THE OPPORTUNITY SPACE OF 3D PRINT IN THE **MARITIME** INDUSTRY

GREEN SHIP OF THE FUTURE

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INTRODUCTION

Over a period of 6 months, Green Ship of the Future and 20+ industry partners have explored the opportunity space of 3D printing (3DP) and additive manufacturing (AM), in order to assess and comprehend the potential of the technology and derived opportunities for the maritime industry. In the process of rising the knowledge level of 3DP and AM, it has been confirmed that the maritime industry is [still] considerably behind, when it comes to strategic investments in 3D printing. Only few have taken real steps to test the implementation of 3DP in prototyping, fewer have implemented 3DP technology in tooling or molds and none have implemented AM in their current production line.

In order for the maritime industry to move forward with their efforts on 3DP, AM and related digital technologies, it is our conclusion that we need to generate hands-on experience with the technology and maritime case stories that our industry can relate to. In addition, there is a need to explore and understand how the technology can affect and develop our current business models and the maritime value chain.

For anyone who considers 3D print the next addition to their technology portfolio or manufacturing line, it is imperative to understand that, 3D print is not just another machine by the assembly line, but rather a technology with the ability to change our business models and current supply chain. Even more so in combination with related emerging technologies such as robotics, automation, artificial intelligence, augmented reality and so forth.

Digital technologies, such as 3D print, are characterized by evolving exponentially. This makes the speed of development almost impossible to comprehend, when we apply our normal linear approach. What seemed impossible one year, is possible the next.

To truly understand and exploit the technology, we need to think differently: we need to apply a different mindset. This applies to our short term assessment of the technical competences needed, but, more importantly, it also applies to our strategic outlook and understanding of the long term perspectives of this technology for our industry

A survey by PwC from 2016 shows that respondents believe that 3DP's greatest disruption potential will be exerted on customer relations and restructured supply chains. It also shows that companies are anticipating 3DP driven savings in transportation costs. (PwC 2016) .The question then remains, where, in that paradigm shift, will shipping and the maritime industry find its place?

This report builds on our experience and learnings throughout the project, collected in a dynamic baseline document available at our website. The report represents our take on the maritime opportunity space of 3D print and additive manufacturing.

On behalf of the project partners Alfa Laval, Create.dk, DNV GL, Maritime Development Centre, J. Lauritzen and OSK ShipTech: ***A very special thanks to the Danish Maritime Fund for making this journey possible, but indeed also to the many participating companies, industry partners and 3DP experts for playing a long.***

Enjoy!

Feel inspired!

Think Additively!

WHAT IS 3D PRINT AND ADDITIVE MANUFACTURING

and why is it so important?

Additive manufacturing is a manufacturing method that builds objects by adding successive thin layers of material until the object takes its final form. 3D print, in general, uses less material and can produce more complex structures than traditional (subtractive) manufacturing methods such as grinding or milling.

3D print has been around for about 30 years. It had a rather linear development curve, until the technology, as we know it today, took off exponentially in the mid 2000's with improved process reliability, better 3D printing materials, the internet and, not least, the expiration of a number of important patents in 2009. Over the past decade, significant technology leaps have been taken within 3D print, and the technology has transformed the way products are designed, prototyped an manufactured.

One of the most important realizations, when exploring 3D print, is that a 3D printer is not just another machine in the production line. Rather, it offers an opportunity to rethink traditionally accepted manufacturing constraints (Stratasys 2016) and challenge the existing supply chain. By 3D printing an object, one can take advantage of new possibilities such as novel design, lightweight structures, a higher degree of customization and integrated functionalities. However, the long term impact of the technology may also offer new business models, reshoring of production facilities, significant changes in the supply chain, open innovation and the list continues.

The appliance of 3D print is often divided into 3 categories:

- Rapid prototyping, where 3D print is used in the design and development process
- Rapid tooling where 3D print is used for moulds and production tools
- Rapid (additive) Manufacturing where 3D print is used in actual production

HOW DOES IT WORK?

To 3D print an object, you need a digital 3D design file. The design file is then "sliced into thin layers" and sent to the 3D printer.

