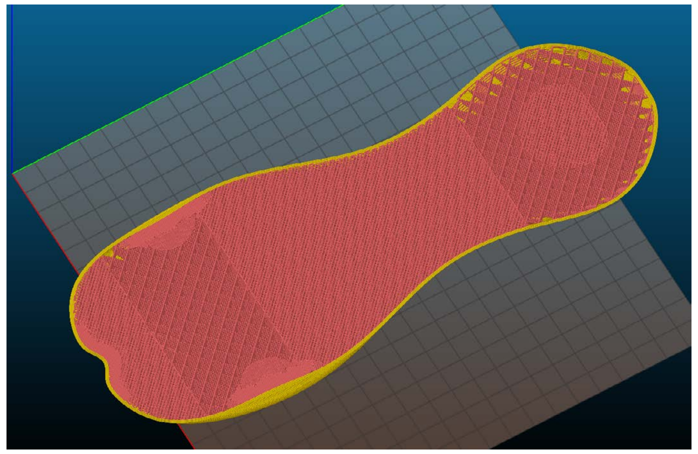


Why Slic3r does not work with the UP! Printers.

The UP! Printers and software is produced by Beijing based Tiertime Technology Co., Ltd. and unfortunately is not open source. This basically means the UP! software cannot read external slicing software/external G-Code. The only Slicing software the UP! printers can understand is the UP! software itself. This is apparently due to proprietary reasons.
In contrast to this for example, RepRap is a fully open source 3D Printer which can use a variety of slicer software.

Modifiers - Currently there is a G-code transcoder for the UP! printer in development by an external party. With a G-code transcoder developed for the UP! printers, external slicing software could be used and applied to the UP! printers.
See sources for details.



Slic3r
G-code generator for 3D printers

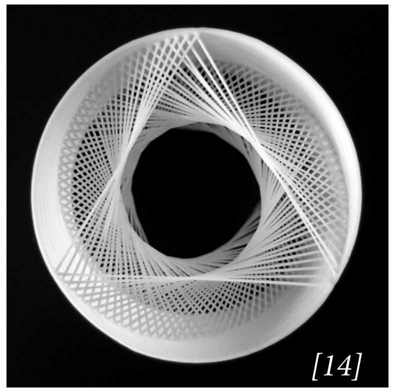
Grasshopper

Grasshopper is an algorithmic modeling plugin for the 3D modeling software Rhino. It is powerful piece of software and has an expansive application for the development, testing and modeling of variable density prints.

Listed are several plugins for Grasshopper which would be helpful in the development of variable density prints.

SilkWorm

“Silkworm is a plugin that translates Grasshopper and Rhino geometry into G-Code for 3d printing. Silkworm allows for the complete and intuitive manipulation of the printer G-Code, enabling novel printed material properties to be specified by non-solid geometry and digital craft techniques.”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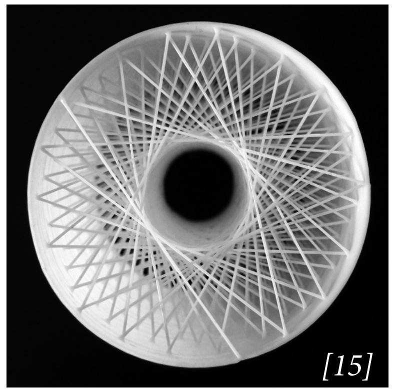
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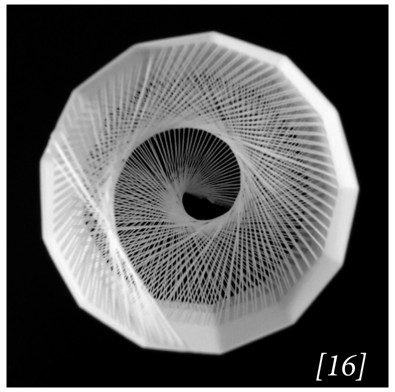
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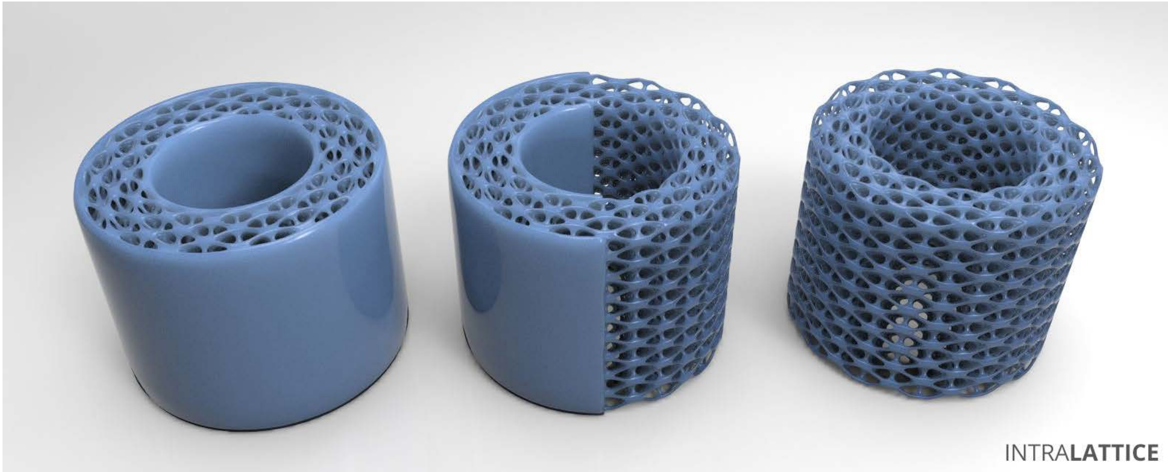
Intralattice

