COMING TOGETHER TO LEAD THE WAY

A SWEDISH AGENDA FOR RESEARCH AND INNOVATION WITHIN ADDITIVE MANUFACTURING AND 3D PRINTING

[Additive manufacturing, AM] is defined by ASTM F2792 as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

(ASTM F42 committees, www.ASTM.org)

Photo at front: Photo courtesy of Vèive Couture

>> We want to make Sweden, its industries and people, leading innovators within Additive Manufacturing – a vibrant, rapidly growing and potentially deeply transformational field of development and growth. And we want this agenda to be the first building block of co-operative leadership within the field, releasing the potential of Sweden's industries, universities, entrepreneurs and makers. <<

AGNETA MARELL,
Deputy Vice-Chancellor for External Relations and Innovation, Umeå University

Photo courtesy of thecreatorsproject.vice.com

CONTENT

THE AGENDA

– THE FIRST STEP TOWARDS CO-OPERATIVE LEADERSHIP WITHIN ADDITIVE MANUFACTURING

Industrial revolutions, they don't come along very often. At least not in the sense of the original one - changing the way we innovate, design, make and use goods and products. But lately a new field, merging the digital and the physical through ground breaking new manufacturing technologies, has developed into a strong contender for the title of 'the next industrial revolution'.

Starting out as a rather niche, highly technical and isolated area of expertise - of interest only to an exclusive group of a select few - additive manufacturing (AM) has grown from a whisper to a roar. With exceptional exponential growth, it is now believed by many to be on the verge of a public break through, catapulting manufacturing into the next stage of industrial (r)evolution.

It is a field of great potential and opportunity - for industries, innovators, designers and makers. And at the same time, AM is a cluster of potentially disruptive and world changing technologies, which poses numerous challenges - calling for co-operative leadership within research and innovation.

This is why the development of a Swedish agenda on AM was initiated by Umeå University, and funded by Vinnova - the Swedish Innovation Agency. The aim of the Agenda is to identify both potential opportunities and challenges, and recommend actions to move towards a common goal. The vision is to make Sweden, its industry and people, competitive and a leading nation in AM.

To achieve this goal, and develop an agenda with the potential to be the first building block of co-operative leadership within the field, releasing the potential of Sweden's industries, entrepreneurs and makers, the agenda-process has been one of inclusion and collaboration in a large group of key stakeholders. In addition to the six founding member organisations, Algoryx Simulations AB, Linköping University, LKAB, SP Processum, Umeå University and Volvo Trucks, the project group has expanded continuously. The process has been led by a working group of six people. Kenneth Bodin, CEO, Algoryx Simulations AB; Johan Ölvander, Professor, Linköping University; Johanna Stiernstedt, Senior Scientist, Swerea IVF; Mi Åberg, Technical Concept Designer, Tetra Pak; Marlene Johansson, Assistant Professor, senior lecturer, Umeå University and Mats Falck, area manager innovation at External relations, Umeå University. There have been four project meetings/workshops where input was given and aim and direction decisions were taken. Individual dialogues and interviews have been conducted with project partners and other stakeholders.

To spread the word about the Agenda, two short animated films have been produced and open seminars arranged at conferences including Swedbanks Tillväxtdagar (Umeå), SweCAD (Linköping), Impact of Culture by Tillväxtverket (Umeå), agenda meeting arranged by Vinnova May 2014 (Stockholm) and seminars at Mälardalens Högskola (Eskilstuna). There is a dedicated website[1] for the Agenda and there have been articles about the work published at 3dp.se and in media outlets such as Dagens Nyheter, Ny Teknik and Arbeidsliv i Norden.

Members of the project group have participated in meetings and conferences like the *EC Innovation Convention* 2014 (Brussels), the *EC Workshop on Additive Manufacturing in Horizon 2020 and FP7 (Brussels)*, *3D-skrivare en ny värld av möjligheter* (Stockholm), *Den industriella 3D-revolutionen* (Stockholm and Malmö), *Fablab10* (Barcelona), *Inside 3D printing – Conference and Expo* (Hong Kong and Berlin), *EuroMold* (Frankfurt), *Workshop Metalliska Material* (Stockholm), *DDMC-Fraunhofer* (Berlin), *Hannovermässan* (Hannover), *Läget för additiv tillverkning* (Stockholm) and *Entreprenörsdagarna in Båstad*.

It may also be of some relevance to clearly state that this agenda makes no claim to be a scientific paper or report. It is the product of constructive dialogue within a large group of stakeholders within the industry, research, and entrepreneurial communities involved in the field. By presenting this agenda we hope to reach and engage investors, both within the public sector and in the industry, and to broaden the group of contributors and stakeholders even further including innovators, entrepreneurs, designers, makers and others working within AM. We hope that this agenda, through further dialogue and the development of arenas for collaboration, may be the first step towards co-operative leadership within the field – setting out to realise the vision of making Sweden, its industry and people, competitive and a leading nation in additive manufacturing.

AGNETA MARELL
UMEÅ, NOVEMBER 2014

1 www.er.umu.se/am

WHAT IS IT, AND WHY IS IT GETTING ALL THIS ATTENTION?

– UNDERSTANDING ADDITIVE MANUFACTURING

AM, also called 3D printing, free form fabrication, rapid manufacturing and rapid prototyping is the collective name for several manufacturing methods to make objects by joining materials.

AM allows for the fabrication of a 3D product in a process which slices up a virtual 3D computer model into thin slices and builds it in a layer-upon-layer process in which each layer is built on top of the previous one. Depending on the technology being used, different processes and materials are used to "print" each slice of the model, until the part is complete. Today only the tip of the iceberg of possibilities with AM has been explored - it has near endless potential, only limited by our imagination.

2.1 ADDITIVE MANUFACTURING TODAY

Until recently, 3D printing was principally used as a 'prototyping' process. The technologies were not able to produce components of the same strength and surface quality as conventionally mass-manufactured components. For this reason it was mainly used to test out ideas and concepts from an aesthetic or functional point of view, but had limitations in its use because of the structural weakness and surface finish of the components. This is no longer the case as fully functional production components can now be manufactured in a variety of plastics and metals (titanium, aluminum, steel, etc.).

AM of metallic parts has been available for more than a decade, using either laser melting (Selctive Laser Sintering - SLS, Selective Laser Melting - SLM, etc.) or Electron Beam Melting (EBM®). The latter technology was introduced by the Swedish company Arcam AB and their first machine was released in 2003. Today, Arcam is one of the key players on the market. Many of the metal AM methods are today used for one-of-a-kind production but in a growing number also for serial production.[2]

Inkjet technologies are also now being used in rapid manufacturing processes. Materials range from polymers for engineering components to biological molecules for tissue engineering.

2 Currently there are two metal powder machines within universities in Sweden; one Electron Beam Melting (EBM) machine at Mid Sweden University and one Selective Laser Sintering (SLS) machine at Stockholm University.

Airbox made for a race car. Photo courtesy of Protech/Stratasys

Some of the advantages AM offer over conventional manufacturing include:

- Complexity for free: AM does not care how complex a component is. With traditional manufacturing, the more complex a component, the more it costs to manufacture and, at some point, it becomes impossible to manufacture. With AM, the more complex a component, the better it is suited to the process. Even though many designs still requires considerable post production work with todays technologies and depending on material.
- Low waste rate: This doesn't apply for all methods and cases but due to the layer-wise manufacturing, much material can be saved and for rare and expensive metals, this is a competitive advantage.
- Mass-customisation: With conventional manufacturing it is uneconomical to produce parts unless they are produced in large quantities, and every component is the same. With AM, it is not more expensive to produce a batch of components in which all components are the same, or all components are different. This opens up the door for production where each product is custom made to fit the user. An excellent example of this is the production of inner-ear hearing aids, the vast majority of which are today manufactured using AM, every hearing aid being uniquely manufactured to fit the user's ear.
- Part consolidation: With AM it is possible to consolidate many separate components into a single component, in some cases including moving parts, which reduces product complexity, assembly costs and can increase reliability and serviceability.
- Trying ideas at no risk: With conventional manufacturing, there is a large capital cost involved in the tooling needed to get a product to market. This start-up cost can become a barrier to individuals and companies testing their product to the market. AM dramatically lowers this barrier as it allows products to be brought to market with minimal start-up costs.
- Catalyst for innovation: AM is a physical innovation stimulation tool that acts as a catalyst to bring people from different disciplines together and sees them collaborate and innovate in an unprecedented manner.
- Material enabler: The possibility to process materials that are difficult, or even impossible to process with conventional methods such as turbine blades in titanium aluminide for the aerospace industry.

