ALL HANDS ON DECK

European work heritage in shipwright for present and future

NEW BUILDING TECHNIQUES AND INNOVATIONS

MODULE 11

Module 11 New building techniques and innovations

Objective

At the end of Module 11 the student will be able to differentiate between traditional and modern boat building techniques and is able to select a proper building technique for the purpose. Once this is known, a student will be ready to work with modern boat building materials and techniques as a boat builder, boat repairer or technician. The module stimulates idea development, creative utilization of future-oriented materials and construction techniques

Duration

30 hours.

Training content

1 Can describe boat building techniques:
   - traditional techniques (carvel, clinker)
   - modern boat building techniques (stitch and tape, ply on frame, strip plank, clinker ply, cold-moudled)

2 Can explain differences, advantages and disadvantages of boat-building techniques

3 Is able to select a proper building technique for the purpose

4 State the factors influencing trends and technologies in shipbuilding

5 Can name new materials in boat building, including fiberglass resin and fiberglass materials types

6 Can name advanced boat building techniques, including vacuum bagging and vacuum infusion.

7 Can list new technologies for:
   - increasing of ship's efficiency
   - reduction of hazardous emissions in the atmosphere
   - containment of the environmental impact
   - improved efficiency by design

8 Can identify key elements of digital transformation in the boat and shipbuilding sector

Outcome

Understands techniques, technologies and trends in boat construction.
Knows how to identify proper boatbuilding techniques for the purpose.

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UNIT 1 TRADITIONAL VS MODERN BOATBUILDING TECHNIQUES

1 INTRODUCTION

In this unit we look back and remember what are the boat building techniques that are considered traditional and which contemporary boat building have developed over time and are used today. Then we move forward and discuss techniques or methods that can be considered new or innovative.

2 TRADITIONAL BOAT BUILDING TECHNIQUES

Traditional construction means that the structure of the boat's framework and planking is assembled using solid wood and mechanical fastenings.

There are a variety of **planking methods**. Each method has advantages over the others and results in different characteristics and appearance. The finished hull relies on accurate tight joinery and swelling of the wood to achieve watertightness (*Nomad boatbuilding*, 2018).

The traditional wooden construction method consists of building your entire boat out of wood, using planks of different sizes. They are either assembled next to each other (freeboard planking) or slightly superimposed (as in the case of drakkars), in which case it is a clapboard construction.

Solid wood planks are fastened to steam-bent ribs or sawn frames with clench nails, copper rivets, screws or even wooden trunnels (tree nails). This type of construction goes back to the age of the Vikings and is just as relevant today. Robust and easily repairable, these craft can last for generations.

Carvel (smooth skin) and Clinker (lapstrake) planking methods are the most common.

Carvel planking

Carvel built wooden boats and tall ships are made by fixing planks to a frame with all the planks butting up against one another. This creates a smooth hull that's stronger than a clinker built hull. However, more caulking is needed between the joints in carvel construction than in the clinker method. The framing gives carvel construction a stronger hull, allowing it to carry a full sail plan and have a longer, broader hull.

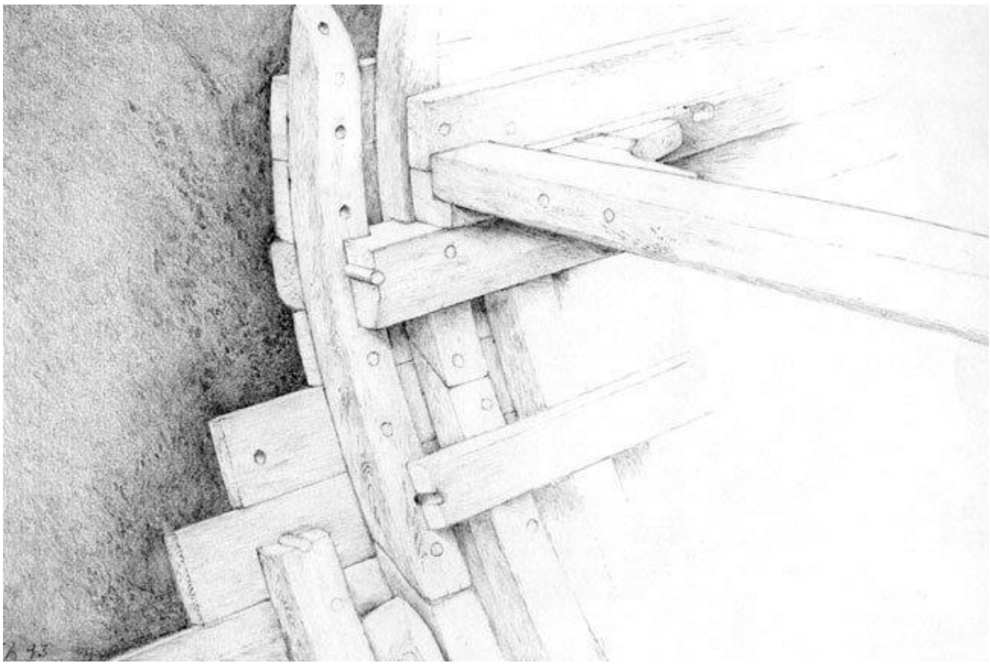


Image 1. An example of carvel construction drawn by Jon Adams. (FUTURELEARN, 2017)

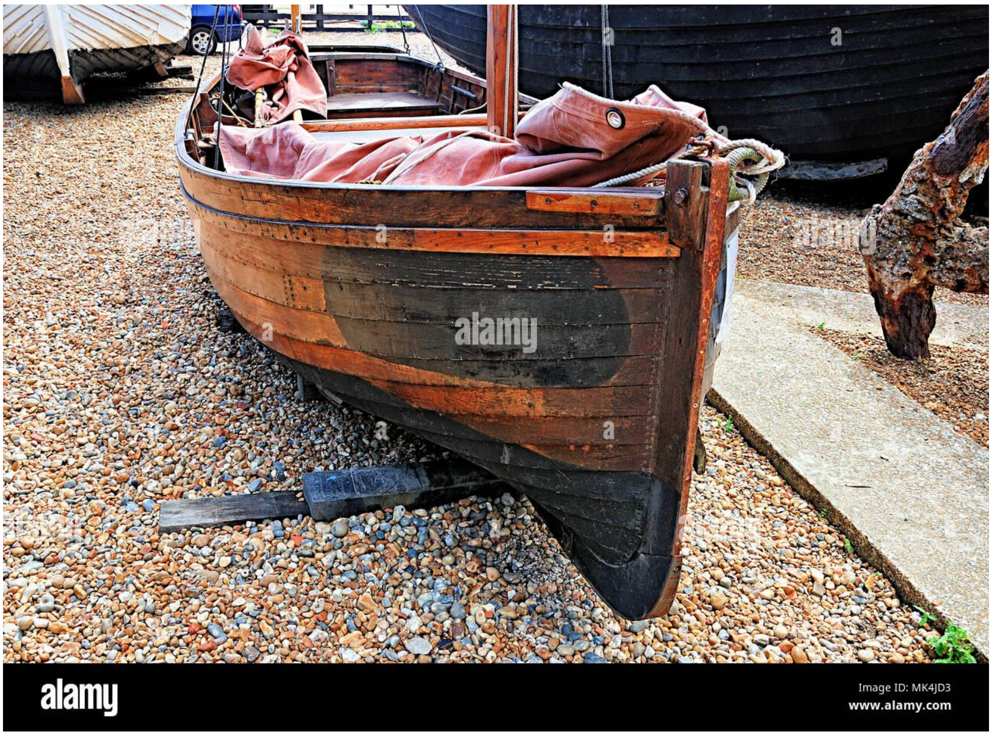


Image 2. Carvel (Alamy stock photo)

This technique was widely used in the Mediterranean: the frames that were shaped first, the planks being attached to them in a smooth edge to edge layer. It is because the frames of Mediterranean-built ships made a more or less coherent structure in their own right that this method is sometimes known as 'skeleton construction'.

Clinker planking

Clinker built (or lapstrake) vessels are lighter as they have less internal framing – with the planks overlapping along their edges. As they're lighter, they displace less water allowing them to move faster. Clinker vessels are less rigid than carvel constructions, limiting the type of sailing rigs the vessel can take.

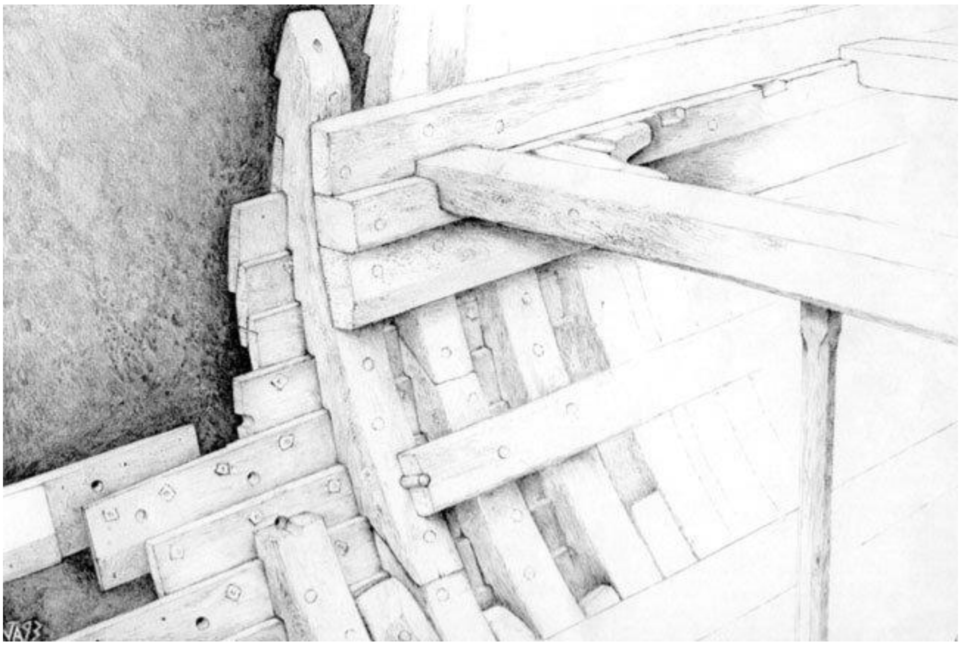


Image 3. An example of clinker construction drawn by Jon Adams (FUTURELEARN, 2017)

The greater and longest-lived tradition of building ships originated in Scandinavia and is known as 'clinker', from the words clinch or clench, because the nails that fastened the planks together were 'clenched' over a rove or washer (see image above).

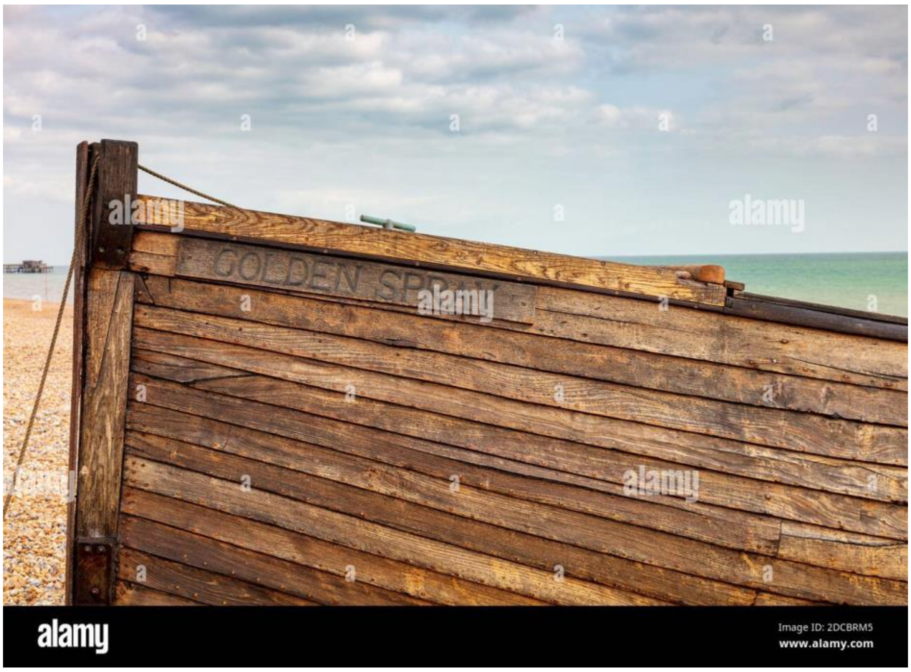


Image 4. Clinker (Alamy stock photo)

The differences between clinker and carvel construction:

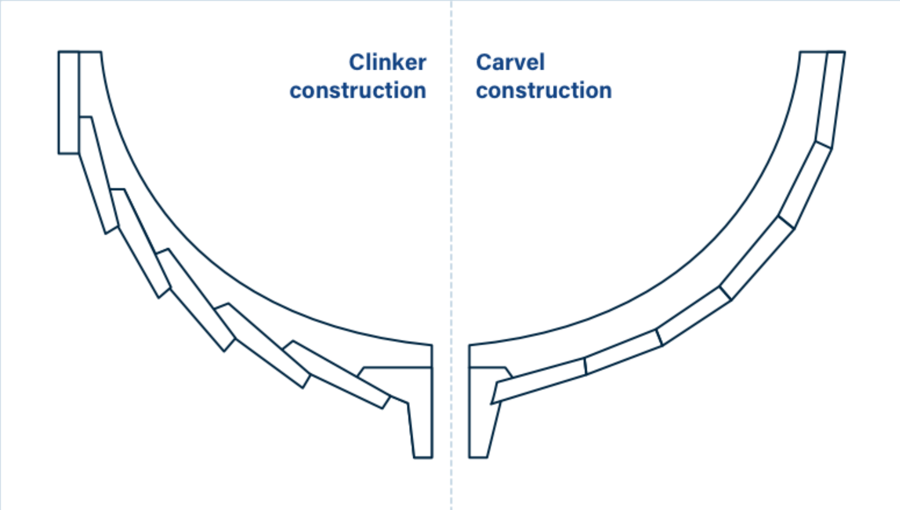


Image 5. The differences between clinker and carvel construction (International -Yachtpaint)

This type of construction requires more skill, but is a truly pleasurable experience. In some cases, traditional construction is faster than modern construction, as you rarely have any down time in the process. The completed boat can go with a simple oiled finish that is fast to refresh each season and will impart a dark aged quality, or paint and varnish can be employed to keep them looking fresh and new.