“Intralattice is a plugin for Grasshopper used to generate solid lattice structures within a design space”.



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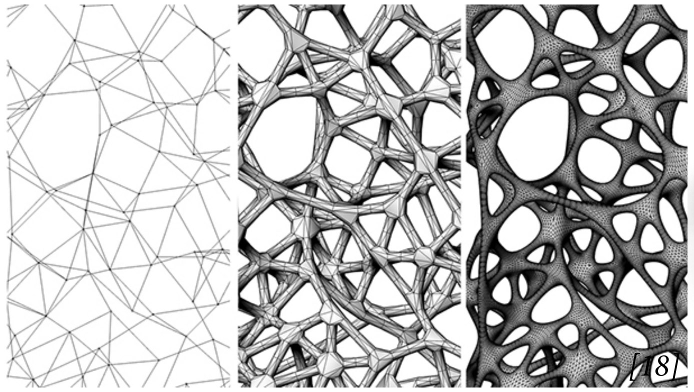
ExoSkeleton

Exoskeleton is a plugin for Rhino/Grasshopper and aids in creating thickened, wireframe meshes.



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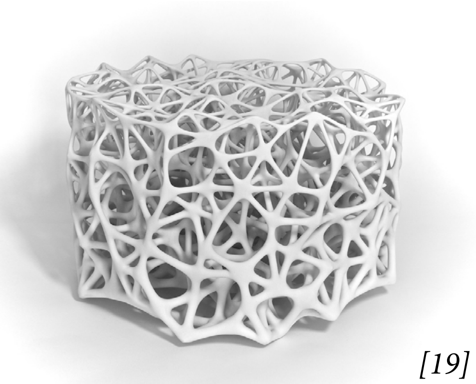

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3-maticSTL

Materialise's 3-maticSTL software offers the ability to reduce the weight of designs and optimise them through a range of changes directly to the STL file. Refer to adidas's 3D printed midsole to see the example of a structure this software can produce.

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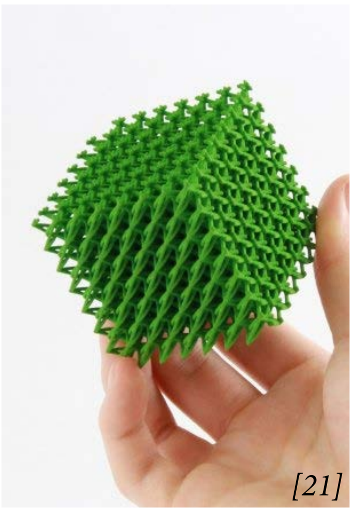

