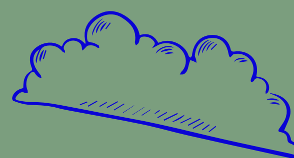
Sustainable Manufacturing of the Future: The Role of Additive Manufacturing

Go Digital



Mind the Materials

Rethink Design

Own your Value Chain

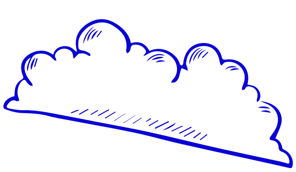
Danish
AM Hub

Executive summary

Change is needed to put the world on track to achieve net-zero emissions by 2050 and meet the 1.5˚C target set out in the Paris Agreement. To date, efforts to tackle the climate crisis have focused on a transition to use renewable energy, complemented by increasing energy efficiency. However, these measures can only address 55% of the emission reduction needed. Meeting climate targets will also require tackling the remaining 45% of emissions associated with making products and embedded in the four key industrial materials; cement, steel, plastic, and aluminium (the paper 'Completing the Picture' by The Ellen MacArthur Foundation).[1] Denmark has been noted to have an international leadership position in the field of sustainability. For the second time in a row, Denmark was named the world's most sustainable country in 2022 by the renowned Environmental Performance Index. Denmark tops the 2022 rankings with notable leadership in efforts to promote a clean energy future.

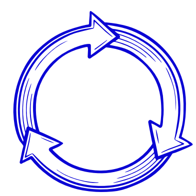
Danish AM Hub is on a mission to promote the use of additive manufacturing (AM), focusing on the abilities of the technology to contribute to more sustainable manufacturing. This document gathers the experiences and elaborates on the Danish AM Hub approach to promoting AM technology for more sustainable manufacturing. It is targeted at the AM ecosystems in Denmark and internationally with the purpose of disseminating our approach and inviting conversations and cooperation on the topic.

The Danish AM Hub approach is presented in four interlinked steps towards more sustainable manufacturing with AM, elaborating on concrete cases from Denmark and a neighbouring region. Key takeaways for each of the four steps are summarised below.



1. Go Digital

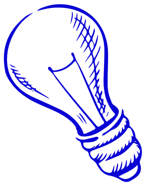
'Go Digital' involves utilising the potential of AM by producing locally and on-demand. One of the biggest benefits of 3D printing is that it enables on-demand manufacturing, thereby rethinking the concept of warehousing. As a product is made on-demand, it can be immediately shipped to the consumer, eliminating the need for storage. Since AM does not rely on long-to-produce moulds, the production can start right after the order is received. The 3D print production typically takes between a few hours and a few days, compared to a typical lead time of weeks or months in injection moulding. While traditional business models are concentrated in geographical locations to achieve economies of scale, 3D printing can eliminate the distance between the production and consumption point. Thereby, it supports the ongoing trend of moving from centralised to more decentralised production, where the digital file of a product can be sent to be produced locally.



2. Mind the Materials

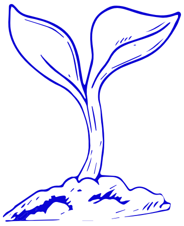
Material substitution is a significant part of the solution to reducing carbon emissions. It refers to the use of renewable, low carbon, or secondary and waste materials as alternative inputs to new production. These materials provide the same function but contribute to reducing emissions. AM is a useful technology in this regard, allowing optimisation of the material flows by incorporating or reusing waste. The development and use of AM for waste materials and the recycling of filament are emerging rapidly. There is a wide spectrum of ways to exploit recycled plastic waste for 3D printing. But also waste from electronics, magnets, glass, sand, concrete, and rubber tires can be used in filament for 3D printing. To ensure that products are recycled, manufacturers can establish take-back systems for their products.

2 Ellen Macarthur Foundation (2021). Completing the Picture: How the Circular Economy tackles Climate Change. 2021 Reprint.



3. Rethink Design

Today, too many products are designed to be disposable. Although it sometimes seems like waste is inevitable in certain situations, waste is the result of design choices. AM technology contributes to enhanced resource efficiency, reduced use of materials, and designing for repair and restoration. AM allows the creation of complex geometries, reducing material usage, part consolidation, simplifying assembly lines, increasing product functionality, and reducing energy consumption. A part can be optimised through topology optimisation considering the applied stress and required stiffness, resulting in lighter structures. Furthermore, AM allows optimising part design and guiding it towards easy maintenance, repair, and restoration. A way to facilitate this is by creating digital databases where spare part designs are stored and can always be utilised for various supply chain functions.