Industrial production machines are still expensive and require training to use, but this is changing fast. In 2012, IP for some Fused Deposition Modelling (FDM) patents expired[3] and we can see now the effects of that with over 200 different sub-US$ 5000 desktop 3D printers on the market. The consumer market with do-it-yourself

3 For example U.S. Patent No. 5,121,329.

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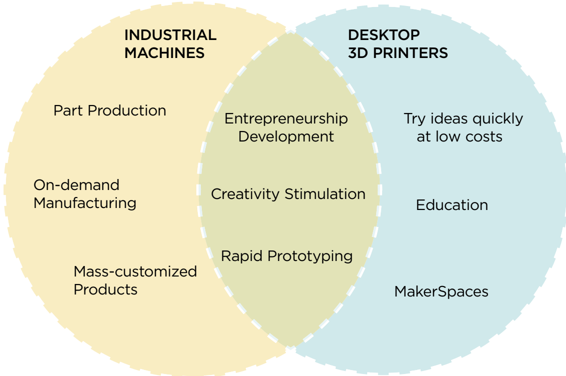

Figure 1: Fields of application for different types of 3D printers. *Source: Olaf Diegel, Professor Machine Design, Lund University*

(DIY) printers and the Maker Movement has exploded thanks to open source and cheap consumer desktop 3D printers. A similar explosion is currently starting with low-cost photopolymer based machines. The same is expected to happen for Selective Laser Sintering (SLS) where many patents will expire during 2014. This will lead to a lot of new players on the market and also make the equipment for the industry cheaper with a wider range of machines and materials.

It is however, important to distinguish between industrial AM machines used for production, and desktop 3D printers used largely for prototyping or hobby work. Both are fantastic in their own right, but what can be achieved on a desktop 3D printer is not normally the same as what can be achieved on an industrial machine. The recent media hype around 3D printing has tended to blur the distinction between the two.

2.2 SUCCESS STORIES

When used correctly, AM can save impressive amounts of time and resources. It has helped Tetra Pak for example, to trim weeks and even months of their design loops and prototyping process. The Swedish company VBN Components is utilising the technology to manufacture cutting tools with outstanding wear performance. The material used is so hard that it is almost impossible to process by CNC machining and tests at Volvo Construction Equipment have shown that the lifetime of these tools is estimated to be 2-3 times longer than conventional cutting tools.

Several other companies have realised the potential of AM and invest extensively to stay at the forefront of development and to implement the technique in their own production. One example is Airbus who now use AM to produce cheaper and lighter aircraft components. Before, with traditional production methods, they could consume 15 times more material than the finished product weight. Today with AM the used material factor for metal printers is just 1.05 times the finished product weight.

Another example is Volkswagen that uses AM to print sand cores of complex shapes to increase productivity and reduce scrap in the foundry production process. The complex cores can be printed in one piece instead of an assembly of several cores. Still another example is the use

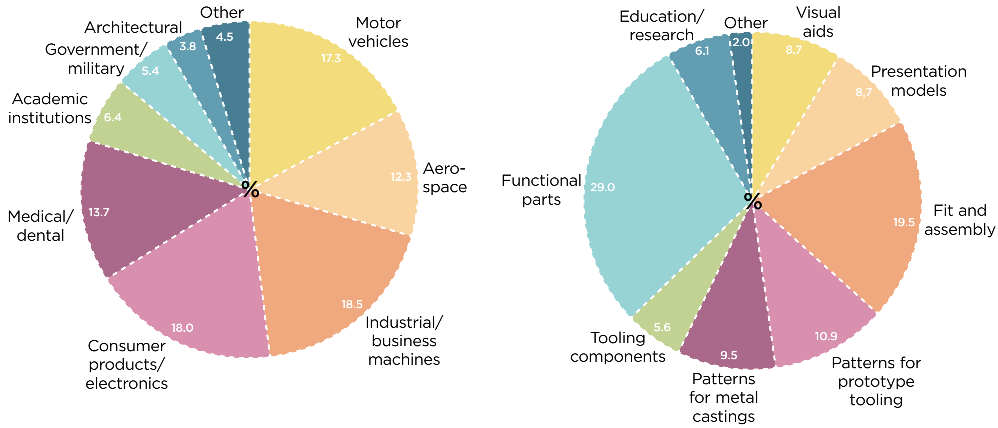

Figure 2: Use of industial AM systems; industrial sector and applications.
The Wohlers Report 2014. *Source: Wohlers Associates, Inc.*

of AM in medical implants. Today, several companies, for example Lima Corporate (IT) and Exactech Inc. (US) have realised that the possibilities of AM can result in products that are cheaper to manufacture, with even better functionality than comparable implants manufactured by conventional methods. Material savings, together with the possibility of designing and manufacturing functional surfaces for bone ingrowth, have made these companies pioneers. Their implants are currently manufactured, and used in operation, in their tens of thousands. Another example is the jewelry and design brand Lumitoro, that uses AM as a mechanism to launch the company and brand. What is different from other brands is that both prototyping and production uses AM technologies to create new and unique products. Something that would not have been possible just 5-6 years ago. These are only a few examples of AM's ability to be a method not only for prototypes and small series production, but a manufacturing method able to compete, and even be superior to conventional methods.

The figure above shows some of the areas in which AM is being used today, and what it is being used for.

The Wohlers report (2014) shows that, the AM industry has grown in the double digits for 17 of its 26 years. In 2013, all AM services and products worldwide grew by 34.9 percent to $3.07 billion and are expected to quadruple to about $12.5 billion by 2018.

2.3 FIELDS OF DEVELOPMENT AND INNOVATION

AM is driving innovation in a number of fields, and it is not within the scope of this agenda to cover them all. However, we have selected a few examples to illustrate the current development.

Medical technology

Implants are high-value products and many of them are manufactured using rather expensive materials such as titanium alloys. The ability to manufacture intrinsic geometries which can promote bone in-growth, together with low costs for waste material,

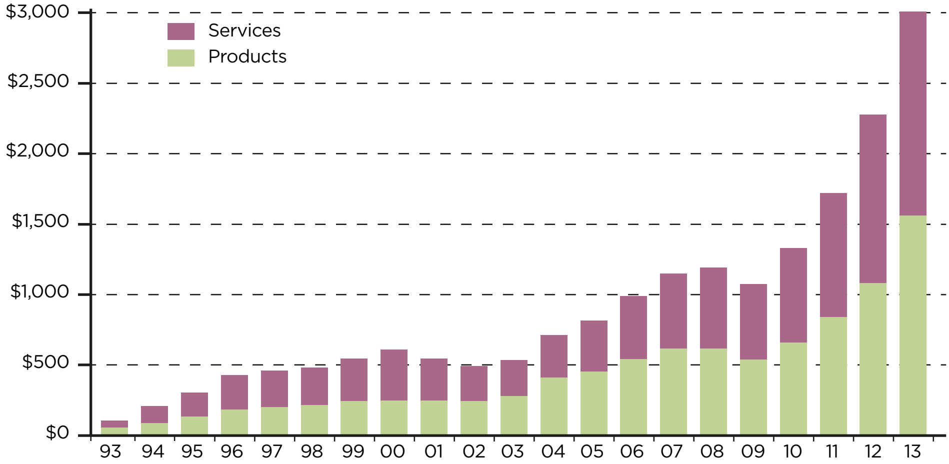

Figure 3: Industry Growth. The Wohlers Report 2014. *Source: Wohlers Associates, Inc.*

are some of the drivers for this industry and today, there are several examples of companies that have adopted this technology for serial production of implants. Also, the possibility of designing and manufacturing customised implants where conventional implants don't really fit, has attracted companies willing to invest in the technology. But many research questions are still unsolved, for example which kind of surfaces should be used to best promote bone in-growth, what is the best methodology for the design and manufacture of patient specific-implants, etc.

