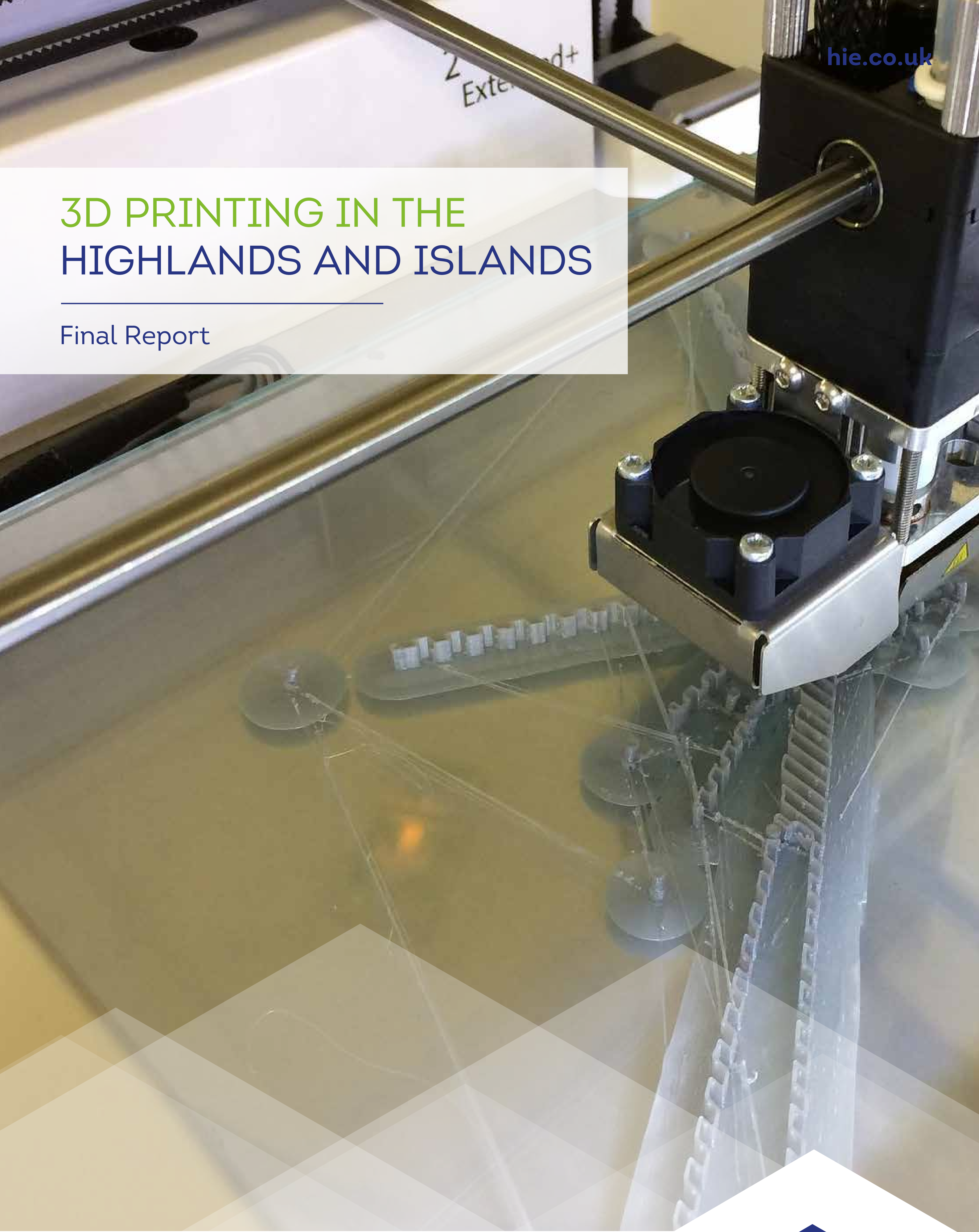

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3D PRINTING IN THE HIGHLANDS AND ISLANDS

Final Report

frontline
we help you do things better

Loughborough University
Centre for Research in Social Policy

HIE
Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

Contents

1 INTRODUCTION

Highlands and Islands Enterprise (HIE) commissioned Frontline Consultants Ltd (Frontline), in partnership with Loughborough University, to undertake exploratory research to investigate the potential of Three-Dimensional (3D) printing in the Highlands and Islands.

1.1 RESEARCH OBJECTIVES

Scotland's Economic Strategy[1] recognises the role of manufacturing in boosting productivity and highlights the importance of innovation in achieving this. The Highlands and Islands has seen growth in manufacturing over the last few years, such that in 2017 there were 1,160 manufacturing enterprises in the region. While dominated by micro businesses, the sector employs 16,700, an increase of 7% since 2011 against a Scottish average increase of 3% (178,810 to 184,210).[2]

Given the impact of manufacturing and the opportunities it presents to the region, HIE wanted to explore the use and applications of 3D printing. This research study sought to consider the following four objectives:

1. **Global trends in 3D printing:** provide an overview of global trends in 3D Printing and its role as an emerging digital technology.

2. **Applications for manufacturing in the Highlands and Islands**: explore the current application of 3D printing technology in manufacturing, particularly in Scotland's growth sectors, and the extent of its use across these sectors in the Highlands and Islands.

3. **Barriers and support needs:** explore the barriers that may prevent manufacturers from capitalising on the benefits of this emerging technology, and what support might be required to help the business community adapt to the change.

4. **Disruptive effects and implications of non-adoption**: explore implications to industry and public sector.

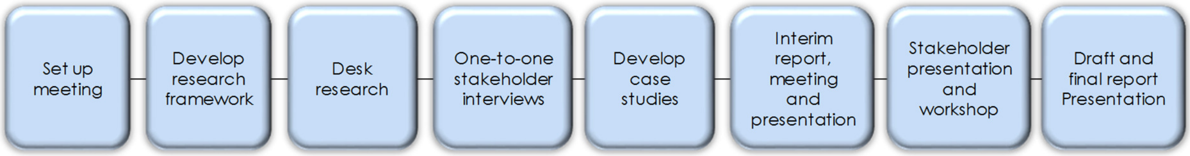
1.2 OUR APPROACH

The approach included a mix of desk research and extensive consultation across a range of public and private sector stakeholders. A total of 51 face-to-face and telephone interviews were conducted with 30 stakeholders and 21 businesses and a half day workshop was carried out with HIE staff to explore how they could develop the opportunities from 3D printing. Stakeholders included representatives from industry leadership groups, publicly funded organisations, education and the third sector.

Following consultation, a series of case studies were developed, including visits to companies and initiatives that were using 3D printing and supporting technologies. Findings were shared during a workshop with staff from across all areas of HIE, to develop their knowledge and awareness and to explore further where opportunities could arise. Appendix 1 presents the full list of stakeholders interviewed.

[1] http://www.gov.scot/topics/economy/economicstrategy
[2] IDBR (2017)

The diagram below summarises the approach.



1.3 REPORT STRUCTURE

The report is structured as follows:

- **Section 2** provides an overview of global trends in the 3D printing market.
- **Section 3** explores the commercial benefits associated with 3D printing, and how the technology can be applied to businesses in the Highlands and Islands economy.
- **Section 4** considers some of the barriers businesses may experience when adopting 3D printing technology in the Highlands and Islands, the potential disruptive effects associated with 3D printing, the implications for the region of not adopting the technology and the role the public sector can play in supporting businesses.
- **Section 5** highlights the conclusions of this research and provides recommendations around what support public sector and partners could provide in future to help facilitate the uptake of 3D printing in the Highlands and Islands.

2 GLOBAL TRENDS IN 3D PRINTING

2.1 HOW 3D PRINTING WORKS

The term 3D printing is increasingly used as a synonym for additive manufacturing (AM), but 3D printing is one of several AM processes. The key AM processes are described in Section 2.2. AM describes the technologies that build 3D objects by adding layer-upon-layer of material.

Figure 2.1 provides an overview of the key steps taken to develop a 3D printed object:

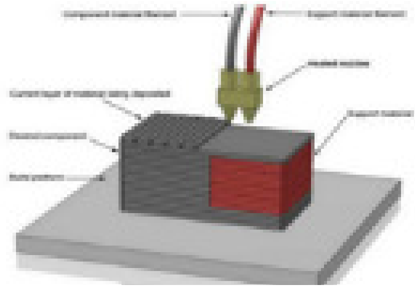
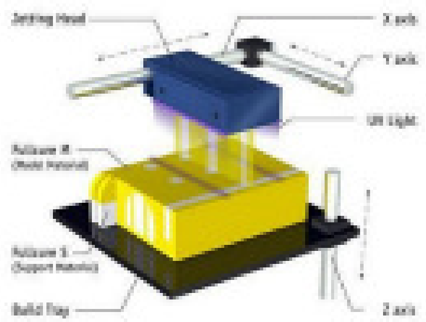
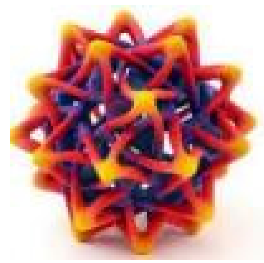
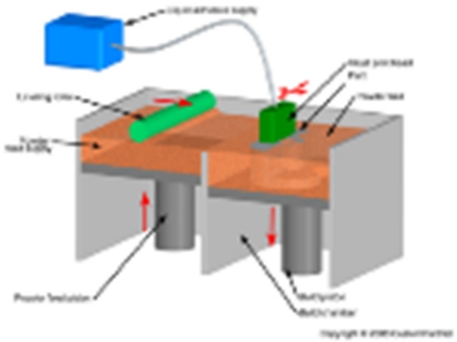
- Step 1 – create a 3D model of the object to be printed (e.g. with computer-aided design (CAD) software)
- Step 2 – convert the CAD file to a standard additive manufacturing file format (e.g. an STL file)
- Step 3 – transfer of the STL file into slicing software to produce layer slices
- Step 4 – layer slices are converted to tool paths to control the 3D printer movement
- Step 5 – the 3D printer builds the model layer by layer
- Step 6 – the model is ready to be removed from the 3D printer and additional post processing may take place (e.g. cleaning, polishing, painting and finishing of the surface)

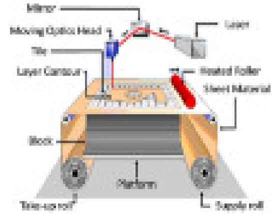
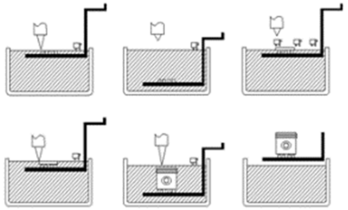
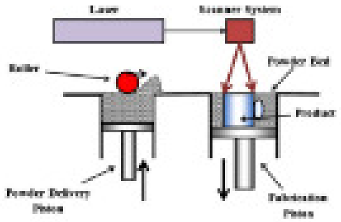
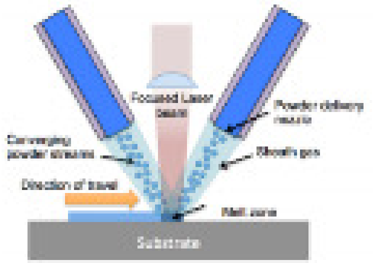
Figure 2.1 Steps taken to develop a 3D printed object

2.2 TYPES OF 3D PRINTING PROCESSES

In 2010, the American Society for Testing and Materials (ASTM) International Committee F42 on Additive Manufacturing Technologies voted on a list of AM process category names and definitions. The committee approved the classification processes into seven categories as presented in Table 2.1.

Table 2.1 The Seven Categories of Additive Manufacturing Processes

Process	Definition	
Material extrusion	This is the most popular method for low-cost machines. Molten thermoplastic material is selectively dispensed through a nozzle or orifice.	 
Material jetting	Droplets of build material are selectively deposited. Liquid photopolymer resin "ink-jet" is printed onto a platform. Capable of multi-material or multi-coloured parts.	 
Binder jetting	A liquid bonding agent is selectively deposited to join powder materials. Liquid binder is "ink-jet" printed onto a powder substrate. Capable of multi-coloured parts. Parts normally require post-process infiltration to acquire strength.	 

Sheet lamination	Sheets of material are bonded to form an object. Each sheet has a 2D profile cut into it by a blade or laser. Capable of multi-coloured parts.	 
VAT photopoly-merisation	Liquid photopolymer resin in a vat is selectively cured by light-activated polymerisation. Top surface of resin is solidified by laser or UV lamp. Recently available as a low-cost machine.	 
Powder bed fusion	Thermal energy (e.g. laser or electron beam) selectively fuses regions of a powder bed. Very robust parts can be created, including metal parts.	 
Directed energy deposition	Focused thermal energy is used to fuse materials by melting as the material is being deposited. Powder material is blown into path of a laser beam to create a “melt pool”. Alternative technology uses a wire feed material. Very expensive process, mostly used for metals.	 

Source: Wohlers Associates, Inc.

2.3 MATERIALS THAT CAN BE USED FOR 3D PRINTING

The different methods that the seven categories use to process material are compatible with different types of materials. Some of the categories can process a wide range of materials, e.g. binder jetting and powder bed fusion, whereas others can only process a limited range of materials, e.g. directed energy deposition. This depends on the melting point of solid materials, the viscosity of liquid materials and whether the materials will change phase when subjected to light. The different types of materials compatible with the seven categories are shown in Table 2.2.

Table 2.2 3D Printing Compatibility

	Material extrusion	Material jetting	Binder jetting	VAT photopoly-merisation	Sheet lamination	Powder bed fusion	Directed energy deposition
Polymers, polymer blends	X	X	X	X	X	X	
Composites	X		X	X		X	
Metals			X		X	X	X
Graded/hybrid metals					X		X
Ceramics			X	X		X	
Investment casting patterns	X	X	X	X		X	
Sand moulds and cores	X		X			X	
Paper					X		

Source: Wohlers Associates, Inc.

In future, a greater range of polymers and metals will become available. Materials test standards are becoming increasingly available through the ASTM International F42 Committee and other international standards organisations. The most common materials used are:

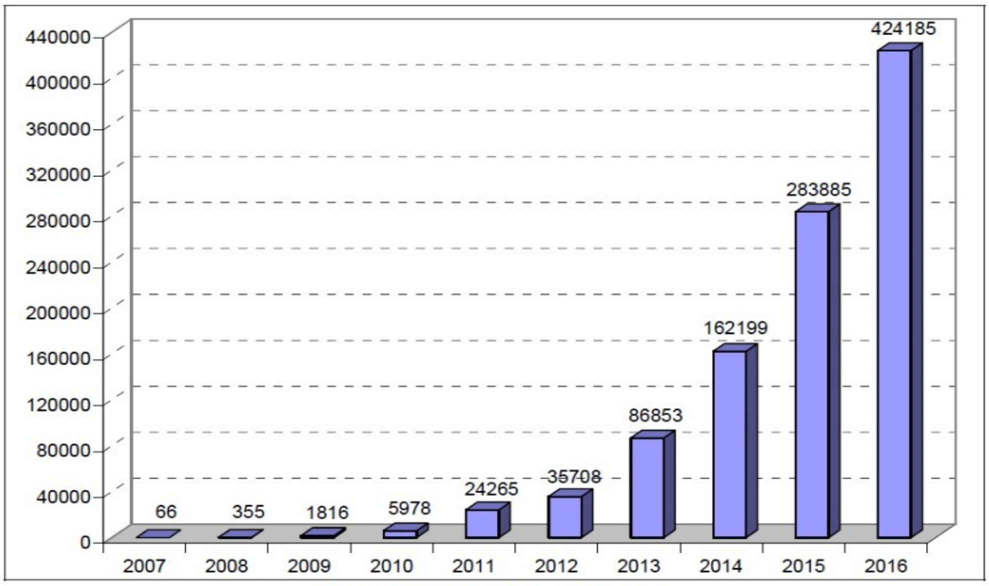
- general purpose plastics and polymers – affordable, durable and widely available plastics like nylon, ABS, PC and PLA
- metals – steel, titanium, aluminium, cobalt chrome alloy, precious metals
- ceramics – silica/glass, porcelain, silicon-carbide
- specially formulated photopolymers that try to replicate the material properties of common plastics

2.4 THE COST OF 3D PRINTING

The consumer 3D printing market was only established in 2009. This followed the expiration of the patent which applied to fused deposition modelling (FDM). Prior to 2009, 3D printing was confined mostly to industrial cases. (Thomson Reuters, 2016)

3D printers can cost anything from £300 to over £1m, with many low-cost options now available. Figure 2.2 illustrates the growing demand for low-cost 3D printers, generally accepted as costing less than $5,000.

Figure 2.2 Increasing sales of low-cost 3D printers (less than $5000), Sales Volume per Year



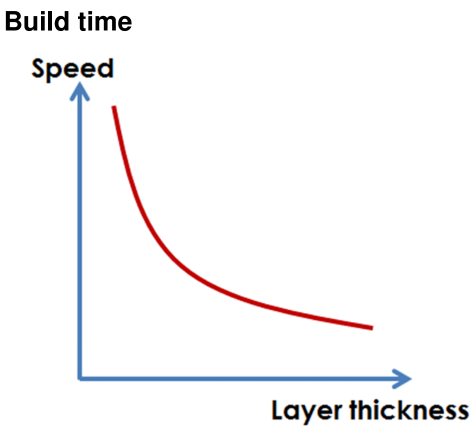
Source: Wohlers Associates, Inc.

Low-cost systems are mainly material extrusion systems suitable for "garage" manufacturing. High-cost systems are typically laser-based powder-bed fusion systems used predominantly in large original equipment manufacturers (OEMs), service bureaus or universities.

2.5 LENGTH OF THE 3D PRINTING PROCESS

The build time (i.e. the time to print) is typically measured in millimetres per hour and depends heavily upon the layer thickness - the thinner the layer the longer it takes to build the product. Both the printer and the design impact on layer thickness and quality of output.

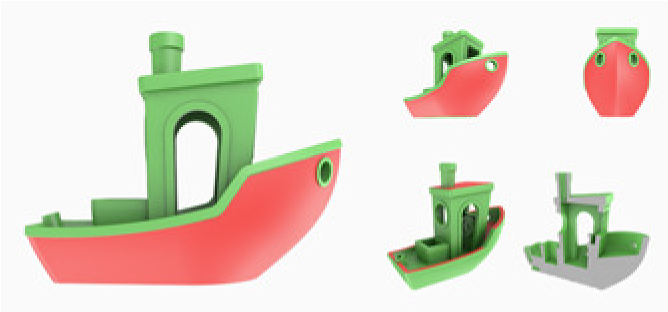
Figure 2.3 Build-time of 3D printing



The build method also plays a key role with laser scanning being quicker than extrusion. Until 2015, the maximum speed under any method was around 25mm per hour. However, with the introduction of their high-speed jet fusion system in 2016, Hewlett Packard (HP) claimed printing speeds of up to 10 times faster than previously possible.