4. Own your Value Chain

The need for manufacturing companies to document their carbon footprint has increased in recent years, not least after the introduction of the UN Sustainable Development Goals (SDGs). The EU Commission's Corporate Sustainability Reporting Directive is also underway, which includes documentation of a company's value chains. This is, in some cases, further complemented by national documentation requirements. To capture a holistic, detailed, and accurate environmental footprint of a product, a comprehensive life cycle assessment (LCA) is required. An LCA considers the full environmental impact of products from the use of materials, manufacturing, distribution, use, repair, and maintenance to recycling or disposal. Using 3D printers for manufacturing requires a relatively high electricity consumption compared to other manufacturing methods. This calls for establishing AM/3D printing centres where it is possible to power the 3D printers from renewable energy sources. While the initial energy consumption can have a negative impact on the LCA of a 3D printed product, it is often outweighed, e.g., by the improved strength or the reduced weight of the product, which entails lower energy consumption in the lifetime of the product.

Cases demonstrating the adoption of AM for sustainable manufacturing

This report includes several cases of companies using AM towards more sustainable manufacturing to illustrate the concrete measures that are taken under each of the four steps.

The cases include established companies that are changing their strategies to: produce locally, on demand with AM (Monoqool); establishing a new company to manufacture recycled metal powder for 3D print (Nordisk Staal establishing Nordic Metals); use renewable and waste materials (Signify); disrupt the orthopaedic shoe sole industry with a circular business model and distributed manufacturing (Create it REAL and GeBioM); and use design optimisation to create lightweight tools in manufacturing (BEWI).

The cases also include startups founded to utilise AM to create a circular business model (Tons, Nordic Metals, Lostboyslab, and WOHN). This includes a focus on 1. 'Going digital' with distributed, on-demand manufacturing, 2. 'Minding the materials,' using recycled waste materials in production, and establishing take-back systems or incorporating information on recycling, 3. 'Rethinking design' for optimisation with AM, longer lifetime, and repair of products, and 4. 'Owning your value chain' by documenting the carbon footprint with LCAs.

At Danish AM Hub, we celebrate the good examples. However, they also illustrate that there is still strong potential to disseminate knowledge and share good practices with established manufacturing companies on how AM can contribute to reducing carbon emissions. As part of this mission, we have started to conduct LCAs on cases that include the development of new components or products in Danish AM Hub innovation programmes. An example of this can be found in this report (Airflight).

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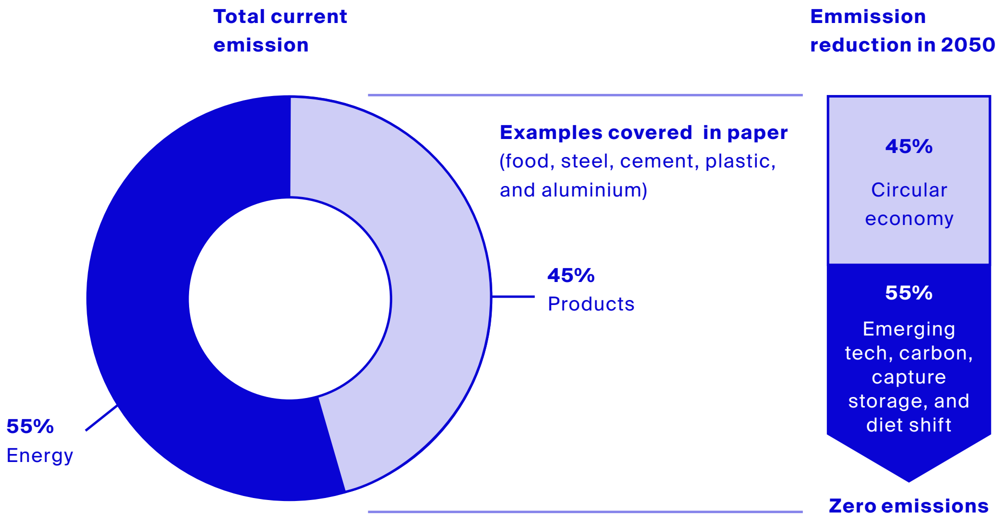
Danish AM Hub is the focal point for Additive Manufacturing in Denmark. Our goal is to strengthen Danish business competitiveness by promoting Additive Manufacturing and 3D printing. Our focus is on small and medium-sized businesses and developing new business models that induce growth, innovation and sustainable solutions. We help Danish production companies take the first steps towards a future where we produce with less waste, less material, less transport and with less CO2 emissions. Danish AM Hub is initiated by The Danish Industry Foundation.