Dental

Crowns and bridges are typically made using a solid body of metal and/or ceramic covered with veneering ceramics. Solid bodies in metal are today manufactured using traditional methods such as investment casting, forging or machining. Additive methods in metals and alloys represent a transformational option for the production of dental implants. Like today's accepted methods, the parts produced by additive processes may require final machining or hand finishing, but allow significant flexibility of manufacture for custom, short-run, cost effective and complex or otherwise complicated manufactured parts. However, some issues remain to be addressed if AM-methods are to be used in the dental industry. For example, mechanical properties of the manufactured parts will affect the design of the crown or bridge, as well as the surface quality of the adhesion of the outer ceramic layer. Tolerances are also important for the fitting of the crown or bridge.

Tooling

AM can be a viable way of processing very hard material that cannot be CNC machined for example, and the tools manufactured with this material will have an outstanding lifetime, in comparison with materials used today. AM can also be used to produce forming tools, tooling inserts or other types of tools. The ability to offer customised cooling channels within the die or inserts, gives AM a unique advantage compare to conventional technologies. The cooling channels will allow heat control and enable faster cycle times, longer tool life and improved part quality. In Sweden AM produced plastic forming tools are sometimes used in the development process of plastic injection moulding, vacuum and sheet forming.

Aerospace

Many components are today produced from steel plates and require a huge amount of machining leaving only the frames of the material. Until now the cost of producing these brackets in titanium have been too high due to material waste cost and slower machining operations. By introducing AM titanium material, the weight could be reduced by 40 percent due to the lower density of titanium without increasing the total cost of producing the component.

>> AM in the automotive industry has mainly been seen as a method of rapid prototyping for design/geometry. It is now being used to make early test components using new materials and in the making of tools and fixtures. <<

Automotive

AM in the automotive industry has mainly been seen as a method of rapid prototyping for design/geometry. It is now being used to make early test components using new materials and in the making of tools and fixtures. The main goal being cost reduction in the product development process. The wish in the future is to produce tools and fixtures that are used in stamping and welding processes in order to reduce stock and transportation cost. There is also an interest in producing articles with high diversity and low volume with AM. AM is a natural next step for the automotive industry after 3D layouts and blueprints. Another advantage with the introduction of AM in the automotive industry is that it results in lighter components that reduces the overall weight of the vehicle and thereby the energy consumption. The development of lighter crash protection adapted to different models will contribute to a safer traffic environment and as such be a contribution to the national target of zero fatal casualties. Also, recent research shows that by being able to process for example amorphous metal by AM, mechanical springs for the automotive industry can lower the weight by 90 percent, with even better spring performance compared to conventional springs. But before this becomes a reality, more research in the process development is needed to be able to get a material with these unique properties.

Construction/architecture

Explorations of AM techniques in the field of architecture are becoming more and more widespread internationally[4]. They range from 3D sketch models illustrating ideas between client and designer, to complex machinery placed on site, producing the actual buildings and landscapes for people to inhabit. There have been several successful demonstrations of 3D printed concrete structures. In the field of architecture, 3D printing technologies are now amongst the main focus areas abroad. Sweden however is not currently doing any research into 3D printing in relation to the building sector. Research areas that have potential for Sweden include materials, design

4 Canal House by DUS Architects, Amsterdam; Landscape House by Universe Architecture; Freeform construction Project by Foster and Partners and Loughborough University, are developing a printer for complex geometrical shapes for building purposes; development of Contour Crafting technology at the University of Southern California.

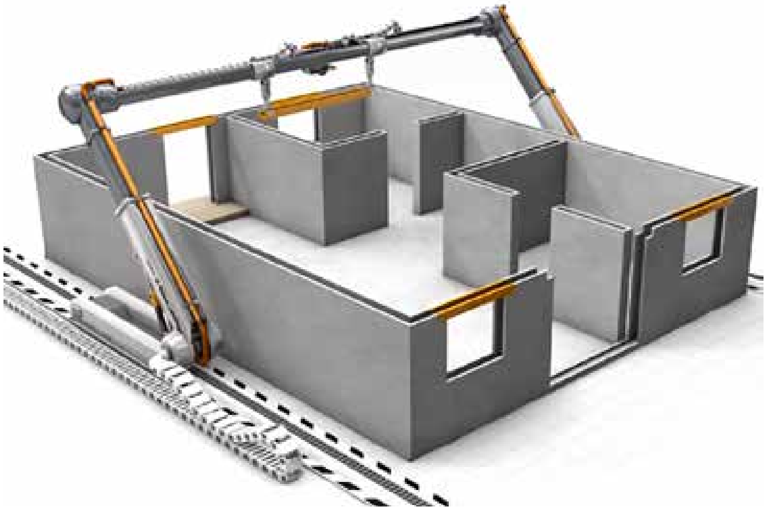

Photo courtesy of Contour Crafting. jasongrant.squarespace.com/

(including biomimetics), sustainability, health and safety, and in specialised architectural design software for architectural AM.

Interaction Design

As it has become possible and expected to integrate embedded electronics into the objects around us, the distinction between digital technologies and analogue objects is fading. As a result, the field of interaction design has become closely entangled with other creative practices; for example architecture (e.g. smart environments), industrial design (e.g. intelligent products) and fashion (e.g. wearables). Moving our interactions with digital technologies off the screen and into the physical world around us provides many opportunities for the design of engaging, meaningful and intelligent products. The act of making, i.e. the creation of physical sketches, prototypes and models, is increasingly taking centre-stage in the design processes and methodologies that are used to explore these experiences. Here AM provides a number of opportunities.

>> Art and design is possibly one of the fastest growing areas of AM. This is partly because of the arrival of low-cost desktop 3D printers, and partly because of the design freedom AM offers. <<

Interaction Design, detached from a specific context and closely working with other disciplines, provides opportunities to explore more disruptive material innovations for AM. For example: embedded electronics or hybrid materials and shape shifting interfaces (analogue or digital).

On a process and methodological level, there is an opportunity to explore how AM can be employed as a creative and generative tool. Contemporary AM technologies are often interfaced through CAD programs, new interfaces between designer, developer or maker and AM technologies are needed to expand the impact of AM on design processes, and to fully integrate these technologies within the development process.

Art and Design

Art and design is possibly one of the fastest growing areas of AM. This is partly because of the arrival of low-cost desktop 3D printers, and partly because of the design freedom AM offers.

A search of on-line 3D printing portals reveals over 100,000 unique art, design and jewellery related 3D printed products available for sale. This demonstrates the ability AM gives to create micro-businesses for artist, creatives and entrepreneurs at minimal cost and risk. Many artists, including sculptors, fashion designers, and digital artists, have also adopted 3D printing as a medium to produce their work. In Sweden two examples are ODD Guitars that produces a range of 3D printed electric guitars[5] and Lumitoro that produces jewellery and designer home decor[6].

Toys

In five or ten years, a child watching Santa Claus' toy factory might expect to see some 3D printers in work, assisting the hard-working elves. 3D printers are used to produce toys just for the sake of watching a figure or object take shape but also to produce parts difficult or impossible to manufacture at home. Examples are 3D printed figures from digital fantasy games and avatars. Also available on the web are 3D printed interfaces between popular construction sets like Lego and Fischertechnik.

The entertainment and gaming industry is also present. Mojang, the Swedish developer of the popular game Minecraft, has introduced several projects, including LEGO and a free-to-use program to 3D print the digital Minecraft creations.