Taking the example of the 3D Benchy boat (shown in Figure 2.4), a 3D model that is specifically designed for testing and benchmarking 3D printers, we can show a typical build speed for extrusion-based 3D printers. The boat is 6cm long, 4.8cm high and 3.1cm wide. Based on an extrusion speed of 100mm/s, the boat took on average of 2 hours to print using an Ultimaker 2 system (using recommended parameter settings) (Source: aa3sp.com).

Figure 2.4 3D Benchy boat



Source: 3DBenchy.com

While the cost of 3D printers has decreased, the length of time required to print a small object remains ineffective for low value and quick turnaround goods. An increased 3D print speed can be generated by using:

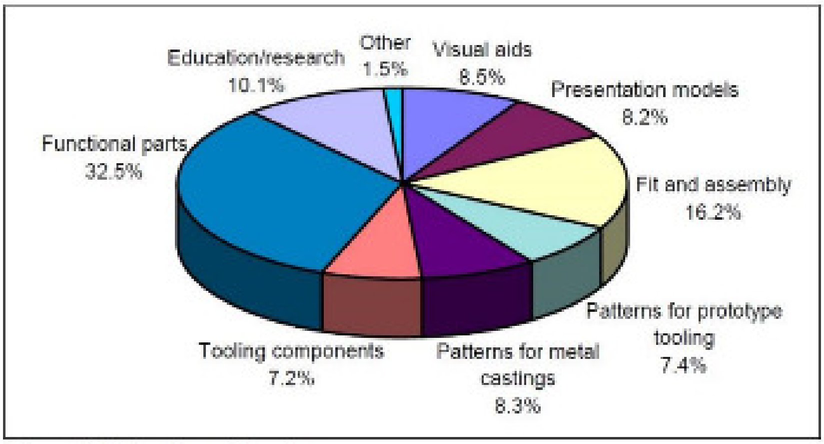
- multiple lasers
- thermal accelerators in powder bed systems
- variable extruder diameters
- printing thicker layers accompanied by machining of edges
- or creating larger build areas so that time per part is reduced

While the low-cost 3D market may be confined to small size and longer print times, academic-private collaborations promise to deliver a step change in 3D printing speed for the industrial market.

2.6 SIZE OF THE GLOBAL 3D PRINTING MARKET

Figure 2.5 shows the different uses for 3D printed parts. The largest sector is *"functional parts"*, which refers to end use components. This sector has grown rapidly in the past decade as the capabilities of 3D printers have improved. It was less than 10% in 2006 and is now over 30%. Most of the other sectors are either related to different kinds of prototypes or tooling applications.

Figure 2.5 Different uses for 3D printed parts (2016)



Source: Wohlers Associates, Inc.

Market projections forecast significant growth in the coming years. Gartner (2016) projects that:

- the 3D printing market globally will grow from $1.6bn in 2015[3] to $13.4bn in 2018, attaining a 103.1% compound annual growth rate (CAGR)
- shipments of 3D printing devices are expected to double each year to more than 5.6 million in 2019
- 3D printers costing less than $1,000 will account for over 25% of devices costing up to $2,500 (2016), but will increase to over 40% by 2019

Siemens also predicts that 3D printers will become 50% cheaper and 400% faster in the next five years (Forbes 2015).

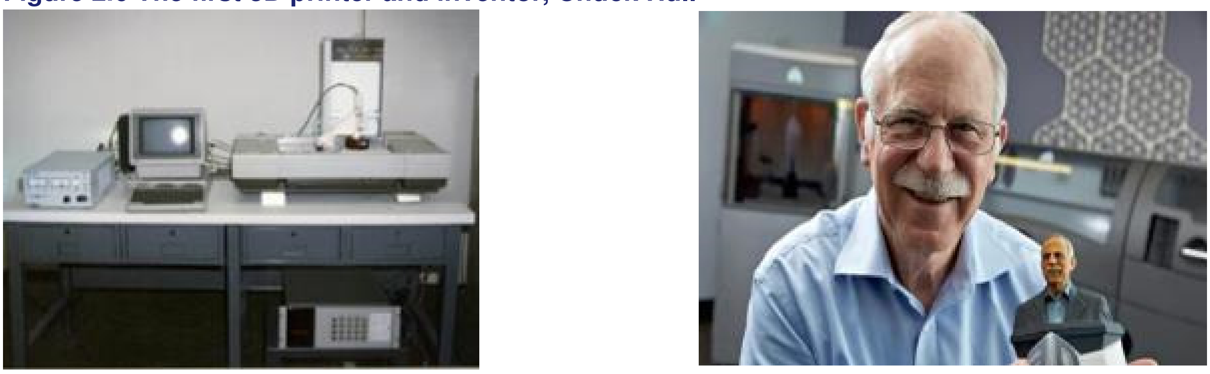
Market trends include:

- a developing desktop/consumer market – more than 278,000 desktop 3D printers (under $5,000) were sold globally in 2015 (Wohlers, 2016) and 85% belong to the desktop/consumer segment (Context, 2015)
- increased demand for desktop 3D printers in schools and academic institutions
- a growth in personal usage to develop sculptures, avatars and figurines
- better availability and cheaper materials (metals and wax) are driving market growth (M&M, 2016)
- laser metal deposition (LMD) is expected to be the fastest growing technology in the 3D printing market during 2016-2022 (M&M, 2016)

2.7 HOW THE MARKET EVOLVED

Chuck Hull invented the first ever 3D printer, the "SLA-1" in 1983. The stereolithography apparatus (SLA) machine was created to speed up the lengthy time-frame for prototype development.

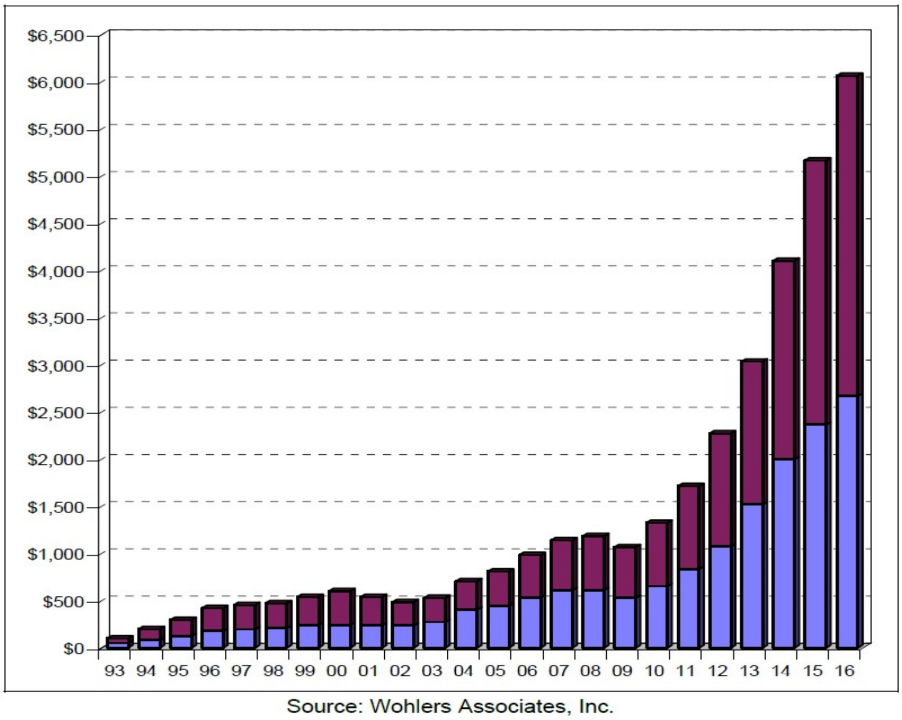
Figure 2.6 The first 3D printer and inventor, Chuck Hull



In the 1980s, a 3D printer would cost in the region of $300,000, which translates into current values at almost $650,000 (Wohlers, 2016). Machine costs have therefore reduced considerably in real terms. However, since the 1990s, the monetary size of the 3D printing market has grown considerably, as presented in Figure 2.7. While this growth has slowed from 32.7% with a market size of $2.3bn in 2012, to 17.4% with a market size of $6.1bn (2016), it is still very high and expected to remain in double digits. (Wohlers, 2017).

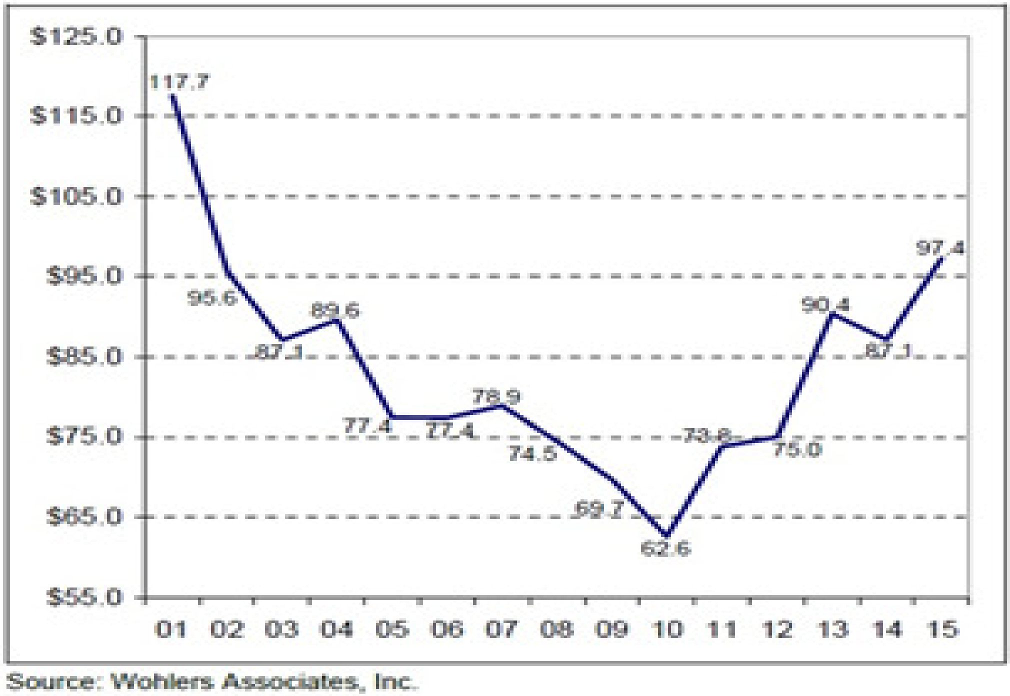
[3] This is less than the Wohlers projection quoted in Section 2.7 which assessed market size at $5.2bn in 2015 (and $6.0bn in 2017). From our understanding, Wohlers looked at the overall AM market including materials and services.

Figure 2.7 Growth of 3D printing market – Value ($bn) vs Year – Split by Blue – Materials and Red - Services



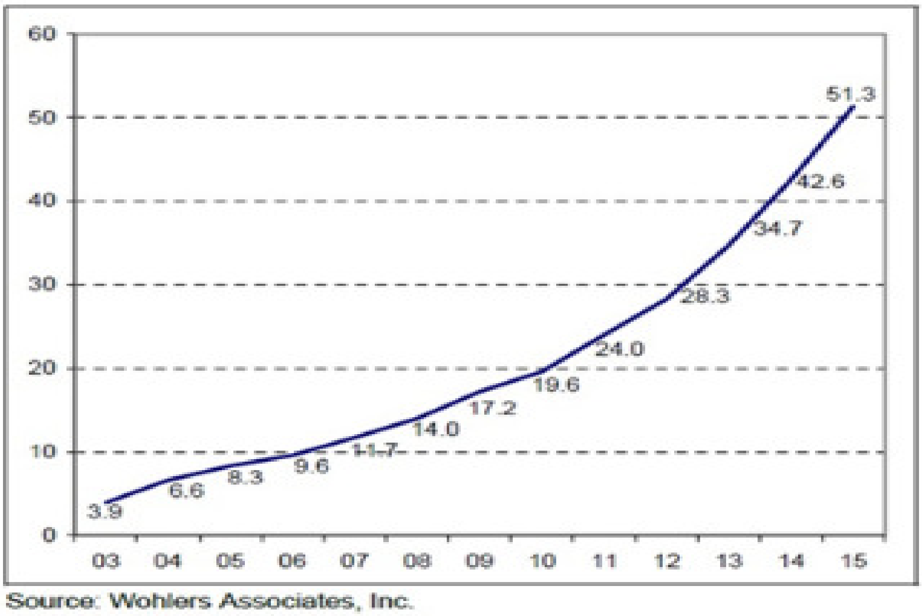
This market growth is in line with the increasingly accessible price of industrial 3D printers, the growth of the consumer 3D printing market and the increasing use of 3D printing in production (as presented in Figures 2.8 and 2.9).

Figure 2.8 Average selling price ($k) of industrial 3D printers between 2001 and 2015



The rise in average selling price after 2010 is due to a growth in the sale of expensive metal systems which cost above £500k per machine.

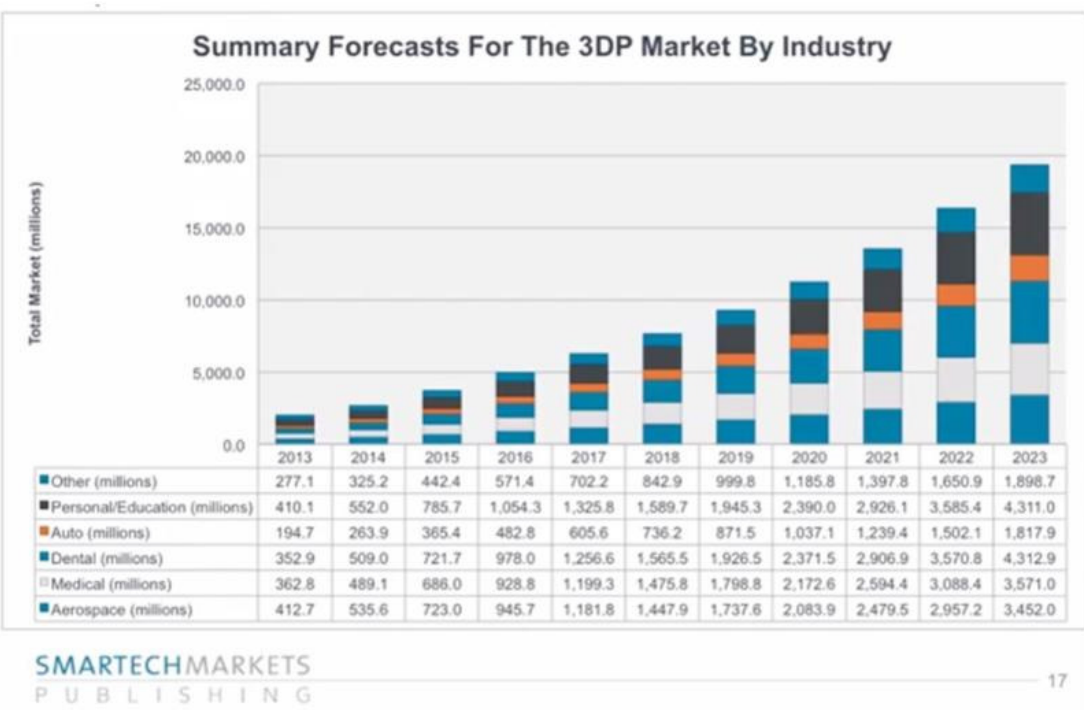
Figure 2.9 3D Printing increasingly used in production (% of market versus year)



In 2016, Ingersoll and the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) announced that they will soon begin developing the world’s largest 3D printer which will feature a build volume of 7m x 3m x 14m. **It is expected to take 3D printing up to 450kg of material per hour, transforming large-scale 3D printing.**

Figure 2.10 shows that the market for 3D printing is expected to see steady growth through to 2023 across all sectors. Strongest growth will be in dental and personal/education, which will increase to $4.3bn (from $0.35bn and $0.41bn respectively in 2013). Medical will reach $3.57bn and aerospace $3.41bn (from $0.36bn and $0.41bn, respectively).

Figure 2.10 Summary forecasts for the 3D printing market by industry



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Other (millions)	277.1	325.2	442.4	571.4	702.2	842.9	999.8	1,185.8	1,397.8	1,650.9	1,898.7
Personal/Education (millions)	410.1	552.0	785.7	1,054.3	1,325.8	1,589.7	1,945.3	2,390.0	2,926.1	3,585.4	4,311.0
Auto (millions)	194.7	263.9	365.4	482.8	605.6	736.2	871.5	1,037.1	1,239.4	1,502.1	1,817.9
Dental (millions)	352.9	509.0	721.7	978.0	1,256.6	1,565.5	1,926.5	2,371.5	2,906.9	3,570.8	4,312.9
Medical (millions)	362.8	489.1	686.0	928.8	1,199.3	1,475.8	1,798.8	2,172.6	2,594.4	3,088.4	3,571.0
Aerospace (millions)	412.7	535.6	723.0	945.7	1,181.8	1,447.9	1,737.6	2,083.9	2,479.5	2,957.2	3,452.0

Source: 3D Printing 2014 A Survey of SmarTech’s Annual Market Findings. (Forbes, 2015)

2.8 EARLY ADOPTER

Two of the biggest early adopters of 3D printing have been the automotive and aerospace industries, the sections below discuss some of the ways in which they have used the technology.

2.8.1 Automotive

The automotive industry has been researching the applications of 3D printing since the early 1990s. Their adoption of 3D printing is projected to increase from $365.4m in 2015 to $1.8bn in 2023, attaining a 22% cumulative annual growth rate (CAGR). For many years, automotive manufacturers have been using 3D printing for prototyping, but the industry is now applying the process beyond the manufacturing of small custom parts.

Figure 2.11 A 3D print of an Aston Martin steering wheel

Source: ComputerWeekly.com

In 2011 KOR EcoLogic in partnership with Stratasys introduced the Urbee Car ("urban electric"). This included the world's first 3D–printed car body, an ultra-aerodynamic design that was highly energy efficient. The full prototype, launched in 2013, used electric motors, backed up by a small ethanol-powered engine, and was capable of 200 miles per gallon (mpg)[4]. The company is currently developing Urbee 2, an enhanced version which they plan to drive from San Francisco to New York, using just 10 litres of biofuel.

