3D-PRINTED VESSELS

TAKING DESIGNS TO NEW DIMENSIONS

3D printing for marine applications is still in it nascent phase – though ambitious projects in the US, Denmark and the Netherlands are rapidly casting light on the potential for 3D-printed vessels

The 3Dirigo was produced by the world's largest 3D printer within 72 hours

With a history rich in shipbuilding and a thriving composites manufacturing industry, it's perhaps fitting that the US state of Maine has been pioneering the use of 3D printing in boatbuilding.

In October 2019, the world's largest 3D-printed composite boat, the 3Dirigo, was assembled and launched by the Advanced Structures & Composites Center of the University of Maine (UMaine). The launch event came shortly after the facility had installed the world's largest 3D printer (as recognised by Guinness World Records), supplied by Ingersoll Machine Tools. Measuring 18.3m x 6.7m x 3m – and, at the time, featuring a production rate of 150lb (68kg) per hour – the printer turned around the 3Dirigo within 72 hours: a fact that wasn't lost on local ship- and boatbuilders seeking to minimise newbuild turnaround times.

The 3Dirigo was based on the composite Seablade class developed by Navatek – a small patrol boat with a length of 7.6m, a breadth of 2.6m and a 510mm draught. Weighing 5,000lb (2,268kg), the 3D-printed version of the boat turned out to be around 400lb (181kg) heavier than its conventionally built equivalent. Equipped with twin 150hp Mercury outboards, the 3Dirigo is reportedly capable of a cruising speed of 22knots, with the ability to push this beyond 35knots.

However, Habib Dagher, director of the Advanced Structures & Composites Center, stresses that the 3Dirigo is very much a demo boat, unsuited to offshore operations in its current state. Instead, demos were conducted in a wave basin at UMaine, and with the use of a wind machine. Fortunately, he adds, the Center has made much progress in the three years since, and has ambitious plans for new 3D-printed boat launches.

100% recyclable

For a start, Dagher tells *Ship & Boat International*, the facility's printer has been upgraded to produce up to 420-500lb (190-227kg) per hour, depending on the resin used – an increase that perfectly aligns with the Center's predictions three years ago. The onsite printer can produce objects that measure up to around 30m in length, 6m in width and 3m in height – dimensions that would naturally cover a significant cache of small leisure and professional boats, and other surface and subsea vehicles.

The 3Dirigo was produced in carbon fibre-reinforced thermoplastic. Dagher says: "The materials have the same strength as ABS carbon fibre, and are 100% recyclable – if the next generation doesn't want to maintain this boat, they can grind it up and put it back into the printer to create something else." The printer can also produce objects in bio-based materials: for example, the Center has produced a wood-reinforced biopolymer roof mould for a superyacht tender.

The potential for quick, cost-efficient and sustainable vessel production is appealing, though Dagher points out that these are still early days for the technology: the majority of 3D print projects in the foreseeable future will most likely focus on the creation of moulds for boat parts and components. Examples could include deck hatch covers, structural sections (including whole hulls) and interior/exterior flooring. The Center estimates that producing a laminated structural part via the 3D printer could reduce labour costs by as much as 70%.

"This isn't a solution for 25m+ yachts or 90m destroyers – we're not going to beat conventional shipbuilding methods for those vessel types," Dagher says. "The same goes for yards that produce hundreds of similar vessels. Additive manufacturing will mostly benefit specialty vessels, bespoke newbuild projects and one-offs."

Funding for the factory

Nonetheless, the Center is continuing to explore what's possible in getting a 3D-printed craft onto the water. Dagher reveals that late 2022 saw the at-sea demo of an uncrewed craft, "significantly bigger than the 3Dirigo", in the Pacific for an unspecified client. Although the details of this particular vessel remain guarded, it's known that UMaine delivered

3D printing could bypass "labour-intensive" composite boatbuilding methods, says Jonas Pedersen, Tuco Marine

two 3D-printed demo boats to the US Marine Corps in Q1 2022, the larger of the pair reportedly featuring the capacity to carry two 20' containers. Although this is speculation on *Ship & Boat International*'s part, the aforementioned uncrewed vessel was most likely produced for a naval or military client.

"We also intend to have a 3D-printed vessel capable of carrying crew and passengers operating in the Gulf of Maine before the end of summer 2024," Dagher confirms.

Future UMaine projects have been given a boost thanks to funding by the Maine Technology Institute, which will enable the Center to work closely with Maine's boatbuilding sector to assess the feasibility of additive manufacturing. Beyond marine applications, the Center is also focusing on the production of sections of an 182m 'bio-house'.

Dagher adds that the Center is working on the creation of a 'factory of the future'. With regards to what 3D printing can offer the marine sector, Dagher says: "We're only skimming the surface at present…the factory project will take us much further."

RoboPrint project

Meanwhile, over in Denmark, boatbuilder Tuco Marine Group has signed up to the RoboPrint project – an initiative keen to establish continuous fibre composite (CFC) 3D printing on an industrial scale.

CFCs are advanced composite materials that offer superior mechanical properties (such as high strength, stiffness and improved fatigue resistance). These materials comprise continuous fibres (including carbon, glass, aramid, basalt, etc) combined with a polymer matrix, which binds these fibres together and protects them. Common matrices include resins such as epoxy or polyester.