The barrier for the widespread use of 3D printing for toys and entertainment is the lack of simple and intuitive modelling software. Some very simple apps are available. As they evolve so will the use of 3D printers for the creation of toys.

5 www.oddguitars.se
6 www.lumitoro.com

2.4 AN INTERNATIONAL PERSPECTIVE

Around the world we can see that the governments in many countries have identified the potential of AM and put it in a wider future perspective, AM could for example, increase regional production because companies begin to bring home their production from countries they were earlier outsourced to. Below follows a set of examples of such governmental activities from throughout the world.

In the **USA,** Barack Obama announced on March 9, 2012 his plan to invest $1 billion to catalyse a national network of up to 15 innovation institutes. He stated in his 2013 state of the union address, that 3D printing "has the potential to revolutionise the way we make almost everything."

The US Administration has recently launched a partnership, the National Additive Manufacturing Innovation Institute (NAMII), with the aim of mainstreaming AM within industry. The institute intends to bring together a network of universities, colleges, industry partners and non-profit organisations with the ultimate aim of building a national presence and network for AM.

In **China** the 3D Printing Research Institute of China was launched in August 2013 at at Zijin High-tech Zone of the Nanjing city. The Institute intends to carry out applied research in 3D printing technology, equipment, materials and seek opportunities for its commercialisation and industrialisation. The aim is to position China as a leading force in the field of 3D printing and to foster a group of companies around the industry.[7]

Singapore will over the coming five years inject a total of $500 million into advanced manufacturing techniques in order to maintain its competitiveness and become the high-tech capital of the Asia-Pacific region. Included in the investment is a pledge to commence work on "exploring the potential of building a new 3D printing industry ecosystem" in the country. Moreover, part of the multi-million-dollar cash injection will be steered towards developing training initiatives to help workers and engineers define and utilise next-gen manufacturing technologies.[8]

7 news.nost.org.cn
8 news.nost.org.cn

Photo courtesy of ODD Guitars

New Zealand, in 2013, invested NZ$12M in the creation of the NZ Product Accelerator, an AM focussed hub that brings together researchers from academia and industry in order to revitalise manufacturing, and add value to NZ industry. The NZ Product Accelerator has established a number of open-access AM labs at universities around NZ that allow companies, researchers and individuals to explore the possibilities of AM[9].

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The **Australian** government, has also invested greatly in efforts such as the RMIT Advanced Manufacturing Precinct, another example of bringing industry and academia together to add value to the country's capabilities[10].

Manufacturing has been highlighted by the **European Union** as one of the key enablers to tackling some of the European challenges and their subsequent targets, in particularly for growth and creating high quality value-adding jobs. Horizon 2020, the Framework Program for Research and Innovation is proposing[11] to take action to support and promote business research and innovation in enabling technologies. One of the priority actions will cover advanced manufacturing and processing. The European Union's Europe 2020 Strategy[12] is looking to advance the growth of the European economy through smarter, more sustainable and more inclusive means. MANUFUTURE, an industry led initiative, was set up in 2004 to define and implement research and innovation strategies for driving forward and growing the manufacturing output of Europe. The AM Sub-Platform, initiated by the MANUFUTURE Technology Platform[13], acts as a focal point, where key stakeholders in the field, propose and develop activities for increasing the competitiveness of AM[14]. These stakeholders have jointly published a Strategic Research Agenda[15] where priority areas for future research are highlighted and divided into two different sub-groups; Technical Challenges and Economic, Social and Environmental Challenges.

As a result of national surveys conducted to create a British roadmap for AM the government in **United Kingdom** has allocated some £7 million of government investment towards innovation in AM technologies for research and development, universities and science. It was quoted that "AM has the potential to change the face of manufacturing across the globe". The University of Nottingham was first to adopt the new technique and has today some 70 researchers.[16]

In **Germany** the Direct Manufacturing Research Centre (DMRC)[17], based at the Heinz Nixdorf Institute and the University of Paderborn was created in 2008 and is a

9 nzproductaccelerator.co.nz/
10 www.rmit.edu.au
11 European Commission, COM(2011) 808 final
12 European Commission, COM(2010) 2020 final
13 Manufuture (CNR-ITIA, 2004)
14 AM platform, AM SRA
15 www.rm-platform.com
16 www.innovateuk.org
17 dmrc.uni-paderborn.de

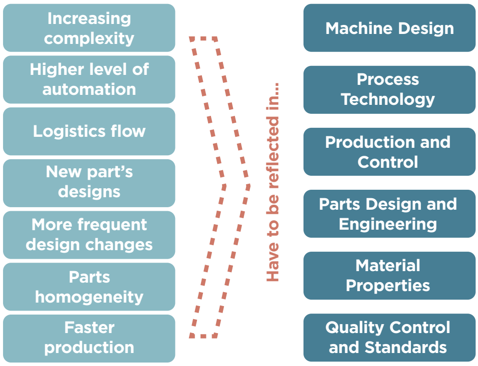


Figure 4: DMRC list of needs and demands for successful implementation of AM, DMRC annual report 2012.

joint industrial and academic centre aiming to advance AM technologies. The overall budget is approximately 11 Million Euro for the 5 year plan[18].

DMRC has conducted a survey for the German engineering industry to set up a roadmap for Germany. Seeing as how the German industry is very much like the Swedish industry we are almost able to copy and paste the fields of research we need to engage in to adapt the technique to the Swedish engineering industry. DMRC has stated the following as necessary (Figure 4).

The Fraunhofer Institutes are setting up separate centres to focus on AM[19]. One is in Bremen where they among other things do research on how to improve tooling and the component's properties. Germany has also taken action to implement the AM in what they call "Industrie 4.0[20]" or the Internet of things.

The chart below shows the cumulative industrial AM systems installed by country from 1988 through to the end of 2013 (Figure 5).

Overall, it's clear that many countries believe AM is here to stay and that being ahead of or at least at level with the rest of the players is essential.

2.5 ADDITIVE MANUFACTURING IN SWEDEN TODAY

As can be seen from Figure 5, Sweden is lagging behind the rest of Europe in its adoption of AM. Despite two excellent manufacturers of AM systems, and some well-equipped AM bureaus, there is comparatively little research in AM happening and, beyond prototyping, there has been relatively little adoption of AM by industry.

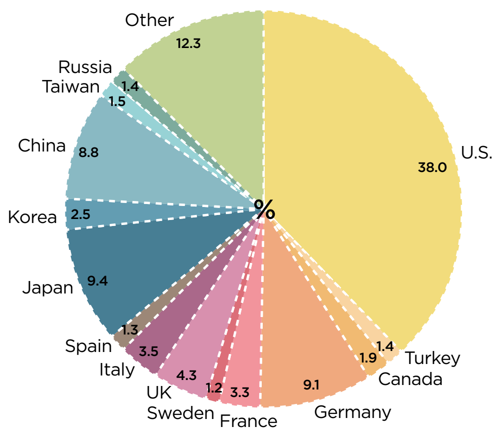


Figure 5: Industrial AM systems installed. The Wohlers Report 2014. *Source: Wohlers Associates, Inc*

18 www.rm-platform.com

19 Fraunhofer Institutes www.fraunhofer.de
20 http://www.plattform-i40.de/

Stickii necklace. Photo courtesy of Lumitoro

The level of infrastructure in Swedish universities is also well below that of its European and most other international counterparts.

In the late 90s, Sweden was one of the most prominent countries when it came to AM research but due to several factors, such as difficulties in attracting funding, many of these groups vanished and some of the senior researchers moved abroad. But after a decade, this negative trend has changed direction and today, there are several initiatives throughout the country and Sweden has been able to attract a couple of experienced researchers in the AM area. AM research at Swedish universities and institutes is carried out at for example at; Blekinge University (sustainability), Chalmers University of Technology (bioprinting and metal powder development), Karolinska Institute (bioprinting), Lund University (design and tooling), Mid Sweden University (medical applications and process development), Royal Institute of Art (design), Stockholm University (tailored microstructures), Uppsala University (process development), Umeå University (design), University West (process development), Swerea (material and production development) and SP (characterisation and process development).