Figure 2.12 The world's first 3D printed car body on the Urbee

Source: Kor Ecologic (2013)

[4] BBC News, 2011; https://3dprint.com/124086/3d-printed-urbee-2-car/; https://korecologic.com/

Wider applications of 3D printing in the automotive industry include Formula 1, where bespoke 3D products have been used to improve performance. Other examples include:

- consolidation of multiple components into a single complex part
- creating production tooling
- producing spare parts and components
- decreasing the product development cycle with rapid prototyping, form and fit testing

Case Study – CA Models Stirling

In Scotland, Stirling-based CA Models uses 3D printing among other techniques, to create models for a wide range of clients, including Formula 1 race teams requiring parts for wind tunnel tests. In 2016, CA Models invested £805k in the UK's largest commercially operated SLM metal 3D printer with funding support from Clydesdale Bank. (Source: Business Quarter)

The printer was manufactured in Germany and is the only machine of its kind in the UK available for commercial use. CA Models is now increasing the number of parts it produces for Formula 1 cars. They will print components with internal fluid-air channels which is not possible by standard machining operations.

2.8.2 Aerospace

To stay at the cutting-edge of innovation, key players in the aerospace industry have long been researching the uses of 3D printing in aircraft production. The aerospace industry's adoption of 3D printing solutions is projected to increase from $723m in 2015 to $3.45bn in 2023, a 19% CAGR (Forbes, 2015).

Figure 2.13 3D printed aerospace parts

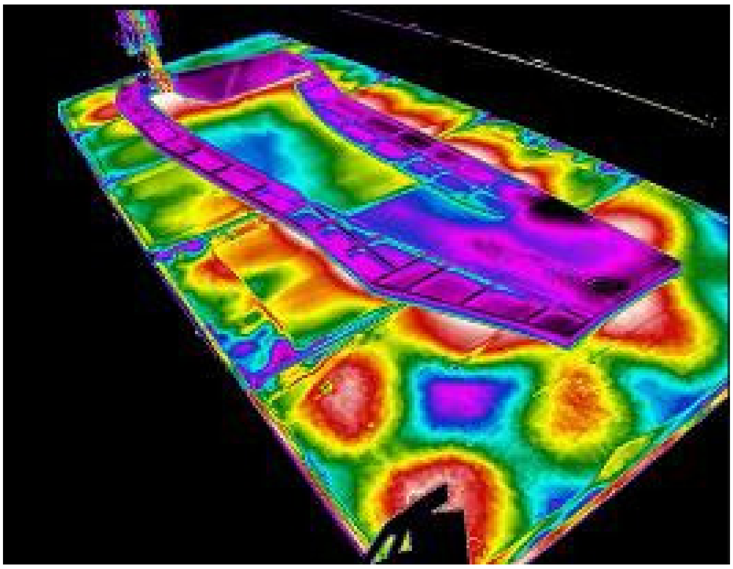
In the aerospace industry, 3D printing has been used to deliver greater efficiencies to develop a single product that would otherwise have had to be the sum of multiple parts joined together. 3D printing also helps to deliver less waste compared to traditional manufacturing methods as 'waste cut offs' cannot generally be reused in aerospace. Other benefits within the aerospace industry include:

- creating lighter parts
- creating complex geometry parts not possible with traditional manufacturing approaches
- controlling the density, stiffness, and other material properties of a part

Boeing has been researching 3D printing since 1997. They have been working with the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) since 2014 to deliver a week-long training programme for engineers focused on 3D printing. Currently there are around 50,000 3D printed parts flying on Boeing commercial, space and military products (Boeing.com).

In 2016, Boeing and the ORNL created the largest solid object 3D-printed in a single piece. The printed product, referred to as a "trim-and-drill" tool, will help create the wings of Boeing's next-generation 777X jet. The world record breaking-piece is 17.5 feet long, 5.5 feet wide, and 1.5 feet tall, and is comparable in length to a large sport utility vehicle (see Figure 2.14).

Figure 2.14 Still frame of an infrared video of the making of the world's largest solid 3D printed item



Source: Boeing.com

Boeing believes that 3D printing tools "will save energy, time, labour and production cost and are part of our overall strategy to apply 3D printing technology in key production areas". In 2014, BAE Systems said that British fighter jets had flown for the first time with components made using 3D printing technology. BAE Systems printed 3D parts for four squadrons of Tornado GR4 aircraft and aim to save £1.2m of maintenance and service costs over the next four years. BAE Systems believe that 3D printers of tomorrow could be so advanced by 2040, that they will be able to create small unmanned aircraft. These unmanned aerial vehicles (UAV) could then be deployed as a group of wide-winged aircraft for protracted or enduring surveillance or as rotary-winged UAVs to rescue civilians or soldiers from dangerous situations (BAE Systems); an artist impression is shown in Figure 2.15.

Figure 2.15 Artist impression of a small unmanned aerial vehicle (UAV) carrying a person

Source: BAE Systems/PA

In Scotland, CA Models has been working in the aerospace industry for over 20 years, providing prototype models that have played key roles in industry developments. They are now using metal additive manufacturing parts with integral honeycomb structures to retain maximum strength whilst substantially reducing weight. They are also developing Fused Deposition Modelling (FDM) fire retardant production parts for use across the aerospace sector. (Source: CA Models)

2.9 HOW THE MARKET AND THE TECHNOLOGY IS EXPECTED TO EVOLVE IN THE FUTURE

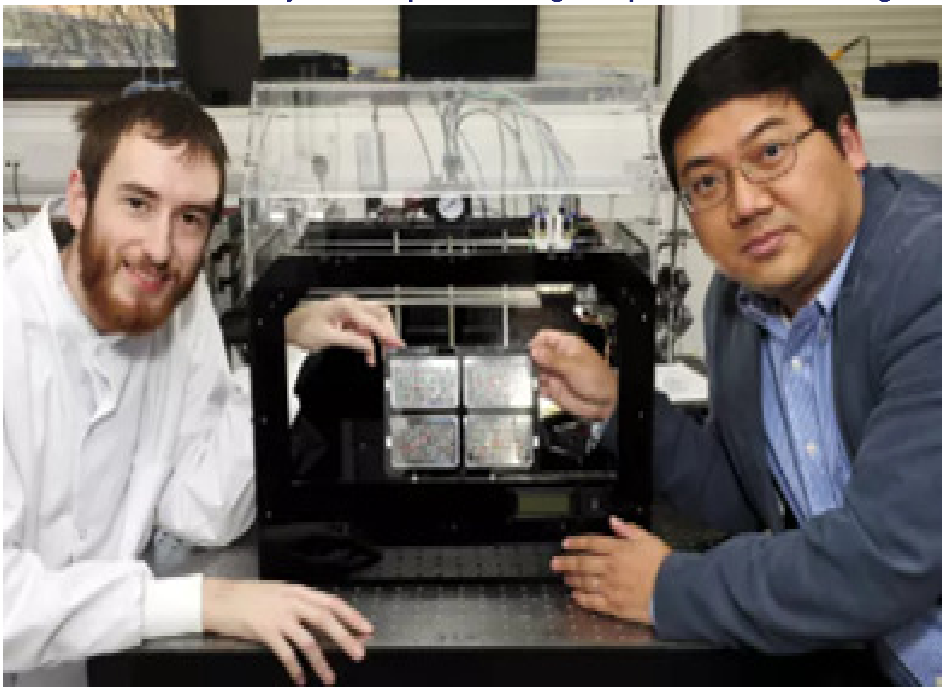
Future trends in 3D printing include the rise of the DIY Maker Movement and an increase in file-sharing and web-based collaborative problem-solving in open source web use. There will also be a greater range of materials, reduced costs and faster print speeds, moving closer to the economic printing of complete products.

3D printing has the potential to revolutionise the way in which we live and work in tomorrow's world. A sample of innovative and potentially life-changing 3D printing projects include:

- Heriot-Watt University's 3D bioprinter has developed a new DNA gel to enable production of artificial organs
- Wake Forest Baptist Medical Centre, USA has printed a custom-made ear
- 3D printed office in Dubai

Heriot-Watt University believe that their technique could be used to help ensure copies of body parts including the heart, liver and kidneys are available immediately, potentially bringing an end to years of waiting times for lifesaving transplant operations. This could also replace the practice of animal testing. They believe this project has been a good example of cross-disciplinary team effort, as chemists, engineers and biologists have come together from China and Scotland, to produce, test and demonstrate advantages of the product. Heriot-Watt added that the large-scale "bio-factories" – capable of manufacturing stem cells in quantities sufficient for mass-manufacture of organs – are still years away.

Figure 2.16 Heriot-Watt University - developed a DNA gel to produce artificial organs.



Source: Heriot-Watt University

A team at Wake Forest Baptist Medical Centre developed a new technique that 3D-prints a tissue filled with micro-channels, like a sponge, to allow nutrients to penetrate the tissue. The research team reported that the sections of bone, muscle and cartilage all functioned normally when implanted into animals. Their research raises the hope of using 3D printed living tissues to repair the body, such as an ear as shown in Figure 2.17.

Figure 2.17 A custom-made 3D printed ear

Source: • Wake Forest Baptist Medical Centre

In 2016, the Dubai Museum of the Future Foundation developed what it describes as the world's first '3D printed building' using cement-based printing materials. The building was developed over 17 days at a cost of about $140,000, after which the interior and exterior design details were added. While one person was employed to monitor the 3D printer, a further seven people were responsible for the installation of building components on-site, and another 10 electricians and other specialists looked after the engineering. **Building the office in this way generated reported savings of 50% on normal labour costs.**

Initially, the office housed the Dubai Future Foundation and will eventually be used as a workspace and may also be used to host exhibitions, workshops and other events. Dubai plans to 3D print 25% of all buildings by 2030.

Figure 2.18 3D printed office in Dubai

In a recent article by Quartz Media (March 2018), it was reported that "In the near future, building a new home may be as easy as printing out an airline boarding pass."

New Story, a charity that works to build houses for people in developing nations, and Icon, a robotics construction company in Austin, Texas, unveiled what is believed to be the first 3D-printed house that meets all regularity requirements and is habitable. Each house features a living room, bathroom, a bedroom, and a study/second bedroom.

The two organisations came together to show that it's possible to build an easy-to-replicate house in under 24 hours. They plan to take this proof-of-concept and start producing small houses for families in countries like Haiti and El Salvador. The 800-sq-ft house cost around $10,000 to build using Icon's proprietary Vulcan printer, but the company plans to eventually bring that price down to around $4,000 and build in six hours.

Figure 2.19 House in Texas, 3D printed in under 24 hours

The Vulcan printer, while very large is still portable. The printer excretes a custom blend of concrete that hardens as it's printed. The concrete is laid in 100 roughly one-inch-thick strands that hold their shape as they harden. Icon cofounder Evan Loomis told Quartz that the strength of the printed walls is stronger than cinderblocks after a few days of hardening, although the house is entirely habitable after it's been set up.

Figure 2.20 Vulcan concrete printer (2018)

2.9.1 Mass customisation

Mass customisation aims to develop products that are tailored to different customer requirements at a cost comparable to mass production. There are many technologies and manufacturing strategies that can contribute to mass customisation including modularisation of products, co-design with customers and 3D printing. The role of 3D printing within mass customisation is to produce a wider range of component designs with smaller production runs.

3D printing can do this economically because it does not require tooling and so the cost per component of large and small batches is similar. For example, in bicycle design, it is possible to design a frame that is perfectly matched to the size of an individual customer. The frame can then be produced using tubular sections cut to different lengths and 3D printed brackets that hold them together at different angles. This approach has been used to great effect by Robot Bike Co as presented in Figure 2.21.

Figure 2.21 Customised bike frame using 3D printed metal parts

Overall the cost of 3D printing is still too high to make this approach relevant for mainstream products, but it is applicable to the higher end of markets. However, as the cost of 3D printing reduces, we can expect to see this approach more widely adopted in any market where customers want a product that meets their specific needs.

One example where mass customisation is already happening is in the **digital hearing aid market.** Hearing aids come in many forms, including the 'in-the-ear variety' which is the most convenient and comfortable. Due to differences in ear canal shape, designers need to customise the hearing aids according to the shape of the user's ear canal to ensure user comfort. With 3D scanning, CAD/ CAM technology, audiologists, manufacturers and service centres can design and produce the perfect customised hearing aid shells, ear moulds, noise protection and soft moulds for customers. Companies like Shining 3D in the USA is now providing integrated digital solutions for the hearing aids industry by using ear impression scanners, rapid shell modelling software and 3D printing.

Figure 2.22 Mass customised 3D printed hearing aids

Source: http://en.shining3d.com/solution_detail-4165.html

2.10 IN SUMMARY

While 3D printing technology has existed since the early 1980s, it is only in recent years (since 2009) that it has seen its most rapid rate of growth, increasing from $2.3bn in 2012 to $6.1bn in 2016. And while growth has slowed it will remain double digits for at least the medium term. Businesses and consumers are now able to 3D print objects to a higher specification, with a wider range of materials, more quickly and cheaply than ever before.

3D printing has and will continue to create extensive new opportunities for prototyping and mass customisation. It has already led to an increase in global take-up of the technology, particularly in automotive, aerospace and life and medical science related sectors. There has also been a trend in the 'DIY maker movement' where individuals and SMEs are testing the potential of 3D printers to support hobbies and enable in-house development, particularly since the cost has substantially decreased. While still a long way to go, from the trends above, 3D printing has the potential to revolutionise the way in which we work and live.

3 APPLICATIONS FOR MANUFACTURING IN THE HIGHLANDS AND ISLANDS

3.1 SIZE OF THE MARKET FOR 3D PRINTING GLOBALLY – UK AND SCOTLAND

In 2016 the estimated size of the total global AM market was almost $6.0bn (Wohlers, 2017), a 15% increase on 2015. North America has the highest market share (39.7%), followed by Asia (27.5%) and Europe (excluding the UK) (23.9%). However, compared to their GDP figures, North America and Europe lead the way in adopting AM (Table 3.1) with rates of 1.28 and 1.30 respectively compared to only 0.81 for Asia. The UK has a 4.3% share of the global market and an adoption rate of 1.23 - slightly lower than those of North America and Europe.

The European figure is boosted significantly by Germany, which has approximately twice the number of 3D printers as the UK for an economy that is 1.32 times the size of the UK. Germany *"punches above its weight"* in AM due to the number of machines made there by companies like EOS and Voxeljet and the overall large size of the manufacturing base. In comparison, only one UK company has a significant share of the AM market (Renishaw) and the UK manufacturing base is smaller, pro rata. Comparison between Scotland and the rest of the UK is more difficult, as no "Scotland only" AM market figures are available (although we estimate it to be around 0.4% of the global market).

Table 3.1: Percentage of AM market by region compared to percentage of world GDP

Region	% share of world AM market*	% share of world GDP	Adoption Rate[5]
Scotland	0.4 (est)	0.3	unavailable
UK	4.3	3.5	1.23
Europe (excluding UK)	23.9	18.4	1.30
North America	39.7	31.0	1.28
Asia	27.5	33.8	0.81
Rest of the World	4.6	13.3	0.35

*Source: Wohlers Report 2016

The breakdown of private companies (or bureaus) offering industrial level 3D printing services in the UK (Table 3.2) shows that Scotland has only one company listed (CA Models Ltd) while the number of bureaus in England has increased from 15 to 23 between 2016 and 2017.[6] However, this does not take account of the market share that these companies have, or the extent of services provided by colleges and universities to the private sector. Scotland has AM installations in many of its cities and large towns (Figure 4.3, Section 4), including, for example, university-based printing capabilities in Inverness, Aberdeen, Dundee, Stirling, Glasgow, Edinburgh and St Andrews. This puts it on a par with the rest of the UK.

The marked difference between Scotland and the rest of the UK is that there is a large land area that is remote from the nearest 3D printing bureau. This can be partly remedied by access to low cost desktop printers, but these are hardly a substitute for the industrial level machines available at most bureaus.

[5] The number of members of a society who start using a new technology or innovation during a specific period of time. The rate of adoption is a relative measure, meaning that the rate of one group is compared to the adoption of another, in this case share of world AM market to share of world GDP

[6] There may be other companies who offer 3D printing as part of a service, however these have not been documented in the supplier directory.

Table 3.2: Number of 3D Printing bureaus (private companies) in the United Kingdom

Region	Number of 3D Printing bureaus	
	2016	2017
England	15	23
Wales	2	2
Scotland	1	1
N. Ireland	0	0
Total	18	26

Source: TCT Supplier Directory, TCT Magazine (2017)

3.2 COMMERCIAL BENEFITS OF 3D PRINTING

While it is conceivable that at some future date, 3D printing technology can be utilised for large scale mass production, the main business applications of 3D printing at present lie in the following four areas:

1. **Rapid prototyping/proof of concept:** 3D printers allow the printing of design demonstration prototypes quickly and cheaply. However, the prototypes may not be structurally robust enough to be used for product testing purposes. 3D printing has also been used to develop small demonstration models of large pieces of technology, such as oil rigs, for display at exhibitions.
2. **Manufacture of simple components:** the technology enables companies to quickly and cheaply make simple (limited load bearing) components such as jigs and brackets. Spare parts manufacturing in remote communities is a recurring theme.
3. **Small batch production**: while injection moulding remains the most cost-effective means of large batch production, 3D printing is now a cost-efficient way of making products in small batches as it removes the requirement for developing moulds. With the ability to mass customise, we will begin to see larger batches becoming more cost competitive.
4. **Bespoke products and customisation/personalisation**: 3D printing enables the development of bespoke products that meet the needs of a customer. This offers potential for the life sciences sector, for example, allowing the development of lattices and splints that are bespoke to the size and shape of a patient. However, there may be a requirement for clinical trials to use 3D printing for any *in vivo* devices. There are also applications for jewellery making and customisation of products.

The report will provide more detailed, sector specific examples of some of these benefits later in this section.

3.3 BENEFITS FOR RURAL ECONOMIES

3D printing has the potential to have a particularly transformative impact in rural economies such as the Highlands and Islands. For example, it can enable businesses to design a 3D application at their own premises, perform the testing in-house and then sell the design around the world without incurring any transportation or production costs. This effectively means that distance from suppliers is no longer a source of competitive disadvantage in the design and prototyping stage of the production process.