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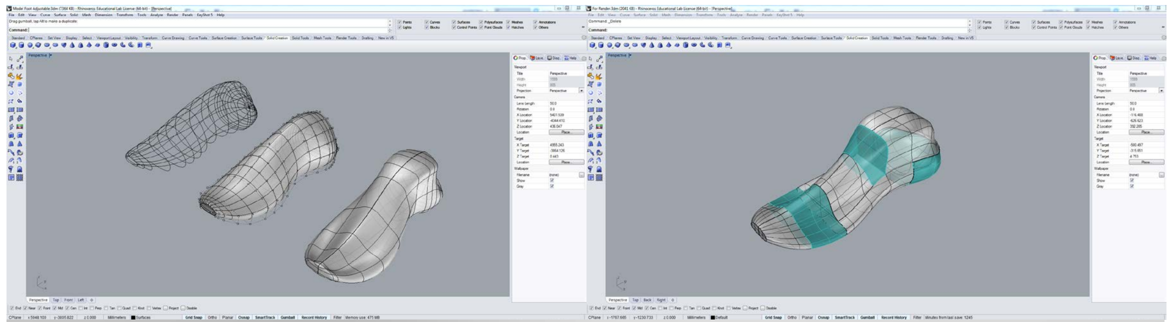
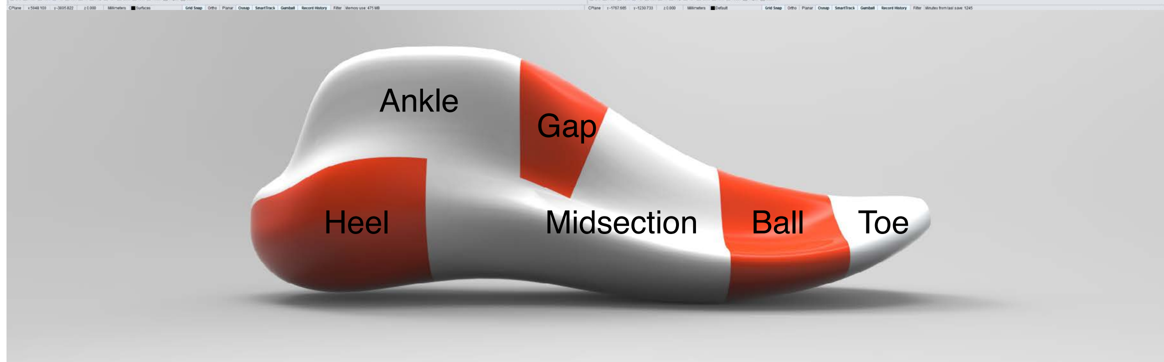
With 3-maticSTL you can:

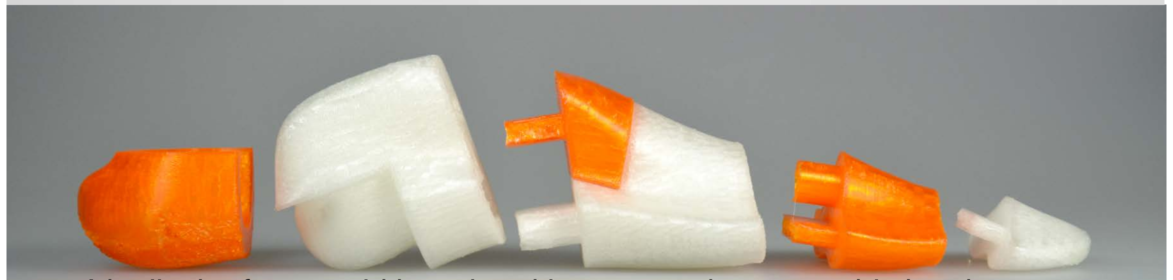
- Prepare your data for a quick and efficient finite element analysis;
- Design or repair missing or badly scanned components;
efficiently create textures, perforations and patterns on your STL data. Start from a 3D bitmap to be converted into textures or from a single pattern element to design an elaborate 3D patterning;
- Design impressive lightweight structures that lower weight without compromising on strength or that allow you to create variable flexibility and rigidness within a part;
- Efficiently change your design so that it can be tested in a wind tunnel