Sweden has at least two very bright shining stars in the AM arena, Höganäs Digital

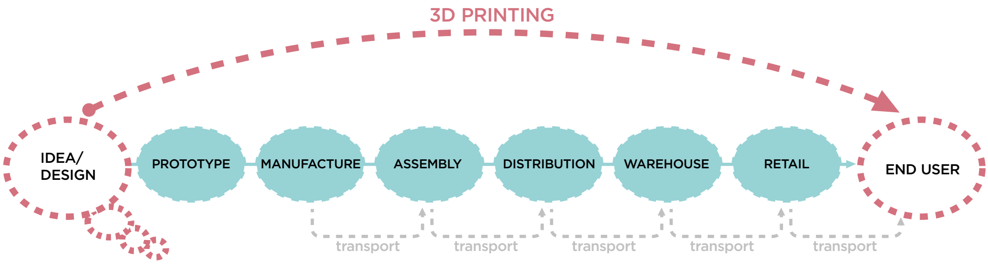


Figure 6: Low-cost 3D printing enables anyone with a digital design to bypass the traditional supply chain and manufacture a product themselves. What are the implications for companies operating in the supply chain? *Source: CSC*[21]

Metal and Arcam. Both develop machines for direct manufacturing in metal alloys and they show good growth but need support in areas such as material development, material standardisation and AM educated engineers if Sweden is going to compete with market leaders as Stratasys and 3D Systems. In 2012 Arcam sold 24 units compared to Stratasys 3026 units and 3D Systems 1359 units. Even though this comparison is biased since the Swedish company makes printers for metal only, as opposed to the polymer and metal printers made by 3D Systems and Stratasys. The numbers are still a good indication of the big potential market for Swedish made machines.

Institutions of higher education, research institutes, education centres and companies around the country have invested in low-cost desktop 3D printers to try and keep abreast of the areas potential, but very few have had the capability to invest in higher end industrial level machines. It is therefore of major importance to have a clear strategy to take advantage of the full potential offered by AM. This is especially the case since AM has the potential to increase the competitiveness and innovation capabilities for Swedish industry, for both established companies and startups.

It is essential that AM gets the attention it deserves, in the Swedish media and elsewhere, as a growing and in some cases disruptive technology. 3dp.se is a website that focuses on both Swedish and international news and developments in the world of AM, open to everyone interested in finding out more.

2.6 IMPLICATIONS FOR INDUSTRY

As described above, AM is currently used for much more than rapid prototyping and innovative art projects. The possibilities are enormous and many industries are affected in different ways throughout a product's life cycle.

2.6.1 CONSUMER IMPACT

Consumers will affect AM in different ways and play a crucial role in changing the industry. Through AM, consumers will directly affect product development, product design, product delivery and logistics. If consumers can design, develop and produce at any given location, raw material will be delivered rather than prefabricated

21 assets1.csc.com

>> Consumers will affect AM in different ways and play a crucial role changing the industry. Through AM consumers will directly affect product development, product design and product delivery/ logistics. <<

products. Design and safety rules may be overridden by the consumer, possibly impacting the trademark holder. Moreover, new ways of using IT in manufacturing will affect the way the transfer of knowledge occurs, together with its generation and dissemination. When industries change and consumption patterns are altered, financial transfers and flows will evolve, in turn leading to a change in industry context, competition and ultimately in legislation.

2.6.2 NEW BUSINESS CONTEXT AND NEW BUSINESS MODELS

From a business development perspective, AM will challenge the established business models and open up new business opportunities through business model innovation. The technologies by themselves, do not bring a specific value; value is created by the business models used to bring new products and services to the market.

A business model describes how a company communicates, creates, delivers and captures value out of its value proposition. From a business model perspective AM will be one of the technologies that enables value co-creation[22]. The opportunities created with the technology in the form of the possibility of rapidly testing out new ideas, designs and products will bring new solutions and lower the barriers to creating new market niches and customer segments.

22 Co-creation: a business model where value is not delivered, but experienced by the user/customer.

The opportunities of rapid prototyping, open source and small scale productions can create new forms of open collaborative business models among companies and entrepreneurs. Business models influenced by the concepts of "open innovation" and other forms of collaboration are likely to develop in clusters and at manufacturing sites. In this vein industry experts foresee how AM can bring back job opportunities, with significant implications for regional labour markets[23].

AM technology opens up the possibility to develop faster, more sustainable and cost-efficient supply chains. Local production is made possible in a new way which will re-structure the current global supply chains.

Sweden has the possibility to capture the opportunities of a restructuring towards regional or local manufacturing sites with AM, production of spare parts, repair jobs, material recycling jobs closer to the customers etc. National support of the building of manufacturing sites can increase the economic activities in regional areas with new supplier structures, which over time can build new regional clusters of small firms with opportunities to exchange ideas and learn from each other and thus spur innovation and new businesses.

In the realms of AM we need to advance the existing knowledge of how new business models are created and implemented and contribute to further growth and competitiveness for the businesses involved.

23 Kilkenny M (2014) *3D printing – economic and public policy implications*, Näringspolitiskt forum Rapport #6, Entreprenörscentrum.

Photo courtesy of www.creativeapplications.net

2.6.3 DESIGN AND PRODUCT DEVELOPMENT PROCESS

AM will naturally influence the way products are produced in the future as both the technologies and materials are being improved. However, there is also a big change to be expected in the way products and services are being designed. AM can inspire new ways of ideating, supporting the rapid creation of physical sketches as a generative tool to impact both the design and development process of products. AM offers the opportunity to quickly visualise ideas and concepts with physical models which will influence the way in which we use and develop both physical as well as virtual prototypes in the future, and hence change the product development process accordingly.

Furthermore, in a traditional development process, manufacturing is a time-consuming bottleneck, but with AM-technology this bottleneck is removed and therefore the more creative design phases increase in value. Hence the way we use tools for Computer-Aided Engineering (CAE), such as CAD-models, simulations and optimisations, in the product development process need to be improved and adapted to utilise the full potential offered by AM. One aspect is to create a framework of flexible digital models that enables rapid interaction between the virtual digital world and the physical world. Another aspect is to develop a knowledge base on how to design for AM and use the properties and limitations of each AM technology to best advantage for each particular product. Yet another


Photo courtesy of Ambra Trotto/Interactive Institute

involves the development of co-design software that may allow the customer to participate in the design of their own product.

2.6.4 DISRUPTIVE DESIGN SOFTWARE

To create truly unique items and products that have not existed before, it is not enough to modify existing CAD/CAE tools. Designers and engineers are locked into a "curse of knowledge" in that they are limited to the tools that the current design software provide.

To be able to generate truly unique products allowed by 3D printing technology, there is a need to develop and learn to use design tools that have non-traditional input mechanisms and that let the software suggest or grow shapes and forms that fit the application and requirements at hand. It might be that the optimal design for a building or a fixture looks like something organic/grown/created by nature, rather than having straight or commonly known geometric forms.

Perhaps we need to involve computer game developers, artists and young students with no prior knowledge of CAD/CAE design or engineering in the development and research of such design software. To fully leverage AM and speed up design, online design collaboration platforms such as Youmagine, 3DShare, etc. should be evaluated and the best ones promoted and co-developed by skilled software developers. Swedish software developers are among the best in the world and would be able to contribute a lot to a shared collaboration platform.

2.6.5 VALIDATION AND STANDARDISATION

Investments in industry grade AM machines are expensive. SP and Swerea have identified a need for a number of test-beds for AM around the country. The aim of the test-beds is to gather Swedish companies, institutes and universities interested in AM and share resources and test facilities, as well as to help all of Sweden understand how AM can add value. 3D printing requires more development and improvement in production speed, surface roughness, reproducibility etc. to become a really competitive manufacturing process. Before large companies start using 3D printing in their production the techniques must be validated. Working together, validation of the techniques will be faster and more cost efficient. There is also a large amount of tacit knowledge around AM which must be collected and well documented to better benefit all users. One possibility is to start a number of semi-industrial AM-workshops across the country.