The case study below provides an example of how 3D printing technology has helped to transform the remote Swedish town of Ostersund into a centre of excellence in metal 3D printing. The Highlands and Islands could learn the lessons of Ostersund and assess the feasibility of similar centres to be developed in the region. To do this, however, there must be sufficient demand such as a focus on a 3D printing process, e.g. precious metal printing for the creative industries sector.

Case Study - AIM Sweden

AIM Sweden is a private company that originated from a partnership between Mid-Sweden University and AIR Sweden AB. It builds upon the research excellence of the university, particularly in metal 3D printing. It provides a bureau service to companies wishing to use 3D printing for medical and industrial products. It also offers a consultancy service, participates in joint research projects, and provides education and training in metal 3D printing.

AIM Sweden has become a centre of expertise in additive manufacturing

The commercial arm of AIM Sweden AB and the additive manufacturing research group at Mid Sweden University came together to create a unique level of competency in the use of additive manufacturing (AM) for metal and plastic parts. AIM Sweden has close links with both groups and has direct access to experts in design, manufacturing and commercialisation. This link between education, research and development, and manufacturing sets AIM Sweden apart from other AM service providers. Customers have access to a range of industrial AM technologies including Laser Sintering, Fused Deposition Modelling, and Electron Beam Melting (EBM). The first two technologies are polymer-based whereas the third works in metals. AIM's philosophy is outlined by Lars-Erik Rannar of Mid Sweden University: *"Companies need to learn about the technologies and have third-party access to them, since they cannot afford to purchase industrial 3D printing systems for themselves."* AIM Sweden is a prime example of university expertise being translated into meaningful support for local companies.

Products developed through AIM Sweden

AIM Sweden's metal AM competence lies in the manufacturing of Ti6Al4V[7] using the EBM method for both series production and bespoke production. The latter is particularly suited to the manufacture of medical implants. The image on the left below shows a solid implant used for pinning a damaged bone. In addition, AM allows a part of or the whole implant to have an open lattice structure to create opportunities for the in-growth of bone tissue. Complex structures are ideally suited to AM which facilitates porosity, built-in channels, and other shapes that are a challenge for conventional manufacturing. The product on the right below shows part of a bicycle frame which exhibits such a complex structure. Using AM has enabled the weight of the part to be reduced while its load-bearing capabilities are maintained. Consequently, the part uses less material and could have less overall environmental impact.

Learning and implication of this approach for Highlands and Islands

AIM Sweden is located in a fairly remote region of Sweden showing that geographic remoteness is not necessarily a barrier to national or even international renown. This is a model that could be viable in the Highlands and Islands. Opportunities for industry-academic partnerships that could develop into centres of excellence in specific AM applications could be explored. These would typically lie where a cluster of companies or practitioners already exists, e.g. for the oil and gas industry or perhaps the life sciences and healthcare sectors.

[7] is one of the most commonly used titanium alloys

3.4 HOW THE TECHNOLOGY CAN BE APPLIED TO EACH OF THE HIGHLANDS AND ISLANDS GROWTH SECTORS

The following section considers the 3D printing opportunities aligned to the Highlands and Islands growth sectors. It draws on the consultation and desk research phases of the study.

3.4.1 Energy

The Highlands and Islands is home to extensive wind, wave and hydro-electric natural resources, modern fabrication and port facilities, and transferable skills from the oil and gas industry. With the European Marine Energy Centre (EMEC), Beatrice Offshore Windfarm and MeyGen (the largest planned tidal stream project in the world) all located in the region, the Highlands and Islands has become a world leader in the development and production of renewable energy, particularly offshore. There are 515 enterprises active in the energy sector, employing 4,430 people.[8] This includes a wide range of supply chain companies including electrical installers, crane hire, haulage and environmental consultants which help support the sector from research to full-scale commercial implementation of projects.

The use of 3D printing in energy is still viewed as in its infancy, and this research did not identify any examples of where the technology is currently in use in the Highlands and Islands energy sector. Stakeholders agreed that outside of the region, 3D printing has been used in the sector for prototyping and the design of high value, low volume, niche products, they also commented that the highly regulated energy industry is keeping a watchful eye on 3D printing before committing to wider use.

Examples of 3D printing used in the energy industry include:

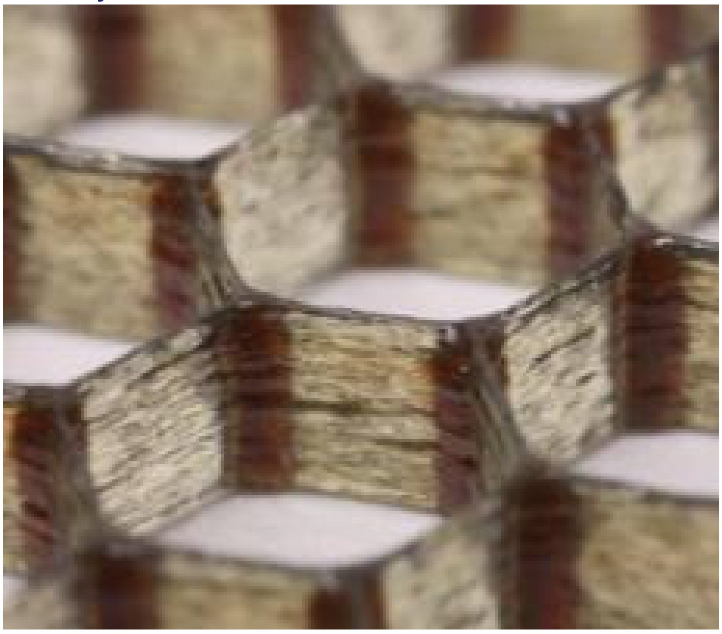
- making scaled down models of oil platforms for display at expos
- a plug device for temporary cutting off the flow through pipelines
- lighting products using sustainably sourced materials
- making lighter wind turbine blades
- solar cells

One consultee spoke of the opportunities to support 'on-rig' printing to minimise the need for expensive shipping of goods as well as reducing downtime; however, other consultees viewed this as a long way off.

Harvard School of Engineering and Applied Sciences (SEAS) and the Wyss Institute for Biological Inspired Engineering have developed a new lightweight and rigid cellular composite material, used to make lighter wind turbine blades (Figure 3.1). Given the range of renewables opportunities in the Highlands and Islands, this development may be of direct interest.

[8] IDBR data, 2017 – Highlands and Islands

Figure 3.1 3D printed honeycomb structure



Source: Harvard School of Engineering and Applied Sciences

A team of 50 Australian scientists from various fields have been working over the past few years to develop paper-thin, organic printable solar panels as part of the Victorian Organic Solar Cell Consortium. They have developed 3D printed organic solar cells capable of powering a skyscraper.

Figure 3.2 3D printed paper-thin, organic printable solar panel

Source: 3ders.org

According to the research consortium, the technology has the potential to:

“Dramatically reduce the dependence on more traditional sources of electricity in developed countries such as Australia, and provides a cheap, easily deployable source of electric power for remote regions beyond the reach of the grid in developing countries.”

The opportunity for Highlands and Islands businesses in the energy sector will most likely focus on support for energy supply chain companies given that this is where the majority of them currently operate. Exploring the possible market opportunities for 3D printing technology, such as in renewables, and helping businesses to understand potential applications will be of value. Supporting skills development will also be critical. As well as upskilling existing staff, this may include drawing in skills through graduate recruitment, or modern apprenticeships. A recent development in the energy sector in Highlands and Islands is the proposed construction of a £5.4 million renewable energy focussed research and innovation campus in Orkney (ORIC), funded by HIE and ERDF. It is hoped that this will encourage business growth and the creation of new businesses in Orkney.[9]

3.4.2 Life sciences and health

The life science and health sectors are an area of huge global demand and one where, in recent years, the region has achieved some major successes in attracting inward investment. There are around 45 businesses in the life science sector in Highlands and Islands employing around 1,450 people.[10] The sector predominately consists of small enterprises, working in human and animal health, marine biotechnology, natural products, chemical and pharmaceutical sciences and digital technology, it typically delivers high levels of innovation with particular strengths and opportunities in digital health and wellbeing and marine biotechnology.

While this research did not identify any examples of commercial 3D printing activity taking place in this sector in the Highlands and Islands there were a number of examples where it had been used to support product development. This includes Inside Biometrics International who used 3D printing in developing lifelike models and templates. A university-based company in Inverness, Organlike, is taking to market innovative technology for the provision of 3D printed hyper-realistic organ models for practice surgery and training. The company hopes to enhance surgical outcomes, patient recuperation and efficiency in surgery, and are currently growing their business.[11] The use of MRI and CT scan data allows the company to create almost exact copies of organs that require surgery; 3D printed models have a better appearance and texture than currently used hard-plastic, silicone, rubber or hydrogel-based models. The company has already received private investment, in addition to an £160,000 start-up grant from HIE and will be based at the life sciences development, Aurora House. This will create new jobs at the Inverness campus as part of the funding will be used to hire five highly skilled staff. Additionally, the product received recognition after being reviewed at a recent training bootcamp for surgeons. More widely, 3D printing has become an established manufacturing method in the formation of prototypes, medical models and dental products within the life sciences and healthcare industry globally. This has resulted in the world market for 3D printing in the healthcare industry forecast to be worth $4bn in 2018 (Visiongain, 2015).

Advantages of 3D printing over traditional manufacturing methods for the healthcare industry include:

- facilitating the production of highly specific complex geometries and surfaces
- design of high quality, patient specific products; particularly in orthopaedics
- mass customisation of bespoke patient products such as hearing aids

[9] Energy Voice: New £5million Orkney research campus to focus on renewable energy: https://www.energyvoice.com/otherenergy/166544/new-5million-orkney-research-campus-to-focus-on-renewable-energy/
[10] IDBR data, 2017 – Highlands and Islands
[11] Inverness Campus.co.uk: Revolutionary organ printing technologies company now recruiting. Available at: www.invernesscampus.co.uk/news/2018/revolutionary-organ-printing-technologies-company-now-recruiting/

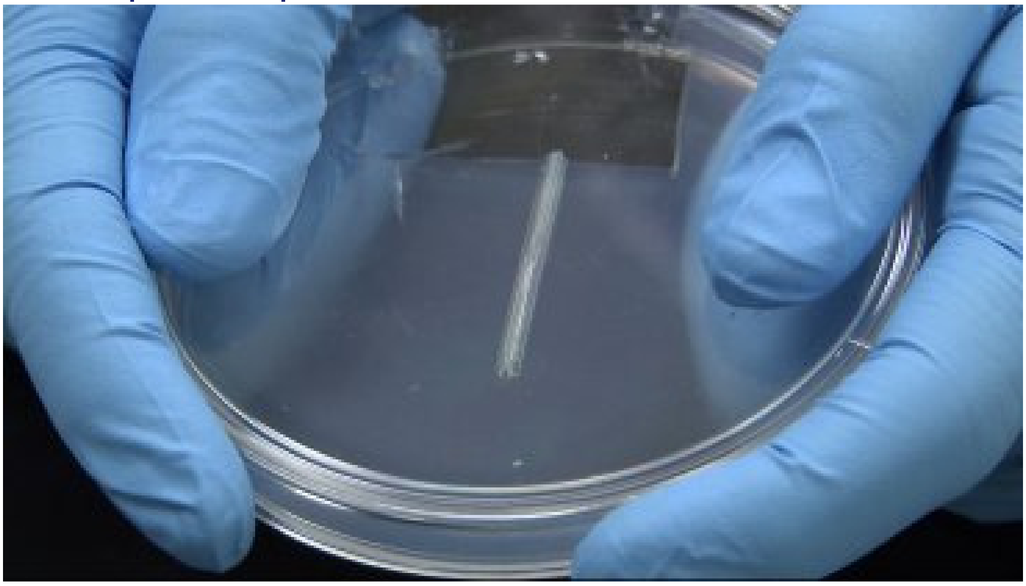
Consultees confirmed that 3D printing is already widely used within the life sciences and healthcare industries globally and to a lesser extent Scotland and the Highlands and Islands. **Examples of 3D printing in the life sciences sector included: bioprinting and organ tissue, medicines, bones and prosthetics, and on medical support drones.** Further information on each is provided below.

Bioprinting and organ tissue

An area of increasing activity is in **bioprinting**, the fabrication of organs from biomaterials using a 3D printer. The global bioprinting market was worth $451m in 2013 and is estimated to almost double in value to $888m by 2018, growing at a CAGR of 15% (TechNavio 2015). Visiongain report that bioprinted tissue will become commercially available for both drug development and therapeutic purposes within the next ten years and will become an important subsector of the 3D printed products industry.

Other opportunities include **3D printed tissues which last 40 days compared to 2D printed tissues lasting 48 hours.** This allows more testing on the same tissue and over a longer time to test long term dose effects of drugs. US-based 3D bioprinting firm Organovo is currently developing a 3D printed liver tissue model to be used for R&D during toxicology and efficacy testing. These types of tissues can speed up the drug discovery and development process allowing drugs to be tested and rejected earlier, with the potential to save billions in R&D.

Figure 3.3 3D Bioprinted sample of human tissue



Source: Organovo

Closer to home, **researchers at Heriot-Watt University and Roslin Cell are demonstrating the ability to replicate human tissue.** They have developed a method for 3D printing of clusters of human embryonic stem cells on which pharmaceuticals can be tested, aiding in-vitro drug development and toxicity-testing. In the longer term, this could mean the creation of human organs for transplant based on the patient's own DNA, thus reducing the risks of rejection.

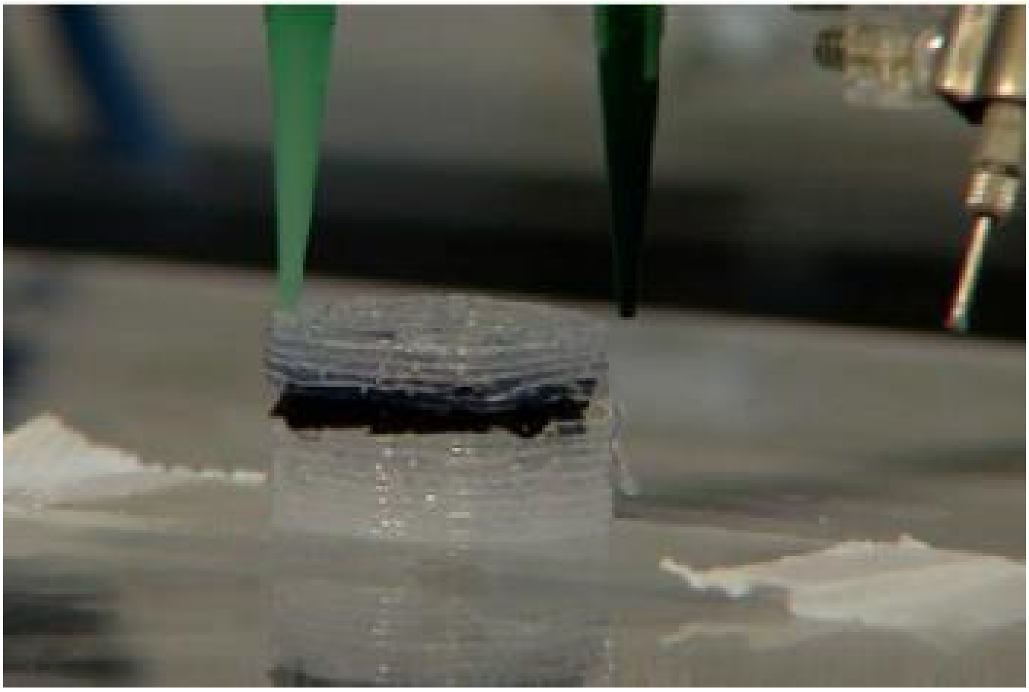
Medicines

Several consultees mentioned the application of **3D printing in medicines – printing bioorganic circuitry, and digestible circuitry** so that clinicians and researchers know who is taking medicine and who is not. In 2014, researchers at the University of Glasgow developed a process to print drugs using 3D printing technology which they believe could lead to people having a *"personal pharmacy"* dispensing of medicines at home. Consultees comment that 3D printing layers of polymers blended with a drug can support targeted delivery of a tablet to the point of concern.

For example, 3D printing of drugs may allow for the personalisation of medication to suit an individual's height, weight and body fat percentage. This tailor-made approach could also allow children to choose the shape, colour and design of their own tablets, potentially encouraging consumption. Researchers state that this is likely to be available within the next decade.

As revolutionary as this system may be, there are worries and potential drawbacks to the technology. Some critics say that there is a danger of blueprint mislabelling, drugs being filed inaccurately and medication being stronger than advertised. There are also concerns regarding blueprint hacking and that the technology may fuel the illegal drug trade. However, Professor of Chemistry at Glasgow University, Lee Cronin, claims that the requirement of drug validation, as is practised currently, would help mitigate such concerns. Further regulatory challenges are likely and would need to be addressed before this became a fully usable technology.

Figure 3.4 3D printer developed for drugs at the University of Glasgow



Source: BBC

Bones and prosthetics

NHS Innovations highlighted opportunities to **produce lattices for broken arms, prosthetic limbs, orthotics insoles and stents for treating arteries**. They also note reservations regarding stents and other in-vivo applications due to regulatory constraints.

The benefits of 3D printing of bones and prosthetics are wide-ranging and include:

- **improved fit, comfort, installation and performance for maxillofacial projects where a jaw bone is missing** - this used to be a labour-intensive process and inaccurate with poor fitting, however using scanned data and 3D print allows production of customised parts
- **reduced wear and tear and reduced costs for the NHS** – layers are printed to ensure there are no seams or points of interaction that could fray. For example, for a hip replacement, 3D printing allows the ball and socket to be printed together so that there is no wear. As well as enhanced performance of the hip for the patient, it lasts longer, thus reducing costs for the NHS
- **improved quality of life for young people** – 3D printing enables faster development of child prosthetics meaning prosthetics can be updated more frequently in line with child growth. (Figure 3.5)
- **personalisation of products** – mass customisation of hearing aids to exactly fit the clients ear is a good example of this (as highlighted in the previous section)

Figure 3.5 Prosthetic hand made with 3D printing technology

Source: BBC

Glasgow Caledonian University (GCU) is leading a £3m EU funded study to see if 3D printing of orthopaedic products can help millions of people suffering from disabling foot and ankle conditions. These conditions are said to affect 200 million European citizens and current methods of manufacture are slow, expensive and difficult to reproduce. GCU is already successfully producing insoles and splints via 3D printing.