1. Introduction

Danish AM Hub is rooted in a strong focus on sustainability in our efforts to promote additive manufacturing (AM) use in manufacturing companies. Denmark is often referred to as an international leader in sustainability. For example, for the second time in a row, Denmark was named the world's most sustainable country in 2022 by the renowned Environmental Performance Index, EPI. Denmark tops the 2022 rankings - rooted in a strong performance across nearly all issues tracked by the EPI, with notable leadership in efforts to promote a clean energy future.

Change is needed to put the world on track to achieve net-zero emissions by 2050 to meet the 1.5˚C target set out in the Paris Agreement. To date, efforts to tackle the climate crisis have focused on a transition to renewable energy, complemented by energy efficiency. However, these measures can only address 55% of emissions. Meeting climate targets will also require tackling the remaining 45% of emissions associated with making products. The paper 'Completing the Picture' by The Ellen MacArthur Foundation shows that when applied to four key industrial materials (cement, steel, plastic, and aluminium), circular economy strategies could help reduce emissions by 40% in 2050 (45% including food). This is illustrated in figure 1. Essentially it involves a transformation in the way we design, produce, and use goods.



Underpinned by a transition towards renewable energy, a circular economy can help tackle the overlooked 45% of emissions by transforming the way goods are made and used.

Figure 1 Completing the Picture: How the Circular Economy Tackles Climate Change (The Ellen MacArthur Foundation, 2021)

The notion of sustainable manufacturing can be seen as a paradox because, naturally, all manufacturing will have an impact. What is essential is to produce with minimum use of energy and natural resources. Since 2018, Danish AM Hub has actively promoted the contribution and potentials of AM towards more sustainable manufacturing.

This document gathers the experiences and elaborates on the Danish AM Hub approach to promote AM technology for sustainable manufacturing. It is targeted at the AM ecosystems in Denmark and internationally to disseminate our approach and invite conversations and cooperation on the topic.

The Danish AM Hub approach to how AM technology can contribute to reducing emissions through more sustainable manufacturing, can be summarised in four overall steps. A brief presentation of the steps is introduced below.

1. Go Digital

Manufacture products only when it is necessary. Digitalise your warehouse and produce on demand with minimum use of energy and materials. This will reduce your need for warehouse space and your dependency on global supply chains. AM has a significant role in the ongoing shift from centralised to decentralised supply chains, allowing the possibility to print locally and on demand.

2. Mind the Materials

Use recycled materials whenever possible. Develop a take-back system for your product, which ensures that products are reused or recycled. This will minimise the use of resources and reduce your carbon footprint. With AM technology, it is possible to reduce the use of materials and use recycled waste and recycled filament in production

3. Rethink Design

Rethinking design entails abandoning the linear take-make-waste system. Many products could be circulated by being maintained, shared, reused, repaired, refurbished, remanufactured, and, as a last resort, recycled. AM technology has potential, especially for resource efficiency and reduction of materials use, e.g., through topology optimisation and designing for repair and restoration.

4. Own your Value Chain

Adopt a holistic perspective that incorporates the whole value chain and life cycle of your products. Document your carbon footprint, also taking into consideration your suppliers. Danish AM Hub has started to provide documentation for the environmental impact of AM through carbon footprint estimations.

The four steps are elaborated on in more detail in the following. First, each step is introduced, followed by an elaboration of the role of AM, concluding with a short introduction and links to cases that can be found in full length on the Danish AM Hub website.[2]

2 In the creation of this document, Danish AM Hub has drawn on existing research and online sources on the topic of sustainable manufacturing and circular economy. The bibliography is available in Annex 1.