The actual printing process varies by technology, starting from desktop printers melting a plastic material to industrial machines using a laser to melt metal powder at high temperatures. Materials vary from plastics, rubber, sandstone, metals and alloys, but some printers also allow for the use of composites and new materials as well as a combination of more than one material. Depending on the applied technology, the printed object may need post-processing and finish before it can be used.

The available hardware for 3DP and AM is increasingly diversified and accordingly difficult to cover in one term. Case in point:

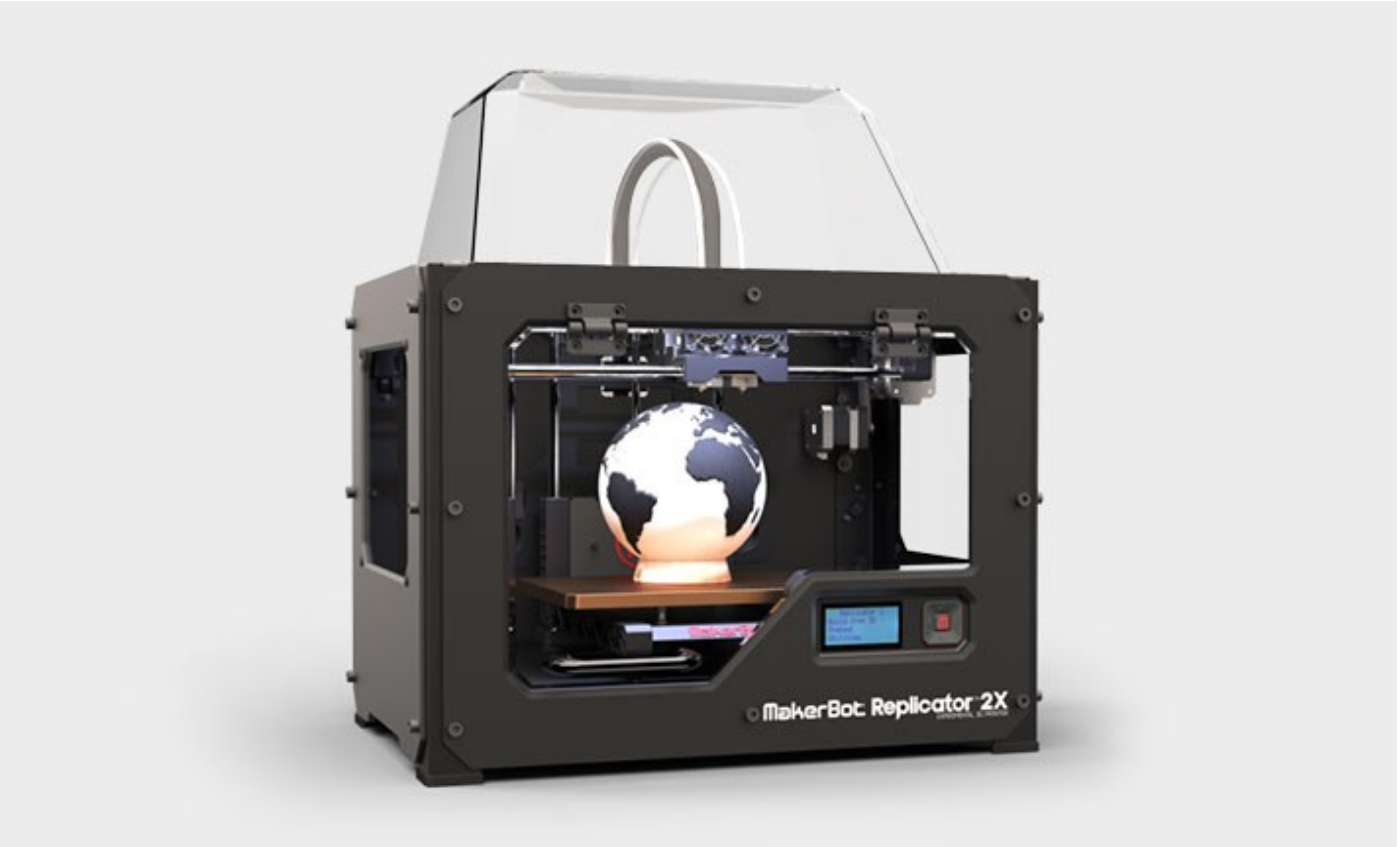
- Print volumes from 3 to 220.000 liters
- Accuracy from 0,00001 mm to 5 mm
- Price from DKK 3.200 to 12.000.000+
- A wide range of materials and mix of materials