Medical support drones

Consultees commented on the potential use of 3D printing in **medical military applications** using drones to deliver care packages with on-board 3D printing. Instead of planning in advance, the military could deploy a drone with organic compounds to deliver the right kinds of medicines to points of military need or humanitarian intervention sites as and when required. In the US, the military is said to be utilising and expanding their adoption of 3D technology for food, weaponry, medication and prosthetics. This could lead to less dependence on the civilian industry to design, prototype, test and manufacture products, as they develop their own capability.

Opportunities:

This sector was generally recognised by consultees as having the greatest potential for 3D printing technology in the Highlands and Islands. With a wide range of small and innovative companies operating in the life sciences sector, there was consensus that the focus should be on encouraging more extensive use of 3D printing - from prototyping to small scale production to customisation and personalisation.

There are a number of existing funding mechanisms such as SMART: Scotland R&D funding and wider innovation support grants that could help part-fund activities. Collaborations with university and clinical research environments would also help with testing, trials and adoption. Organisations such as Interface already play a critical role in fostering links between business and academia, and there may be opportunities to further build on this.

As with the energy sector, adoption of 3D printing technologies by businesses will bring a skills development requirement. Exploring routes to supporting this will be key to capitalising on the associated opportunities.

3.4.3 Food and drink

The food and drink industry in the Highlands and Island contributes £1bn to the Scottish economy and has been at the centre of the region for centuries. The region has successfully established itself as a premium producer in the areas of red meat, fish, seafood, whisky and baked produce. In 2017, the sector comprised of 5,190 enterprises and employed 20,410 people.[12] It is demonstrably a very important part of the economy as a recent survey by VisitScotland indicated; 62% of holidaymakers said trying locally sourced food and drink is an important aspect of their visit.[13] In the sector, whisky continues to be a significant export for Scotland.

Stakeholders described the food and drink sector as traditional, with 3D printing largely viewed as a novelty application rather than a serious process that should be integrated into their current manufacturing processes. 3D printing innovation in the sector tends to be low unless associated with the engineering side of agriculture and aquaculture, such as applications around fish feed systems.

Despite being unable to identify specific examples of 3D printing currently being used in the Highlands and Islands food and drink sector, there is agreement among consultees that the technology does present opportunities for food and drink packaging, and in food prototyping and production. Current applications in the sector are explored below.

In 2014, Allied Glass, a premium glass bottle manufacturer based in Leeds, became the first glass container manufacturer in the UK to invest in 3D print technology. The company used 3D printing as a means of achieving cost and design efficiencies, customer differentiation and product customisation – offering customers the opportunity to create a bottle from scratch in hours.

[12] IDBR data, 2017 – Highlands and Islands
[13] Highlands and Islands Enterprise: http://www.hie.co.uk/growth-sectors/food-and-drink/overview.html

Figure 3.6 3D printed bottles from Allied Glass

Source: Allied Glass

Allied Glass report that their 3D printer can produce models with fine feature details, with the strength to withstand rigorous testing. 3D printing allows the design team to quickly refine form, fit and function – to get the product to market quicker – whilst cutting development and production costs.

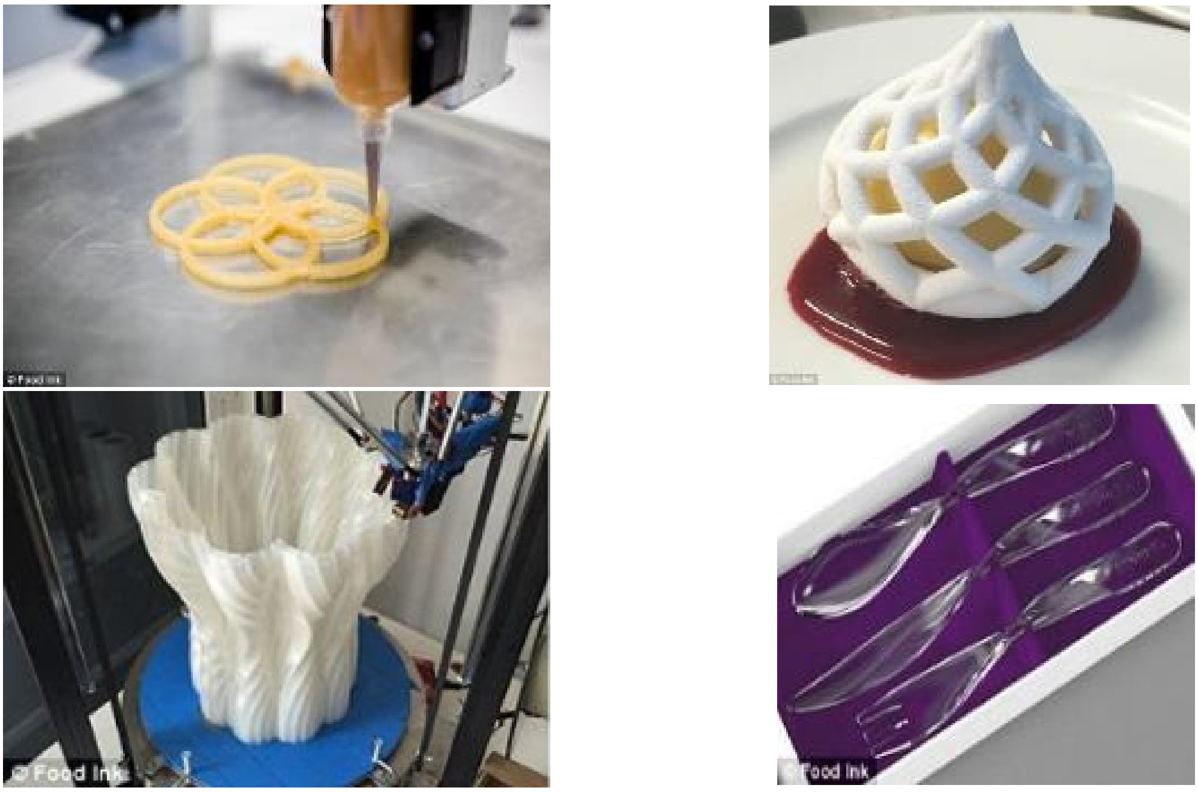
As part of a marketing campaign, Dumbarton-based whisky distiller Ballantine partnered with the Open Space Agency (OSA) and designed a 3D printed zero gravity 'space glass' for whisky. The glass has been specially designed for the microgravity conditions of space. With a 3D printer already on the International Space Station, Ballantine wanted their space glass to be a part of the 3D printing development.

Figure 3.7 Ballantine's 3D-printed Space Glass

Source: 3ders.org

In 2016 London-based Food Ink was reported to be the world's first 3D-printed restaurant. They established a three-day pop-up in Shoreditch, with the food, furniture and cutlery all produced “live” in front of guests, using 3D printing technology.

Figure 3.8 3D printed food, cutlery and furniture at Food Ink



Source: Food Ink

Other 3D printing food and drink applications highlighted by stakeholders included moulds for bakery businesses, and for customising pasta with pasta-makers.

In Germany, an innovative application of 3D printing has been noted in **food research. Specifically targeting elderly people in care homes who have problems swallowing,** researchers have used a paste to 3D print food resembling meat and vegetables (Figure 3.9). It is reported that up to 60% of nursing care home residents suffer from dysphagia (the difficulty to swallow food). Given Scotland’s ageing population and considering that this is even more marked in the Highlands and Islands, 3D printing of food could significantly impact this aspect of elderly care, offering a unique and inclusive way of combatting feeding and nutritional challenges arising from issues such as dysphagia. Although consultees recognised the potential benefits of this application, they saw it as a novel and interesting rather than financially viable use of 3D printing. Production at the required levels was considered to be too expensive to be feasible in the short to medium term.

Figure 3.9 3D printed food for the elderly

Source: 3ders.org

Overall, the opportunities for Highlands and Islands businesses in the food and drink sector are less apparent, still tending more to "novelty application" and likely to be realised only in the longer term. The greatest potential is likely to relate **to food and drink packaging and customisation**. Supporting food and drink manufacturing businesses to capitalise on this opportunity will become increasingly important as the use of 3D printing technology becomes more mainstream**.**

3.4.4 Creative industries

The Highlands and Islands has a distinctive creative and cultural sector, and has produced several hugely successful artists, designers, performers and craftspeople. The sector has 1,000 registered enterprises and employs 5,090 people.[14] The sector comprises many sub-sectors, namely music, art, design and performing arts. The building of a creative hub in Inverness is a notable development in the region. This £5.7m community arts hub, led by Wasps Artists Studios, will provide quality workspaces for those in the industry, such as visual artists, theatre groups and craft makers to media companies or businesses at the cutting edge of digital art; it could even be a hub for 3D printing access. Mareel in Shetland (the UK's most northerly music, cinema and creative industries centre) could act in a similar way.[15]

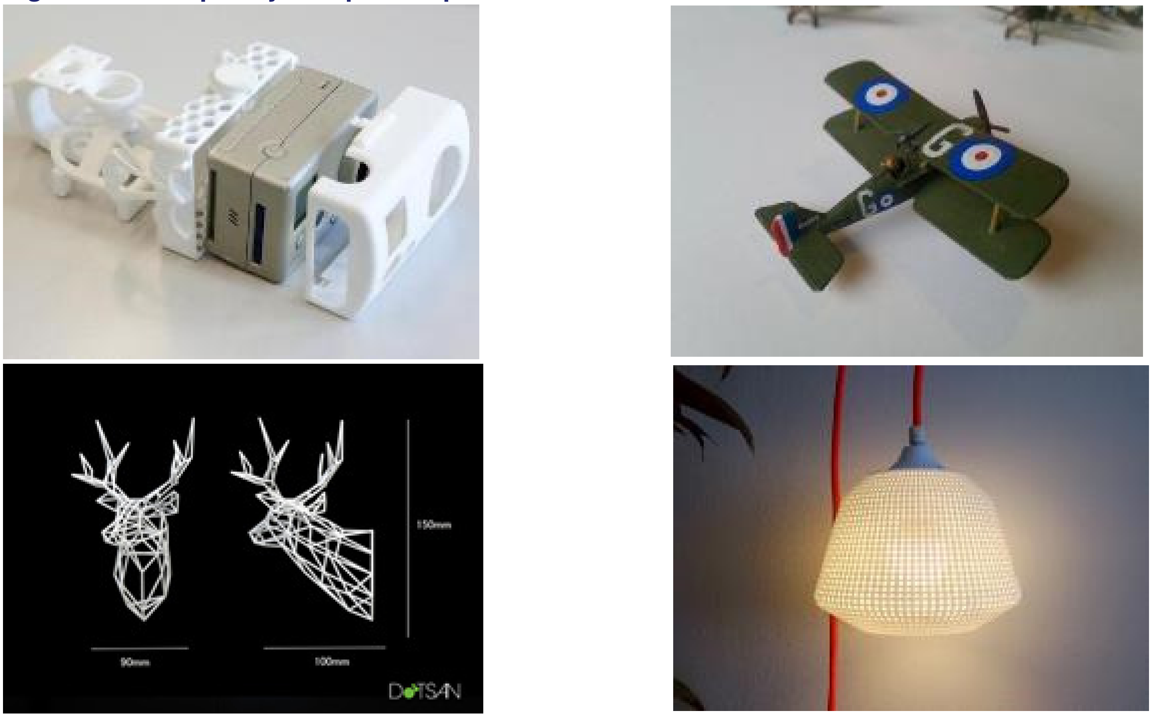
Consultees in the study considered 3D printing applications within the creative industries sector to be extensive. They recognised the added value the technology offered in facilitating the production of bespoke and highly customised products, whilst reducing the time to market. Examples of 3D printing used in the creative industries are provided below and include:

- prototype tools, moulds and patterns
- decorative prosthetics (Section 3.4.5)
- model/concept development
- fashion design
- customisation for jewellery and ceramists

Shapeways.com, based in New York, is a leading 3D printing marketplace and community. Their website illustrates the wide range of applications of 3D printing within the creative industries including **jewellery, art pieces, home products, games, miniature collectables and technology accessories**. Examples are shown in Figure 3.10.

[14] IDBR data, 2017 – Highlands and Islands
[15] Insider.co.uk. Available at: https://www.insider.co.uk/news/inverness-creative-academy-57m-project-11757872

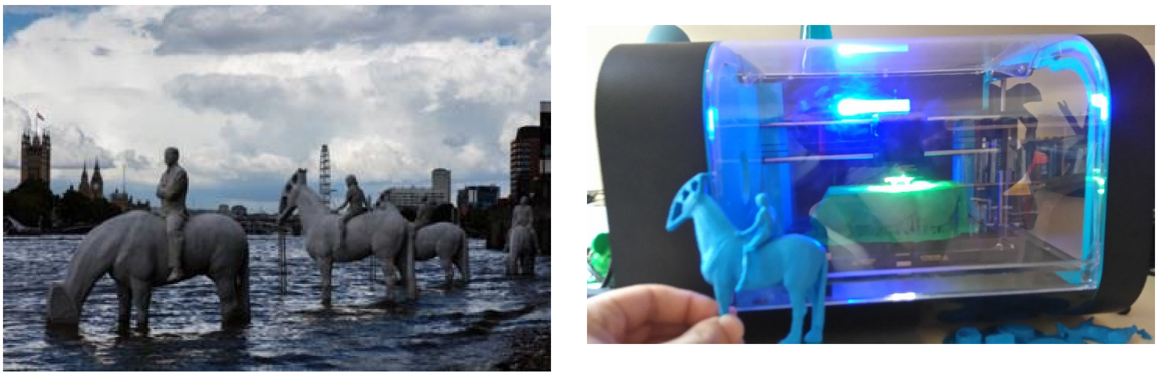
Figure 3.10 Shapeways 3D printed products



Source: Shapeways.com

3D printing is also being used in **model/concept development** to visualise large-scale sculptures which presents a more cost-effective approach than traditional clay. Keep Art, a London based company, used this approach and the support of Geo Int 3D in Harris to help development of the 3D model for sculptor Jason deCaires Taylor. Keep Art highlighted that they would not have bid for the project if they had to use traditional clay model. The use of 3D modelling meant that the turnover gained was all additional. They have since bid for further work using 3D modelling.

Figure 3.11 3D printed was used to visualise this sculpture by Jason deCaires Taylor



While 3D printing in **fashion has mostly been confined to haute couture** as shown in Figures 3.12 and 3.13, there is a belief amongst consultees that 3D printing could one day offer consumers the chance to print items of clothing at home to their exact measurements.

Figure 3.12 A 3D printed ensemble by Iris van Herpen for her haute couture line

Source: Metropolitan Museum of Art

In 2015 Danit Peleg, a student from Israel's Shenkar Art and Design School, produced her entire graduate collection using a 3D printer. This was the first full collection designed to be produced on the smaller machines that can be used in people's homes. Danit used a material called FilaFlex which allowed the pieces to be wearable and flexible.

Figure 3.13 3D printed fashion by Danit Peleg

Source: Guardian

In the summer of 2016, Danit was invited to design a 3D printed dress for the headline dancer at one of the most moving segments of the Opening Ceremony of the Paralympics Games. **In the summer of 2017, Danit launched a customisation and personalisation platform on her website, enabling customers to personalise and order the world's first 3D printed garment available to purchase online**.

Danit stated that printing costs and production time remain high for example, Danit's red "Liberté" jacket took 220 hours to print and is estimated to cost at least 600 euros for printing, not including design, assembly, and electricity. However, as materials and technology improve, she believes that one day *"customers could download the patterns, just like music files and print them".*

The opportunity for Highlands and Islands businesses in the creative industries is broad, especially as the Glasgow School of Art launched a creative campus in Moray which has access to 3D printing technologies. In addition, there are several businesses across Scotland that have an established operation that supports the creative sector, such as Glasgow based 4C Design (see case study below).

A key opportunity for the Highlands and Islands is likely to focus around the craft industry especially bespoke jewellery, ceramics and textiles, **where customisation and personalisation via 3D printing will add value**. Skills development and access to facilities will, however, be an issue as the majority of these 'craft' businesses will be sole traders and micro businesses, often located in geographically dispersed or remote communities. Facilitating access to 3D printing technologies (including technical skills), access to training and supporting general awareness-raising will be important in helping these micro-businesses to realise the opportunities associated with this technology.

Case Study – 4C Design

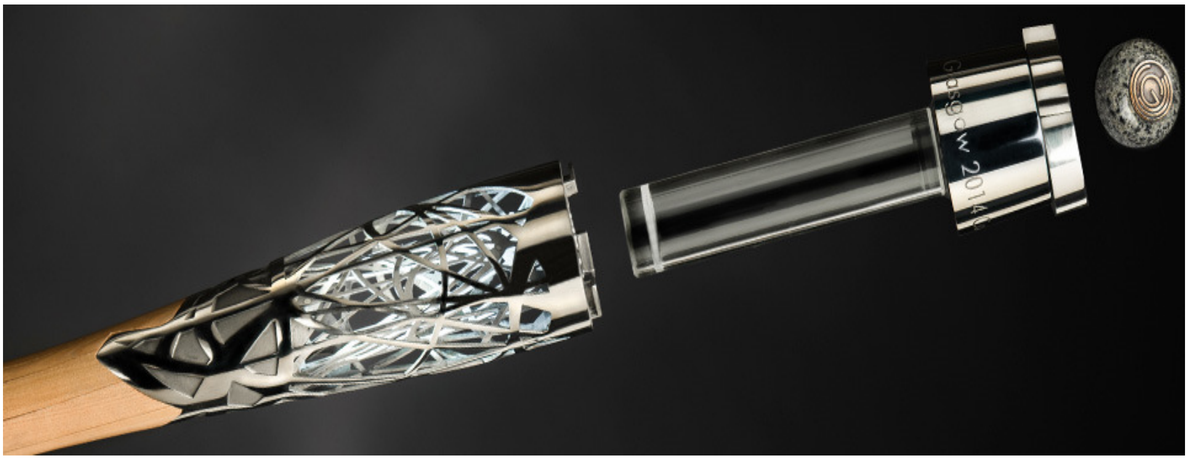
4C Design is a product design engineering consultancy based in Glasgow. They provide outsourced innovation to businesses seeking to develop new products, question product design or carry out customer research to try to identify potential improvements to their product design.

Their areas of work include wind energy, electric vehicles, and special needs products; however, the project that they are best known for is the 2014 Commonwealth Games Baton, which they designed.

In making the baton, they first developed a rapid prototype of the design for the lattice section in plastic using one of their in-house printers. They then developed a brief and contracted 3TRPD, a company based in Newbury, Berkshire, to print out the lattice section of the final product in titanium.