1. Go Digital

Manufacture products only when it is necessary. Digitalise your warehouse and produce on demand with minimum use of energy and materials. This will reduce your need for warehouse space as well as the dependency on global supply chains. AM has a significant role in the ongoing shift from centralised to decentralised supply chains, allowing the possibility to 3D print locally and on demand.

Manufacturing companies can embrace the opportunity to digitalise their warehouse, reducing warehouse space and manufacturing on demand utilising a distributed manufacturing approach. This will reduce not only storage space, energy, and material consumption but also the company's dependency on global supply chains.

Reliability and efficiency have long been the top priorities of supply chain management. Even before COVID-19, the supply chain model was under pressure. Global trade tensions, instability, disruptive technologies, and the increasingly severe effects of climate change exposed their inflexibility. The pandemic shattered supply chains worldwide and made resilience – the ability to heal, reroute, or substitute – the top priority.

While large-scale production will continue to dominate some segments of the value chain, distributed, small-scale local manufacturing has emerged to provide a sustainable alternative to how goods are produced and shipped. Industry 4.0 technologies like 3D printing, AI, and Big Data are increasingly becoming important for supply chains because they can redefine the framework of supply chain operations and increase the potential of distributed manufacturing.

The Role of Additive Manufacturing

AM has a significant role in the ongoing shift from centralised to decentralised supply chains. While traditional business models are concentrated in geographical locations to achieve economies of scale, 3D printing can eliminate the distance between the production and consumption point. AM supports this system because the digital file of a product can be sent to be produced locally. This concept is seen as a potentially sustainable alternative for centralised mass production because of shorter supply chains, reduced inventory space, transportation, and decreased overproduction through on-demand supply, and localised repair and recycling. For example, in the aircraft industry, AM has helped reduce the inventory of spare parts, which can be printed on-site when needed.

Since AM does not rely on long-to-produce moulds, production can start right after the order is received if the capacity and materials are available. The AM production typically takes between a few hours and a few days, compared to a typical lead time of weeks or months in injection moulding. One of the biggest benefits of 3D printing is that it enables on-demand manufacturing. 3D printing, alongside distributed manufacturing, can help to replace an often inefficient "make-to-stock" with a "make-to-order" model, rethinking the concept of warehousing. As a product is made on-demand, it can be immediately shipped to the consumer, eliminating the need for storage and, therefore, reducing inventory costs.

Cases

The following cases demonstrate how manufacturing companies have gone digital, exploiting the potential of reducing the dependency on global supply chains and the need for warehouse space. The companies Monoqool and Tons produce locally on demand.

Monoqool relocate manufacturing from Japan to 3D print on demand

MONOQOOL®

Eyewear manufacturer Monoqool has relocated manufacturing from Japan to Denmark and started to manufacture glasses only with the use of 3D printing and only in smaller units according to demand. With the introduction of AM/3D printing, Monoqool has built a new value chain. Conventional development and manufacturing typically take up to 12 months from the development phase through to the complete collection. Previously the company would wait for one to two months to receive a prototype, which was produced, e.g., in China. Using 3D printing has allowed Monoqool to finish the entire process in approx. two months, also enabling the company to react fast to new market trends.

Monoqool has contracted the 3D printing firm Prototal Damvig to manufacture their glasses. According to Monoqool, looking at the manufacturing process in isolation, the costs of 3D printing are higher compared to the previous manufacturing method. However, the flexibility that is gained in shifting to on-demand production entails that the stock as well as time-to market have been significantly reduced. Furthermore, Monoqool today has waste material of only 2% from production, which is compared to the normal 85% for the eyewear industry. This has meant that Monoqool shifted its status from near bankruptcy in 2013 to being named one of the fastest growing companies in Denmark in 2018 (with the Børsen Gazelle award).

3D printing cycling and fitness gear on demand using compostable materials

tons™

The startup Tons design and produce cycling and fitness gear with a minimalistic look and feel. Products are 3D-printed on demand in Denmark by the startup. Tons' products are made exclusively from corn-based plastic and oak materials, which means they can be composted.

To be competitive in a global market, Tons is focused on saving as much as possible on overhead costs. The biggest challenge in this regard is the high cost of electricity for 3D printing. However, the benefits outweigh this cost because it is possible to reduce waste and use of materials with AM, and there is no need for storage space. The minimised dependency on global supply chains is also essential for the startup.