3 MODERN BOAT BUILDING TECHNIQUES

Today, there are a surprising number of construction options and here is a run down of the main ones.

Stitch and Tape

This is generally the fastest, easiest, and least expensive means of building a boat with a plywood hull.

Ply hulls were traditionally made from the "inside out" - in other words, a solid framework was built first on a strongback. This had longitudinal frame components - chine and gunwale stringers and hog (internal keel) added and everything was beveled ready to receive the ply hull skin which was put on oversize and then trimmed back.

Whilst this method produced a very strong hull it had the disadvantages of producing a heavier hull because many of the frame components became redundant after the hull was complete - it also took longer to make and required more in the way of carpentry skills and because of the redundant materials, it cost more than necessary.

The advent of modern resins (first Polyester based and then Epoxy based) married together with woven glass allowed a radical rethink of the traditional form of plywood hull construction - instead of working from "inside out", stitch and tape construction allows you to work "outside in". With this method, the builder starts with the hull panel shapes which are given on the boat plans - modern computer software now enables Selway Fisher Design to model the hull, check it's hydrostatic properties (volume of displacement, stability etc) and then to fair the hull and develop the hull panel shapes very accurately.

Having marked and cut out the hull panels and then joined them to make up the full panels (most plywood comes in 8' sheets and therefore a panel will be made up from several pieces), the panels are stitched together. This forms a "floppy" basket which is trued up and stiffened by inserting pre-shaped ply bulkheads and frames into the hull. This gives the basic hull shape - the stitched seams are then finished with a combination of glass tape and either Polyester or Epoxy resin. There are many variations on this theme and combinations of thickened epoxy resin fillets plus glass tape etc can be used depending on the type and size of boat being built - one interesting join is the "combi-seam" which utilizes a square wood stringer plus an epoxy fillet beside it - used on larger craft, this seam combines the advantages of both a traditional wood chine stringer and an epoxy seam

This quick and easy boatbuilding method consists of plywood planking panels cut to shape from full-size patterns which are “stitched” and “glued” together at the seams. Such a boat can be assembled in a matter of hours after cutting out the parts. This construction method uses epoxy glue, “stitches,” and detailed cuts to create the hull. You don’t need any special tools or forms to use this method. It’s also called “stitch and glue”. The “stitching” of this type of boat building technique is done with wire, cable ties, or even duct tape. Copper wire is one of the most popular because it is suitable for a marine environment. After the stitches are in place, the area is glued with a thick epoxy and can be covered with fiberglass.

For describing the modern Ply on Frame method we will use a couple of different examples from Selway Fisher Design including canoe Cristine (Selway Fisher Design, 2009).

Having marked and cut out the plywood panel (plank) shapes sets of planks are planed up together (with the Christine, the bow and stern are the same shape and therefore there will be 4 of each shape - bow, stern, port and starboard).

Because the panels (planks) are longer than the standard 8' sheet of plywood, the bow and stern parts are joined - in this case with a simple glass tape butt strap.

The 2 bottom panels are laid side by side and stitching is started along the centreline.

The bottom panels are completely stitched along the centreline and the panels are held apart by using weights in this case.

The next pair of panels are stitched to the bottom panels - stitches are put in every 8" to 12" and may be scrap copper wire, garden binding wire or nylon cable ties which are easier on the fingers.

The third set of panels has been stitched into place and the first of the fourth and last set is also in place - for a canoe, it is better to start stitching from the middle of the boat and then work towards the ends. The second picture shows the Ptarmigan 17 hull stitched together with the forward ply bulkhead in place - note the internal ply butt straps joining the panel lengths together, forward of the bulkhead.

All the panels have been stitched and wood battens are in place to brace the gunwales apart and a temporary hardboard section has been added to get the hull into it's correct shape - in this example, thickened epoxy has then been put into the chine seams to "tack weld" the panels together before taping the inside of the seams.

The inside of the chine and centreline seams is glassed with epoxy resin and allowed to cure - the inwales have also been fitted.

The hull is turned over and the outside of the seams is glassed and the bottom runners fitted prior to cleaning up - in many cases the outside glass tape is omitted.

The finished canoe! - in this case the materials were mainly household products - exterior ply, deal and paints and therefore the costs are minimal - in the case of Christine around £100.

This was just a quick overview of the stitch and tape method - there are many variations.

The tools required stitch and tape method are minimal - just domestic DIY tools and many of our stitch and tape designs have been made by first time builders with no wood working skills.

Ply on Frame

Traditional ply on frame construction consisted of making quite a heavy framework which was usually a combination of transverse frames and longitudinal stringers, hog etc on a flat building berth and then putting on the ply hull skin oversize and trimming it back. The word 'traditional' here is a bit of a misnomer as plywood suitable for marine use has been available for less than a 100 years.

The framework was heavy because it was made up of individual pieces of solid timber traditionally jointed - this framework served 2 purposes - first to provide the correct shape for the craft and secondly to give athwartship and longitudinal strength and stiffness to the hull structure. Once the hull was complete, the first purpose was complete and no longer required which meant that much of the structure was actually redundant.

Modern computer software means that the plywood frames and girders can be developed very accurately before construction begins and the advent of modern epoxies means that much of the wood filleting and framing can now be omitted. So, instead of constructing a framework of many bits and carefully erecting each component onto a flat building berth/floor, we can now cut out computer generated shapes which slot together and which automatically align themselves correctly, even if the building space does not have a flat surface to work on.

This modern "egg-box" type construction also means that the hull framework can be "unitized" into pre-fabricated building blocks constructed in a small space and ready for assembly together elsewhere.

At the chines, the normal stringers can be fitted or, the ply hull panels can be developed by the designer and cut out and attacheed over the framework in stitch and tape style so combing both stitch and tape and ply over frame methods. This is a good compromise - on larger craft, the framework gives points of reference to work to and the panelling can then be fitted using quick, modern stitch and tape methods.

The ply framework can either be joined to the hull panels with epoxy fillets or attached using wood fillets/cleats.

For describing the modern Ply on Frame method we will use a couple of different examples (Selway Fisher Design, 2009).

The above is a picture of the aft section of the Ailsa 22 - she has a flat bottom, flat topsides and rounded strip planked bilge area - in this case her framework was built in 3 pre-fabricated sections and assembled later - note that the ply fore and aft girders and ply bulkheads are slotted together and the joins made up with wood fillets.

A Black Swan out in Saudi Arabia - again the ply components are slotted together - note the transverse bottom floors slotted in place ready to accept the first plank.

Another Black Swan, this time by Henner Ostermeyer in Germany with the flat bottom panel fitted - in this case the chine seams are going to be epoxy/taped rather than have wood stringers.

This Black Swan from Israel with most of the pre-shaped planks fitted - again the seams are to be epoxy/taped.

Sam Watt's CR25 All planked and in the process of being turned up right ready for fitting out.

Finished and launched.

Advantages of working with 'plywood on frame', are that both the tools and materials are generally familiar and since the availability of great bonding resins, it's almost impossible to make a mistake that cannot be corrected—even if that means removing parts and re-doing them. Good marine plywood is tough, resistant and fairly light in relation to its stiffness and strength, though as for all wood products, good workmanship will pay off with longer life. It's also readily available and still reasonably cost-effective. The main thing is to provide both good protection against contact with moisture and sun exposure AND also provide excellent ventilation throughout its life—something that is too often ignored.

Perhaps the most important feature as we move forward in this ever-polluting world, is that wood is a renewable and even recyclable material and far greener that say fiberglass, foam or carbon fiber, and this applies to all methods using wood.

Disadvantages are that it can deteriorate fast in the presence of moisture and without ventilation and the shape of a boat's hull of plywood is limited to flat, cylindrical and/or conical forms. In areas that require framing and bulkheads, the system is also somewhat heavier and takes more manhours than more recent solutions that reduce the need for framing. This same framing also takes up more interior space compared to some of the newer systems and can make things 'uncomfortable'. There is also the very clear fact that a frame and plywood boat is ALWAYS considered amateur built, so regardless of how well it's done, it will always have a lower resale value than a comparable round bilge or glass boat. But by using plywood in simpler areas above the waterline, one can take advantage of its good stiffness-to-weight ratio and then effectively combine it with the use of another more suitable system to achieve a round bilge below the waterline (see review of alternative hybrid methods) (Smalltridesign, 2011)

Strip Planking

Strip planking is a type of cravel planking. The hull of the boat is built over forms by using strips of wood. These strips are narrow and because of that, there isn't much shaping required. The edges are glued and fastened together.

Modern epoxy adhesives are used to hold the hull together, not the fasteners. This method is often used on small boats and canoes. There are many variations to strip planking and most woodworkers will tell you that this method is best suited for those with quite a bit of experience.

Many boat builders, both amateur and professional, would like to build a lovely round bilged boat but the skills and tools required to achieve this have often precluded such a boat from being attempted. Traditionally, the hull shape has had to be "lofted" (drawn down full size) and faired so that the frame or mould shapes could be accurately taken off the lofting. The frames or moulds were then erected on a strongback with the keel member etc and then the solid planking added - the planks had to be carefully tapered towards the ends and then the seams were "caulked". This is the traditional "Carvel" method of boat construction.

Today, we can produce a lovely round bilged shape without many of the tools and skills required for traditional round bilged construction by using the strip planked method. Basically this method entails marking and cutting out mould (sectional) shapes from a cheap material like chipboard and erecting these upside down on a simple strongback. The hog (internal wood keel), stem and transom are then positioned onto the strongback (and also sometimes the bilge stringers and inwale may also be added). Some of the moulds may be substituted with permanent ply bulkheads.

Once this "jig" is completed, the edges of the moulds, hog etc are beveled to suit the planking which is in the form of narrow parallel strips of wood - usually Cedar. The Cedar strips are temporarily fastened to the moulds but permanently glued to the hog, stem, transom etc and to each other. Once the hull has been covered with the Cedar strips, the Cedar is cleaned up and then sheathed. Cedar is quite soft and therefore needs sheathing whilst other timbers may not.

The sheathing is often woven glass cloth in epoxy resin which allows the natural wood to show through and gives the Cedar a protective hard outer surface. Alternatively, the Cedar may be overlaid with wood veneers often laid diagonally.

Skegs and outer wood keels etc may then be added before the hull is released from the jig/strongback and turned over. Once up the right way the inside of the hull is cleaned up and may be sheathed. What you now have is a hull "shell" which is much lighter than a conventional carvel planked hull but just as strong and ready for fitting out.

The advantages of this method, apart from the fact that you end up with a beautiful round bilged hull, are lower cost, weight and time when compared with traditional carvel construction and the need for less skills and tools.

For describing the modern strip planking method we will use a couple of different examples ((Selway Fisher Design, 2009).

The chipboard moulds (sectional shapes) are carefully erected onto a simple wood strongback.

In this case, the internal stem has been laminated but may be made up from solid wood - note the hog which is laminated in situ on the moulds.

Planking starts - in this case from the gunwale until bending the wood strips becomes too difficult - in some cases, depending on the hull shape, you can plank right from the gunwale up to the hog.