COMMON TECHNOLOGIES

Fused Deposition Modeling (FDM)

FDM is the technology of choice for quick and low-cost prototyping and can be used for a wide variety of applications. More recent innovations in FDM 3D printing include the ability to manufacture functional end products with embedded electronics and mechanical parts such as drones. Due to some design and material limitations, FDM 3D printing is not recommended for more intricate designs.

Materials include plastic-based such as ABS, PLA and nylon, but also blends incl. carbon, bronze or wood. **Technology:** The FDM printing process starts with a string of solid material called the filament. This line of filament is guided from a reel attached to the 3D printer to a heated nozzle inside of the 3D printer that melts the material. Once in a melted state, the material can be extruded on a specific and predetermined path created by the software on the computer. As the material is extruded as a layer of the object on this path, it instantly cools down and solidifies – providing the foundation for the next layer of material until the entire object is manufactured.



Example of desktop printer with FDM technology: MakerBot Replicator 2X Experimental 3D Printer (photo: MakerBot)

Stereolithography and Digital Light Processing (SLA & DLP)

SLA & DLP 3D printers produce highly accurate parts with smooth surface finishes and are commonly used for highly detailed sculptures, jewelry molds, and prototypes. Because of their relatively small size, they are not recommended for printing large objects.

Materials are limited to resins but new varieties have appeared recently providing strength or flexibility to the final objects.

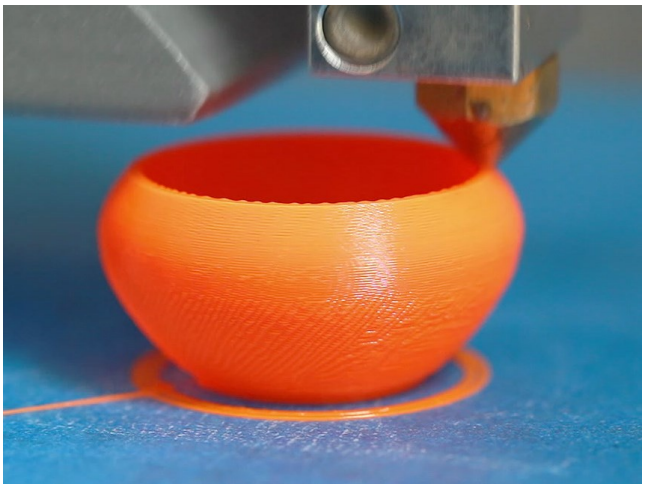
Technology: Both Stereolithography (SLA) and Digital Light Processing (DLP) create 3D printed objects from a liquid (photopolymer) resin by using a light source to solidify the liquid material.

To create a 3D printed object, a build platform is submerged into a translucent tank filled with liquid resin. Once the build platform is submerged, a light located inside the machine maps each layer of the object through the bottom of the tank, thus solidifying the material. After the layer has been mapped and solidified by the light source, the platform lifts up and lets a new layer of resin flow beneath the object once again. This process is repeated layer by layer until the desired object has been completed. There are two common methods today differentiated by the light source: SLA uses a laser, whereas DLP employs a projector. These 3D printing technologies are also available in desktop 3D printers.

Digital Light Processing (DLP) (photo: think3d.in)

Selective Laser Sintering (SLS)

SLS is mostly used for industrial 3D printing applications. However, the first desktop versions are available and the technology is expected to move further into the mainstream. SLS is widely used for producing functional prototypes and parts as well as some end products. The biggest advantage of laser sintering is the almost complete design freedom; excess unmelted powder acts as a support for the structure as it is produced, which allows for complex and intricate shapes to be manufactured with no additional support needed. As a side effect of this process, finished objects require more time to cool and thus, cause longer lead times. **Materials** include various plastics such as polyamides (nylon), polystyrenes and thermoplastic elastomers.