When it is time to scale up the business, Tons' ambition is to relocate manufacturing and produce locally in locations where the demand is highest.

2. Mind the Materials

Use recycled materials whenever possible. Develop a take-back system for your product, which ensures that products are reused or recycled. This will minimise the use of resources and reduce your carbon footprint. With AM technology, it is possible to reduce the use of materials and use recycled waste and recycled filament in production.

In industry, growing demand for materials coupled with a slow adoption rate of renewable electricity and incremental process improvements make it especially difficult to bring emissions down to net zero by 2050. According to the Ellen MacArthur Foundation, the global demand for industrial materials is projected to increase by a factor of two to four by 2050. Material substitution is a significant part of the solution to reducing carbon emissions. It refers to the use of renewable, low carbon, or secondary and waste materials as alternative inputs to new production. These materials provide the same function but contribute to reducing emissions.

To ensure that products are recycled, manufacturers can establish take-back systems for their products. A take-back system is an initiative organised by a manufacturer or retailer to collect used products or materials from consumers and reintroduce them to the original processing and manufacturing cycle. A company may implement this system in collaboration with end-of-life logistics and material processing firms.

The Role of Additive Manufacturing

New hybrid designers focused on reusing and recycling materials, also referred to as “material designers” are emerging. AM is a promising technology in this regard, allowing optimisation of the material flows by incorporating or reusing waste. The development and use of AM for waste materials and the recycling of filament are emerging rapidly.

Recycling of waste: The plastics industry has demonstrated a wide spectrum of ways to exploit discarded plastic items in many applications and fields. The most common procedure to treat plastic waste for 3D printing is to crush it and cut it into small parts, which are then extruded into a filament. Another way to utilise plastic waste is to mix it with new material, even metal, which has been proven to greatly improve the final product’s mechanical properties. In addition to plastic waste, examples are also found of waste from electronics, magnets, glass, sand, concrete, and rubber tires being used in filament for 3D printing.

Recycling of powder: The more AM becomes acknowledged, the more powder is needed as raw material, thus highlighting the need for its recycling and reuse. The reuse of recycled powder can yield both economic and environmental benefits. Reducing the cost of filament through the reuse of used powder mixed with virgin powder and the consequent reduction in the amount of virgin powder required enhances the tendency of more industries towards the utilisation of AM.

Cases

The following cases include both examples of manufacturing companies that are developing new, recyclable filament from waste materials (Nordic Metals and Lostboyslab) and manufacturing companies that are focused on the use of recycled materials and establishing take-back systems (Lostboyslab, Signify, Create it Real and GeBioM, and WOHN).

Renewable metal powder for 3D printing

Nordic Metals was established in 2020 as a sister company to Nordisk Staal. They collect machine and steel parts that would otherwise have been sent abroad as scrap, to instead recycle them into metal powder for AM and industrial 3D printing. The company supports an easy, tailored, and circular approach, where customers can hand in their scrap and have it remelted so that they can get it back either as steel laces, as a powder for 3D printing, or both. The powder for 3D printing is particularly suitable for producing and repairing tools.

Nordic Metals' metal powder has unique properties regarding strength and durability. According to Nordic Metals, due to the enhanced strength, the tools last 30-50% longer than tools manufactured with conventional steel. The special properties are achieved due to the Spray Forming technology that the company uses, where the metal powder production takes place together with the production of steel laces.

Nordic Metals supplies the industry with a material for 3D printing that is far more sustainable than the alternatives, and at the same time, they support a circular economy by recycling their waste material. An LCA has demonstrated that the CO_2 footprint of the metal powder is reduced by 61 percent compared to conventionally manufactured metal powder. This is further supported by using only renewable energy for production.

Circular design studio and 3D print farm use 90% waste materials

Lostboyslab, a circular design studio and 3D print farm, based in Malmö, Sweden designs and manufactures products for different types of clients. In each case, they use a "7R" model that takes the product/client through the different steps of the circular economy. With this model, Lostboyslab aims to address one of the greatest global environmental challenges, which is the management of waste, especially plastic waste. For this reason, circular economy is at the core of the business, which, for example, means that 90 % of materials used are made from recycled waste.