In this case, planking was stopped at the bilge and then started again from the hog to meet the previous planking - this means that some of the strips have to be tapered at their ends. If the builder prefers - to make sure that the planking can be done without the need to stop and change direction - the first plank can be positioned at the bilge and allowed to lay along the "great circle" route - planking then continues above and below this first plank.

In some designs, other internal items are fitted before the hull is planked - in this example, a bilge stringer has been laminated in situ on one of our 25'6" Snow Bunting designs.

Once planking is complete and cleaned up the hull is sheathed in glass cloth or wood veneer.

External wood keels/skegs can be laminated on the hull whilst it is still upside down, cleaned up off the boat and then refitted before the hull is turned over - the example above is one of our Edwardian 26's.

The hull with stem etc laminated over the glass sheathing and turned upright.

The finished boat - above the 17'9" Indian Runner

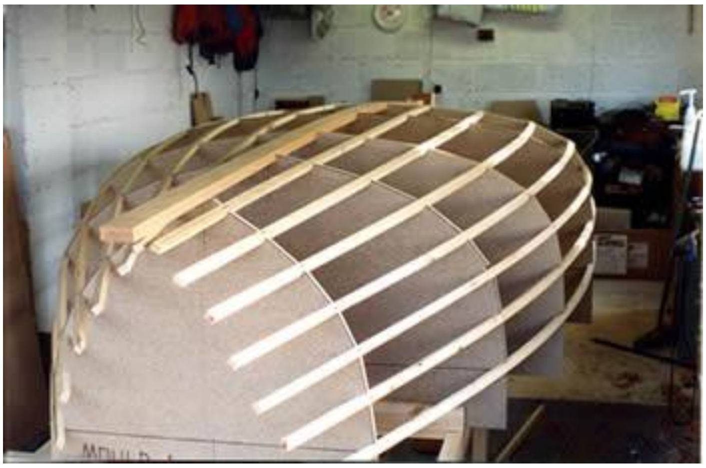
Clinker Ply

As discussed in the section of Traditional techniques, this method of constructing the hulls of boats is done by using wood planks in such a way that their edges overlap. This is an ancient form of wooden boat building, with the Vikings being the most successful in its application. They used wood planks and iron plates. Today, the iron plates have gone by the wayside, but the method is still used with wood planks.

This method is also known as Lapstrake. A boat crafted from this construction technique is lighter and it tends to move more efficiently. This is due to less water being displaced to the sides while moving. Obviously, this type of boat building will take a lot of knowledge about the clinker ply or lapstrake method, but the results are quite exceptional.

With the advent of modern epoxies, this traditional process could be modified to make the construction simpler and stronger. The wood planking, rather than being solid (often Larch, Mahogany etc) was substituted with good quality marine plywood which is dimensionally stable and easier to get hold of than the required clear lengths of relatively thin solid wood. Also, the seams between the planks, rather than being held together with copper nails against steamed timbers are glued with thickened epoxy producing a lighter weight shell construction which has the appearance of traditional clinker. the modern clinker building process has similarities to the traditional process shown below.

For describing the modern Clinker Ply method we will use a couple of different examples (Selway Fisher Design, 2009).



First a building jig is built using chipboard molds (section shapes) - these are usually given with "corners" or lap points - is "cornered" shapes so that the clinker laps are pre-determined by the design. The transom, inner stem (missing from the above photo at this point) and the hog (inner keelson) are all fitted - the inner stem, hog and transom are all glued/fastened to each other but are only temporarily fastened to the molds.

Ribbands (stringers) are fitted into slots cut at the plank land positions on the molds but are kept short of the inner stem and probably only fry butted against the forward side of the transom.

The garboard and next 2 planks are in place - the ribbands help define the shape of the planks and give something to clamp the plank edges too - screws used to hold the planks together whilst the epoxy cures and which go into the ribbands, are later removed - it important that no glue comes between the inside face of the planks and the ribbands unless, of course, the ribbands are to be permanent stringers within the hull structure.

Here is the view inside the bow of a clinker Kane Beach Punt showing the inner stem attached to the hog.

A similar bow on the outside - note 2 items here - first, the outer stem which has been laminated directly over the exposed edges of the plywood planks and second, the fact that the planks are all "flush" with one another at the stem - a similar view of the planking at the aft end would also show the planks "flush" with each other as they go over the transom. If this was not done, the planks would stick out over each other with gaps needing filling with the inner stem and the wjole affair would look very ugly - to avoid this and end up with a nice flush appearance each plank has a "let" or "gain" cut into it. This is a tapering rebate which goes from nothing in depth a few feet back from the stem to full plank thickness depth right at the end of the plank. The width of this "gain" is the width of the overlap between two adjacent planks - therefore one plank gradually sits in this rebate ending flush with it at the extreme end.

This is the hull of a clinker Islay Skiff (Pandora by Rob Johnsey) with the jig removed from it - the inner stem was laminated over a former attached to the first mold.

The clinker shell of a Kane Suffolk Beach Punt by Ian Gardner recently removed from it's jig.

An example of finished boat Ron Johnsey's Islay Skiff.

Advantages are enjoyment of construction in small steps; economy of wood; a stiff, rugged hull without need of much internal stiffening; attractive appearance; round bilge design. Laps make boat more resistant to rolling and add a cushioned ride. Also, well made epoxy-glued lapstrake (clinker) boats rarely leak.

Disadvantages for a multihull are: increased resistance due to plank edges; concentration of narrow strips mostly under the waterline in order to achieve desired shape; slightly heavier overall weight than several other options.

Cold-molded or multi-diagonal boatbuilding

Cold molding is a composite method of wooden boat building that uses two or more layers of thin wood, called veneers, oriented in different directions, resulting in a strong monocoque structure, similar to a fibreglass hull but substantially lighter. Sometimes composed of a base layer of strip planking followed by multiple veneers. Sometimes just veneers are used.

Cold-molding is popular in small, medium and very large, wooden super-yachts. Using different types of wood, the builder can lighten some areas such as bow and stern and strengthen other high-stress areas. Sometimes cold-molded hulls are protected either inside or out or both with fibreglass or similar products for impact resistance, especially when lightweight, soft timber such as cedar is used. This method lends itself to great flexibility in hull shape.

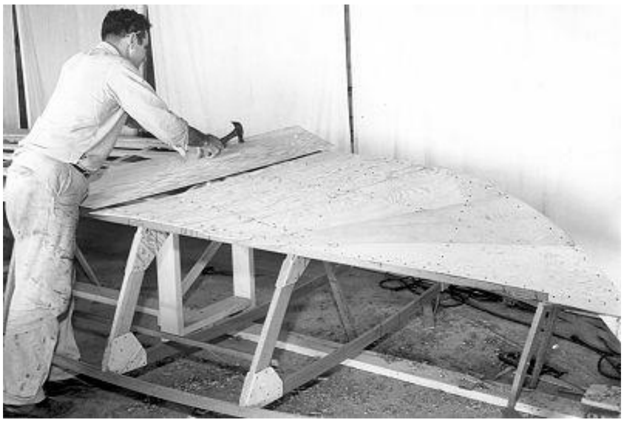
Cold-molded refers to a type of building one-off hulls using thin strips of wood applied to a series of forms at 45-degree angles to the centerline. This method is often called double-diagonal because a minimum of two layers is recommended, each occurring at opposing 45-degree angles. The "hot-molded" method of building boats, which used ovens to heat and cure the resin, has not been widely used since World War II; and now almost all curing is done at room temperature.

Epoxy is the recommended adhesive.

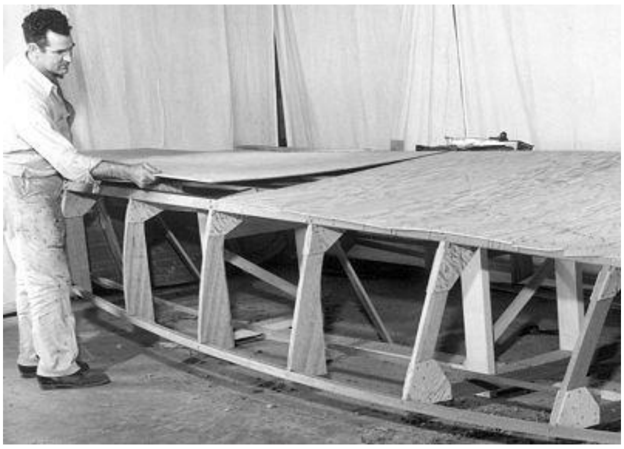
So cold-molding or Multi-diagonal planking is used when the hull incorporates compound shapes that cannot be formed with sheet plywood. Often, this only occurs in the forward section on the bottom or the bottom and sides, but some hulls may require the method for the entire hull. This method is also referred to double diagonal or triple diagonal, depending on the number of laminations required. The starting point for the following photos is the same as described for sheet plywood planking.

For describing the cold-molding method we will use examples from Glen L Marine Designs.(Glen L Marine Designs).

The builder is shown fitting the initial layer of a diagonal planking bottom. While the initial strips can be applied at any convenient point, this builder has begun at the bow. Notice how the pieces fan out. The strips are laid in place and shifted until they lay flat, then fitted to the previous piece. Each planking strip must be edge fitted to the preceeding one for a tight joint. It makes little difference whether the edges of the pieces are parrallel or more triangular in shape as long as they make the bend and contact hull members.



As the flatter areas of the hull are reached, less edge fitting is required and the size of the planking pieces can be increased as much as the form of the hull will allow. Notice that with this planking method, fastenings are driven into all hull members, even the athwarship frames. This differs from sheet plywood planking that is fastened only to longitudinals, stem, and transom.



As the transom is approached, it is often possible to use a full sheet of plywood. It may be applied as a single thickness or in multiple layers, depending on the hull shape. Only the junction with the preceeding planking strip requires special fitting. The planking, from the junction with the planking strip aft, should no longer be fastened to athwartship frames. Any overhanging pieces will be trimmed off and faired prior to applying the side planking

The second lamination of diagonal plywood is applied at right angles to the first layer as much as practical. Before applying the planking strips, the surface is liberally coated with POXY-SHIELD epoxy resin, thickened with silica filler. Fasteners are used through both layers into all contact members, plus along the plank edges to minimize curling of the edges of the planking strips. Note: The first layer can be applied with temporary screws, which can be removed before applying the next layer

This hull has been completely planked. In this case, the side is also diagonally planked. Finishing the job from this point is the same as with sheet plywood planking

After the 2nd layer, modern builders are now often enclosing the whole surface with plastic and vacuum-bagging the bond to improve pressure between the surfaces while curing. But this requires that the working surface of the mold be made air-tight and that is impossible with an open frame+stringer arrangement. One interesting method is to seal the first layer airtight and then vacuum bag to that. Either way, if it can be done, vacuum-bagging is surprisingly effective and not that difficult either as long as certain precautions are taken (Smalltridesign, 2011).

Advantages are: If well executed, this system produces a very tough, long-lasting hull that is stiff and resistant to damage and rot. It requires only the minimum of internal stiffening. Still a useful option where labor costs are low or just not counted.

Disadvantages: The system is pretty labor intensive and solid veneers of moisture-resistant wood are also becoming expensive and difficult to obtain in some parts of the world. The system also requires a good, solid mold prior to construction, which has no further use after the hull is lifted off. The surface, both inside and outside, also requires a considerable amount of sanding and the outside will need additional fairing to get a professional finish. As this is more work than other competing systems, this system is now used less and less, except where labor costs are low or discounted. The Constant Camber system was first developed to try and overcome this high labor issue—see separate article.

Differences, advantages and disadvantages of boat building techniques

There are many methods of construction available to the home boat builder - on this page we discuss the most popular methods used and compare them so that the new builder can make a good choice for his/her boat building project.

The method used will depend on the materials chosen or available, the skills and the tools available.

At the end of this course your will be prepared to work in different boat construction techniques as a boat builder, boat repairer or technician. You will be able to explain the key features if each technique but also to select the proper building technique for the purpose.

Therefore this is the right time to recapitulate shortly the main methods and their advantages.