Selective Laser Sintering (SLS) (photo: Global Britannica)

Technology: Selective Laser Sintering (SLS) uses a laser to melt and solidify layers of powdered material into finished objects. When the printing process begins, a laser maps the first layer of the object in the powder, which selectively melts – or sinters – the material. Once a layer has been solidified, the print bed moves down slightly as the bed containing powder moves up; and a roller spreads a new layer of powder atop the object. This process is repeated, and the laser melts successive layers one by one until the desired object has been completed.

Material Jetting (PolyJet and MultiJet Modeling).

Material Jetting offers many advantages for rapid tooling and prototyping, as it allows the user to create realistic and functional prototypes with accurate details and precision. These technologies are very precise and can print with up to 16-micron (that's thinner than a human hair) layers.

Materials are limited to liquid photopolymer that can provide the final objects various properties including toughness, transparency or rubber-like flexibility. Some systems allow for the combination of different material properties and colors by applying multiple jets.

Technology: Material Jetting (Stratasys PolyJet and 3D Systems MultiJet Modeling) technologies are similar to inkjet printing, but instead of jetting drops of ink onto paper, these 3D printers jet layers of liquid photopolymer onto a build tray and cure them instantly using UV light. The build process begins when the printer jets the liquid material onto the build tray. These jets are followed by UV light, which instantly cures the tiny droplets of liquid photopolymer. As the process is repeated, these thin layers accumulate on the build tray to create a precise object. Where overhangs or complex shapes require support, the printer jets a removable gel-like support material that is used temporarily, but can be removed after the print is completed.

Binder Jetting

Binder Jetting is used in industrial 3D printing. It is relatively affordable compared to SLS as the printing process requires less energy, however the printed objects are less strong. The ability to print in full color has made sandstone popular for architectural models and sculptures. Similar to SLS, the benefit of this process is that the excess unmelted powder acts as a support to the structure as it is being produced, which allows for complex shapes to be made and no additional supports are required.

Materials include (full-color) sandstone.

Technology: With binder jetting technology the printer uses thin layers of powdered material to build up an object, using a binding agent extruded from a nozzle.

The process starts with a nozzle spreading the binding agent across the first layer of the object. Once the first layer has been fused with the binding agent, the printing bed moves down slightly and a thin layer of new powder is spread atop the object. This process repeats until the desired object has been fully formed. After it is removed from the print bed, the object is cleaned from excess powder and coated with an adhesive glue to give it strength and to make it resistant to discoloration.

Metal Printing

(Selective Laser Melting and Electron Beam Melting)

Selective Laser Melting and Electron Beam Melting (SLM and EBM) are two of the most common metal 3D printing technologies and primarily used in industrial 3D printing.

Materials include various metals and alloys including steel, titanium, aluminum, cobalt-chrome and nickel.

Metal printing is considered the “holy grail” of additive manufacturing and 3D printing; it is widely used in the aerospace, aircraft, automotive and healthcare industry for a range of high-tech, low-volume use cases from prototyping to final production. 3D printed metal parts allow for monolithic construction (reducing the quantity of components), miniaturization and mass reduction. SLM and EBM have evolved to a stage where these prints are comparable to traditionally manufactured parts in terms of chemical composition, mechanical properties (static and fatigue) as well as microstructure.

Technology: These processes create objects from thin layers of powdered material by selectively melting it using a heat source: a high power laser in the case of SLM or an electron beam for EBM.

During the printing process, the machine distributes a layer of metal powder onto a build platform, which is melted by a laser (SLM) or an electron beam (EBM). The build platform is then lowered, coated with new layer of metal powder on top and the process is repeated until the object is fully formed. Both SLM and EBM requires support structures, which anchors the object and overhanging structures to the build platform and enables heat transfer away from the melted powder. In addition, SLM takes place in a low oxygen environment and EBM in vacuum, in order to reduce thermal stresses and prevent warping.

The descriptions above are shortened versions of those available from www.3Dhubs.com. At www.3Dhubs.com more pictures, detailed descriptions and visual guides are available.

THE OPPORTUNITY SPACE OF 3D PRINT AND ADDITIVE MANUFACTURING IN MARITIME

Related industries

3D print and additive manufacturing (AM) is used on a daily basis in a wide range of industries such as automotive, aerospace, aviation, defense, medical, architecture, design and fashion etc.