The 7R model includes a focus on recycling. Almost none of Lostboyslab's clients say no to using recycled materials. Instead, they become interested in learning more about the source of the materials and use it in their marketing. Lostboyslab collaborates with some of the few suppliers of recycled filament that exist today. This also involves collaboration on the development of new recycled filaments. In fact, Lostboyslab have also themselves become a manufacturer and supplier of recycled filament. The recycled materials comprise rPLA, rPETG, and Addnite, which is a new and strong material, created using a combination of PETG and rubber. The waste materials are all sourced from inside the borders of Europe. Lostboyslab encourages clients to consider taking back their products. All materials can be recycled and used for the manufacturing of new products.

Expanding the use of recycled materials for 3D printed lamps

Signify (previously Philips Lighting) use the filament polycarbonate, which is a strong, high-quality material and 100% recyclable for their 3D-printed polycarbonate lamps. According to Signify, a polycarbonate lamp has a 47% lower CO2 footprint than a traditionally manufactured metal lamp. In addition, there is no glue and fewer parts, and the lower weight saves 35% CO2 in connection with shipping.

Signify has the vision to become even stronger on the sustainability agenda through utilising the potential of recycling different types of material. Signify converts old CDs and fishing nets into filament and prints new lamps from that material, and they are expanding into using more waste materials. In the longer term, the plan is to establish a take-back system for their products and recycle the material to be used for new products.

Disrupting the orthopaedic shoemakers' industry with a circular business model

Danish Create it REAL, in cooperation with the German company GEBioM that delivers equipment for orthopaedic shoemakers around the world, have disrupted the traditional industry with new technology and a more sustainable manufacturing method. Specifically, they have developed a circular business model, which includes a take-back system for the 3D printing of individually adapted orthopaedic insoles.

Create it REAL supplies the 3D printer to produce the tailored insoles, and they have developed the so-called "gradient infill", which ensures that there is a smooth transition between the soft and hard area of the sole. The 3D printer has been developed to be of sufficiently good quality and cheap for all orthopedic shoemakers to purchase and use.

Thereby, they are adopting a distributed manufacturing approach. The customer has their foot scanned by the shoemaker, and the tailored sole is designed and 3D printed locally within one hour. Every time an insole is sold, the customer pays a deposit of EUR 2, which is refunded when the sole is handed in. 80% of the material is then recycled and used to produce new soles.

3D printing tiny homes with waste materials

WOHN is a Danish startup with a vision to democratise access to the housing market, as well as make construction more sustainable. With Additive Manufacturing (AM) technology, WOHN produces so-called 'tiny homes', which are built up from modules in the size of 20 m2. This is with the use of recycled plastic waste and waste wood. This entails that the CO2 footprint is reduced by over 90 percent compared to the construction of similar homes made of concrete and steel. Four tonnes of waste material are tied up per 20 m2 of housing.

The material composition is essential for the startup's circular business model. In 2022, WOHN conducted tests for the necessary approvals for the first material fraction, which enables the construction of the first homes. There are plans to further expand the range of fractions on the material. The right material composition has been developed with a collaboration partner, which supplies the filament to WOHN.

WOHN has fixed suppliers of waste plastic and waste wood. The startup plans to expand production to new markets. In connection with this, finding the right local suppliers of waste materials will be of high priority.

WOHN will deliver life cycle analyses (LCAs) on the homes, and they will develop a take-back system. The houses have an expected life of 50 years. The material can be recycled up to seven times.

3. Rethink Design

Rethinking design entails abandoning the linear take-make-waste system. Many products could be circulated by being maintained, shared, reused, repaired, refurbished, remanufactured, and, as a last resort, recycled. AM technology has potential especially for resource efficiency and reduction of materials use, e.g., through topology optimisation and designing for repair and restoration.

The problem (and the solution) starts with design. For many products on the market, there is no onward path after they are used. They are designed to be disposable. Although it sometimes seems like waste is inevitable in certain situations, waste is the result of design choices. Therefore, strategies for circular design will focus on designing for attachment and trust (products that will be used longer) and designing for easy maintenance and repair. Designing for disassembly and reassembly ensures that products can be separated and reassembled easily. Circular design strategies can also include a focus on standardisation and compatibility, which means that parts can fit other products. They can also include a focus on upgradeability and adaptability so they can be expanded to be useful under changing conditions. Finally, the recyclability of the material used is essential in circular design strategies (covered under step 2: Mind the Materials).