The work with standardisation of AM was started a few years back, one result being the definition of AM cited in the beginning of this report. SIS, Swedish Standards Institute, is working on standardisation of AM on national, European and international levels, in cooperation with Swedish manufacturers and users of AM machines.

2.6.6 LEGAL IMPLICATIONS

AM raises several legal aspects when it comes to intellectual property rights (IP rights), such as patent, designs, trademarks and copyright, as well as rules on product safety.

Intellectual property rights

IP rights can be used to isolate (eliminate all competition by stopping those who want to use the specific IP rights) or to co-operate (e.g. licensing to competitors or consumers). The industrial rights (patent, designs and trademarks) do not offer any protection against private copying. Due to the fact that AM makes production of copies easier, there is a risk that IP rights lose their strength and consumers are misled about the origin of a product. The information technology research company Gartner predicts that by 2018, 3D printing, will already result in losses of 100 billion USD per year in IP globally.[24]

In 2018 and beyond into the distant future, IP rights will still be a usable tool to protect competitive advantages. Since AM makes isolation more difficult, cooperation will become more important. We will see new structures for agreements and licensing of completed products, CAD-designs/modules etc. Parallels can be drawn to the digital music industry, where private and pirate copying has driven the development of legal licensing and copying services in which the consumer has demanded and embraced the legal alternatives created.

The development and spread of AM will certainly give rise to new jurisprudence and legislative changes in the area of IP-law but the industry's own agreements and

24 www.gartner.com/newsroom/id/2658315

3D printer. Photo courtesy of Arcam

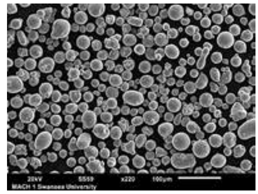
standards will be equally important, not least because of the time normally required for legislative changes.

Product liability

Product liability regulation currently presumes that it is possible to identify either a producer or another operator with responsibility for the product. This identification will become more difficult when AM makes it possible for not only multiple actors in the supply chain but also for the end consumer to modify the product.

Current product liability regulation will have to be reviewed. Meanwhile, different solutions with labels of origin and disclaimers covering modifications of products will most likely increase in importance. AM and digital technology extends across national boundaries and calls for further harmonisation of product liability rules.

With a critical approach to IP, balance can be achieved between continued technological development, the industry's interest, the consumers' interest and existing legislation. In order to create such balance in a world of AM, in which IP rights must continue to be a tool for protecting competitive advantage and where liability for products created through AM must be identifiable, it is likely that legislation, as well as the industry's own structures and practices need to be developed.



Maraging steel powder grades. Photo courtesy of Sandvik Osprey Ltd

2.6.7 MATERIALS

AM utilises several techniques and materials, with different pros and cons. The most common materials are polymers, followed by metals and ceramics, whereas wood and biomaterials are in a very early stage of development. There is expected to be an increasing future demand for AM materials and this, therefore, represents a growth opportunity for Sweden. The base for such R&D is already present, with the important Swedish wood/pulp industry and also, the largest metal powder manufacturers in the world such as Carpenter, Erasteel, Höganäs and Sandvik being located in Sweden.

Polymers are, by far, the most common materials for 3D printing. Several techniques and types of polymers are used. The cheapest machines, using FDM[25], are

25 Fused depostition modeling

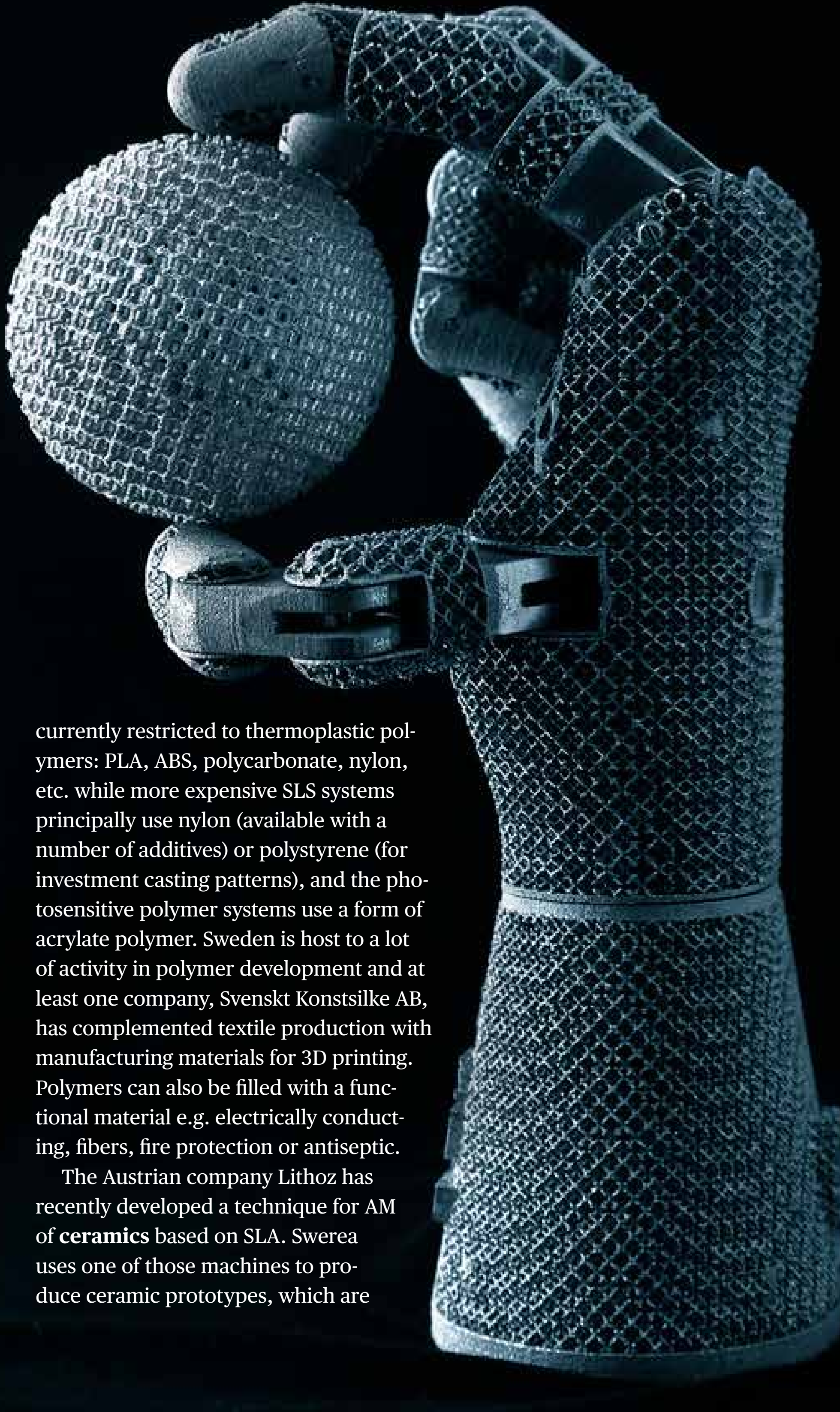


Photo courtesy of Oak Ridge National Laboratory's Manufacturing Demonstration Facility

currently restricted to thermoplastic polymers: PLA, ABS, polycarbonate, nylon, etc. while more expensive SLS systems principally use nylon (available with a number of additives) or polystyrene (for investment casting patterns), and the photosensitive polymer systems use a form of acrylate polymer. Sweden is host to a lot of activity in polymer development and at least one company, Svenskt Konstsilke AB, has complemented textile production with manufacturing materials for 3D printing. Polymers can also be filled with a functional material e.g. electrically conducting, fibers, fire protection or antiseptic.