Taken directly from Materialise website

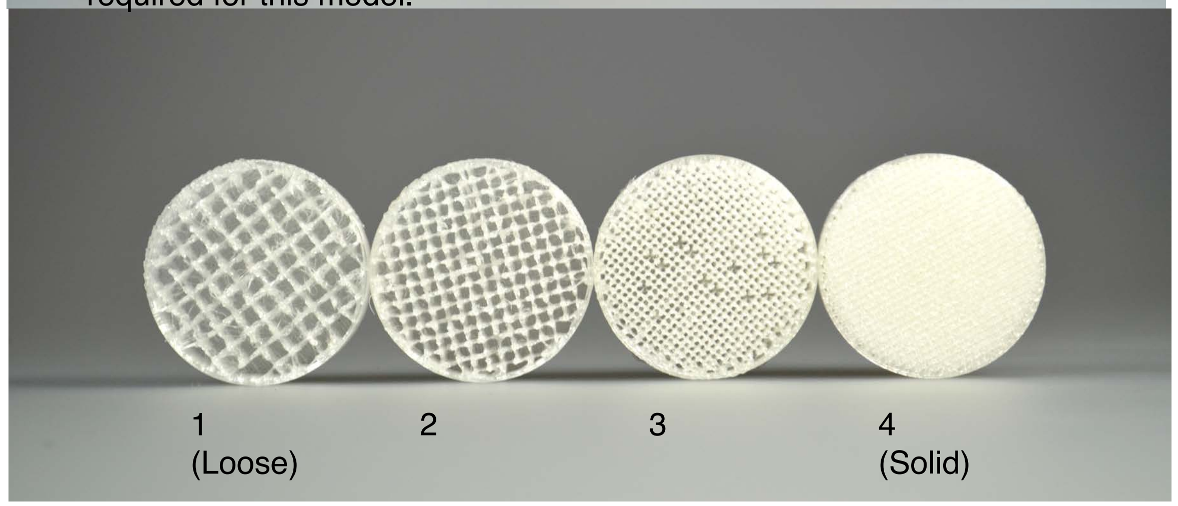
The prosthetic foot seemed an appropriate place to begin exploring variable density printing in TPU due to the foot requiring specific movements while maintaining strength, support and stability. The foot model was simplified and two types of areas were focused on to begin with; hard/dense areas and soft/loose areas. The dense areas are around those which need support and strength, e.g. the 'ankle', midsection and end 'toes', while the loose areas are those which need movement, flex and give, e.g. the 'heel' on heel strike, the gap between ankle and midsection and the 'ball of the foot section'.







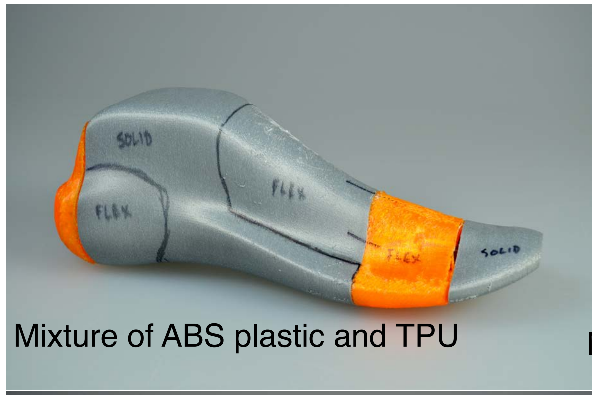
Ideally the foot would be printed in one go - but assembly has been required for this model.



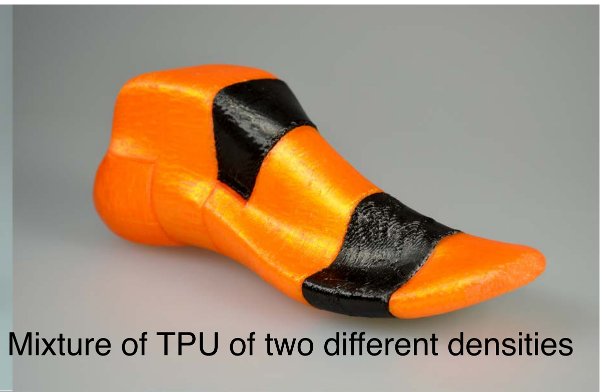
Testing the flex of the toe area. Each toe section was printed with a number 2 fill.

Testing flex of TPU

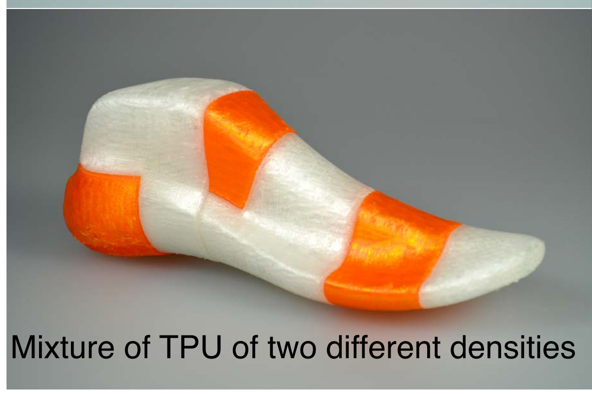
Print Fill 3 in TPU



Mixture of ABS plastic and TPU



Mixture of TPU of two different densities



Mixture of TPU of two different densities

One material print - TPU

INFORMATION DRIVEN

Areas We Addressed

- After initial discussions with the NZALS we addressed the future service of prosthetics. Looking at the user and the difficulties faced by amputees when it comes to getting another limb, going in for fittings and the process they must go through.