Table 1. Overview of main methods and their advantages

Method	Description	Advantage / disadvantage
Traditional boat building		
Carvel	Individual tapered planks edge to edge and fastened to a framework.	Requires high skills, expensive materials, traditional caulking between planks or glued splines and heavy framework
Clinker / lapstrake	Individual tapered planks with over lapping edges fastened to transverse timbers.	Requires high skills, expensive materials. Requires regular maintenance and is difficult to repair. Can suffer from leaks as the hull gets older.
Modern boat building methods		

Stich and tape (stich and glue)	Pre-shaped panels of plywood stitched edge to edge giving a multi-chine shape with ply frames added.	Can use low cost materials, requires low skills and only basic tools. The quickest, cheapest and easiest form of construction. requires the use of epoxy joins which can be messy. Good for lightweight hulls.
Ply over frame	Plywood glued/fastened over a rigid framework.	Moderate skills required - does not need extensive tools - takes longer than stitch and tape due to the conventional framework. More expensive in smaller boats than stitch and tape but perhaps less so in larger plywood boats. Heavy weight construction.
Strip planking	Parallel strips of wood glued edge to edge over a temporary building jig and covered in glass/epoxy or wood veneer.	moderate skills required but more expensive/time consuming due to the building jig required. Fairly easy to repair. Fairly lightweight.
Clinker ply	Similar to traditional lapstrake/clinker but with joins between planks glued with epoxy rather than copper clench nailed	Requires expensive materials (ie high quality multi laminate plywood), high skills and extensive tools (ie. rebate planes etc). Not easy to repair. Lightweight construction.
Cold molded	Similar to conventional cold molded but sometimes vacuum bagged.	Similar to traditional cold moulding but often used in conjunction with strip planking to produce a very tough hull. Lightweight construction.

Source: adapted from Selway Fisher Design, 2009.

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1 INTRODUCTION.

Prior to the development of fiberglass construction techniques, boats were built of wood, steel, and other materials, by assembling pieces and parts into a structure which was then sheathed with a hull.

With fiberglass boat building, however, the major components of the boat – the hull, deck, liner, and large parts like consoles—are molded from fiberglass. Usually, this means starting with a female mold. The mold is first sprayed with gelcoat, then fiberglass cloth is applied, and then resin is used to saturate or "wet out" the fiberglass. When the resin cures, you have a hull or a boat part.

Structural reinforcements like stringers and bulkheads can be molded separately and then fiberglassed to the part, or may in some cases be laid up at the same time. While the hull is still open and exposed, items that will be located below deck level like fuel and water tanks or inboard engines can be mounted. This is also when plumbing and wiring may be run. Then the major components are assembled. For most modern powerboats, that means the deck and/or liner is lifted, often with a crane, and lowered into the hull.

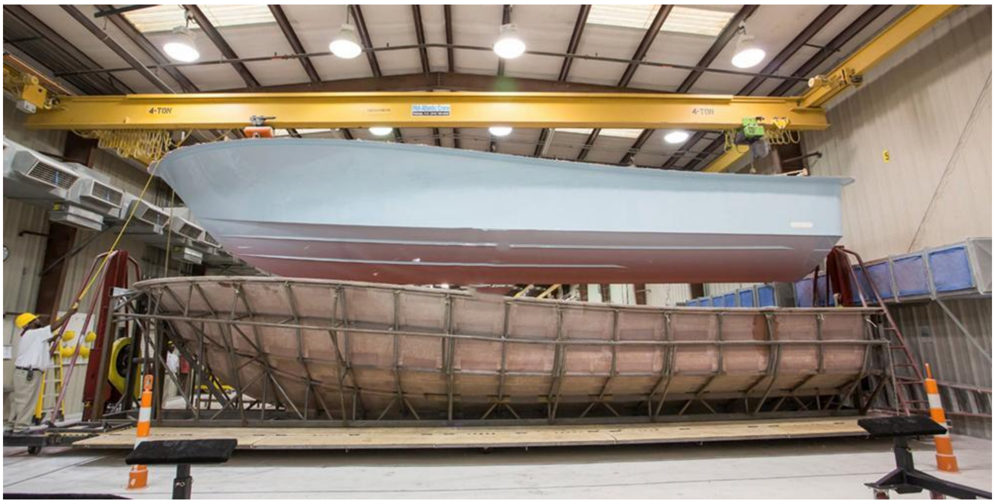

Image 6. Overhead cranes are often used to lift major boat parts, like this hull for a Regulator fishing boat, out of the molds and into position for further assembly (boats.com)

Many boats are designed with a "shoe-box" joint where the hull and deck have mating flanges, or overlap one another. Often mechanical fasteners such as screws or through-bolts are used to secure the parts together, in addition to the use of a chemical bonding agent and sealant like methyl methacrylate or 3M 5200, which also makes the joint water-tight. Additionally, some builders fiberglass around the perimeter of the hull to deck joint (boats.com). With the major parts of the boat assembled, interior fittings like seats and steering wheels can then be added. Finally, the details and finishing touches can be taken care of.

The first revolution in modern boatbuilding was obviously the shift from mostly wood to mostly fiberglass construction, but a second one has been much more subtle. There has been a transition from conventional fiberglass methods to a host of exotic materials and techniques which can befuddle even the experienced yachtsman.

The concept remains essentially the same, however.

Fiberglass (properly called Fiberglass Reinforced Plastic, or FRP) is still a fiber material set in a binding substance of resin. In the very early years, fiberglass was literally fibers of glass, but that soon changed to fibers of various synthetic plastics (boats.com).

For many years, a fiberglass construction has been from cloth, roving, mat, and resins you can buy in any hardware store. More recently it came to include more advanced materials like Kevlar and carbon fiber, which many people are familiar with from their use in other products. Today, however, there are so many different materials being used that a degree in chemical engineering is helpful when reading the brochure for a new boat.

Much of the research and development actually came from the aircraft and aerospace industries, where strength and light weight have always been prime concerns.

2 NEW MATERIALS

Fiberglass resin and fiberglass materials

Fiberglass reason types

There are three types of resins: polyester, vinylester and epoxy. Each has a place in the boat-building world. The important factor is for the builder to correctly match the resin to the type of reinforcing material being used so that the strengths are matched. For example, a vinylester resin is ideal for S-glass but, when used with E-glass, the reinforcing material will fail before the resin.

Polyester

This is the resin most commonly used for boatbuilding today, and most boat owners are familiar with it. It is inexpensive and generally all-purpose. It has low stretch (elongation) properties so it is not used on modern high-performance boats, but it is perfectly adequate for most boats. The most common polyester is an orthophthalic base, but newer isophthalic based polyesters are gaining in popularity. The isophthalics are more resistant to water and chemicals, are more abrasion resistant, and have higher impact and fatigue (flex) performance. Most modern gel coat finishes are made with isophthalic resins.

Vinylester

An alternate to polyester, vinylesters have better stretch characteristics than polyesters, so they more closely match the strengths of the various exotic reinforcements. Vinylester also has good water resistance and fatigue properties, but it is more expensive than polyester resin. One important feature of vinylester is that it has excellent secondary bonding strength, so bulkheads or stringers added to a cured hull will have a better bond than on a polyester hull.

Epoxy

This is high-performance resin, with a matching price tag. Epoxy resins have had a reputation for being hard to work since early epoxies were thick, but many modern epoxies are quite liquid. Epoxy will adhere better than any other resin to a wide range of materials, which makes it ideal for attaching cores, stringers, or other items.

Types of fiberglass cloth

Woven fabrics using continuous strands are the most common cloths, with weights ranging from four to 15 ounces per square yard. Heavier weights, usually called roving or woven roving, consist of untwisted yarns of fiber in weights that range up to 48 ounces per yard. The finished roving resembles a coarse burlap and, like all cloths, has good bi-directional strength. The lighter cloth weights can be found in a variety of weave patterns, such as twill, satin and matt, for different purposes.

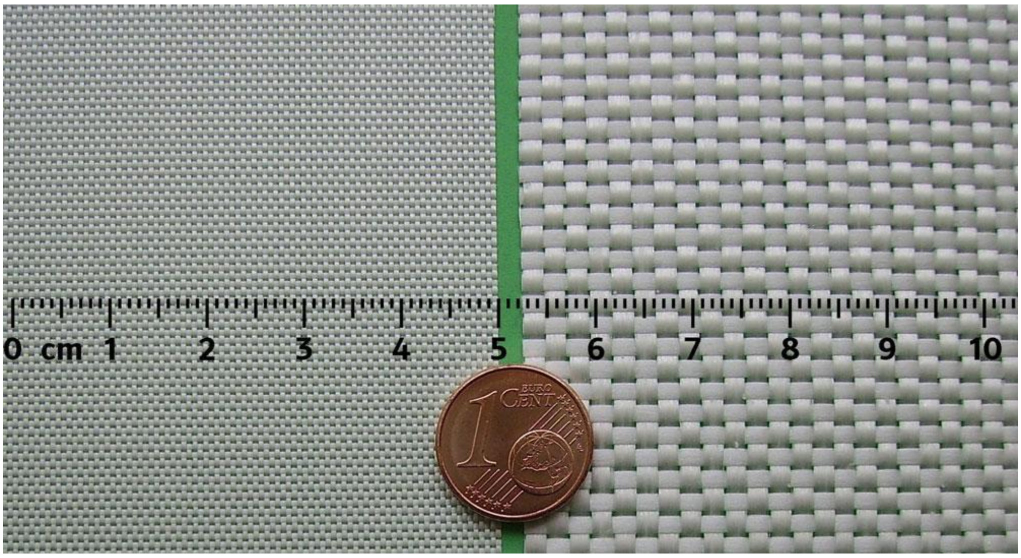

Image 7. Two examples of fiberglass cloth: the fiberglass at the left is significantly thinner and lighter, but provides less stiffness (boats.com)

E-Glass

This is the most commonly used fiberglass cloth in boatbuilding today. You can buy E-glass at a marine supply store, and bond it with polyester resin. It is made from molten plastic spun into fine fibers that are then either woven into cloth or loosely gathered into roving.

S-Glass

This is high performance fiberglass cloth from the aircraft industry. It is three to five times more expensive than E-glass, but it is also much stronger. Developed by Owens-Corning, it has 20 to 40 percent higher tensile, impact, and flexural strength than E-glass. There are two types of S-glass: S-1, which meets critical aerospace standards and is blindingly expensive; and S-2, which is used in the marine industry. In Europe, S-glass is called R-glass.

Mat

Mat is usually made of E-glass, and consists of random two- to three-inch fibers held in place by a binder that is resin soluble. Mat is used primarily for building thickness and stiffness into fiberglass layups. Mat resists "print-through," where the weave of roving shows in the outer layer of the hull, but it also soaks up a tremendous amount of resin and is low in strength for its weight.

Uni-Directional Fibers

This is one of the advances in reinforcing materials. It consists of strands of fiber running in one direction only, held together by single fibers that are glued or sewn laterally, much the same way that a bamboo fence is held together by a few wires. Obviously it has very high directional strength, so it can be used in areas where the loads are specific. Because it is not woven, there are no kinks and it’s easier for workers to wet out with resin since it doesn't hold air like a cloth fabric.

Bi-Axial Fibers

Technically most cloth is bi-axial, but the modern definition means a fabric made from layers of unidirectional cloth that are not woven through each other. One layer simply lays atop the next layer to produce a kink-free band of fiber.

Tri-Axial Fibers

This is a layered material similar to bi-axial cloth, except that the fibers are oriented in three directions, often at 120 degrees to each other to spread the loads.

Advanced fiberglass construction materials

Carbon Fiber

These fibers of graphite provide superb stiffness as well as high tensile and compression strengths and are often used in conjunction with S-glass or other exotics to provide acceptable impact resistance, which is otherwise quite low. Carbon fiber is very expensive, but it can outperform metal in many situations. Many companies produce carbon fiber worldwide and the usages depend upon the carbon content of the fiber itself, with some being intended for high strength applications and others being aimed for high modulus (stiffness) situations. It is the most expensive type of fiber reinforcement available, costing as much per pound as 100 times common E-glass. Second only to Kevlar in specific strength, carbon fibers are superior to any other fiber in stiffness.

Kevlar

The trademarked name for a DuPont product, it is used to refer to aramid fibers of which Du Pont is the sole producer worldwide. An aromatic polymid (usually shortened to aramid), Kevlar is a form of nylon that was originally developed in the mid-1960s as "Fiber B" to reinforce radial tire belting. It's unique properties soon were put into other uses, and the public usually thinks of Kevlar in terms of bullet-proof jackets. There are, in fact, two forms of Kevlar available. Kevlar 29 is used for lines, cables, and flak jackets, while Kevlar 49 is used as a reinforcement fiber in plastic composites. On a strength to weight comparison, Kevlar has the highest specific tensile strength of any commercial fiber. It is five times stronger than steel and twice as strong as E-glass, which allows a Kevlar hull to maintain the same strength as an E-glass hull at a fraction of the weight. Impact strength is also a Kevlar forte, and it is able to withstand repeated impacts as well as resist the tendency of other reinforcing fibers to allow cracks to spread. The negative side to Kevlar is a marked weakness in compression strength, so it is often used in conjunction with other fibers that balance that trait.

Nomex

A chemical developed by DuPont, Nomex is most famous for its fireproof qualities, and it is used in fire-resistant suits for firemen and race car drivers. It is an aramid, which is turned into a paper-like substance for use in honeycomb.