They find that having access to in-house printers is useful for fast-paced rapid prototyping, as it means that once they commit to developing a CAD file and outsource the printing of the final product, they are confident that what they get back will be right.

While they originally bought the printers solely for use in rapid prototyping, they have found that printed products are of adequate quality for use in demonstration prototyping and, in some cases, additive manufacturing of finished pieces. For example, they use it to produce jigs, brackets, and anything that takes a light load for the products that they develop.



3.4.5 Tourism and cross sectoral opportunities

The tourism industry is crucial to the economy of the Highlands and Islands[16]. In 2017 there were 2,260 registered enterprises in this sector employing 26,810 people.[17] The region is home to several globally recognised destinations and events and has a strong reputation for providing a quality visitor experience. New technology and innovations are increasingly defining how consumers search and book holidays, and how tourism businesses market their products and services, presenting new opportunities for tourism businesses and destinations.

Opportunities for the use of 3D printing in tourism are considered minimal compared with other sectors. Where 3D printing has been used, it has tended to be cross-sectoral, (relating more to the target audience). For example, working with the creative industries sector to create scaled down models of existing tourism and heritage attractions as souvenirs, or recreations of medieval sites to aid interpretation. One consultee pointed out the potential of printing geographical landscapes, such as scale models of Munros, as gifts for hill-walking enthusiasts.

Nature-inspired designs can also be made in sustainable bio-based materials. Specific examples of 3D printing used in the tourism sector include:

- replica of the Rhoetosaurus of Roma which will measure 15 metres long and 4 metres high to be printed for Queensland Museum (Figure 3.14)
- souvenir of the Templo de las Inscripciones in Mexico (Figure 3.14)
- sculpture prototype models by Jason deCaires Taylor (Figure 3.11)

Figure 3.14 3D printed replica of the Rhoetosaurus of Roma and souvenir of the Templo de las Inscripciones, Mexico

The demand for 3D printing in the **tourism** sector appears low at present; however, as the price of printing continues to fall, there may be opportunities in the future for adoption**.**

Other **cross-sectoral** examples include the life science and creative industries sectors where 3D printing is increasingly being used to **make prosthetics more attractive, lighter, and polished so that they can be used for form as well as function**. William Root, a recent graduate from the Pratt Institute in New York City, developed a system to 3D print super-lightweight prosthetic legs with fabulous styling (Fig 3.15).

[16] http://www.hie.co.uk/growth-sectors/tourism/overview.html
[17] IDBR data, 2017 – Highlands and Islands

Figure 3.15 3D printed super-lightweight and styled prosthetic leg

Source: Wired.com

3.4.6 Recycling and the circular economy

Scotland's Economic Strategy includes a commitment to:

> "*Create conditions for a more circular economy that helps companies embrace new business models and manufacturing processes, and which transforms used products into assets that support industries like remanufacturing, reuse, product disassembly and reprocessing.*"[18]

Recycling and the circular economy is another potential area of opportunity for 3D printing and is already being used by Highlands and Islands based social enterprise and charity ReBoot, as outlined in the following case study.

[18] https://beta.gov.scot/publications/scotlands-economic-strategy/pages/5/

Case Study - ReBoot

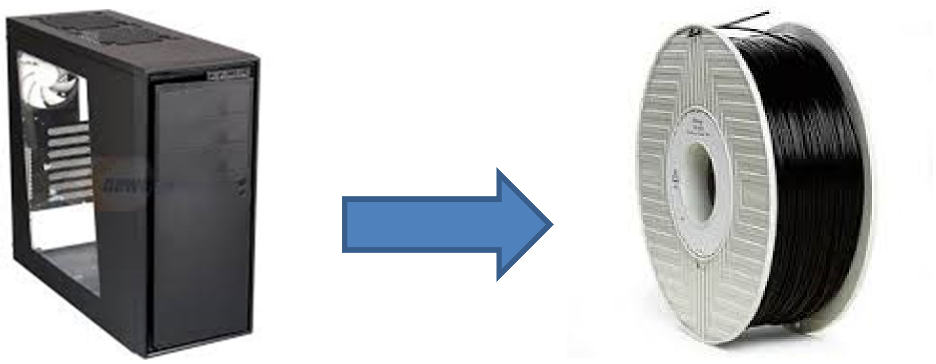
ReBoot is a social enterprise and registered charity based in Forres, which specialises in gathering unused IT hardware and recycling it for the benefit of the local community. They offer a hands-on training experience for the long term unemployed, people with extra support needs and retirees in the local area. They have six members of staff and about 35 volunteers.

ReBoot source their materials from local donations and affordable sales and recondition these for the purposes they were originally made for; returning printers, laptops and photocopiers to their original condition.

As part of their work, they gather significant volumes of excess rigid ABS plastic for which, they previously found difficult to find a practical use. However, they are currently undertaking a research project to identify a mechanism to granulate this locally and extrude it to produce coils for 3D printing. They will then look to develop a printer that can print in this material and use this to produce corporate giveaways (e.g. key rings) for local businesses.

They will also look to sell the coils to other 3D printing businesses as an additional source of income. This should help them maintain a self-sustaining model for their organisation and allow them to continue to deliver social benefits to their local community.

In October 2017, Reboot was honoured as having made the biggest environmental impact to Moray in awards organised by tsiMORAY.



3.5 IN SUMMARY

3D printing can offer a source of competitive advantage to businesses in the areas of rapid prototyping, manufacture of simple components, small batch production and bespoke product customisation and personalisation. It offers advantages to rural businesses by stripping layers out of the product supply chain and removing the need for time consuming and costly deliveries.

While there is limited evidence of 3D printing technology being currently employed in the Highlands and Islands economy, research suggests that the greatest sectoral areas of opportunity include life sciences and health, energy and creative industries. **The table below summarises the applications, benefits and challenges.** As the research demonstrates, some of the greatest and recurring challenges are access to technology, skills and cost which are exacerbated for small businesses and the rural communities. These barriers are discussed in more detail in the next section.

Sector	Application	Potential Benefit	Challenge
Life sciences and health	Surgery, rehabilitation and prosthetics developing lattices and stents used in hip and joint replacements and maxillofacial projects. Printing medicines and printing bio-organic circuitry e.g. digestible circuitry. Medical support drones to deliver care packages.	Improved performance and durability. Cost savings aligned to reduce over-ordering, less repeat surgeries, better fit to patient. Direct point of care application and personal medicine. Medicine tracking. Deliver the right kinds of medicines to points of military need or humanitarian intervention.	Health and care markets were described as *"very risk averse to change".* Regulatory constraints aligned to personalised medicine. Access to quality printers to support specialist output. Drone regulation. Regulating onsite manufacture.
Energy including oil and gas	High precision and high value low volume components. Single unit components. Maintain parts offshore reducing costs and time (but viewed as long term).	Production of single piece components – very cost-effective approach given current market developments in printing metals; bespoke and fully customised design.	Still too expensive compared to traditional methods for majority of components.
Creative industries	Prototyping to speed up design times and to deliver bespoke end-products. Sculpture mock ups.	Bespoke customisation; personalisation; more cost effective and less time consuming than traditional materials.	Knowledge and skills to create the 3D modelling drawing (CAD); access to technology that is capable of a quality product.
Food and Drink (packaging and design)	Greatest opportunity aligned to design of innovative packaging, bottling and canning of products.	Market differentiation.	3D printed food accepted as still more of a fad – when aligned to actual food. Still too expensive to become a regular approach.
Tourism	Personalised models of tourist attractions either as souvenirs or interpretative aids.	Personalised souvenirs. Improved visualisation of attraction.	Knowledge and skills to create the 3D modelling drawing (CAD). Access to technology locally.

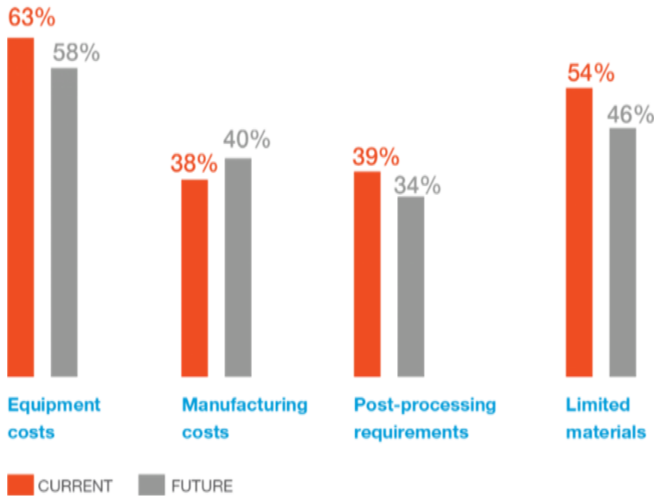
4 BARRIERS, DISRUPTIVE EFFECTS, RISKS OF NON-ADOPTION AND SUPPORT NEEDS

4.1 WHAT BARRIERS PREVENT BUSINESSES FROM ADOPTING THE TECHNOLOGY

4.1.1 The global picture – evidence from literature review

While research evidence points to a prosperous and high growth market, the global AM market remains at less than 2% of the entire manufacturing market (Wohlers, 2016). In an industry survey of 700 professional users of 3D printing, key challenges included equipment and manufacturing costs, access to materials and post-processing requirements (Stratsys, 2015).

Figure 4.1 Key challenges of 3D printing



Other challenges identified by the research included:

- lack of in-house additive manufacturing resources
- lack of expertise and/or training among workforce/employees
- lack of repeatability (accuracy from build to build)
- lack of formal standards
- lack of proven documentation of additive manufacturing's capabilities, software development and capabilities
- longer production timelines
- risk of litigation/legal implications and data storage requirements

4.1.2 The Highlands and Islands picture – evidence from consultations

At a Highlands and Islands level, qualitative evidence from consultations suggests that a lack of skills, low levels of awareness and understanding of 3D printing, and high cost are the top three barriers restricting uptake of 3D printing. Other factors included access to printers and materials as well as a lack of understanding of the digital tools/modelling software to make it work. These are discussed in more detail below.

- **lack of skills** – this focussed on skills shortages aligned to those who understand how to use digital 3D design tools as well as a lack of awareness of the potential application of 3D printing for students and business. *As part of the Manufacturing Action Plan for Scotland, SDS commissioned research to map out manufacturing and engineering related training* *provision (including those related to 3D printing) in colleges and universities across Scotland. Further information is presented in Section 4.5*

- **Low awareness and understanding of processes, applications and limitations of 3D printing**. Outputs from 3D printing vary greatly depending on cost, printer type and material used. However, expectations of what is possible remain high. For example, the 3D part produced by a laser sintered printer with high strength and functionality will not be produced using a desktop 3D printer. To illustrate the difference between processes and sectors, in the creative industries, a jewellery designer may use precious metals and would therefore require a 3D printer which can print directly in metal. This requires a printer with a small build area, a high-power laser and close control of process parameters to keep temperatures constant and maintain high levels of accuracy. Whereas, in the health care sector, to print plastic orthotics e.g. wrist splints, accuracy is not as critical; the build area is bigger and the printer requires low power.

- **Digital tools** – while digital tools are improving all the time, standards are variable and speed of change is rapid. This places a responsibility on businesses to keep up with multiple formats. Many consultees were still using an old data transfer format which was developed over 30 years ago but is limited in its capability. Academics have developed their own data transfer format, but this was viewed by industry as too complex and lacking commercial application, resulting in them developing their own or using traditional formats.

- **Materials** – lack of understanding around material usage, coupled with the cost and limitation of materials currently available were additional challenges. Also, the same material used in two different 3D printers can yield different results in surface finish and strength.

- **Cost** – the cost of 3D printing is variable and too high for many small-sized businesses. Consultees stated that until 3D printing can be made more cost-effective, people are unlikely to make the investment. While low cost printers were viewed as beneficial for producing prototypes and supporting education, it was recognised that producing functional parts to the requisite high levels of accuracy and consistency requires more expensive 3D printers and more expensive materials.

- **Lack of confidence in the technology** – 3D printing is still viewed by some as "unproven" and there is a concern that the degree of variation between different 3D printers could have a knock-on effect on quality. Consultees commented that the market is driving towards machines that have more consistent supply chain materials and fixed parameters, so a batch of products will be the same across the board; however, this increases costs and adds to the adoption barriers.

- **Set up and development costs** - many companies view R&D as a cost rather than an investment. For some, 3D printing is still viewed as a novelty and 'nice to have' rather than essential business tool, which is perpetuating this view.

- **Access to 3D printers** – stakeholders believed that there is a lack of visibility of and access to 3D printers to really showcase its potential. While makerspaces or demonstration centres have a range of printers and offer open access sessions, there are limited open access facilities in Scotland, especially in remote and rural settings. The demise of MAKlab[19] as a result of them not securing continued development funding has restricted access further still (see case study in next section).

[19]Due to lack of development funding, MAKlab was liquidated in July 2017 and the service is no longer available.

4.2 EXAMPLES OF HOW CHALLENGES HAVE BEEN ADDRESSED

The following case studies summarise interventions that have taken place in the Highlands and Islands and elsewhere to help address challenges outlined above:

1. **FabBus** – a mobile fabrication unit developed by Aachen University in Germany
2. **I2P Labs** – a network of product innovation support centres in South Africa
3. **MAKLab** – was a network of makerspaces across Scotland
4. **Project Nautilus** – a community project in Tarbert, Isle of Harris, to help young people develop skills in engineering, design, science and technology

Case Study – FabBus

Aachen University of Applied Sciences in Germany has introduced the "FabBus" as a means of bringing 3D printing and related technologies to schools, community groups, and trade exhibitions. The FabBus is an old double-decker Berlin city bus that has been converted into a mobile 3D printing and computer-aided design (CAD) laboratory.

The Fab Bus provides a mobile means of demonstrating 3D printing and related technologies to future users
The upper deck of the FabBus offers a perfect learning environment and is equipped with eight workstations, each consisting of a computer and 3D printer. The lower deck has many example components and drawers full of technical literature that makes the technology easy to understand. Visitors can model their design on a CAD system and then watch it being built on a MakerBot 3D printer. The bus also houses a 3D scanner, a small coffee bar and an area where discussions can be held. One disadvantage of using the FabBus is that it travels quite slowly (maximum speed 70 kph) and can take several days to reach the parts of Germany that are furthest from Aachen. However, the University believes that its ability to reach communities in remote areas outweighs this.

The Fab Bus has been used both for student education and industrial training
By integrating an experience with school lessons held before and after the FabBus visit, 3D printing and topics from the world of teaching can be combined and linked. This helps to provide an integrated learning approach for the STEM subjects. The FabBus provides an excellent opportunity to teach principles and application of science, mathematics, technology, engineering and design. The FabBus offers companies the opportunity to conduct training and workshops in the field of 3D printing directly on site. Small and medium-sized businesses particularly benefit from the mobile training facility since they are unlikely to have such facilities on site. Training can be tailored to the needs of Individual companies or whole sectors and offered at a reasonable cost.

Learning and implication of this approach for the Highlands and Islands
The FabBus offers a replicable model for the Highlands and Islands to help raise awareness of and access to 3D printing technologies. Using modified vehicles to take services to remote and rural communities is already commonplace in the region, with examples including the ScreenMachine (Scotland's mobile cinema)[20] and NHS services (e.g. breast screening and blood donation trucks). Development of the concept as a 3D printing training and demonstrator centre would require extensive collaborative effort involving the public sector and industry, with support from academia and schools to support delivery and development of curriculum materials for schools and colleges. Training materials for companies could be based on web resources that are readily available from CAD vendors and 3D printer manufacturers.

[20] https://www.screenmachine.co.uk/

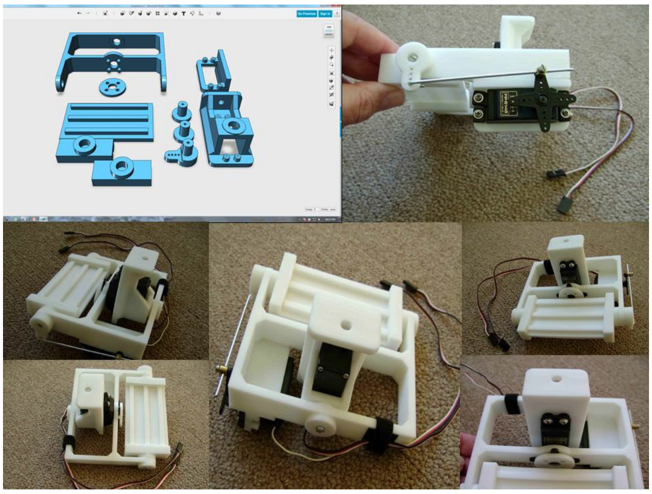
Case Study – I2P Labs

Prof Deon de Beer, currently at North West University in South Africa, conceived the I2P (Idea to Product) Lab model while working at Vaal University of Technology, also in South Africa. I2P Labs offer support for technology transfer into local industry by offering low-cost access to CAD and 3D printing technology. I2P Labs is now running in several countries including Sweden and the USA. They are used by small businesses, entrepreneurs and students with a product idea they want to commercialise.

I2P Labs are designed to transform ideas into working prototypes
South Africa in general (but more specifically the poverty-stricken areas such as the Southern Gauteng) is challenged with low levels of skills development, underpinned by insufficient job opportunities. As part of the solution, I2P Labs was proposed as a strategic intervention. Entrepreneurs from the surrounding region are provided with appropriate skills development and infrastructure, enabling them to develop new products that can be tested and modified according to customer needs. There is no fixed definition of exactly what technologies an I2P Lab should offer. Instead, technologies are chosen according to local availability and the knowledge of support staff. Typically, the technology offering will include some sort of 3D scanner, one or more CAD systems, low cost 3D printers, and other fabrication technologies such as laser cutters or printed circuit board manufacture. The “hand-holding” offered by the Lab manager is equally important as he or she will guide users on which technologies they need, and where they can access training resources (often on the Internet).

Example of successful I2P Lab project
Shown below is a collage of images that represent the complete development of a radio-controlled gimbal and mount, crucial for the stabilisation of, for example, a camera mounted on a drone. Part of the achievement is that the I2P Lab concept was introduced to a hobbyist/entrepreneur who saw the opportunity to develop drones for specific remote inspection applications. After consulting with the I2P Lab manager regarding the use of 3D printing versus conventional machining technologies, the entrepreneur started to use Autocad 123D to design the complex integrated mechatronic devices, as shown below. The designs were then made on UP Mini low-cost 3D printer. He went on to design and manufacture various connectors to be used with standard extruded aluminium sections. The experience he gained with this project and the processes that he used, encouraged him to develop a new niche-market company.