The goal is to develop a CFC extruder and incorporate it into a robotic printer, with the ultimate goal of 3D-printing a full-scale boat. The four-year RoboPrint project has received DKK19.7 million (US$2.9 million) in funding from the Danish Innovation Fund, and, alongside Tuco, brings together: lead partner DTU – which, together with FORCE Technology, will develop the CFC technology; Robot At Work (RAW), which is supplying the 3D printer; and US-based Cosine Additive, which is responsible for developing the printer head.

Reduction of waste

Jonas Pedersen, Tuco Marine Group CEO, tells *Ship & Boat International* that the printer is capable of producing a boat of approximately 8m x 2.5m in size, and that the boat's design will be based on the builder's established ProZero range of professional vessels.

"Currently, the production of composite boats is a labour-intensive process involving manual cutting, laying and laminating of glass or carbon fibre in a mould," the RoboPrint partners comment. "These manual methods pose risks of material defects, require careful handling of materials [due to health considerations] and result in significant material waste. Moreover, design flexibility is limited by the need to create a mould for each new design.

"The digitalisation of the manufacturing process will also enable automated storage facilities and the production of new 3D designs. CFC 3D printing enables production of complex geometries and fibre architectures otherwise not feasible with conventional methods."

The RoboPrint partners will also develop a digital twin of the CFC 3D printer hardware. "Virtual 3D CFC printing enables optimisation of the structure to be printed prior to physical printing," they explain.

Pedersen echoes Dagher's opinion that, as a relatively novel solution, 3D printing may take some time to become 'the norm' in maritime circles. "We'll most likely see 3D-printed parts before we start working on hulls," Pedersen comments, adding that it will be necessary to secure flag state and class society approval for 3D printer-produced newbuilds – "especially the case for Tuco, as we specialise in professional boats", he adds.

Olympic ferry

If all goes to plan, however, we could get to see a 3D-printed small ferry in action at the 2024 Paris Olympics and Paralympic Games.

In April, Dutch builder Holland Shipyards Group (HSG) hosted its first "keel-printing" ceremony as it commenced work on an autonomous, all-electric ferry that will shuttle passengers across the Seine River during the Olympics. For this project, HSG worked alongside fellow Dutch firms 10XL – a specialist in XL hybrid manufacturing using recycled waste, which was tasked with producing the ferry's hull – and Royal3D, which produced the vessel's superstructure. Meanwhile, Amsterdam-based start-up Roboat, a specialist in AI solutions, provided the vessel's autonomous system.

The fourth partner in the project is river boat operator Sequana Développement, which will oversee the ferry's operations. The boat will provide a useful connection

A render of the electric, autonomous ferry being prepared for the 2024 Paris Olympics

between the Athlete's Village site and the island of L'ile-Saint-Denis throughout the duration of the event.

Recycled material

The completed ferry underwent river tests in late August, Leendert Hoogendoorn, director at HSG, tells *Ship & Boat International*. The vessel measures 9m in length and 3.9m in beam, and can carry up to 35 passengers – thereby seizing the 3Dirigo's title as largest 3D-printed vessel in the world. The Roboat system grants the newbuild Level 4 automation, including the ability to dock and recharge its batteries automatically.

The ferry's hull is constructed in rUltraMarathon 3D (r-UM3D), a fireproof material made from post-consumer waste (PCW), produced by Rotterdam-based recycler Transmare CirQlair. 10XL says that it has previously used r-UM3D to successfully create bridges, boat components and furniture.

The actual printing of the ferry took about 15 days, Hoogendoorn recalls. "This is because the ferry incorporates three layers of r-UM3D, to ensure that we had full hull redundancy, and because this was our first time doing this," he explains. "In future, it may be necessary to use just one or two layers, which would shorten the production time."

One tremendous advantage of additive manufacturing, Hoogendoorn notes, is that builders can complete the hull "outright", incorporating all components (such as cable trays, ducts and benches) into the build in one hit, rather than having to spend time and money sending the completed hull to be outfitted separately.

Autonomous tech

The autonomous tech package includes two sensor hubs, installed on either end of the ferry. Ynse Deinema, Roboat CEO, tells *Ship & Boat International*: "These sensor hubs contain several digital sensors that perceive the environment: LiDAR, an array of cameras, RTK GPS and an inertial measurement unit.

"The processed data generates super-accurate, centimetre-precise localisation and a 3D, 360° full view of the direct environment around the vessel. Other boats and floating objects are detected, as is the docking station to which the boat connects". The Roboat system steers the ferry via an advanced control module that provides commands to the four thrusters tasked with driving the boat forwards. "This is especially challenging during docking/undocking, which is also performed 'hands-free'," Deinema explains.

Hoogendoorn explains that the ferry was equipped with four fixed thrusters, two on the sides and two at the bow, granting the newbuild enhanced manoeuvrability in line with the "drone principle". He estimates that the ferry should undertake its short-hop journey across the Seine at a speed of 4knots.

Looking beyond the Olympics, the combination of sustainable production, smoke-free river crossings and crew-free operations make this an obvious one to watch for those interested in developing net-zero urban riverine passenger services. An optimistic Deinema comments: "Autonomous navigation makes ships more efficient, more safe and cheaper to operate – a welcome innovation, since it is expected that in 2030 there will be 20,000 unfulfilled roles in inland shipping. Self-driving technology enables relatively small-sized boats to become economically viable." **SBI**

The autonomous ferry for the Seine was produced in 15 days