In the aviation industry, 3D printing has also become an integrated production method as industry leaders, such as Airbus and General Electric have invested heavily in the technology and pushed the boundries for both appliance, but also the development of new and improved parts used in airplanes. The GE fuel nozzle for the LEAP engine is a known example of a functional part that can only be manufactured via 3D print due to the integrated flow lines. 3D printing also allowed engineers to use a simpler design that reduced the number of brazes and welds from 25 to just five (GE 2016).

SpaceX Main Oxidizer Valve body (photo: SpaceX)

In aerospace, SpaceX has also been evaluating the benefits of 3D printing and perfecting the techniques necessary to develop flight hardware. Their first major success was the Super Draco Engine Chamber, printed in late 2013. On January 6, 2014, SpaceX launched its Falcon 9 rocket with a 3D-printed Main Oxidizer Valve body (picture) in one of the nine engines (SpaceX 2016). The US navy have explored 3D print both through their Print the Fleet program, but also in several spin-off programs. In 2016, they successfully launched a Trident II D5 missile that was equipped with a 3D printed component from Lockheed Martin (US navy 2016).

The mentioned examples show the readiness and reliability of 3D printing technology, and the level of investments made in industries we usually compare with maritime.

With the extensive appliance in industries similar to maritime such as aviation, automotive and aerospace, it is imperative to explore the opportunity space in maritime as well. The maritime industry is heavily regulated and the mentioning of 3D print is often followed by hesitation and questions related to quality assurance and classification, IP and safety. These issues should be taken seriously, but they can not be solved before the industry starts exploring the technology. Throughout our journey, it has, however, been confirmed that the different maritime stakeholders should apply different approaches to the technology and distinguish between both short – and long term appliance, but also short- and long term consequences:

How can we, in the maritime industry, use the technology to develop and improve our product and/or service ahead of competitors (and who will our competitors be in 5 or 10 years)?

How will it affect our industry when others, outside the maritime industry, adopt the technology and e.g. re-shoring of production or disrupting business models become reality?

3D print may *seem* more relevant for suppliers to the maritime industry than e.g ship owners; however, assumed that this technology will affect the maritime supply chain in general, product development and innovation may be applied across. In general, it is important that the maritime industry generates maritime experience and industry case stories to truly move the appliance of 3D print forward.

Maritime appliance

In our process, the following areas, appears relevant for further exploration and testing within the maritime industry.

- **Innovation and product development**
- **Improved product design in terms of e.g. customization and efficiency**
- **Repair and reproduction of (obsolete) parts**
- **Improved supply chain**

Innovation and product development

With rapid prototyping, a manufacturer is allowed to manufacturer and test a product throughout the innovation and development process. That can speed up the development process, but it also enables a higher degree of co-creation, because a supplier can evaluate a product with an end-user (e.g. a ship owner) at an early stage. The available 3D print technology allows for prints at all stages and costs, from cheap plastic mock-ups to expensive test parts in different metals. In the maritime industry, one could imagine a designer creating a 3D printed model of the interior of a ship, in order to visualize ideas and designs. Or, a supplier, developing a part customized to fit the specific needs and operational profile of a ship. Both examples can be created with 3D print technology and tested without the need for expensive manufacturing or re-tooling.

Improved product design in terms of e.g. customization and efficiency

Due to the production method, 3D print allow for significant improvements in terms of design and optimization. The designer is no longer limited by the constraints of traditional manufacturing. Components can be designed in a way that was previously impossible or highly uneconomical to manufacture and which allows for e.g. consolidation of several parts into one. This also enables structures that are more organic or simple, but still increasingly stronger compared to traditional manufactured alternatives. Light weight structures, inspired by nature such as honey comb is also enabled by 3D print technology. Increased complexity enables integrated functionalities such as cavities. General Electric has produced a fuel nozzle that utilizes the cavity capability of 3DP to circulate the minus 50 degree jet fuel underneath the surface in a way that enables higher combustion temperature and lower fuel consumption. This can also be applied to improve production methods. By integrating cooling channels in moulds, production capacity can be increased because the subjects cool faster. The latter is referred to as (rapid) tooling. The term is applied when 3D print is used to optimize production tools and moulds. In the maritime industry, 3D printed sand moulds are tested in the production of casted items such as impellers, turbines and pump casings.