Learning and implication of this approach for Highlands and Islands
The Highlands and Islands economy is dominated by micro and small businesses, operating in local and domestic markets. Using the I2P approach in the set-up of one or more I2B Labs in the region could provide access to facilities and knowledge that is otherwise not available. Central to this approach is the need for a full-time lab manager, who is knowledgeable about all the technologies on offer. Providing technologies in isolation is a recipe for misuse and disappointment. The I2P approach could also be incorporated into the mobile lab(s) initiative described in the FabBus case study above.



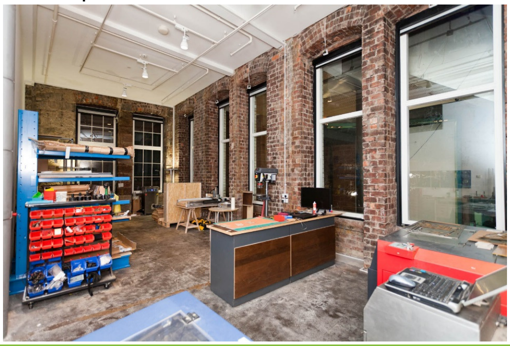
Case Study – MAKLab

MAKLab was a charity set up in 2010, operating until July 2017. It was Scotland's only open access community digital fabrication studio, offering access to a range of innovative digital fabrication and traditional techniques from 3D printing and milling to digital knitting and jewellery-making. MAKLab viewed physical making as an important way of both helping people develop technical skills and soft skills and offered a mixture of teaching workshops, community outreach programmes, professional development and accredited learning.

MAKLab offered 3D manufacturing services and training programmes for young people
There were five MAKLab sites and a mobile unit. The sites included a head office in Glasgow; a manufacturing site (also in Glasgow) which included several high-spec 3D printers; a site in a retail premises in Dumfries; another in Dundee; and one in Wick High School. They also had several mobile 3D printers, laser scanners, virtual reality kits and other technology. MAKLab offered a 3D manufacturing service to businesses, with all funds generated being invested back into their training programmes for young people, adding new equipment to their studios, and enabling groups to realise their projects. They had a broad selection of equipment to use for commission work, and experienced staff to carry out the work. They also had assembly and finishing spaces to cater for the design, fabrication and assembly of large projects.

MAKLab North – providing access to the latest digital tools to the future generation
Launched in 2015, in partnership with Wick High School, MAKLab North provided access to the latest digital tools for the young people of the school and surrounding area, as well as the local community and industry. The project involved establishing a fixed workshop at Wick High School to give pupils the opportunity to accurately design and construct components using 3D printing technology. It aimed to produce a group of skilled and motivated young people for employment in engineering, renewable energy and the creative sector. A mobile van facility was also established allowing the young people and their school to offer workshops, events and outreach projects across the North East of Scotland. MAKLab North was mostly managed by the pupils of Wick High School, and generated income from the local business community who accessed its printing facilities. A project delivered by MAKLab North brought together the pupils from the school with the users of West Highland Men's Shed to promote intergenerational knowledge exchange, helping shed users better understand new technology while helping the pupils learn from the life experiences of the shed users. In addition, any business in the Caithness area could use MAKLab North for 3D printing advice and support.

Learning and implication of this approach for Highlands and Islands
Setting up a network of local makerspaces would allow people in peripheral areas to learn about and access 3D printing technology. This could involve central makerspaces which work with high schools, as well as other 3D printing providers such as the Glasgow School of Art who already have a facility offering 3D printing in Forres. This kind of model could also link to the mobile maker bus example cited in the previous case study. Developing these spaces will not be without challenges, particularly around ensuring sustainability, as the recent demise of MAKLab demonstrates. The ability to leverage existing resources and developing multi-purpose facilities as well as looking for sponsorship or funding linked to community and skills development should be considered as mechanisms to create more sustainable solutions.

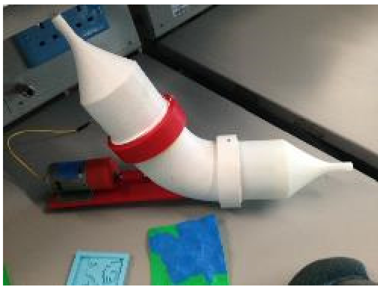


Case Study – SIR E Scott School and Project Nautilus

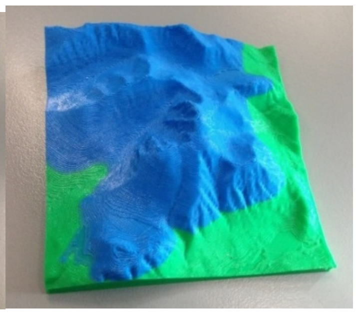
Sir E Scott School in Tarbert on the Isle of Harris established an Engineering and Science Club (commonly known as 'Tech Club') with the support of science and engineering teacher David Smith. In 2012 Jeeves Tour, a local businessman and director of GeoInt 3D, worked with the school to establish Project Nautilus, a community venture to provide youth training, guidance and networking. The aim of Project Nautilus is to promote excellence in engineering design, science and technology, and to encourage innovation.

Project Nautilus provides students with the opportunity to work with industry standard software and hardware. Through the project students learn how to use Solidworks, Makerbot, Robox and the Up 3D printer, as well as a Roland milling machine with 3D scanning head, marine survey equipment and laser scanners. The project also has access to specialist training in 3D survey and scanning, laser scanning, computer coding and engineering through volunteer industry staff.

Project Nautilus has supported skills and career development and aspirations, as well as providing a platform for local business and community engagement
In 2013 the Tech Club entered the MakerBot Challenge as part of the national Big Bang competition. The Challenge was to design and print a water pump which could pump as much water as possible in one minute. A minimum of 80% of the Pump was to be 3D printed. The pump was designed by members of the Tech Club and drawn as a 3D model on SolidWorks CAD. The SES pump was printed on the School's '3D Up!' and 'Makerbot' printers. The students worked with Strathclyde University to print the outlet as their school printer did not have the capability to do this.



The students also make lots of 3D models and have sold some for charity. In addition, they worked with the Harris Distillery to create a working 3D printed jelly bean dispenser, as part of the distillery's sensory tour. The students have used 3D printing for creating working tools, such as this torque wrench which is used on the International Space Station, and models of landscapes, including Ben Nevis.



Learning and implication of this approach for Highlands and Islands
With the support of the North Harris Development Trust, GeoInt and an industry partner, there are plans to expand the Tech Club into a youth club with a technology/innovation theme. With appropriate support, this model could be extended into other island and rural communities, helping to raise awareness of new technologies and addressing skills gaps from school age onwards. Further value could be gained if a mobile provision was developed.

4.3 HOW 3D PRINTING IS LIKELY TO DISRUPT THE HIGHLANDS AND ISLANDS ECONOMY

The concept of disruptive innovation was pioneered by Karl Marx in his book Das Kapital, and was developed by Joseph Shumpeter, who argued that markets evolve through "a perennial gale of Creative Destruction" in which new technologies replace old ones, and those businesses that effectively utilise the technologies take over from those who do not[21].

Stakeholders commented on the disruptive effects of 3D printing on the supply chain and business models, with most feedback describing this as ***"positive disruption".*** A few stakeholders believe that **3D printing would not be disruptive at all**. They commented that traditional methods of manufacturing would remain, with 3D printing providing an additional means of manufacturing rather than a single way ahead.

4.3.1 Positive impact

Most stakeholders focused on the benefits the technology would bring, describing a future where rather than buying a part, one would purchase the design electronically and print on-site or more locally. This would significantly reduce the supply chain, cutting out the current maker, removing warehousing requirements and minimising delivery. This would also save on costs and carbon. It was noted that this scenario would have the greatest adverse impact on businesses that provide small batch injection moulding services.

In the healthcare market 3D printing is viewed as "adventurous" and that until leading health care providers such as the NHS mainstreams this approach, 3D printing would not happen on a large scale and would be confined to the private healthcare market. It was noted, however, that while the UK is yet to see this scale of adoption of 3D printed health products, other countries such as the USA are using 3D printing including for bespoke hearing aids and dental "Invisalign" braces. In Italy, Lima Corporate produces 3D printed metal hip implants to a large scale. These implants are of standard design, are not personalised and have replaced the traditional machined or forged parts. A few stakeholders commented on how the dental industry was being radically changed by metal 3D printing use in dental frameworks replacing manual casting. This was producing more accurate, stress free, distortion free support systems which could be fired more and had minimal waste.

In the **pharma market**, it was reported that 3D printing through the provision of point-of-care and on-demand medication had **the potential to cut out the whole supply chain** delivering faster results for patients and cost savings for health providers. This was, once again, seen as a long-term opportunity.

Stakeholders commented that 3D printing could lead to the **re-localisation of production around communities.** However, it was recognised that we are still a long way away from local communities being able to match the productive capacity of global manufacturers. It was generally felt that **public sector intervention should focus on supporting businesses in areas where adoption could be the highest, and the benefits greater.**

Within the Highlands and Islands, stakeholders felt that disruption because of 3D printing would predominantly be positive as the majority of parts that could be made by 3D means were actually being purchased outwith the region. Increasing local capability could save time and money and be more environmentally friendly. The addition of 3D printing to the creative and tourist sectors was seen as a particularly positive selling benefit.

3D printing has the potential to transform manufacturing strategies. Final manufacturing sites may move closer to the customer with a consequential impact on transport and logistics. We may see fluid supply chains and broader global partnerships. The emphasis will be on shortening the supply chain and soon, on-demand production may become the norm.

[21] Capitalism, Socialism and Democracy, 1942

3D printing could essentially create a demand for smaller, localised manufacturing environments capable of customised production, shortened lead time and drastic cuts in transportation costs and overall reduction in carbon footprint. This would result in products previously difficult to obtain being more accessible and consequently, a reduction in costs for those living in rural parts of the Highlands and Islands. Additionally, this could provide an opportunity for small local businesses to thrive and allow for economic growth.

4.3.2 Negative impact

Despite the potentially positive disruptive effects of 3D printing, possible negative effects are also reported. 3D printing will impact most on those industries that are dependent on producing and/or storing spare parts. Where parts are made on demand and more locally or on-site, there will be less requirement for warehousing and off-site production.

According to an ING report, the uptake of 3D printing could lead to a reduction in world trade, particularly in the manufacturing sector, where the technique could account for up to 50% of market share (ING, 2017). One of the areas expected to be adversely affected by this reduction is Harbour Services, as it is said to depend heavily on the trade of manufacturing goods (ING, 2017). From a Highlands and Islands perspective, this could be potentially damaging to small economies who expect to undertake harbour regeneration projects in the future, and who depend on the up-keep of sea travel facilities for transportation purposes. However, this is said to be a possibility only when high speed 3D printing makes mass production with economically viable 3D printers. The timescales for this remain quite distant.

4.4 WHAT ARE THE IMPLICATIONS OF NON-ADOPTION

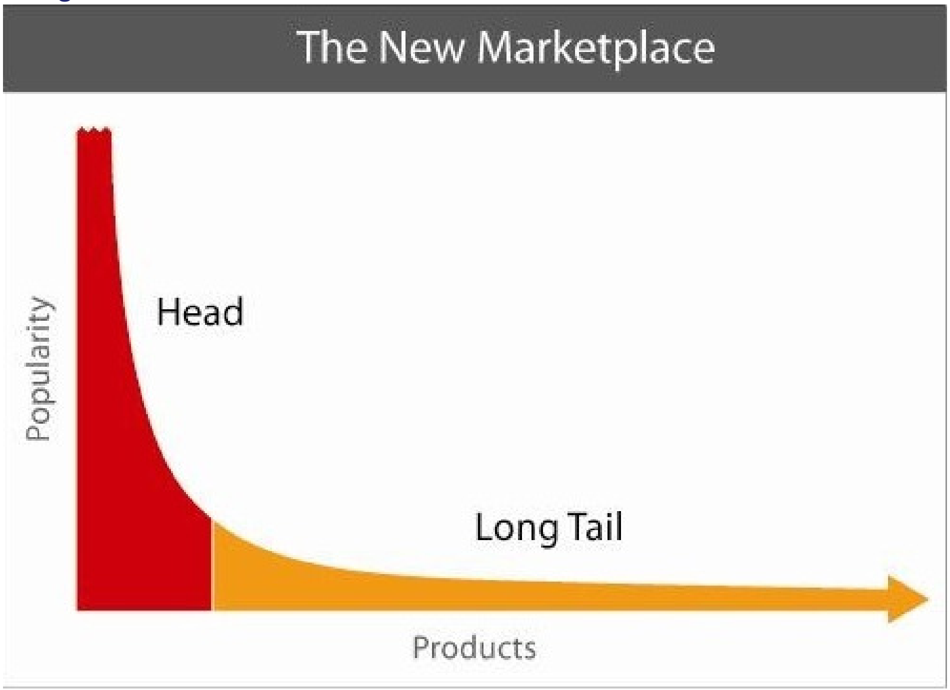
Consultees described 3D printing as a 'game changer' which will remain for the long term. As the technology develops at speed, there is a risk that those who do not keep up will find it impacts negatively on their competitiveness.

Risks of non-adoption, as identified by consultees include:

- being less capable of offering a bespoke-to-user product which could be sold at a price premium delivering greater profit margins – long tail market (see below)
- paying more for components than competitors
- waiting longer for components to be delivered
- not able to resolve problems and fix breakages on demand

Long tail refers to products that are in low demand or have low sales volume which can collectively make up a market share that rivals or exceeds the relatively few current bestsellers and blockbusters, but only if the store or distribution channel is large enough. If, for example, companies in the Highlands and Islands started selling niche products tailored in a personalised way, there is the potential to increase their market share and profitability.

Figure 4.2 Long tail



4.5 WHAT TRAINING AND SUPPORT SCOTLAND'S UNIVERSITIES AND COLLEGES OFFER FOR 3D PRINTING

There is a considerable amount of R&D and skills development utilising 3D printing and associate technologies currently being undertaken in academic institutions across Scotland. A range of university stakeholders (Glasgow, GSA, Glasgow Caledonian, Heriot-Watt and Abertay) were able to provide examples of where 3D printing was being used to support R&D. These examples have already been reflected in the previous section and included:

- **Organlike** – a university-based company in Inverness taking to market innovative technology for the provision of 3D printed hyper-realistic organ models for practice surgery and training.
- **Heriot-Watt University and Roslin Cell** – demonstrating the ability to replicate human tissue and have developed a method for 3D printing of clusters of human embryonic stem cells on which pharmaceuticals can be tested, aiding in-vitro drug development and toxicity-testing.
- **Glasgow Caledonian University** - leading a £3m EU funded study to see if 3D printing techniques can help people suffering from disabling foot and ankle conditions.

Interface, who support business and academic collaboration, has started to map out 3D manufacturing facilities across Scotland; however, they do not provide any detailed information regarding support in this area on their website. They commented that:

"*Opportunities lie in prototyping within the creative industries, creating scaled models of products in engineering, creating 3D models of a tourist attraction, and 3D printing of medicine within life sciences.*"

Figure 4.3 3D printed manufacturing facilities in Scotland, 2016 [22]

As part of the Manufacturing Action Plan, SDS led two research projects to map out manufacturing and engineering related training provision in colleges and universities across Scotland (including those related to 3D printing). The work in the colleges completed in 2017, with the university provision due to complete in 2018. An interactive map of the college activity can be found at http://www.esp-scotland.ac.uk/news/50257-college-resources-map.

4.6 WHAT OTHER SUPPORT COULD BE PROVIDED

This section provides example interventions that could be introduced in the Highlands and Islands to support the development of 3D printing across the region. It is based on the evidence from the consultations and international good practice review. Reflecting the key challenges identified, the section will examine the following areas:

- raising awareness and encouraging uptake
- developing the local skills base
- developing the necessary infrastructure

4.6.1 Raising awareness and encouraging uptake

Actions that could be taken to generate an initial business interest in the concept of 3D printing include:

- organising **demonstration events** to showcase the technology, engage the business base and raise awareness
- disseminating **good and exemplar practice case studies** in partnership with industry groups and businesses – some examples presented in this research will be a useful starting position
- providing access to **learning journeys** to inspire business owners – many countries have been using and promoting 3D printing for a while and sharing learning will help businesses understand the support requirements
- using **UHI and academic institutions learning centres** as potential locations for makerspaces to provide an opportunity for industry to see things happening in local colleges and universities

[22] This map has not been updated since late 2016

- organising **exhibitions, talks and webinars** to raise SME awareness on access, materials, processes, applications and costs of 3D printing – this could build on the Digital Maker events held during 2016
- organising **workshops to help and encourage pioneering businesses to share** good practice examples of how they have been able to take advantage of 3D printing technology with non-competing businesses in their area
- offering **information, advice and guidance (IAG)** on the benefits and challenges of 3D printing, including materials and processes, was considered a priority

Once this initial engagement has been attained, further support could be delivered by:

- bringing **industry leaders together through a 3D printing forum** to discuss the challenges that they are facing with 3D printing adoption and to share best practice
- organising **networking events** to connect companies who can benefit from each other's' experience across the design, modelling and prototyping areas
- providing a **database** of experienced businesses in the 3D printing space (both in the Highlands and Islands and across Scotland); this could link to the maps of skills provision developed by SDS (as discussed in Section 4.5)
- developing a **cross sectoral network and communities of interest** of 3D printing professionals in the Highlands and Islands who can meet (possibly through a **shared maker space**) to exchange knowledge and ideas

Many stakeholders believed that universities (and to a lesser extent colleges) could have a particularly important role to play as a potential partner to businesses for 3D printing activities, offering both research expertise, access to equipment and support for skills development. Interface has already started to map out some of the company and academic capability across Scotland and has a role to play in bringing companies and academics together, so this would be a good place to support promotion. In addition, SDS has mapped out manufacturing skills development capability across Scotland's colleges and is currently undertaking a similar exercise for universities.