The Role of Additive Manufacturing

AM technology has been highlighted to have potential, especially for resource efficiency (reduced use of materials) and designing for repair and restoration.

Resource efficiency through complex geometries: AM allows the creation of complex geometries, which can lead to a reduction of material usage, part consolidation, simplified assembly lines, increased product functionality, and reduced energy consumption. AM can result in energy savings because it is well suited to lightweight design. Through topology optimisation, a part can be optimised considering the applied stress and required stiffness, resulting in lighter structures. This has, for example, been demonstrated in the energy reduction of transport vehicles because of lightweight design with AM.

Topology optimisation is one of several categories of structure optimisation in which additional modifications may be necessary so that the model can be manufactured and the optimal solution can be found. The topology optimisation can be viewed as part of generative design. Generative design encompasses the entire design process. By specifying the construction problem, an optimised model is generated that can be produced directly. Generative design begins with design parameters and uses AI to generate the model. By modifying the design parameters in an increasingly refined feedback loop, it is possible to find highly optimised and customised design solutions to making product components lighter, stronger, and more cost-effective.

Design for repair and restoration: AM makes it possible to optimise part design and guide it towards easy maintenance, repair, and restoration, i.e., ease of assembly and disassembly and consideration of the degree to which the component can be repaired. A way to facilitate this orientation process is by creating digital databases where spare part designs are stored and can always be utilised for various supply chain functions.

Cases

The cases below demonstrate examples of manufacturing companies that have optimised components or products through topology optimisation/generative design as part of the Danish AM Hub innovation project Design for Additive Manufacturing (DfAM).

The purpose of the DfAM project is to re-design the participants' components or products, whereby they can be produced with less material waste, greater strength, and new or better functionality. In the end, the participating companies will be left with a physically re-designed component or product where one or more of the sustainable benefits have been considered. In this way, the participants gain added value and knowledge, which can be anchored locally in their production.

Design optimisation reduces materials use and weight of drone

AIRFLIGHT

The Danish startup Airflight produces some of the world's largest multi-rotors – in principle, an overgrown drone – to fly with components and tools in the wind turbine industry. The largest drone has eight arms and can lift up to 200 kg. Airflight participated in DfAM to investigate the possibilities for optimising the brackets that hold the arms of the drone.

The fittings were generative design optimised with 3D printing so that they were both lighter and able to withstand the loads - and they were 3D printed in titanium. The following key results have been created by Airflight:

- 59% weight reduction on each bracket
- 11 kg weight reduction on the entire drone
- 80% reduction of material use
- Less waste material compared to milling the brackets

As a result, the drones can achieve greater strength-to-weight ratio, which is important in aviation as it means it is possible to fly for a longer time or with a heavier load.

Design optimization reduces weight of manufacturing tool

BEWI is a plastics company that produces polystyrene – also known as flamingo – in customized solutions. As part of DfAM, the company looked at optimising one of the tools that are part of the casting process. In the process, BEWI optimised the design of the tool and thereby primarily reduced the weight by 74 percent compared to traditional tools, but also improved time-to-market, cutting 25 percent of the delivery time. If they implement the design optimized component broadly, BEWI see potentials in lowering the energy consumption of their production.

Overall, BEWI sees great potential in AM. Today, the company has challenges in production that machine settings cannot help with, but by optimising the tool with 3D printing, BEWI achieves greater design freedom, which means that a more complex solution can be offered.

The following key results have been created by BEWI:

- 74% weight reduction compared to traditional tools
- 53% price reduction compared to traditional tools
- 25% shorter delivery time
- Enhanced design freedom and flexibility

4. Own your Value Chain

Adopt a holistic perspective that incorporates the whole value chain and life cycle of your products. Document your carbon footprint, also taking into consideration your suppliers. Danish AM Hub has started to provide documentation for the environmental impact of AM through carbon footprint estimations.

The need for manufacturing companies to document their carbon footprint has increased in recent years, not least after the introduction of the UN Sustainable Development Goals (SDGs). The EU Commission's Corporate Sustainability Reporting Directive is also underway. It will set requirements for comprehensive sustainability reporting on environmental, social, and governance (ESG) indicators from companies with more than 250 employees. This includes documentation of their value chains, which entails that small and medium-sized companies (SMEs) with fewer than 250 employees will also indirectly be comprised by the legislation when the larger companies will come to make demands on their sub-suppliers and clients. This is, in some cases, further complemented by national documentation requirements.