Hybrids

These are reinforcing fabrics that combine two or more different types of fiber. One common hybrid is a mixture of Kevlar with carbon fiber. The Kevlar provides high impact resistance, while the carbon fiber supplies the stiffness. Combinations of S-glass, Kevlar and carbon fiber are also available to optimize certain properties at minimum cost.

Advanced core materials

Core materials are often used to reduce weight and increase stiffness. Some builders core the entire boat; others construct with solid fiberglass from the waterline down and coring above, and still others use some mix of coring and solid glass throughout the boat.

Image 8. You can see the core (with checkered appearance) in this part, about to be vacuum-bagged at Sabre Yachts (boats.com)

Balsa Core

When first used as a hull stiffener boat builders laid long planks of balsa into the hulls, but this method led to rot and structural failure when water "wicked" through the entire plank. It's taken balsa a long time to live down this beginning, but modern balsa is now a widely accepted coring material in boats. The solution came from slicing through the grain, turning it on edge, and producing a checkerboard pattern of end-grain pieces that do not transmit water. The result is a stiff, light and inexpensive core with good impact quality and high compressive strength. An added feature is the insulation quality of balsa against sound, thermal change, and vibration. One negative factor is that balsa can absorb resin, making the hull heavier, but quality workmanship can keep that from happening.

PVC Foams

Airex and Klegecell (pronounced kledge-a-cell) are the most popular commercially produced foam cores that are used today. Both are closed cell foams made from polyvinyl chloride, but each has different characteristics. Airex is a non cross-linked PVC, making it more flexible and resistant to damage. Klegecell is a cross-linked foam that is extremely rigid. Foreign-built boats often use Divinycell, a Scandinavian version of Klegecell.

Honeycomb

Honeycomb is just what it sounds like: a waffle-like pattern of material to give the highest stiffness of any core of equal weight. The compression and shear strengths are second to none, which might be expected from a material originally used in aircraft for flooring and bulkheads. Nomex honeycomb is the most commonly found on yachts, although it is definitely a high-ticket extravagance for owners in search of the last ounce of weight savings. Surprisingly enough, some honeycombs are made of paper. A kraft paper is impregnated with resins and then formed into a honeycomb, making it water resistant as well as sturdy, but the paper honeycomb is heavier than Nomex. "Skinned panels" are ready-made sheets of honeycomb resembling a piece of plywood, and are available with teak veneer or various other overlays that can be cut into ready-made honeycomb bulkheads.

3 ADVANCED BOAT BUILDING TECHNIQUES

Along with these new materials, methods of laying them up into what will eventually become a boat have also advanced in recent years. Again, minimizing weight while maximizing strength is virtually always the goal.

Vacuum Bagging

This process begins like an open molding layup, but the wet laminate is enclosed in a plastic film and a vacuum is applied to draw out excess resin. Excess resin doesn't add strength – that's what the fiberglass is for – but it does add weight. So the vacuum bagging process reduces the boat's eventual weight without sacrificing any strength.

Vacuum Infusion

The vacuum infusion process similarly incorporates plastic film and a vacuum to attain an ideal resin-to-glass ratio. However, rather than beginning with a wet lay up the vacuum, along with a set of resin feeding lines, introduces and draws the resin through the cloth in the first place. This allows for a more precise measurement of the materials and the ability to apply even pressure across a large area, so you can lay up larger parts.

Additional reading and materials:

1. Get some insight into how core works inside a fiberglass part by watching the Understanding Foam Cored Boat Construction video here: https://www.boats.com/on-the-water/boating-tips-understanding-foam-cored-boat-construction/
2. For a simplified explanation of how the vacuum process works when molding boats, watch the Understanding Vacuum Bagging video here https://www.boats.com/on-the-water/boating-tips-understanding-vacuum-bagging/

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1 INTRODUCTION.

Modern technologies and techniques could give a big boost to wooden boats in the market, especially in terms of economic and environmental sustainability of the product.

Innovative boats combine high performance with low costs and maximum eco-sustainability. This combination must be present both in the end product and the processes used to build it.

Generally wood offers several advantages in boatbuilding thanks to its intrinsic properties such as strength, reliability, ease of working and pleasing aesthetics. Today however there are other new materials and combination of materials that lead to new technologies that we should be aware of.

This unit highlights the key technologies and the new materials that arise from the shipbuilding needs in the field of increase of energy efficiency and reduction of environmental impact.

2 TECHNOLOGIES FOR THE INCREASING OF SHIP'S EFFICIENCY

Appendages for the optimization of the propeller flow power required [-2 - 8%] According to the technology and compared to the c configuration without appendages; mainly applied on cargo ships):

There are different technologies that provide the equipment of various supplement at the prow, round or stern of the propeller. The objectives are to optimize the incoming water flow to the propeller, to maximize the thrust and to improve the wake. These systems can belong to the original ship project or even being design to improve the performances of the existing ship (*Bluetech.eu, 2016)*.

Image 9. Figure (on the left side) the stator pre-swirl developed by Daewoo Shipbuilding & Marine Engineering – South Korea, (on the right side) a system with a rudder bulb and an interceptor developed by Scandinavian study (HOLLENBACH, 2011).

The research of mathematical models even more advanced for the development of software and equipment in the computational fluid dynamics and experimental fields. The objectives are to obtain more efficient propeller-ship system projects and to make possible that a more sophisticated design could create an added value to the ship product in order to give a impulse to the local shipbuilding.

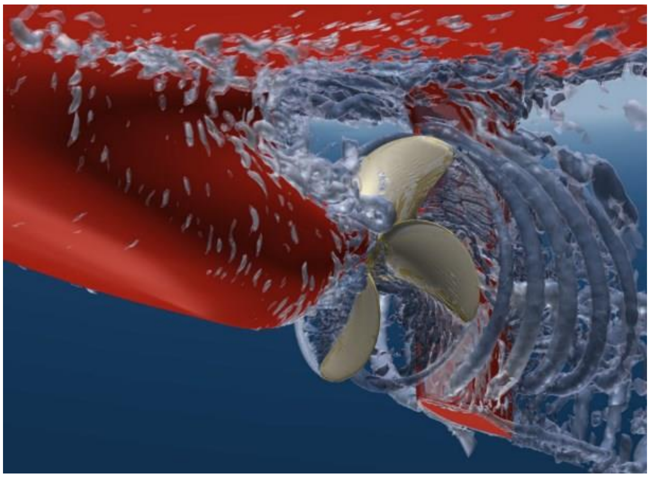

Image 10. An unsteady simulation of the working propeller carried out by the department of Shipping and Marine Technology of Chalmers University of Technology Gothenburg, Sweden (HOLLENBACH, 2011).

Paints designed to reduce friction between the wetted surfaces of the ship and the water during navigation (-3% absorbed power, fuel consumption -10% in 10 years with silicon paint compared to a conventional antifouling paint) but which do not release harmful substances to the environment:

- nanostructured super hydrophobic coatings that trap air / steam reproducing the effect of the air cushion;
- diffusion of silicon coatings that minimize friction, prevent the creation of sealife such as algae and molluscs on wetted surfaces, provide long life, even for pleasure boats.

Image 11. Coating refitting of the hull of M/V Cartour Delta, owned by Caronte & Tourist shipping company (Bluetech.eu, 2016).

Diffusion of hybrid propulsion and on-board electric balance management systems (diesel-renewable-battery-electric):

- performance improvement (duration, efficiency, capacity/volume, capacity/weight) of electric accumulation systems (lithium, salt, etc)
- diffusion of hybrid energy system

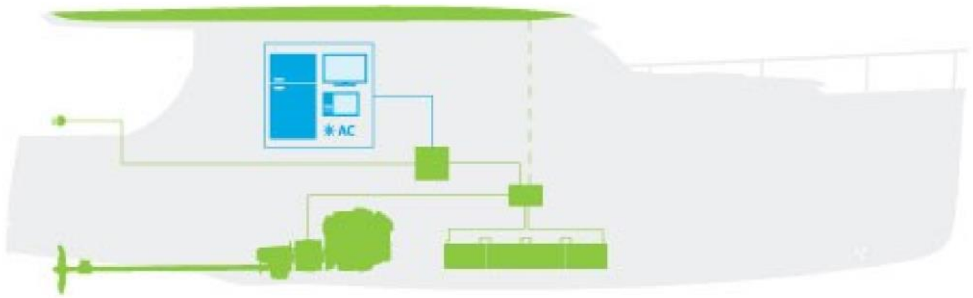

Image 12. Operating grid of hybrid system developed by Greenline, Begunje na Gorenjskem, Slovenia (BlueTech.eu, 2016)

Image 13. Teseo I, the first hybrid commercial fishing vessel built by Cantiere navale Tringali6 (Augusta SR, Italy) in the framework of research project PON TESEO: High Efficiency Technologies for Energy and Environmental Sustainability On-board (BlueTech.eu, 2016)

3 TECHNOLOGIES FOR THE REDUCTION OF HAZARDOUS EMISSIONS IN THE ATMOSPHERE

Renewable energy sources on-board:

- application of piezoelectric floors on cruise vessels aimed to electric energy production against the natural movement of passengers;
- development of performing and optimized photovoltaic surfaces for maritime purposes (self-cleaning, non-oxidable, durable and with low aesthetic impact);
- application of air-generators for electric energy production while the ship in the port or close to the harbour.

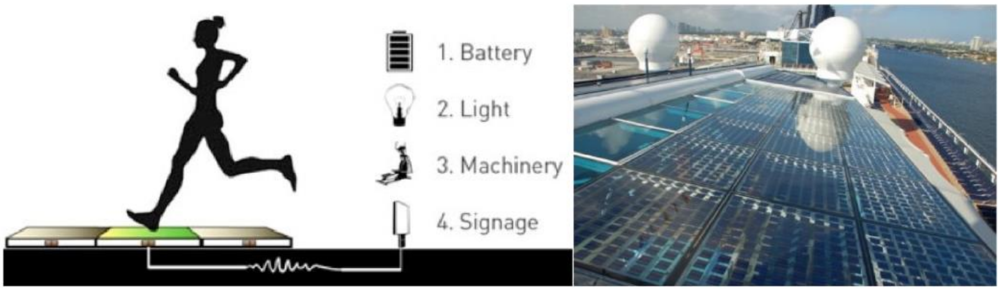

Image 14. To the left, the piezoelectric floor; right, transparent photovoltaic surface installed on the cruise ship Celebrity Solstice (Royal Caribbean) (BlueTech.eu, 2016)

Underwater robot for cleaning of wetted surfaces of operating ship:

the progressive increase of organisms on ship's wetted surfaces, lead to a gradual deterioration of hydrodynamic efficiency related to a friction increase with the water.

Cleaning process of these surfaces is carried out periodically when a ship reaches the dry dock and this operation is normally carried out one every three years. The possibility to keep wetted surfaces clean, with competitive costs, during the ship operation, could help to keep hydrodynamic efficiency in average higher of some percentage points in spite of the normal timing of dry docking.

Image 15. On the left – ship keel cleaner produced by Fleet Cleaner Grijpskerk - The Netherlands, on the rights - ship keel cleaner produced by Hulltimo, France (BlueTech.eu, 2016)

4 TECHNOLOGIES FOR THE CONTAINMENT OF THE ENVIRONMENTAL IMPACT

Construction of boats

Today, it is very interesting the use of recycled and low-cost materials for the coating surfaces (decks, bulkheads, furniture) both in nautical and ship sectors.

Indeed, these materials are ecological (recycled and recyclable), performing (they have an internal structure that makes them light) and economic (emulating materials as wood, marble and other finest materials).

Smart lightweight materials will reduce the weight of the ship and therefore the energy consumption required to be displaced. Adaptive materials and structures will also improve vessels and platforms ability to operate in ever-changing conditions. Therefore, smart materials and design solutions will bring more flexible and efficient vessels (*USWE, 2020*).

New materials are promising:

- Weight reduction
- Environmental protection
- Efficiency gains
- Reduce hull resistance

On the other hand, smart coating, plastics, and materials with sensors will also be used and will indicate when they should be replaced or repaired.

Image 16. Example of Example of plastic composite panels (BlueTech.eu, 2016).

Hulls for recreational craft are mainly made out of glass reinforced plastic (GRP), with carbon fibre being deployed on some high-end/luxury vessels. Both of these materials are challenging to recycle and the industry is increasingly looking into alternatives to reduce environmental impacts associated with disposal of boats, as well as to promote a circular model for resource utilisation within the industry.

New materials being developed in the industry include **natural fibres.** Among these, **flax fibres** currently represent one of the most promising options, with comparable performance in terms of pressure, tension and kinking (*Carbon Trust, 2021)*.

Flax fibre is lighter compared to GRP and cost is lower compared to carbon fibre, as well as being significantly less carbon intensive.