- Can design be used to benefit this process? Do prosthetics have to look like a pole, can we add some aesthetic element as well as adding function.

- What potential does structure have when it comes to printing physiology? Does subtle structure movements allow for controlled limb movement.

Speculative Amputee Process

As of now the amputee process takes around 6 weeks from start to finish including three visits by the client to one of the five clinics around New Zealand. This is not always easy for the patient.

We are speculating that the process a patient will go through will be focused around an improved service giving the patient the ability to order online from a distance simply due to the storage and generating of anatomical information. Firstly the patient will step into the generic limb where the size is adjusted to the patient. Then through a series of bioengineering and mechanical engineering an algorithm corrects the patients alignment, and stores these plot points as a file. After the information of the patient is generated, it is then made into a CAD model which can then be sent to print.

Most importantly, looking at the entire service this change in process generates a data base for NZALS. This data base can be used for added services and health care such as tracking health trends and having the ability to re print a patients limb without having to go through the entire process again like currently happens.

Speculative Amputee Process

1

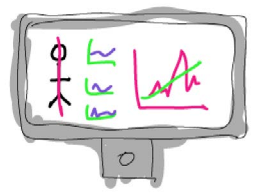
Patient Arrives

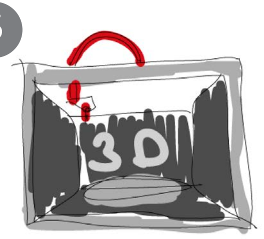
2

Generic Limb Fitted

3

Series of Exercises

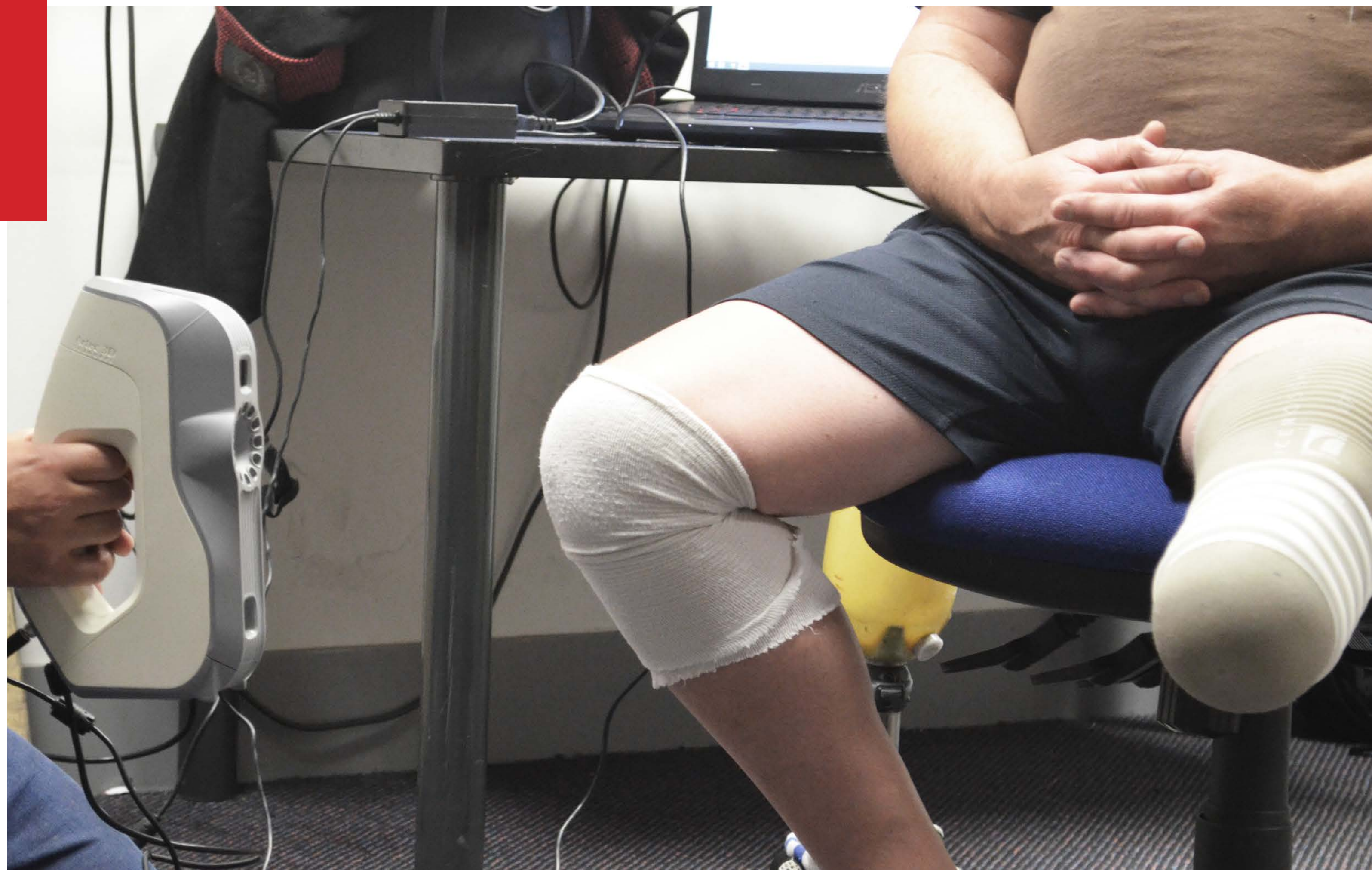
4

Accurate Static & Dynamic Data Generated

5


Data Analysed + Printed

6

Delivered via Courier



INFORMATION
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Mono-Material