To capture a holistic, detailed, and accurate environmental footprint of a product, a comprehensive life cycle assessment (LCA) is required. An LCA considers the full environmental impact of products from the use of materials, manufacturing, distribution, use, repair, and maintenance to recycling or disposal. Today, there are consultancies specialising in conducting LCAs on behalf of manufacturing companies. For SMEs in Denmark, it is also possible to seek assistance from the programme "klimaklar produktionsvirksomhed".

Essential for manufacturing companies is to manage and document not only the carbon footprint of individual products but for the company. The GHG Protocol Corporate Standard categorises greenhouse gas emissions associated with a company's Corporate Carbon Footprint as scope 1, scope 2, and scope 3 emissions.

Scope 1 emissions include direct emissions from the company's owned or controlled sources. This includes on-site energy like natural gas and fuel, refrigerants, and emissions from combustion in owned or controlled boilers and furnaces, as well as emissions from fleet vehicles (e.g., cars, vans, trucks, helicopters for hospitals). They encompass process emissions that are released during industrial processes and on-site manufacturing (e.g., factory fumes, chemicals).

Scope 2 emissions represent one of the largest sources of greenhouse gas emissions by accounting for at least a third of it. This includes indirect greenhouse gas emissions from purchased or acquired energy, like electricity, steam, heat, or cooling, generated off-site and consumed by companies.

Scope 3 includes all indirect emissions that occur in the value chain of a company. Scope 3 emissions are the result of activities from assets not owned or controlled by the company but that the organisation indirectly impacts in its value chain. Even though these emissions are out of the control of the reporting company, they can represent the largest portion of its greenhouse gas emissions inventory. Based on the financial transactions of the reporting company, the Greenhouse Gas (GHG) Protocol divides the scope 3 emissions into upstream and downstream emissions and classifies them into 15 categories. Upstream emissions encompass the indirect greenhouse gas emissions within a company's value chain related to purchased or acquired goods (tangible products) and services (intangible products) and generated from cradle to gate. Downstream emissions include the indirect greenhouse emissions within a company's value chain related to sold goods and services and emitted after they leave the company's ownership or control.

The Role of Additive Manufacturing

As demonstrated from the cases introduced above, AM holds great potential to support the transition towards more sustainable manufacturing, e.g., through reducing material consumption and using recycled materials. Using 3D printers for manufacturing requires a relatively high electricity consumption compared to other manufacturing methods, which calls for establishing AM/3D printing centres where it is possible to power the 3D printers from renewable energy sources. This involves consideration of the company's scope 2 emissions, but it also involves scope 3 emissions, i.e., taking into consideration the CO2 emissions of the company's value chain.

The initial energy consumption can have a negative impact on the LCA of a 3D printed product. However, this is often outweighed, e.g., by the improved strength or the reduced weight of the product, which entails lower energy consumption in the lifetime of the product. To further document the sustainability potential of the technology, as part of innovation programmes initiated by Danish AM Hub, LCAs will systematically be carried out from 2022 onwards in cases that include the development of new components or products. An example of this is the project DfAM.

Cases

The case below includes the example of an LCA calculated on Airflight that participated in the Danish AM Hub project DfAM to optimise their product through generative design.

Lifecycle assessment: the case of Airflight

AIRFLIGHT

On behalf of Danish AM Hub, a lifecycle assessment has been carried out for Airflight (case under 3. Rethink design). The startup produces some of the world's largest drones to fly with components and tools in the wind turbine industry. Fittings for the drone were generative design optimised with 3D printing so that the drones can achieve a greater strength-to-weight ratio, which is important in aviation as it means it is possible to fly for a longer time or with a heavier load.

The lifecycle assessment compares the product manufactured with AM against its conventionally manufactured counterparts, focusing on Global Warming Potential. This is done with the use of an environmental impact assessment tool, based on several clusters, to analyse transparently benefits of AM compared to a milling process. The benefits for AM are especially found during the manufacturing phase, as there is much waste in the traditional milling process and in the use phase due to the reduced component weight. The total GWP savings amount to -0,8 t CO2-eq.

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