Currently, there are few examples of natural fibres being used as the sole material for hull manufacturing, however, more frequently, they are being used to develop semi-structural parts of a boat or boat moulds.

Boat manufacturers including Greenboats (Germany) and Baltic Yachts (Finland) have manufactured vessels using flax fibres.

Cork is another natural based solution being deployed as decking material. Along with being more sustainable, cork also provides good insulation from noise, vibration and temperature, as well as being nonslip and resisting well to scratches and deformations.

Replacing petroleum-based epoxy resins is also an issue being looked at by the industry. While **bio-resins** exist, the share that can be used on boats to maintain the performance levels required is estimated to be around 30%. Linseed oil, produced from flax fibres, is an example of bio-resin being used by boatbuilders to replace part of conventional epoxy resin.

In pleasure boating, extremely interesting becomes today the possibility to realize boats or at least part of them exploiting the 3D print techniques. Even now several researches on materials and the development of bigger machines have to be made.

New UVA polymerization resin for boat repair and composite components production. The new matrix allows to eliminate the use of accelerators and catalysts and reduce of about 60% the emission of styrene during the polymerization. Thixotropic resin is formulated both for hand-layup applications than infusion processes. Complete polymerization with 300sec of UVA exposure. Polymerization released by the environmental conditions.

Advantages: elimination of issues related to resin working time; abolition of risks associated with the use of accelerators and catalysts; removal of problems related to migration of styrene, reduction of the environmental impact due to lower styrene release.

Linset & Co (advanced composite material technology center in Fano, Italy – Marche Region), formulate the new UVA resin product and a smart repair Kit composed by Prepreg tissue with UVA resin, UVA polymerization resin and filler, UVA paint, UVA lamps.

Image 17. Smart Repair Kit (left), UVA resin and filler at the World International Composites event in Paris 2016 (right) (BlueTech.eu, 2016)

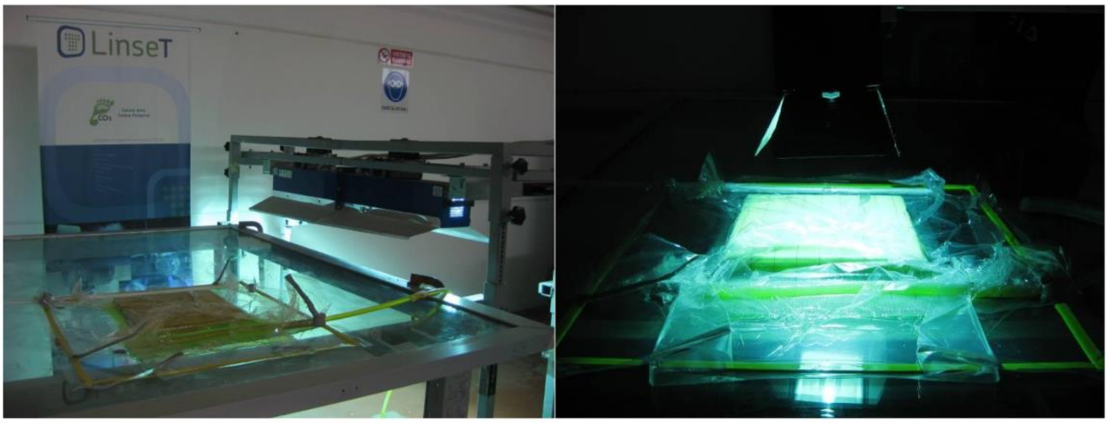

Image 18. Use of UVA resin for composite components made by infusion process (BlueTech.eu, 2016)

Corset & Co (builder of high technology composite material components in particular for marine sector) builds, at its shipyards in Fano (Marche Region) e Forlì (Emilia Romagna Region), hulls, decks and small pieces of pleasure boats for the groups: Ferretti, Cantieri del Pardo, Doufour Yatch, Mida Yatch; using the most innovative low environmental impact production technology such as infusion process, RTM and ecofriendly products (low emission resin UVA activated, experimentally vegetable fibers).


Image 19. Hull manufacturing with the infusion process at the Fano establishment (BlueTech.eu, 2016)

Many European companies offer different coverings made from recycled materials. An example is the (Gemona del Friuli – Italy) which realizes urban furniture, games for parks, briccole, bridges and walkways made from recycled plastic.

Image 20. A pier made from PRECO SYSTEM with recycled plastic boards (BlueTech.eu, 2016)

Design for dismantling and disassembling:

- socially and environmentally alternative solutions are ever emerging development of design techniques which take into account the possibility to disassemble and use some materials and parts of the ship at the end of life;
- use of recyclable, recycled or reusable materials for boats and ships outfitting;
- development and promotion of non-conventional materials for the construction of pleasure boats which are reusable or recyclable (aluminum, fiber and natural resins, wood treated with natural resins).

Some recent studies have showed that it is possible to reuse the fiberglass by grinding the boats at the end of life. The results of this grinding process is the possibility to realize conglomerates to employ in the construction industry (civil or industrial) asstructural components of new fiberglass boats or as material to build consumer objects that currently are made of plastic.

Greenboats

Greenboats is an SME based in Germany which has pioneered the use of sustainable materials in boat construction including recycled PET, bio-based resins, cork and flax fibres grown in the EU to replace fiberglass. Their 27ft cruising dayboat, Flax 27 (pictured) was the most sustainable boat shown at the Düsseldorf Boat Show in 2020 – the largest indoor European boat show.

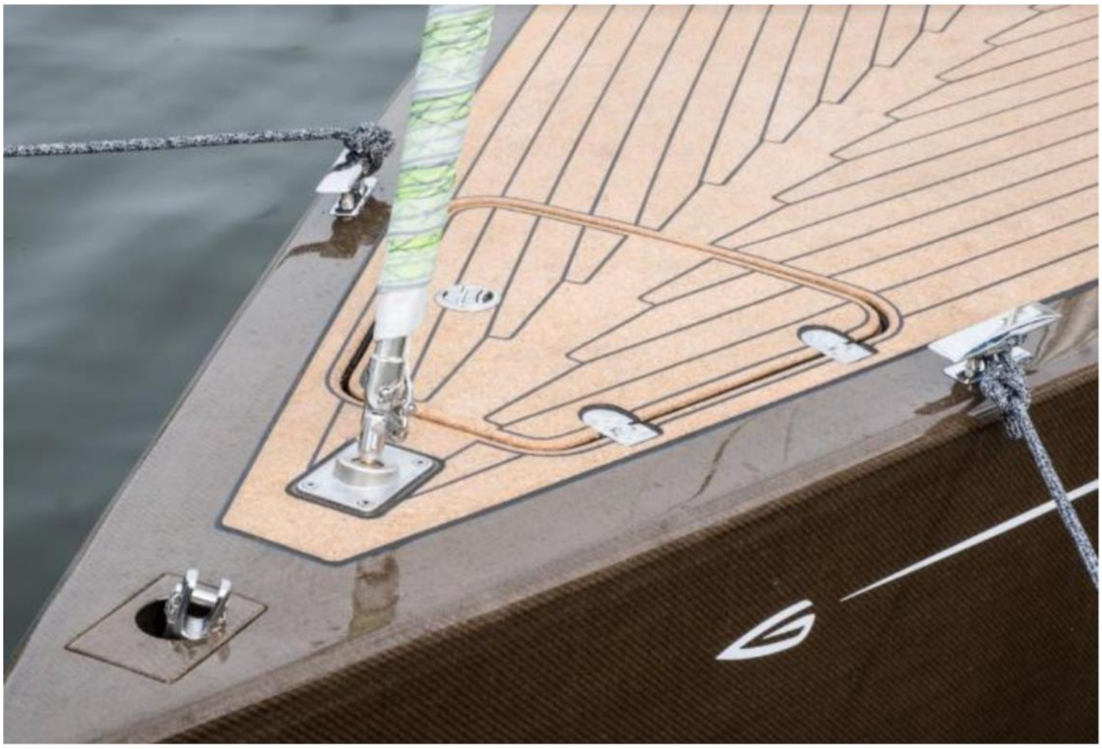

Image 21. Flax by Greenboats green-boats.de (Carbon Trust, 2021)

The Ultimate Boat Company

The Ultimate Boat Company, a UK-based start-up, has developed a patented alternative composite material called DANU, which enables upcycling, remanufacturing or recycling of a hull at EOL. DANU is a composite with hybrid characteristics between GRP and carbon fibre, being stronger and lighter than GRP and less brittle than carbon fibre, and is based on the same manufacturing methods as conventional composites allowing the use of existing infrastructure [71].

Image 22. Coastal High Speed Craft. Ultimate Boat Company ultimate-boats.com/boats/multihull/ (Carbon Trust, 2021)

Alternative fuels

There are a range of potential alternative fuels with lower or net zero emissions that can substitute diesel or petrol within marine engines, including lower carbon conventional fuels, synthetic fuels and biofuels.
However, given the specific design characteristics (e.g. space availability, weight limitations), usage profiles and safety requirements of recreational craft, as well as the refuelling infrastructure available at marinas, not all alternative fuel options available for commercial vessels are applicable to the recreational craft sector.

Biofuels

Biofuel is produced through biomass production and can produce both liquid and gases. Conventionally, the most common types of biofuels are in the form of bioethanol, biobutanol, and biodiesel (Carbon Trust, 2021).
Biodiesel is a renewable, clean alternative to diesel. The oil is produced from seeds and waste oil, or fats, which means it can be produced from food waste, and the combustion of biodiesel produces much cleaner emissions when compared to its conventional alternative.
In some instances, to improve fuel efficiency, biodiesel is mixed with regular diesel. Despite this, there is still a noticeable decrease in emissions. Some engines already have the capability to allow for biodiesel to be used, however, more frequent maintenance and care is required to ensure that internal components do not degrade due to its chemical properties.
For engines which are not currently biodiesel compliant, minor changes would be required to the engine to allow for its use.
Biofuel itself has a short storage life, so it is recommended that the fuel is purchased only before use and not stored for long periods of time – this is a factor which should be considered when looking at changing to biodiesel. As the engine does not require many modifications, it is relatively easy for existing boats to switch to the use of biodiesel.
Extensive research has been undertaken on biobutanol fuel blends for internal combustion engines, an extremely capable biofuel which can reduce CO2 and VOC emissions.
Biobutanol contains nearly 90% of the energy density of regular diesel and is able to be used within an existing recreational craft without any adaptations required to the engine.
As such, all existing combustion engines in recreational vessels are capable of using biobutanol. By increasing the percentage of biofuel in the engine, further reductions in CO2 can be found. Biobutanol blends of 16.1 vol % can reduce the emissions by up to 70% relative to diesel, according to the US Environmental Protection Agency. This does not require changes to the engine or fuel system.

Biobutanol is a drop-in fuel and higher quantities of biobutanol, beyond 24 vol % would need to be further investigated for engine compatibility as many marine engines are not capable of adjusting their air/fuel ratio.

Ethanol fuels can cause issues to the boat and fuel system primarily related to the usage profiles of recreational boats, especially with ethanol fuel mixtures containing more than 10% ethanol by volume.

Most boats, particularly in northern climates, are stored for long periods of time. Ethanol fuels, together with water, lead to phase separation which is highly corrosive to fuel system components. Many engines have found large amounts of damage due to ethanol fuels. Biobutanol conversely behaves a lot more like diesel which does not corrode or damage the engine.

The main barrier for the use of biodiesel comes in the form of cost. The same engine can be used for biodiesel as conventional diesel, however, various adjustments need to be made to accommodate for the new composition of fuel. Rubber inside the engine needs to be replaced along with some components within the fuel control unit. Conversion kits already exist in the automotive industry to allow the use of biodiesel and has varying costs depending on size, with an average of between £1,000 and £3,000 (Carbon Trust, 2021).

Hydrogen

Hydrogen internal combustion engines use the conventional principles of internal combustion, and specifically, they are a modified version of an internal combustion engine with hydrogen as the fuel. During the combustion of hydrogen with oxygen, the resulting by-product is water.

The hydrogen internal combustion engine is simple to develop as it is an adapted equivalent to the conventional internal combustion engine. The adaptations required are primarily focused around reinforcement of internal components. Dual fuel hydrogen combustion engines are already commercially available for commercial vessels, including for example BeHydro's medium speed engine launched in late 2020 (Carbon Trust, 2021).

Companies are starting to produce hydrogen-powered vessels, with notable examples including Cheetah Marine with a hydrogen internal combustion engine-based catamaran, and Yanmar with the development of a hydrogen fuel cell system for maritime applications which should be demonstrated by early 2021.