The Austrian company Lithoz has recently developed a technique for AM of **ceramics** based on SLA. Swerea uses one of those machines to produce ceramic prototypes, which are generally difficult to make, and to offer small scale manufacturing of critical ceramic components. Several currently available SLS/SLM systems are also capable of processing ceramic powders. Other systems use sand to print moulds or cores which are used to produce castings.

Sweden is a world leading producer of **metal** powder (30 percent of world production) and has two companies manufacturing 3D printers for metal, based on powder bed: Arcam and Höganäs Digital Metal. There is enormous potential for the powder producers to enter the 3D printing market.

Bio-based materials are also used. This is particularly interesting for Sweden since it has substantial forest resources, for which new business areas are continuously searched. Wood fibers can, for example, be mixed with polymer and printed as a composite. This is available from 4AXYZ amongst others. Voxeljet uses epoxy to bind wood fibers together. Innventia is developing a new type of cellulose-based material that can be shaped by heat pressing in a mould. This material, or other wood-based materials, such as nano crystalline cellulose (NCC) could potentially be 3D printed.

2.7 IMPLICATIONS ON SOCIETY

A large part of Sweden's future rests in the area of high-value niche manufacturing and the innovative use of design and technology. Conventional mass-manufacturing has, in large part, moved to countries like China and India where labour costs give them a substantial advantage in mass-manufacturing low-value products. To compete with this, Swedish companies need to develop both superior design abilities and competencies in efficient and rapid manufacturing for well-designed high-value niche products.

As this development will affect the industry in many ways, so will there be implications on society as a whole.

2.7.1 HIGHER EDUCATION

The technological development of AM requires new knowledge and skills from students, and engineers in order to really leverage this technology. Today, research and development in AM is to a large extent driven by industry, and AM is only represented in small parts of the course syllabuses at Swedish universities. Therefore universities need to invest in education for engineers, architects, designers and artists. Strategic development of education at different levels as well as substantial hardware investments is needed at the universities to strengthen Swedish competitiveness and take advantage of the opportunities of this new technology.

>> For Sweden, it is crucial that we educate experienced engineers, designers, architects and artists in practically working with AM in order to expand the opportunities of the technology. The transition to AM will influence not only how products are produced, but also the process of how they are best designed. <<

Universities need to develop courses, education materials and curricula at undergraduate, graduate as well as post-graduate levels to feed into a national research agenda.

Engineering, manufacturing, design and artistic programs and courses need to develop and adapt their courses and programs in design, modelling, simulation, visualisation and fabrication in order to reflect the demands and opportunities offered by AM. For Sweden, it is crucial that we educate experienced engineers, designers, architects and artists in practically working with AM in order to expand the opportunities of the technology. The transition to AM will influence not only how products are produced, but also the process of how they are best designed. To learn these processes, both theoretical and practical courses are needed throughout the university curricula. Furthermore, business and management programs need to include the effects of AM in innovation and entrepreneurship courses and new business models, in logistics and supply chain management.

There is also a need to re-educate engineers and designers that are active in industry today, for example by contract teaching and developing customised courses in applied AM and subsequently offering them to Swedish industrial companies.

2.7.2 COMPULSORY EDUCATION AND TEACHER EDUCATION

AM has been adopted by many schools and teachers and applied so that it adds value in a wide range of subjects of the curriculum. There is much optimism and motivation associated with these initiatives. We propose that more systematic measures are taken to scale up these initiatives on a national level.

It is beyond the scope of the Agenda to put forward a detailed plan for schools, curricula and teaching practices. However, related initiatives exist on a national level, e.g. within "Teacherhack" which the Agenda hereby announces its support for along with similar initiatives. The National Swedish Agency for Education is the obvious coordination node for such initiatives.

Photo courtesy of Creative Tools

2.7.3 INNOVATION SUPPORT SYSTEM

The opportunities that come with AM and 3D printing will open up for a number of new startups both in traditional industry and creative industries. Artists, designers, architects and engineers will be given new opportunities to become entrepreneurs. As such, AM will lower the threshold to start a business and allow people to become their own producers.

Business incubators and other actors within the innovation support system need to be prepared in order to support these new entrepreneurs, artists and startups. Sweden needs knowledge and structure to be able to offer support in areas such as IP rights, open source, brand equity and the use of new financing models such as crowd funding.

The business and innovation support system must also develop the knowledge of how to build communities and ecosystems of designers, 3D-modellers, makers and perhaps also users. The current international leaders in AM are working with strategies of how to support these ecosystems of innovations, designers and makers. For example, MakerBot's Thingiverse is a platform for users to upload their free designs for users to download. Shapeways, Cubify, Sculpteo, Ponoko, and others are seeking to expand a platform basis for designs. 3D Hubs and Makexyz are platforms for home 3D printer owners to create a small business using their printer by creating an ecosystem where the printer owner can interface with end users, and compete for pricing with other local 3D printer owners. Many initiatives are being taken on the global market, so the Swedish business and innovation support system needs to be ready to develop its support structures for these new business opportunities.

It is important that the existing incubators at universities get access to makerspaces for creating new products as well as incubator clients getting access to expertise in related product development and innovations in the design process. As already mentioned earlier, AM clearly reduces development cycles and with the right infrastructure, the innovation process for future companies in product development areas can be further reduced.

2.7.4 SUPPORTING THE MAKER

Making is fundamental to being human. Crafting, building and making are not only ways to pass the time, to embed value in an object, they are methods of invention or problem solving. They are a route to passing on traditions and culture, of expressing ourselves, of deepening our knowledge and our understanding of ourselves and the world around us.

>> Business incubators and other actors within the innovation support system need to be prepared in order to support these new entrepreneurs, artists and startups. Sweden needs knowledge and structure to be able to offer support in areas such as IP rights, open source, brand equity and the use of new financing models such as crowd funding. <<

Since the industrial revolution, there has been a crafts movement existing in parallel and often in opposition to standardised mass produced industrial manufacturing. What is happening now with 3D printing and digital manufacturing is a convergence between craft and industry where we move from mass production to mass customisation, where new possibilities of merging traditional craft with advanced technology arise, and where it is becoming easier for anyone to prototype objects for mass manufacturing. This is opening up the field for new sorts of distributed R&D systems, consumer emancipation and true grass root innovation.

Personal projects can be shared with and mass distributed to a global audience through digital means. While 3D printing along with other digital fabrication tools like milling machines and laser cutters has enabled personal fabrication, products like Arduino and Raspberry Pi have made it easy to put computing capabilities into these objects, and online forums and platforms allow sharing of code, 3D-files and circuit diagrams. Crowdfunding websites[26], e-commerce platforms[27] and 3D-libraries[28] facilitate the financing of production, the sale and distribution and the sharing of maker projects to a global audience.

While some early adapters who have the financial means may invest in a desktop printer for their home, most makers access 3D printers and other fabrication tools through maker/hackerspaces that not only provide tools for little or no cost but also serve as a platform for sharing knowledge and building a community of expertise. Around the world, as well as in Sweden, different open innovation spaces are developing in which educators and students, entrepreneurs and hobbyists work on personal projects, launch new businesses and learn vital skills in relation to science, technology, engineering, and maths (STEM). These spaces and communities provide an important breeding ground for the next generation of innovators and inventors, evidenced by the startup communities that form around them.

In order for Sweden to harness the full potential of grass root and maker innovation it is important that all parts of society gain access to digital fabrication.

2.7.5 ENVIRONMENT/SUSTAINABILITY

AM is a production method that can seriously reduce environmental impact. By using AM to manufacture lighter, more complex, and integrated parts, the material used for manufacturing can be drastically reduced. Less raw materials needed, means less impact on the earth's resources. Though AM is, in some cases, more energy demanding to produce a component, (e.g. to produce a cast titanium part may use less total energy compared to a 3D printed part), but the weight of the AM part produced can be greatly reduced in comparison to the cast part and when placed in an aircraft, it has a huge impact on the aircrafts energy consumption, thus reducing the total carbon footprint.