Single material Fused Deposition Modelling printing is the most common form of printing. Printing in a range of materials from Flexible TPU to Strong rigid ABS Plastic and Nylon. This form of printing is most ideal when you need strength of simple organic forms, however it also has the great capability to print very simple and basic structures. (Examples in images)
The NZALS can make most use of these printers, they are economical to run and would provide a successful low end prosthetic for patients, particularly Trans-Tibial amputees together with the speculated information gathering process.

Multi-Material

As the human body is very complex with many movements' prosthetics find it difficult to replicate. Multi-material printing has the potential to provide complex dynamic prints that mimic the movement of a human limb. Today, multi-Material printing is still at the stage where is would not be sufficient to use as part of a limb due to the strength and brittle nature of current materials. However in the future this technology will improve to a reliable level.
This form of printing is not an economical option with both set up and running costs high. Therefore this would be used for high end printed physiology where the patient needs more human like dynamic movement.

ABS FDM Printing I Mono-Material

Evill, J. 2013.

Cortex Cast - Jake Evill 2013

Jake Evil's Context Cast is a great precedent for the use of a lattice structure within a healthcare product that is 3D printed. By using minimal material Cortex remains very light-weight yet still holds strength.

There is no reason why prosthetics in the future can look like this. Being lightweight, will aid the amputee as they do their day to day activities and as it will be made of plastic can easily be put in a standard dishwasher for its weekly or monthly clean.