At this point, 3DP technology is limited in terms of the size of the print beds. This means that the vision of 3D printing an entire ship is (still) somewhat into the future. However, if the current speed of print technology development continues, there is no reason to believe that it will remain impossible. What seemed impossible last year, may very well be possible the next. Accordingly, 3D print of larger structures such as hull sides with an embedded honeycomb structure might not be that far into the future. Whether it is financially feasible, is an entirely different discussion.

3D print is mainly considered a viable manufacturing method for one-of-a-kind production (or small badges), or for parts with a high degree of customization, such as hearing aids. Customization is increasingly interesting to consider in the maritime industry, where most ships are produced as one-of-a-kind and/or for a specific purpose. If parts are energy optimized in accordance with the operational profile and needs of the ship in question, it makes sense to assume that they will have a positive effect on the total energy consumption of the ship. Other criteria apply when you consider the 3D print eligibility of a product such as complex design, high kg prize of component, urgency of delivery, the possibility of consolidating several components into one or value leverage due to improved performance. Of particular high interest to the maritime industry is the factor of time and sense of urgency. By 3D printing (rapid manufacturing) spare parts, lead times and expensive layovers can be limited and may even be avoided if the parts are produced in port hubs, such as the Port of Rotterdam or on board.

Finally, new materials and the continued advancement of print technology suggest that integrated functionalities, such as movement over time (4D print) might become reality within a foreseeable future.

Repair and reproduction of (obsolete) parts

Certain types of 3D print technologies allow for repair or reproduction of obsolete parts. If a part is no longer produced it is either impossible, or associated with extremely high costs, to re-produce traditionally. In combination with a 3D print scanner, a 3D printer can produce a new matching insert much faster and at a (relatively) reasonable price.

As mentioned above, 3D print is often limited by the size of print beds. 3D Metal Cladding (3D MC) does not abide by to the same limitations, and might be used to build and repair larger items (1x1x5 meters). The 3D metal print process may be compared with the metal casting process in the sense that, the 3D MC process provides a quality of parts similar to casted parts. Printed parts will therefore often require a final tooling step to achieve tight tolerances and required finish. The technology is, at this point, an alternative to normal casting and/or welding processes when creating large parts and structures, but will allow for the inclusion of 3D print benefits such as increased complexity.

Different 3D print technologies, such as metal cladding or potentially cold spray 3D print might also be used for repair. By adding thin layers of metal, a 3D printer can rebuild worn or damaged surfaces. The technology allows for on-site repair or complete reproduction of component or part. This is increasingly relevant in the maritime industry, where a ship's down time can cost millions of dollars by the day and should be further investigated.

Improved supply chain

A central reason for talking about 3D print as a disruptive technology, is the fact that it, in theory, allows anyone (with sufficient knowledge of 3D print technology) to set-up a production facility anywhere. This is also why the technology is often referred to as an enabler for re-shoring of manufacturing i.e. bringing production back to e.g. Europe from Asia. In theory, this means that a traditional supplier can become obsolete if the end customer decides to manufacture the product themselves. In the maritime industry, this allows for the production of parts and components closer to point of use, maybe even on site or on board. In principle, on board production would mean that ship owners or operators can limit lead times and expensive lay overs by ensuring access to spare parts no matter the country they operate in. It also opens up for the theoretic possibility that any excess inventory can be replaced by a 3D printer and print material. For the moment, there are quite a few challenges that need to be overcome, if this is to become reality. In the project 'Print the Fleet', the US Navy explored the idea of on board printing, for some of the same reasons a commercial ship owner would: it can potentially "*save time, decrease cost, and reduce inventory for the U.S. Navy*" (US navy 2016) . At the moment of writing, the US army is the only example of a "ship owner" who has taken steps to test print technology and limitations by placing a 3D printer on board. They tested durability with Desktop 3D printers not vulnerable to tilting. It is still unknown how powder printers and jet printers function at sea. Tilting beyond the stable angle of the powder could, however, be fatal, particularly combined with accelerations. Printers with basin of fluids like STL, SLA and DLP printers will, most likely, not work at sea. Other limitations appear in the shape of size of printed parts, quality assurance of printed parts and the need for post processing. Finally, the ship owner will have to invest in ensuring the needed competences on board. The idea of on board printing re-appears with regular intervals and should be thoroughly explored and tested by a commercial ship owner, to add to the experience of the US navy. Port hubs are not limited by the constrains of on board printing, but will move production closer to the point of use. Furthermore, they enable increased use and cooperation of the print facilities across industries and may be the more viable alternative to on board printing, for now.