With AM, the possibility of setting up production units close to the assembly plant also drastically reduces the transport distance for a component that, if using conventional methods, might have been produced across the globe.

However, the ability to create more complex shapes and the ability to digitally mix materials brings us the dilemma that we need to better understand how to separate parts for recycling. This kind of dilemma will become more frequent in the future, thus creating a strong need to do research in this field.

26 Such as Kickstarter.com
27 Such as etsy.com
28 Such as Thingiverse.com

THE SWEDISH AGENDA FOR RESEARCH AND INNOVATION WITHIN ADDITIVE MANUFACTURING

– A WAY TO GET INVOLVED AND LEAD THE WAY

Figure 7 on next side illustrates areas in which AM is widely used and areas in which it is expected to develop in the near future. Even since this image was published earlier this year, the field of metal printed aircraft parts has already risen to the surface of the sea.[29] This shows how fast things are changing and that, in order to be able to benefit from the possibilities AM offers, one has to be actively involved in it to be able to keep pace.

To meet the challenges from international competition and to make use of all the opportunities that AM gives, Sweden will benefit from a strategy that can point out the threats and opportunities that can make our engineering industry more competitive. Access to the commercial technology is a fundamental prerequisite for competence assurance; however access, on its own, will not grant a long-term competitiveness in the field. To achieve this on a national level, a strategic research and innovation agenda with its own identity is necessary to provide a basis for decisions regarding investments, research priorities and strategies. Notwithstanding the cooperation with other agendas and strategic innovation areas (SIPs) that touch AM in different ways, it is the aim of this agenda to start a process towards co-operative Swedish leadership within the field linking closely with some of the others involved in AM, which include:

- LIGHTer: in which 3D printing is identified as one technique to produce lighter components
- Production 2030: where AM is seen as a method for flexible production and a tool for sustainable production
- Metalliska material: where AM can be a manufacturing method for metal components
- Bio Innovation: that aim to increase the use of biomaterials in production, which can be applied by AM

29 For example: GE's leap engine, and many flying AM parts by Boeing and Airbus.

Figure 7: AM areas, Wohlers Report 2014, *Source: Wohlers Associate, Inc*

- >> Framtidens Logistik: with 3D printing as a new technology that drives the development towards local production and re-structuring of logistics and supply chains
- >> Agenda GAME: with the possibility of co-creating design software and producing real life gaming avatars
- >> Kroppens reservdelar: it's focus on biomaterials and regenerative medicine could benefit from AM
- >> DING, Digital Innovation & Growth: focus on renewal among existing companies through the use of digital strategies and new technology, e.g. AM
- >> InnovAT: advanced and innovative tooling technology where AM is one facilitator
- >> Internet of things: take advantage of innovation and prototyping through AM to develop products and services within the Internet of Things

The next step is a long-term strategy and a plan to realise the actions outlined in this agenda, in which cooperation with the above mentioned agendas, SIPs and other AM friendly initiatives are crucial.

3.1 THE VISION

Sweden has a unique position in well-developed sectors such as design, raw materials, Information and Communications Technology (ICT) and the creative industries. This gives us a great opportunity to build our vision and our goals around already existing, strong, industries, institutions and communities within raw materials and design and art, thus connecting to contexts and developments that could easily become agents of change and innovation within AM.

There are several long and short term goals that will help to achieve this vision.

3.2 GOALS

- >> Expand and revitalise Swedish industry and job creation.
- >> Significantly increased export of AM related products and services.
- >> Introduction of AM/3D printing in the national curricula and in multiple subjects at all levels of the education system.
- >> More funding for research and innovation related to AM to make it world class both in industry and academia.

>> The vision for this agenda is to make Sweden, its industry and people, competitive and a leading nation in additive manufacturing. <<

Photo courtesy of Arcam

- New materials for AM based on natural and biomaterials.
- Make Sweden a leader in unique design software for AM.
- Usage of AM as a creative tool for entrepreneurship, innovation and disruptive products.
- A business and innovation support system that understands and utilises AM.
- Reduced environmental impact compared to traditional manufacturing.
- Continuous cross-border exchange of experience.

Photo courtesy of Höganäs Digital Metal. Actual hight: 20 mm.

3.3 ACTIONS

To achieve the vision and goals of this agenda there are a number of actions to be taken. The stakeholders involved in the agenda-process have identified actions under four main headlines.

3.3.1 CO-OPERATION

1. Coordinate efforts within the field of AM through a strategic innovation program (SIP).
2. Increase international co-operation, in particular through Horizon 2020.
3. Close co-operation between researchers, producers of raw materials, AM machine suppliers and the manufacturing industry in order to identify the potential of new materials and material combinations.
4. Co-operation between startups, maker spaces, universities and industry.
5. Co-operation between AM experts and researchers to explore the expressive and technical potentialities of AM, so that they can inspire research, education and design methodologies.
6. Initiatives and developments of maker spaces where students, entrepreneurs and everyday citizens can meet and use new tools and techniques.
7. Increase awareness of possibilities within AM for qualified decision making.
8. Create an AM network[30].

3.3.2 Demonstrators and Testbeds

9. Set up national centres of competence and testbeds for identified strategic areas, where companies, institutes and universities share resources and test facilities.
10. Pilot projects, beyond prototypes, in new areas.
11. Investigate ways to give investment support for SMEs aiming to introduce AM as a production technology.

30 This has been started by SVEnsk Additiv Tillverkning (SVEAT)

3.3.3 Competence and Education

12. Develop knowledge of AM in the business and innovation support system.
13. Develop and suggest courses in AM at every university in Sweden.
14. Re-educate engineers and designers that are active in industry today through contract teaching and customised courses in applied AM.
15. Adapted national curricula.
16. Offer training in AM to all teachers, at all levels from elementary school to universities.
17. Develop learning centres and arrange open seminars where teachers, students, makers and interested parties can see the technology in action, learn more about it and get involved in using AM.
18. 3D printers at libraries (one per municipality) and schools (one per class) with staff that possess adequate knowledge and training.

3.3.4 Innovation and Research

19. Build knowledge of the entire process and value chain, in order to understand and leverage the full scope offered by AM-technology.
20. Research programs in the form of university-industry collaboration to introduce and analyse new business models.
21. Research regarding optimisation of e.g.:
    - geometry
    - materials
    - density
    - structure and texture
    - characteristics of material and process properties
    - post-processing of products
22. Research in how AM can innovate design (industrial design, interaction design, architecture), in areas like for example:
    - spaces (intelligent or analogue)
    - interactions (intelligent or analogue)
    - shape changing interfaces or spaces
    - products and systems
23. Develop design methods for AM including rules, standards and software support.
24. Research on how AM will influence the whole product realisation process for traditional manufacturing industry.
25. Develop processes and materials for AM based on natural materials that are abundant in Sweden such as lignin and cellulose.
26. Analyse working environments and ergonomics in respect to e.g. printers, hazardous material and manual handling.
27. Optimise design and printing process to reduce material usage and environmental impact.
28. Develop new design software focused on AM that supports the process from ideation to constructive detailing
29. Develop digital platforms for collaboration and shared product design and knowledge.
30. Support Swedish stakeholders in participating in and contributing to the setting of standards for AM processes and materials.
31. Support and initiate the development of AM machines and systems that can deliver to well-established standards; high surface quality, desired color and graphics and required material properties.
32. Support actions that aim to integrate AM into current production lines.

>> More on the Swedish agenda and updates on developments within the field; **www.er.umu.se/am <<**

Denna agenda är framtagen inom ramen för Strategska innovationsområden, en gemensam satsning mellan VINNOVA, Energimyndigheten och Formas. Syftet med satsningen är att skapa förutsättningar för Sveriges internationella konkurrenskraft och hållbara lösningar på globala samhällsutmaningar.

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Arcam AB

Avalon
INNOVATION
CARPENTER
Powder Products
CHALMERS
DM DIGITAL® MECHANICS
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Europeiska institutet för beteendevetenskaplig analys AB
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