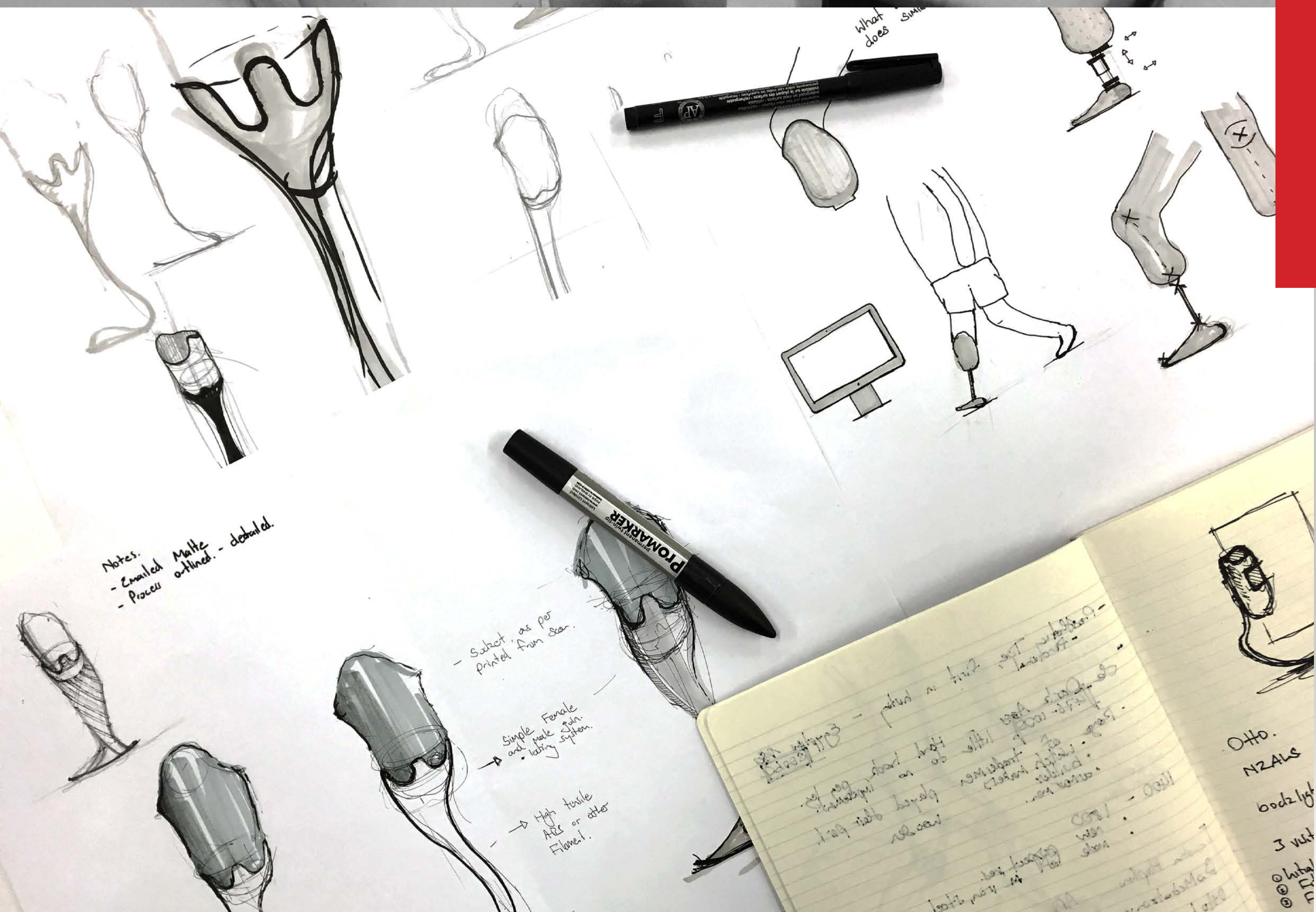
Other Insitutions

AUCKLAND BIOENGINEERING INSTITUTE
THE UNIVERSITY OF AUCKLAND NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

The Auckland Bio-Engineering Institute had four representatives that were present at the end of phase two of this project in December 2015 when presentation initial ideas and directions. Following the Prosthetics project presentation they gave an insight into what they do and ways they believe a collaboration could work.

The first part focused around the advancement in being able to scan tissue density. In the context of prosthetic limbs. The residual limb has many hard bone near the skin surface and man delicate soft tissue. This large change in density means that weight must be dispersed on specific parts and released in others. By having the information of where the dense and where the not so dense parts are it has the possibility to be used when multi-density printing which could both increase the comfort for the patient, yet also improve the patients socket fit.