4.6.2 Developing the Highlands and Islands skills base

The research identified a need to increase 3D printing skills by:

- generating an interest in 3D printing at **school level** - by assisting **STEM Ambassadors** to promote career opportunities for young people in Science Technology, Engineering and Maths, with a view to 'switching young people onto 3D printing and other technology areas; **helping schools to buy 3D printers**, and **providing training to teachers** to give them the confidence to demonstrate them to their pupils
- developing appropriate courses at an **FE/HE level** – for example, by working with universities and local colleges to develop, deliver and promote 3D-CAD courses to address skills gaps and regional needs – this should build on the mapping work currently being undertaken by SDS to help plug gaps and create links to existing provision
- **helping businesses** train their staff in 3D printing – by **fostering networking and collaborations with academia**, and by providing **financial support** to businesses looking to bring in external training providers

One recurring message that came out of the research was the importance of having a network of flexible makerspaces that can be utilised by businesses, universities, colleges and schools. These could be in schools, university campuses, community hubs or mobile maker-buses. The Technology Club in Sir E Scott School in Harris and MAKLab were viewed as good examples of learning centres and maker spaces.

4.6.3 Developing the necessary infrastructure

To create a successful 3D printing eco-system, it will be important to have the appropriate infrastructure in place. This includes:

Strategic alignment
It was suggested that public sector partners should work collaboratively to develop and implement a joined-up 3D printing action plan that fully aligns with the national Manufacturing Action Plan (MAP). The plan would need to cover infrastructure, skills development, raising awareness, engagement, etc and show defined roles and responsibilities as well as targets aligned to specific areas.

Access to 3D printing technology
The development of hubs/mobile units with high quality technology that businesses could use/rent rather than need to buy would be beneficial. It is important to have access to a mix of creative and technical experts in such environments to generate ideas and then work out solutions. Some stakeholders highlighted that high street facilities had already started to appear, including one in Forres supported by Glasgow School of Art.

Clusters and collaboration opportunities
Some stakeholders highlighted that it would not be economically viable to have access to several different technologies in each remote/rural area as this would lead to inefficiencies and high maintenance cost. It would be beneficial to map out clusters of companies or individual practitioners operating in the same field e.g. jewellers, craft work, and identify the most useful 3D printing process to be accessed. Thus, clusters of expertise would be built around a combination of material and process.

Information and communication technology networks
3D printing technology relies heavily on digital communications, extending well beyond uploading and downloading files. A growing trend in design software is web-enabling which allows a program to be accessed online in real-time, as opposed to running on the user's computer. Therefore, if the connection is slow, the user will not achieve a real-time response. **For 3D printing technology to operate successfully in remote rural areas, the internet connection speed must be able to accommodate these data transfer and data process requirements.** With fibre optic superfast broadband rollout taking place in the Highland and Islands, this should be achievable.

Access to advice and support
To ensure that the Highlands and Islands are well placed to capitalise on 3D printing opportunities, stakeholders felt that **public sector organisations could act as the conduit to access information on financial support and wider advice** on what type of printer and process/ material combination, which businesses and industry groups are active in this area, events, and demonstrators. Provision of grant funding like innovation vouchers[23] to reduce business risk and encourage access among SMEs and independent practitioners was suggested.

Access to design expertise
Some stakeholders highlighted that **design expertise was critical and that this was applicable to all sectors.** The presence of Glasgow School of Art and the Digital Health Institute in the Highlands and Islands were both recognised as having the potential for providing support in identifying and developing sectoral opportunity.

[23] Innovation vouchers encourage first time collaboration between businesses and universities/colleges through the provision of funding of between £1000 and £5000 per voucher

4.7 IN SUMMARY

The growing usage of 3D printing technology has the potential to lead to several significant market transformations, including increased customer desire for, and expectation of, bespoke products; the removal of layers from the supply chain (including potential local suppler companies), and the re-localisation of product manufacturing around communities.

While some of these changes may take time to materialise, particularly in the life science sector, the region could obtain a significant competitive advantage by preparing for these now through supporting awareness raising, sharing exemplar practice and encouraging industry leaderships and champions.

Based on the evidence from the consultations and international good practice review the support needs can be segmented across the following themes:

- raising awareness and encouraging uptake
- developing the local skills base
- developing the necessary infrastructure

5 CONCLUSIONS AND RECOMMENDATIONS

This research study sought to consider the following four objectives related to the development of 3D printing technology in the Highlands and Islands:

1. **Global trends in 3D printing:** provide an overview of global trends in 3D Printing, and its role as an emerging digital technology.
2. **Applications for manufacturing in the Highlands and Islands**: explore the current application of 3D printing technology in manufacturing, particularly in Scotland's growth sectors, and the extent of its use across these sectors in the Highlands and Islands.
3. **Barriers and support needs:** explore the barriers that may prevent manufacturers from capitalising on the benefits of this emerging technology, and what support might be required to help the business community adapt to the change.
4. **Disruptive effects and implications of non-adoption:** explore implications for industry and public sector.

This section will explore what conclusions can be drawn against each of these in turn. It will then provide recommendations to help increase the number of people and businesses productively utilising the technology in the Highlands and Islands.

5.1 GLOBAL TRENDS IN 3D PRINTING

The use of **3D printing technology is forecast to grow rapidly over the next three years**, with Wohler projecting that the total value of the global 3D printing market will increase from $1.6b in 2015 to $13.4b in 2018, equivalent to an annual compound growth rate of 103% (i.e. the size of the industry will more than double in each of these three years).

This growth will lead to an increase in the number of 'at home' 3D printers in consumer households, and an increased demand for desktop 3D printers in schools and academic institutions. The growth is also being driven by technological changes which make it now possible to build with a wider range, better quality and cheaper printing materials than has previously been the case.

Laser metal deposition (LMD) is expected to be the fastest growing technology in the 3D printing market over the next six years, and Siemens predicts that 3D printers will become 50% cheaper and 400% faster in the next five years. This could lead to mass customisation.

However, while the sector is expected to grow rapidly, it **should be acknowledged that this growth will stem from a very low base,** and that the additive manufacturing market currently accounts for less than 2% of total global manufacturing.

5.2 APPLICATIONS FOR MANUFACTURING IN THE HIGHLANDS AND ISLANDS

3D printing offers opportunities for businesses to create bespoke, one-off, model or finished products on-site, without having to involve any external third party or to be constrained by a minimum order requirement. It represents a highly disruptive technology, with potential implications for the time it takes businesses to get a product to market, how businesses choose to segment their client market, how businesses organise their logistics, and for the long term economic viability of supply chain businesses.

Some of the potential competitive advantages presented by 3D printing include:

- new opportunities to develop bespoke products to a unique customer specification
- ability to generate a rapid prototype quickly, and to generate more iterative processes for building prototypes
- potential to make low-volume injection moulding services obsolete
- valuable as an educational tool, particularly for training engineers and architects to think in three dimensions

Given the savings in logistics, the technology is likely to be particularly advantageous for remote rural businesses.

The research shows that 3D printing techniques can potentially be applied (to some extent) to each of the priority sectors highlighted in Scotland's Economic Strategy. However, the life sciences and creative industries sectors were identified most frequently as the sectors where the greatest opportunity lies, alongside the cross-sectoral opportunities presented by high value manufacturing.

5.2.1 Life sciences and health

3D printing has become an established manufacturing method in the formation of prototypes, medical models and dental products within the life sciences and healthcare industry. Stakeholder feedback confirms that 3D printing is already widely used within the life sciences and healthcare industry in the UK and is an area of strong growth. Despite this, it is yet to be adopted at scale in the NHS, with the main early adopter being the private healthcare market.

For example, bioprinting, the fabrication of organs from biomaterials using a 3D printer is becoming of increased interest to medical scientists. However, the regulatory challenges associated with securing medical consent for any 3D printing application that goes inside the human body (e.g. an organ) can be time-consuming. Due to the fast-moving nature of 3D printing innovation there is a risk that once these challenges have been overcome the technology will have moved on and newer, better, processes will have emerged. Getting approval for 3D printing applications that go outside of the body (e.g. a cast) can however, be less challenging, so this may be an area with greater short-term economic opportunity.

5.2.2 Creative industries

3D printing can facilitate the production of bespoke and highly customised fashion, jewellery and ceramic products, whilst also reducing the time to market. 3D printing is considered valuable both as a prototype tool and, in some cases, for generating the end product itself. The ability to use 3D printing to create bespoke/tailored luxury consumer goods gives designers the chance to sell something at a higher cost thus generating a better profit margin.

5.2.3 Energy

3D printing is used by energy businesses both for new product development and for process improvement. While stakeholders noted that 3D printing has been used in prototyping and design of high value, low volume niche products, they also commented that the highly regulated energy industry is taking a cautious approach, applying a 'watching brief' to the new technology before committing to wider use.

The technology has the potential to help streamline production processes and reduce costs. For example, one of the businesses interviewed used 3D printing techniques to develop a plug for blocking off pipelines. The dimensions of any such plug need to be very precise and no two products are identical. The ability to rapidly 3D print a plug such as this in-house can lead to considerable time and cost savings. It avoids the risk of a brief being misinterpreted by a manufacturing contractor and allows it to be produced at the time that it is required, on the company's premises.

5.2.4 Food and drink

Applications of 3D printing technology for the food and drink sector were fairly limited. However, some applications were identified in innovation around fish feed systems in aquaculture, in food and drink packaging, and in food prototyping and production, particularly towards the luxury end of the market. The Highlands and Islands has a range of companies that work in these sectors.

5.2.5 Cross sectoral opportunities

With the exception of financial and business services, tourism has seen the least activity within 3D printing of any of the six priority sectors. Where it has been used, it has tended to be within a cross-sectoral framework. For example, 3D printing has been used by tourism and creative industries sectors to create scaled-down models of existing tourism and heritage attractions as souvenirs, or recreations of medieval sites to aid interpretation. Nature-inspired designs can also be made in sustainable bio-based materials.

5.3 BARRIERS AND SUPPORT NEEDS

Levels of awareness of 3D printing technology, its capabilities and its applications appeared limited among businesses in the Highlands and Islands. It was felt that the public sector had a significant role to play in promoting increased understanding of the technology and the advantages that it could bring to businesses across the region. Other types of support identified to help businesses to fully exploit the potential benefits of 3D printing included:

- awareness raising around the opportunities and applications, for example through sharing of good practice and case studies to demonstrate the benefits
- skills training around the development of CAD skills and 3D modelling more generally. Linking with SDS to maximise the opportunities in areas aligned to the Manufacturing Action Plan and the manufacturing and engineering skills maps currently being produced for universities and colleges
- identifying what excess capacity exists in the area, either in terms of under-utilised printers, or under-utilised academic expertise, and identifying opportunities for businesses in the area to make better use of these resources
- fostering networks and collaborations between providers and supply chains – working with and building on the work of GSA who has been very active in this area
- providing access to demonstration spaces and makerspaces, either mobile or in one physical location:
  - to give companies that are completely new to 3D printing an introduction to the technology
  - to give companies that only need occasional access to 3D printers an ability to hire one by the hour
  - to create a community of 3D printing practitioners in the region that can share ideas and insights

Organisations that could support businesses wishing to use 3D printing include:

- **ADS Group** is the UK trade organisation representing the aerospace, defence, marine and security and space sectors – they are keen to provide support
- Construction Scotland Innovation Centre (CSIC) – are linking to businesses and academia
- **Interface** – produced a map of current capability and have an area on their website dedicated to this
- **NHS Innovations** is providing advice for projects in the life science sphere
- **SDS –** supporting the skills development of trainees through the access to programmes such as Modern Apprenticeships

Many businesses may also be able to lower the risk and lessen the learning curve by outsourcing aspects of their 3D printing activities, with companies like CA Models, 4C and Phoenix Instinct all able to provide either professional advice and guidance or take on the CAD file design and actual printing on an outsourced basis.

Given the fact that several private sector businesses and social enterprises already exist that provide 3D printing outsourcing services and training support, collaborative efforts across the public sector, linking to industry, should focus efforts on areas of market failure and on maximising opportunity more generally.

5.4 DISRUPTIVE EFFECTS AND IMPLICATIONS OF NON-ADOPTION

Over the coming years, growing use of **3D printing technologies will have a major, positive, disruptive impact on the Highlands and Islands**, particularly in remote and rural communities. It will enable businesses of all sizes to create product components, source replacement parts for their tooling, and undertake new product development instantly on-site, changing the nature of supply chains and existing logistics, ultimately providing environmental and cost saving benefits.

3D printing can offer businesses new opportunities to develop bespoke products to a unique customer specification. It also offers the ability to generate a rapid prototype quickly, and to generate more iterative processes for building prototypes. A secondary benefit is its value as educational tool, particularly for training engineers and architects to think in three dimensions.

The technology also has the potential to have negative disruptive effects, including:

- having a potentially damaging impact on businesses providing low-volume injection moulding services to companies (effectively rendering the service they offer obsolete)
- putting those businesses that fail to 'move with the times' and start to utilise the technology at a severe competitive disadvantage

Our research has suggested that 3D printing is likely to be a 'game changer' capable of transforming industries. It will become increasingly mainstream in manufacturing in the medium to longer term. Businesses slow to adapt and adopt risk being left behind in terms of competitiveness, skills and knowledge. Those choosing not to adopt the technology will:

- take longer to develop new products than their competitors, and pay more to develop them
- wait longer to source components and tooling than their competitors, and pay more for them
- be unable to offer the same quality of customised, bespoke products to their customers

In addition, businesses in the Highlands and Islands who currently use the services of injection moulding businesses may see their costs rise from their current levels and see their delivery times increase, should providers of these services start to go out of business because of the new competition they face from 3D printing.

The extent to which non-adoption is likely to disadvantage businesses will vary by sector. Sectors such as automotive and aerospace are already seeing it as a key part of their toolkit, while other more recent adopters such as life sciences and energy are using it to develop novel ways of undertaking existing processes. Mass customisation is increasingly becoming a thing of the present, with 3D printing being core to this.

5.5 RECOMMENDATIONS

3D printing is a rapidly growing technology which has the potential to have 'game changing' implications for several sectors of the economy and has the potential to substantially increase the competitiveness of businesses, particularly in rural and remote rural communities.

If businesses in the Highlands and Islands adopt this technology to its fullest level, the region has the potential to become one of the most innovative and productive manufacturing regions in Europe. Non-adoption is likely to leave businesses at a competitive disadvantage.

Collaborative effort is critical in supporting businesses to realise the benefits of this technology. A triple helix approach involving the public sector, academia and industry will be fundamental to this.

Actions that could support the effective uptake of 3D printing in the Highlands and Islands include **ensuring access to the appropriate infrastructure, facilitating knowledge sharing, and supporting skills development.** This is expanded on below.

5.5.1 Infrastructure investment

Developing makerspaces/demonstration centres: create a shared facility showcasing the latest and most advanced 3D printing technology that can be accessed by businesses for new product development, by schools, colleges and universities for research and education purposes and for government agencies for showcasing purposes. While these spaces could be located in more populated and/or accessible areas, providing mobile facilities could help extend manufacturing across the region, while fostering a more inclusive approach.

Creating rural access points: provide a network of further spaces elsewhere in the Highlands and Islands for the demonstration and shared use of 3D printing technologies. These could include a mobile 'makerbus', or permanent 'spoke' facilities of the central makerspace, in locations such as schools, libraries, community hubs, or community focal points (such as the Fort William Men's Shed or Taigh Chearsabhagh in Lochmaddy). The superfast broadband infrastructure under development in the Highlands and Islands will help facilitate the development of the access points.

Helping businesses invest: while shared spaces could be beneficial to businesses in the early stages, it is likely that some businesses will wish to have permanent access to their own in-house printers. An innovation voucher type scheme may help offset costs for businesses wishing to expand into this area.

5.5.2 Knowledge sharing:

Promoting and disseminating good practice: Increase businesses awareness of the benefits of 3D printing through the production and distribution of case studies, and through the provision of exhibitions and seminars. Promote the ‘art of the possible’.

Building a community: Establish a community of 3D printer users in the region, including people who use 3D printers for research and educational purposes, people using the technology in different sectors of the economy and hobbyists, who meet regularly to discuss the challenges that they are facing and to share experiences, insights and discoveries. The makerspaces and rural access points could play host to these meetings.

Promoting knowledge transfer: Help businesses make greater use of 3D printing expertise, including under-utilised equipment that already exists in the region. This could be achieved by creating directories of individuals and equipment that businesses can contact/use for advice and support, or through the introduction of some form of innovation vouchers scheme to encourage collaborative projects. This could be a development of the pre-existing Interface innovation voucher scheme.

5.5.3 Skills development

Schools: support the development of 3D printing skills at school level by providing 3D printers to schools and training teachers in how to use them, and by working with STEM Ambassadors to raise awareness of the career opportunities open to individuals with a 3D printing skill set.

Higher Education/Further Education: introduce accredited qualifications in 3D printing and CAD file design (or at least update currently available courses to include these) to ensure that the region produces enough graduates in these areas to meet the future demands of the area’s employers.

Workplaces: increase access to work-based learning courses in 3D printing and CAD file design to staff employed in the region’s manufacturing businesses to train them in how to use the technology.

In these activities, the public sector and business partners should seek to build on, rather than replicate, the services and support already offered by private sector and third sector organisations working in this area, including maker spaces, ReBoot, and companies such as CA Models. Actions should also align with the strategic priorities outlined in the Scottish Manufacturing Action Plan.

APPENDIX

STAKEHOLDERS

1. Make Aberdeen
2. Institute of Design Innovation, The Glasgow School of Art (x2)
3. Scotland Food and Drink
4. Construction Scotland Innovation Centre
5. University of the Highlands and Islands
6. Digital Health and Care Institute
7. Interface (x 2)
8. Falmouth University
9. MAKLab
10. NHS Innovation
11. Lead SMAS Practitioner for the North Science Skills Academy
12. Scottish Textiles Forum
13. Heriot-Watt University
14. Life Sciences Advisory Board – LISAB
15. Toshiba Medical
16. Centre for Censor and Imaging Systems
17. The Oil and Gas Innovation Centre (x2)
18. University of Louisville (USA)
19. Aalto University (Finland)
20. MIT
21. SCION Research Labs (New Zealand)
22. DataLab
23. Q5 Solutions
24. ADS Group
25. Skills Development Scotland
26. Sir E Scott School (x6)
27. West Harris Trust
28. North Harris Development Trust

BUSINESSES

1. Keep Art
2. Anarkik3D
3. IDE8
4. Phoenix Instinct Limited
5. Digital Design Studio, GSA
6. 4C Design
7. Max Burt
8. Art Bio Sphere
9. Inside Biometrics
10. 4C Engineering Consultancy
11. TriTech 3D
12. WoodBlocX Ltd
13. FMC Technologies
14. Ve Energy Ltd
15. Geoint (x2)
16. Summit Wearable Solutions
17. Moray Reach Out
18. ReBOOT (Moray Computer Recycling)
19. CA Models
20. Harris Distillery

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