3D print communities and port hubs

As other emerging technologies, 3D print is characterized by the ability of gathering users in maker communities enabling sharing, democratization and co-creation. Individuals continuously contribute to the development of the technology and push the boundries of appliance and usage. In reality this means that an extreme amount of talent and experts are available globally. By applying open source innovation, companies can dip into that talent pool, and activate the available talent and openness to co-create in their own product development. In 2013 GE announced a 3D Printing Design Quest challenge, which called on the maker community to design stronger but lighter brackets for a jet engine. The finalists' brackets were 3-D printed at GE Global Research. The winning bracket was more than 80 percent lighter than the original bracket. GE received more than 600 entries and a majority of these where from outside the aviation industry (GE 2016).

In the maritime industry, the thought of applying a collaborative approach when exploring emerging technologies makes sense. While the established maritime community knows everything about maritime, their products and their services, they know very little of 3D print and digitalization. For this, external experts have to be brought in. In 2016, Port of Rotterdam set up Rotterdam Additive Manufacturing Laboratory (RAMLAB). RAMLAB is to provide significant value-added services to the ports major customers in the form of on-demand, large, metal 3D-printed parts.

RAMLAB follows an extensive pilot project, initiated by public agency Innovation Quarter and the PRA, entitled 3D Printing Marine Spares, which focused on manufacturing metal spare parts for mainly maritime applications. RAMLAB is the result of collaboration between local businesses specializing in marine parts supply, solutions and services, quality assurance companies, 3D-printing firms, academic and R&D institutions, enterprises active in design technology, materials selection and testing and a logistics services provider. Companies from other industrial sectors including Fokker (aerospace) and Siemens (software development) also participated in the pilot, which culminated in the printing of seven parts: a propeller, cooled valve seat, spacer ring, hinge, T-connector, seal jig and manifold. While similar initiatives might be under way in Asia and the US, this project is still unique and an important project about the practical appliance of 3D print in the maritime industry.

We have applied a collaborative approach aiming at creating community or LAB feeling among the participants, enabling them to draw on extensive maritime experience, while openly discussing the appliance of 3D print and additive manufacturing.

Knowledge sharing at one of three workshops in the project (2016)

CONCLUSIONS

This report is the conclusion of part 1 and 2 of our project 3D PRINTING IN THE MARITIME INDUSTRY. The purpose of the project was to explore the opportunity space of 3D printing in the maritime industry, while at the same time raising the awareness and level of knowledge about 3D print and additive manufacturing within the industry. Our findings and conclusions are three fold:

We have experienced substantial interest in 3D print technology and a genuine curiosity towards implementation and further exploration of the derived potential from stakeholders representing all parts of the maritime supply chain. We have, however, also realized that success stories from other industries are difficult to transfer to the maritime industry. In order for the maritime industry to move forward with 3D print and to truly understand the potential, we need to generate real maritime experience. The areas that experience should be generated in are: Innovation and product development; Improved product design in terms of customization and efficiency as well as Repair and reproduction of (obsolete) parts. We also need to explore the potentials and challenges for the current supply chain.