Hydrogen is a promising long-term option as both energy storage and propulsion, especially among short sea commercial vessels. Despite the extensive developments in technology, there are various barriers still to be overcome – especially for the use of hydrogen within smaller, recreational vessels. These are mostly connected with:

- the price of hydrogen (compared to a diesel alternative can be as much as ten times)
- storage at marinas (tanks generally require very cold temperatures and/or high pressures to store)

- safety (hydrogen is potentially explosive)

Cheetah Marine

Cheetah Marine started in 1991 building catamaran vessels on the Isle of Wight. In 2016, it modified a Honda outboard engine into a hydrogen internal combustion engine which works in the same way as a traditional petrol engine except with hydrogen as a fuel.

The craft was tested over a 100km distance around the Isle of Wight. The trip was planned to last 12 hours but due to the high performance of the hydrogen engine, it was completed in eight with a large amount of hydrogen still remaining by the end.

Image 23. Cheetah Marine hydrogen powered craft (Carbon Trust, 2021)

Alternative energy sources

Marine solar power systems

Solar panels can be installed on recreational craft to generate electricity that is then used to charge batteries to power boat appliances or to support propulsion (in case of an electric or hybrid powered boat) These marine PV systems have the benefit of reducing operational carbon emissions, mitigating cost of fuel, as well as avoiding noise produced by diesel generators. There are several types of solar panels for boats available in the market (Carbon Trust, 2021) including:

Glass fronted

These are the most popular type of marine solar panel systems, offering the highest power at lower cost compared to other options. There are two types of glass fronted panels:

- Polycrystalline panels: made from small silicon pieces fused together. These panels are the cheapest option on the market, however they have a lower energy efficiency and conversion rating and their performance worsens in hot weather
- Monocrystalline panels: made from large, individual pieces of silicon, these panels tend to have a better efficiency and conversion rating and higher effectiveness in hot weather compared to polycrystalline panels and come at a higher price

Polycarbonate

Panels typically made from polycrystalline technology. They are the most expensive option for marine PV systems. They are more flexible than glass-fronted panels and can be installed as fixed panels via a silicon adhesive. Another key advantage of polycarbonate panels is that they can be walked on. They are thought to be a particularly attractive option for yachts.

Fully flexible

Panels capable of adapting to all surface shapes thanks to their flexibility. These panels are based on amorphous technology, which implies lower efficiency compared to other marine solar PVs. They are more robust compared to other marine panels, however, their fixed location implies their angle cannot be adjusted to maximise efficiency.

Costs of PV systems will vary depending on the number of panels required, as well as on the type of panels being fitted. Industry sources suggest that costs of installing a 200 watt system will start from around £600, while a 400 watt system will start from around £1,000.

Battery capacity and power to weight ratio is the main issue in order to electrify faster/larger boats. However, for smaller craft or boats operating at lower speeds, solar panel systems are already a viable option and the industry has seen consumer demand increasing.

Brodarski institute (research centre for marine technologies located in Croatia) has developed various innovative systems specially for the passenger catamaran MILLENNIUM DIAMOND and implemented into: the integrated system of monitoring and regulation of ship systems, the system of automatic regulation of the ballast tanks that enables automatic adjustment of the vessel’s draught during tide changes, solar panels for a power supply of ship systems. The vessel can use a bio-diesel fuel.

Image 24. Passenger catamaran Millennium Diamond (BlueTech.eu, 2016)

Marine wind generators

Marine wind generators convert wind energy into a rotational motion, which turns an alternator to produce electricity. Electricity is then stored in batteries used to power onboard appliances or support the charging of the propulsion system of an installed electric motor. These systems are applicable for cruising boats, both motorboats and sailboats.

Advantages of using wind generators compared to marine solar panels include the potential to generate power for 24 hours, contingent on wind availability (compared to 5-7 hours for solar panels) and higher space efficiency (Carbon Trust, 2021).

Downsides include:

Noise and vibrations produced by airflow over the blades: this was an important issue in the past, however more recent technology developments, including the use of CAD blade designs have considerably reduced noise levels

Poor performance in low wind conditions: As the relationship between wind and contained energy is cubic, power output decreases exponentially as wind levels drop. Usually, most marine wind generators provide limited power below eight knots. Also, some wind generators need to be shut down manually in high wind conditions, although there are self-regulating models available in the market

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Risks of damage high wind conditions: Turbines operating in storm conditions with winds of around Force eight and above risks leading to serious blade damage, cable burning and battery impairment. To mitigate these risks, some models include a thermal cut-out that disconnects the generator from the battery in case of overheating. Other models rely on feathering blades that can regulate turning speeds in high wind conditions by altering the pitch of the blades (e.g. Superwind generators)

The choice of a specific marine wind generator model will depend on several factors. An essential consideration will be related to the boat's power requirements for on-board appliances at anchor and during cruising. Solar panels have become the most popular option for trickle-battery charging in port, although there are small wind turbines available (e.g. Rutland 504 12V system) that can be used for the same purpose. Hence, wind generators being installed today are usually more powerful systems.

The expected average speed the boat will cruise at, as well as the wind conditions typically encountered en route will be another important factor to determine the most appropriate wind generator model. The build quality of the model will also determine the level of maintenance requirements that can be expected.

Hydro generators

Hydro-generators are a technology that has seen increasing uptake in cruising sailboats, particularly among long distance sailors. A hydro-generator has a reverse propeller, called impeller, that rotates by being dragged by the water behind the boat while the boat is sailing. The rotation applies to an alternator, thereby producing AC power which is then converted to DC for charging onboard batteries for propulsion and/or use of onboard appliances.

Hydro-generators can either be implemented as a standalone technology or in combination with a boat's auxiliary propeller for power generation as part of an electric or hybrid engine system. While early versions of standalone hydro-generators had impellers towed behind the boat through a long line, modern impellers are attached to a submersible leg, similarly to an outboard motor, or fastened under the hull, avoiding risk of loss of the impeller due to breaking of the long line or tangling issues.

The impeller is usually pitched for boat speeds of five to 30 knots, although specific speed ranges will vary between models. While solar panels and wind generators actual outputs are largely dependent on favourable weather conditions, hydro-generators are able to supply constant power at a given speed (although, of course, they operate only during navigation).

While most manufacturers offer units able to provide up to 500-600W at the top end of their speed, checking outputs at actual targeted cruising speeds is important to determine the amount of power generation that can be expected to be achieved during regular cruising conditions (see table below for indicative output values at low speed levels). Additional drag produced by the impeller is considered to be negligible, with producers claims varying from 0.4 knot to 0.1 knot of drag equivalent (Carbon Trust, 2021).

5 TECHNOLOGIES FOR IMPROVED EFFICIENCY BY DESIGN

The efficiency of ships has so far been determined mostly by attention to engine. Over the last ten years of so, more attention has been paid to the hull and superstructure and although ships are still superficially unchanged there have been important steps taken. The bow shape is one area that has changed with the need for bulbous bows challenged by a number of designers and builders.

From offshore vessels to the largest bulk carriers, removal of the bulb and new bow configurations have been said to offer efficiency savings that although small are not insignificant.

Changes to the shape of the superstructure have also been tried with reduced wind resistance the main aim. The main method used has been to add a curved or bevelled shape to superstructures. This has been done mostly on car carriers which have a high wind resistance and less so on other ship types.

Hull design optimization

Hull design optimisation entails the development of a hull design that can optimally meet both technical and operational requirements. Optimising hull design is an important measure that can be deployed on newbuilds to reduce vessel drag, which leads to reductions in fuel consumption and improvements in range.

Hull design optimisation is considered to be one of the “low hanging fruit” that the recreational craft industry could pursue to significantly lower operational emissions of new boats, while also facilitating the uptake of net zero emission propulsion technologies. These improvements will be particularly important on larger or high-speed recreational craft (e.g. yachts towards the 24m range or speedboats), where current potential decarbonisation technologies such as batteries do not currently meet power requirements.

Hull design optimisation is not a new concept, however, identifying the best hull design that is able to meet a range of objectives (e.g. performance, seakeeping and manoeuvrability) has long been a challenging objective for naval architects. Hull design optimisation typically involves an iterative process, with theoretical, computational and experimental modelling techniques applied to develop and assess the performance of novel hull shapes. Generating and modifying such hull shapes is a complex task can be costly, hence usually limiting the number of hull designs that can be developed and tested for optimisation purposes.

To facilitate this process, there has been an increase in the research dedicated to the development of intelligent ship optimisation techniques through the use of information technology. Some of these approaches, including machine learning and neural networks training, are already being applied by some naval architects to achieve optimal hull forms based on multiple objectives. Stakeholders have highlighted that the sailing racing sector invests significantly in hull efficiency improvements as one of the key competitiveness factors. Some large boat builders have been actively investing in improving hull efficiencies for some time. However, advanced hull optimisation approaches are still fairly limited within the sector, with most naval architects still using existing hull forms as a reference and applying modifications to these to achieve new designs.

Rapid prototyping

From initial concept to working plans, today's designers work not only with pencil and paper, but with tablet with three computer design tools: computer-aided design (CAD), computational fluid dynamics (CFD), and finite element analysis (FEA).

Sometimes these tools are used by the builder's in-house designers; sometimes this function is contracted out to firms specializing in design, analysis, and the creation of "kits" from which boats are built. The CAD software creates detailed 3D layering from initial hull form to interior layout to systems installations. The finely tuned level of detail can be astonishing. The design is able to convey accurate colors and even textures of each model's different furniture and upholstery options (*Boat U.S. Association, 2016)*.

For the production staff, the design conveys the precise runs for mechanical and domestic systems such as wiring harnesses, network cabling, ducting, and plumbing.

For the boat's owner, the consistency and record of such runs in the owner's manual makes tracing them later easier.

Once designers create the basic drawings for a new boat, CAD/CAM programs are used. CAM stands for computer-aided manufacturing. At its heart is a five-axis computer-numerical controlled (CNC) milling machine that can create virtually any complex shape.

Image 25. Using CAD programs, designers achieve astonishing detail: colors and textures of upholstery and furniture, precise hose and wire runs, detailed systems installation. These instructions are sent directly to CNC routers to create the parts from which the final boat is assembled. Taken at Sea Ray (Boat U.S. Association, 2016).

Industrial cutting

Reducing production costs means in particular making the phases of cutting and assembly of components more competitive, and this can be done if components are mass produced and not, as happens currently, shaped by master carpenters.
Work centres for woodcutting could help here. They make it possible to produce, with great speed and precision, a large number of components of any shape. Their use in the yachting sector is still widely undervalued, though they could make it possible to make more economic all and higher quality products. In addition, cutting with CNC machines, combined with the use of three-dimensional, parametric and associative CAD software, would have the advantage of permitting considerable customisation of products on the basis of customer needs. In particular, performance in high-speed work is much better when tool paths are based on the development of NURBS (complex 3-D surfaces). In practice, the tool path is defined by CAD software in the desired shape, eliminating the CNC calculations that normally precede operations. Using these 3-D geometries defined directly by CAD we can drastically cut the manhours needed to build a boat with traditional methods.

Image 26. The working process: a) CNC plant; b) wooden panel on the work surface; c) first cut along the lines (FRAGASSA C., 2016)

Additive manufacturing for the construction of lighter components

LAMA FVG (Advanced Mechatronics Lab of Friuli Venezia Giulia) is conducting a feasibility study about the redesign of naval components and construction with additive manufacturing techniques aimed to structural lightening and implementing the Industry 4.0 processes. The laboratory possesses expertise and technology to redesign and build (with additive manufacturing techniques) metal components up to 250x250x260 mm.

Image 27. Additive manufacturing machine into service at the LAMA FVG in Udine (BlueTech.eu, 2016).

6 DIGITAL TRANSFORMATION IN THE BOAT AND SHIP BUILDING SECTOR

Applicability of Industry 4.0 to Shipbuilding 4.0 is not necessarily unambiguous. One of the reasons for which the largest part of shipbuilding processes are not yet automated lies in the very nature of the shipbuilding operations, and in the uniqueness of the industry.

Steel construction apart, the degree of automation of the other processes can be difficult. E.g. the automation in the outfitting could be developed in pipe fitting and pipe workshops. High degree of prefabrication means that major part of pipes is being manufactured in workshops. Bending of pipes and welding of flanges can be automated with relatively small effort and this has been already done to some extent.

In shipbuilding, individualised products are core to maritime industry. Large parts of shipbuilding operations are exactly not repeatable. Shipbuilding also relies heavily on cooperative supply networks and the transfer of concepts from mass production to one-of-a-kind production in challenging.

Digital revolution is taking place across all industries and also shipbuilders are embracing the digital thread. Digital thread is hoped to offer answer to manufacturing world dilemma where more and better quality should be made with less effort, time, and costs (USWE project, 2020).

Here is the short rundown of the technologies awaiting to be used and already used.

Automation and Robotisation

Automation and robotisation are the replacement of human labour with machines or computers and computer programmes.