The second piece of research that is very relevant to the NZALS futures project is what they call "Computational Anatomical Movement". This means that by the use of scanning, tracking and video analysing they can analyse the force of each muscle, the gait that the patient is taking and various other human body movement analysis. When looking at both the foot design and the information driven projects, this piece of research would fit very closely and prove to be very beneficial when tailoring each print to the patient.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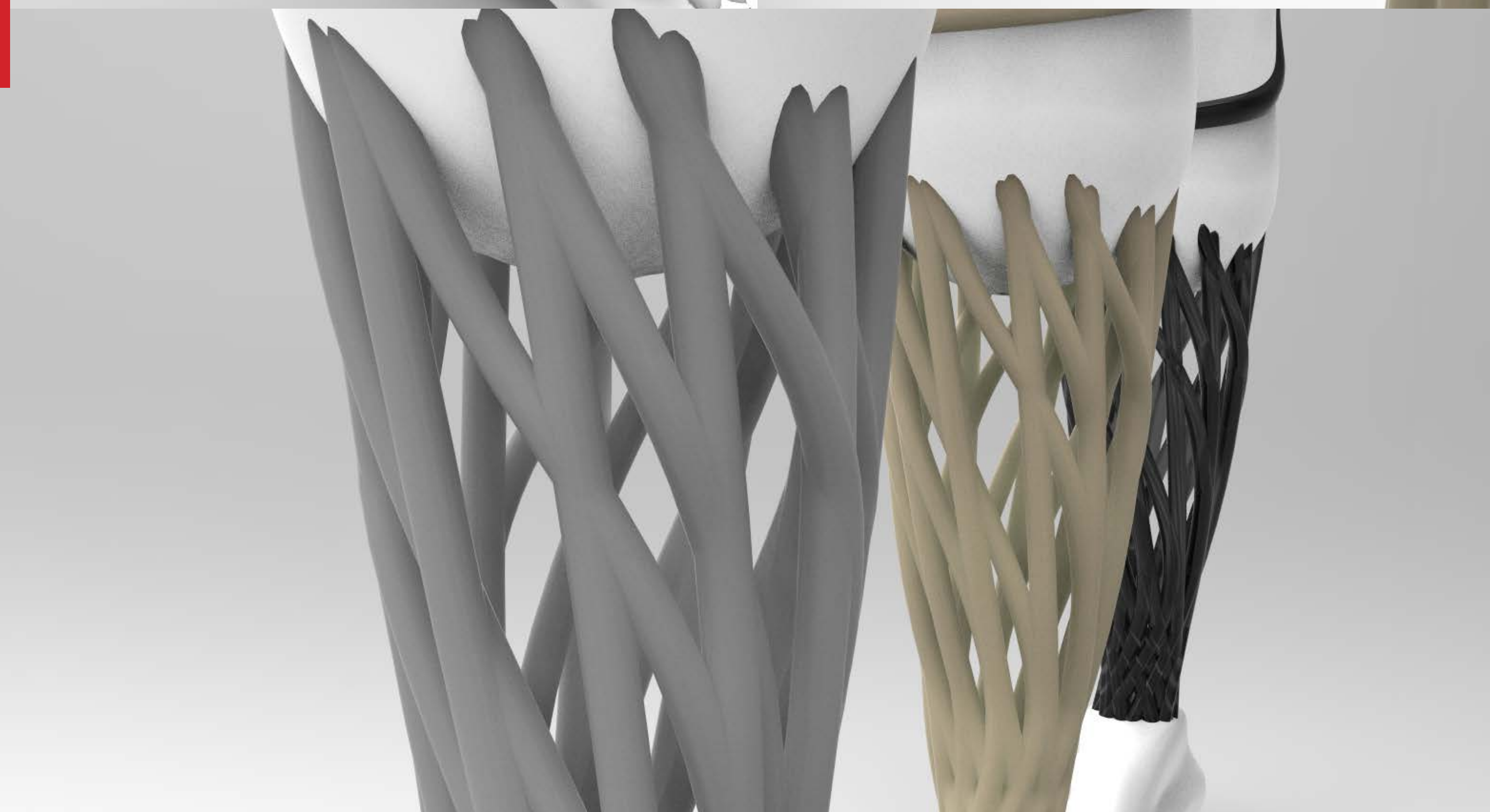

Conclusion

As the initial phase of investigating 3D Printing and Prosthetics Limbs has come to a close there are a few conclusions that can be made and directions that can be taken when moving forward. Looking at all four projects individually they all prove one significant factor. That being, 3D Printing and Prosthetic Limbs have huge potential. There is a gap in the market where these two parties are yet to work together past the conceptual design stage.

With Stratasys now providing tensile strength ratings for their FDM printing material it opens up the possibility for prosthetics to use 3D printing and pass sufficient tests.

The final significant finding and room for development is multi-material printing combine with multi-density scanning. This advancement could improve the comfort of the socket, knowing where to have soft material and where to have hard material would make a great improvement.

The human body is also very complex with multiple movements in a range of directions. As briefly displayed in the Multi-Material Foot, by printing in different densities and materials, it can improve the dynamic movements considerably. However, as multi-material printing is still in its early stages of development and is yet to be strong enough to withstand large forces and strains it is still a while away for this to be incorporated into the prosthetics industry. But the fact is, this will be the way 3d printing will go. Strong, multi-material printing that can withstand high levels of force, thus it is not unrealistic to start planning for this future technology.

What Next...

- Look to colaborate with other research institues like the Auckland Bio-Engineering Institute and/or mechanical engineering institue, developing on their research with multi density scanning and computational anatomical movement. People with engineering knowledge must be included into the project.

- Work with companies that are already in the market for adjustable systems and work together to create the most effective method of use.

- Resolving the issue of printing a variable dense model in one print with TPU, currently with the low end printers used throughout this project this was not achieved.

- Initially form a network with a industrial printing servcie in Australasia, possibly Materialise 3D to establish what will and what wont work when prototyping high end models before considering what printers to invest in if that is the desired direction.

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[16] Silkworm example 3
http://2.bp.blogspot.com/-K-CJ5UF4GkU/U0l5a_XnPJI/AAAAAAAACKQ/TGqIwiUqL6g/s1600/011.jpg?width=640

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