3D print is a competitive alternative to traditional production methods when the product or part is characterized a high degree of customization and low production volumes. In order to benefit from the distinct advantages that 3D print allows for, such as complex structures or lightweigth, the object requires re-thinking and re-design. This requires specific competences and an in depth understanding of 3D print. Although 3D print technology is constrained by size limitations at the moment and the maritime industry per definition deals with large objects, there is no reason to believe that the technology is irrelevant. We do, however, need to explore the current limitations. By applying a collaborative approach and engage with print technology providers and experts, the maritime industry can take part in the technological development, to their benefit. The technology is still in its infancy, but the pace of development, suggests that we need to engage now, if we are to succeed. Danish stakeholders have, traditionally, been on the forefront of global maritime development. It is only natural, that we continue to be, by curiously exploring new technologies and their possible appliance.

If we apply a strategic perspective and look at the long term societal development, it is somewhat impossible to predict the specific impact of 3D print in maritime. That in itself is a reason to continue the exploration. 3D print is one of many emerging technologies moving exponentially. Real disruption will, most likely, come when these are combined. 3D print has the ability to change or impact shipping's supply chain as manufacturers (from all industries) and consumers adopt the technology increasingly. We need to explore how shipping and the maritime industry can be on the forefront of development and be part of the disruption. Whether or not you believe in 3D print as a technology, the current outlook suggests that emerging technologies, industry 4.0 and related concepts will change the way the world operates. And there is no reason not to be part of that change.

Knowledge sharing at one of three workshops in the project (2016)

EPILOGUE

In 2017, GSF will continue the project with a group of partners, in order to start generating maritime experience and examples to move forward with the technology. In four projects we will pursue the vision of enabling large scale 3D print, 4D print, and on site repair methods in the maritime industry. In addition, we will also explore the opportunity space for on board printing and related challenges in the current supply chain and existing technology. The continuation of the projects is kindly supported by the Danish Maritime Fund.

3DP READY?

Applying 3D print technology becomes easier as the technology develops and prices decrease at a rapid pace. Today, anyone can start exploring the technology and challenge their ability to think additively, by investing in a desk top printer. Once you have an understanding of the technology, a thorough self-assessment can be helpful before deciding on a future 3DP strategy.

We have gathered 10 questions, to consider before investing in the (disruptive) world of 3D print:

1. Are you ready to invest? Have you considered experimenting with a desktop printer before investing in an industrial 3D printer?
2. Is 3D printing an integral part of your research and development (e.g. through rapid prototyping)? If not, could it be?
3. Can 3D printing improve the design, performance, customization or lead time of existing products (currently made through conventional manufacturing processes)?
4. Does the advantage of improvement made possible by 3D print, weigh up the additional costs of production, compared to traditional manufacturing?
5. Have you assessed the technical barriers of 3DP for your product (e.g. limitations in terms of material, process quality and post processing needs)?
6. Does your organization have the talent and mindset to launch a 3D printing program (at all levels)
7. Could 3DP present opportunities for your company to diversify into new products and bid on jobs that presently you cannot?
8. Could your business take advantage of the growing global network of 3D printers in ways that could simplify your supply chain?
9. Would it make sense to “buy into” 3DP through an acquisition, joint venture or other business combination in order to acquire the expertise instead of developing it internally?
10. Are you considering 3D print in combination with other digital technologies?

(questions inspired by PwC 2016)

ABOUT THIS PUBLICATION

This report marks the conclusion of the project 3D PRINTING IN THE MARITIME INDUSTRY part 1 and 2. The project was part of the project portfolio of Green Ship of the Future in 2016.

The purpose of the project was to explore the opportunity space of 3D printing in the maritime industry and raise awareness of the technology and its appliance within maritime.

The project was initiated by leadpartner OSK ShipTech and developed with Alfa Laval, Create.dk, DNV GL, J. Lauritzen, and Maritime Development Center and coordinated by Green Ship of the Future.

A very special thanks to the Danish Maritime Fund for supporting the project financially, the many participating companies for daring to play with new ideas and the experts who willingly shared their knowledge throughout our process.

ABOUT GREEN SHIP OF THE FUTURE

Green Ship of the Future is a public private partnership working for a reduction of emissions from the maritime industry.

Through collaborative innovation across the maritime supply chain, our members explore, develop and demonstrate green technology in ambitious projects with the overall goal of making shipping and the maritime industry more innovative, energy efficient and sustainable. We focus on increased appliance of existing technology as well as exploration and development of new technology, services and business opportunities.

Join us, to help create a greener maritime future at www.greenship.org