The reason for this is economic at an initial stage but also has efficiency and health and safety implications: Due to the process of automation, it will be possible to replace more and more human labour with machines or computers and computer programmes.

Implementation costs and efforts are the greatest obstacles to the actual implementation on the work floor of everything that is already possible.

Automation affects the logistical process and the warehouse management and supply of materials which can be transported by automated trolleys. Welding and cutting robots already exist and are being used in many shipyards. Due to robotisation, more and more physical activities are being performed without the intervention of human beings: this is a specific type of automation. It mainly relates to robot arms, mobile robots and drones.

In industry and in the ports, welding robots, unmanned warehouses and the largely unmanned transhipment of containers are already quite common. Because robotisation is an important way of saving costs and therefore remaining economically competitive worldwide larger numbers of more advanced robots are expected to enter the work field and radically change the nature of labour in near future.

Robots that can fabricate metals, carry out repair, lay pipes, apply insulation, connect cables and work on floors. There will also be inspection robots, in addition to the familiar diving robots.

At SeaRay, Tennessee, At the initial layup stage, robots spray gelcoat into the tooling. They're fast and accurate, spraying the same designed thickness every time. With pinpoint accuracy, robots in the cutting booth work with tolerances of 1/8,000ths of an inch. More traditional practice would be for boatbuilders to cut holes and drill and tap by hand, or use jigs or templates, as opposed to a computer-controlled five-axis router that can cut a perfect transom hole for a sterndrive, eliminating concerns about alignment or leaky mismatches.

Image 28. Taken at Sea Ray (Boat U.S. Association, 2016).

3D Printing

3D Printing in shipbuilding is one of the major trends. The shipbuilding industry is adopting the 3D printing technology in order to improve efficiencies and quality of the manufactured part. 3D technology is also expected to improve the design standards.

3D printing is on the rise, both in industry and among private individuals. Some experts forecast that in the future, every household will have a 3D printer that can be used to print domestic applications 3D printing also seems to be an unescapable development in the maritime sector (Rotterdam Study 2017).

3D Printing enables an ecological and time-saving way to produce products. With 3D the prototypes can be easily manufactured of a product without many steps. Its potential for mass production is enormous. As well as 3D Printing, 4D Printing can also play an important role in the production process. Here, parts are printed with a 3D printer and the shape adapts when the parts come in contact with water or heat, for example. This is done without including robotics in the design. For example, it could involve a pipeline that repairs itself if a leak occurs and there is contact with water. 4D printing is an example of a combination of an innovative production process and innovative materials.

Image 29. MAMBO continuous fiber 3D printed boat by moi Composites (3dprintingmedia.network/3d-printing-boats-is-becoming-standard-practice)

The Internet of Things

IoT, machine to machine, Industrial Internet is the communication between the sensors installed in the machines and the business around it. Various cloud services and the Internet of Things produce tremendous amounts of data to help your business get valuable information at just the right time. Data can be measurement data, statistics, analytics, feedback - and much more. The challenge is to use the necessary information to distinguish essential information from irrelevant.

At its best, cloud services and IoT ensure the functionality of the technology while improving customer experience and service. Knowledge of a broken or soon-to-be-maintenance machine rushes before a person using it can even notice a fault.

• Smart sensors and data transfer

• RFID Cards: Radio Frequency Identification will tag products and spare parts facilitating their tracking and tracing during the building process but also once on board.

• Wireless communication systems.

• Devices quipped with sensors that transmit data to a computer via the internet

Machine learning: Represents a leap to determine cause / effect of crashes. They are smart systems which understand complexity and draw conclusion and make decisions by themselves.

• IoT will deliversmart vessels with shore-based control. Remote control. A fully autonomous operation of assets.

It will also bring improvements in:

o Ship design and shipbuilding

o Ship propulsion and powering

o Commercial and operational performance of ship operation

Big Data

Most prominent applications will be on improving predictive maintenance and remote maintenance, or in the foreseeing to fix components. Another application will be to implement the evidence-based design. Big Data will save costs and increase safety and save costs. BD, machine learning and deep learning are key concepts when it comes to autonomous vessels.

Big Data will bring advances in real-time weather data and routing. It will improve the assessment and management of a vessel's energy consumption. The vessel's performance and its engines and general conditions monitoring will also be enhanced by BD. There are a few obstacles to overcome on implementing Big Data. In the first place, data must be accurate, and robustness is still an issue. Then, the computer analysis must be correct. Applications must work in all locations: Standardisation of software and hardware is crucial to be interoperability of applications. Technology must be safe, and cybersecurity is crucial. There must be a focus on the human dimension. Education to train the next generation on multidisciplinary: Focusing on both technology and the humanities.

Simulation can improve productivity without disturbing the factory's normal operations. Improvements are being put into practice much more rigorously than the traditional enterprise and the trial and error model. At best, simulation can be used to design a new factory or production line. This allows you to minimize the investment risks and to choose the production system control principles in advance. Simulation can also be used to develop the order-supply chain. With accelerating digitalisation, industry is shaping up with new ways. Although robotics and automation have been used for a long time, their role in production will increase. Robotics and artificial intelligence are especially used in dangerous objects and even in impossible jobs for people.

Robots are able to work more accurately and faster than a human being is. Nor do they make any mistakes in any environment and focus only on the task assigned to them. In the future, robots will be increasingly easier to program and use, and audio and image recognition will help.

Testing products in **virtual environments** speeds up the manufacturing process and reduces costs. At the same time, it is ensured that what is being done is done.

The **Digital Twin concept** is often referred to in industry. For example, the Digital Twin is a precise digital copy of a process, product, or service. Thus, the product may be at a very early stage, for example, as a 3D model on a computer screen.

Virtual Reality's relevance:

Visual insight, ability to sense how vessels vibrate. Clients will be able to oversee the manufacturing process on remote.

The **Augmented Reality** will also be part of product design. Its importance, for example, as an aggregator of global teams, is enormous: at best, all members of the team around the world can solve the same problem at the same time.

Biomimetic is one of the professional fields that would create many jobs over the coming decades. We can still learn a lot from nature: The biggest innovations of the 21st century will be at the intersection of biology and technology. Proven technologies from nature are: Light weight construction. Underwater adhesives. Resistance reduction: shark skin, layer of air (Salvinia effect)

Nanotechnology makes it possible to work with particles the size of nanometres. At this scale, you can change the properties of materials. This has great potential for technologies that reduce carbon emissions.

Coatings for ships made of nanomaterials, for example, could reduce resistance and accordingly reduce fuel costs and the burden on the environment. The technologies and the impact of change may vary depending on the country and the production technology level, production management etc. of shipyards.

The impact of technologies also depends on the level of competencies of employees and the speed of knowledge transfer. Some of the technologies are implemented already whereas some technologies will emerge only in the future. When analysing the technologies and their impacts we must anticipate their transformational effects, likelihood of implementation, investment attractiveness, and their expected overall impact on the shipbuilding industry in the future. The development of new technologies impacting the shipbuilding processes may vary significantly nationally and by shipyards or manufacturing company. The rapid pace of technology development will continue to accelerate, driven by increasing computing power and growing networks of companies.

Navantia Shipyard has completed the study and analysis of the Industry 4.0 model for adaptation to shipbuilding, called Shipyard4.0. (Navantia, 2021).

The structure of nine technologies or technology themes is useful to illustrate and understand the development of possible scenarios of future shipbuilding 4.0 demands. With transformative digital technologies, the example of Navantia's

Shipyard 4.0 will develop new processes for obtaining the hundreds of systems that compose the ships.

The key elements of Shipyard 4.0 technologies

The impact of future technologies on shipbuilding professions based on Navantia's Shipyard 4.0 Model and technologies:

Fig. 1. Shipyard 4.0 Technologies

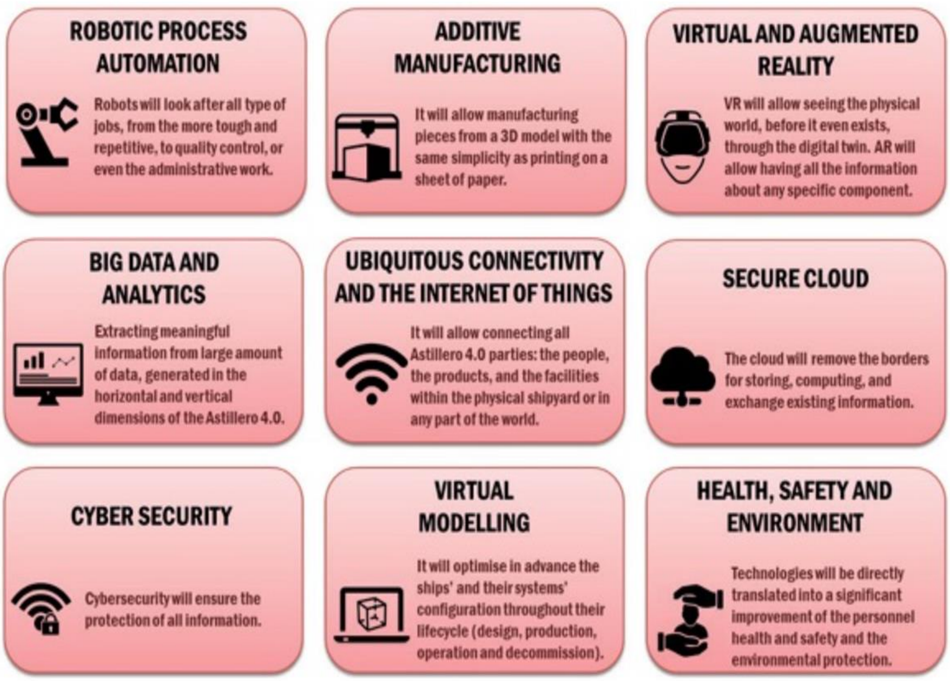

Image 30. Navantia Shipyard4.0. model (Navantia, 2021)

Digitisation of all the workshops' machinery will enable vertical integration through information systems allowing optimisation of the machines' maintenance and energy consumption.

Robotics. Collaborative robotics will allow people and robots to work together. A range of tasks will be automated, from the more difficult and repetitive, to quality control, or even administrative work.

Automatization and robotisation are already integrated into shipbuilding processes. Smart automated adaptive milling technology is now available. Huge for re-skilling e.g. understanding automatic robot welding of large complex ship sections or blocks and e.g. fully automatic robotic pipe spool production. The gantry facilitates robot welding of extreme product sizes such as double bottom hull sections of oil tankers or box ships.

The impacts are understanding the welding processes, technology and the different types of welding processes used today, for different effects and needs. Three of the most common are Arc, MIG (Metal, Inert Gas), and TIG (Tungsten Inert Gas) welding. Professionalism and craftsmanship still are, and will be, appreciated and essential in shipbuilding professions. Different skills can be decentralised, e.g. in welding the skills can be deepened but limited compared to traditional welder -> risks

Additive Manufacturing, or 3D Printing, will allow the manufacturing of complex component pieces from a 3D model with the same simplicity as printing on sheet of paper.

Additive Manufacturing is realistic and already implemented.

Coming to the industry in few years and impacts the shipbuilding profession, Virtual Reality will allow the development of a ‘digital twin' or ship 0 to be created and fully explored ahead of physical construction. Augmented Reality will allow workers easy access to all the information about any specific component. Virtual modelling and AR /VR solutions in e.g. digitalized instructions, blueprints, reporting, timesheets. Virtual Reality, Augmented Reality can be helpful in monitoring, inspections and useful in trainings.

Data Mining will allow the extraction of meaningful information from a large amount of data (big data) generated in the horizontal and vertical integration of Shipyard 4.0.

The Internet of Things will connect all Shipyard 4.0 stakeholders: people, products, and facilities within the physical shipyard or around the world. This could include geographically disperse supply chains or allow the connection of shipyards.

The Internet of Things consists of the communication internet, the logistical internet and the energy internet and is therefore a combined network on Meta level. In the Internet of Things, information is exchanged between devices, sensors, networks and systems

Data is processed and utilized to an increasing extent at different levels of business. Data analytics has an important role to play in the benefits of the industrial internet. In some companies, data analysis expert can be own specialist staff, understanding the IoT processes is needed.

The secure cloud will remove the borders for storing, computing, and exchange existing information. Cybersecurity will ensure the protection of all information. Cyber cloud and cyber security are real challenges in company level.

Virtual modelling will optimise the ships and their systems' configurations in advance as well as simulating the production processes required for their fabrication. The digital twin will be the cornerstone of all the process along the whole lifecycle of the ships.

Virtual modelling in blueprints is new skills what are needed in the future

Digital blueprints. Modelling need competence and understanding of IT technology, using mobile tools/devices (pads, smart phones etc.)

All of these measures will directly translate into a significant improvement of personnel health and safety, environmental protection, and an optimisation of energy consumptions. (Navantia, 2021)

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