ANDREW BREECE

Technology in the Boatshop

The state of the art

by Brendan Riordan

You don't need to be proficient with computers to be a boatbuilder. But for those with a bit of technical savvy, there are some fascinating technologies that can ease workflow in both professional and home-based boatshops. Three-dimensional modeling and rendering allow us to virtually see—and practically go aboard—a boat before we build it. Computer lofting allows us to draw its shape and print it full-sized. And robotic routers allow us to cut out its parts to an incredible degree of accuracy. The aim of this article is to shine a light on these and other computer-related technologies applicable to wooden boat building. None of these concepts are truly novel; rather, they are proven methods that are currently trickling from the large sophisticated shops into smaller ones.

Some readers will view these technologies as part of a continuing and unwelcome encroachment of mechanization into areas hitherto reserved for hand tools and expert craftsmanship. There's no arguing with that, since incorporating computers into your work does indeed displace some time-honored skills. But I believe the loss is replaced by a different sort of skill and proficiency that can be elegant and satisfying in itself. I'm fascinated with these technologies, and believe we've only just begun to understand the many different ways they can be used.

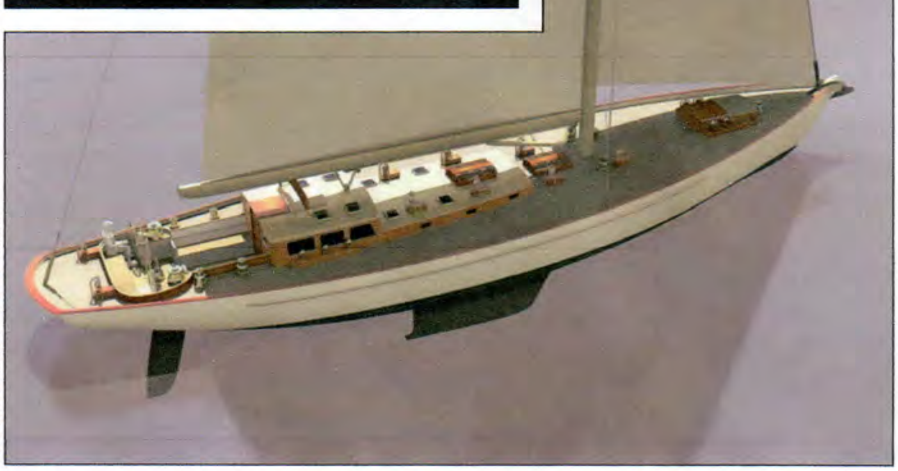
3-D Modeling and Rendering

Leading designers and builders employ three-dimensional (3-D) modeling for a range of applications, from the

Above—**Technology has arrived in in the traditional boat shop. From measuring to cutting to recording to rendering, computers can increase accuracy and speed. In the photograph above, David Cockey is recording the hull shape of a Pulsifer Hampton motor launch using photogrammetry (see page 82).**

ROCKPORT MARINE

ROCKPORT MARINE



STEPHENS WARING YACHT DESIGN

Recent advances in computer rendering allow designers to create lifelike images of yet-to-be-built boats. In addition to being powerful sales tools, such images can also indicate where a design in progress might be altered.

design and evaluation of complicated piping and mechanical systems to clarifying structural arrangements not well detailed in the architect's plans. In fact, some of the most compelling uses of 3-D modeling in marine manufacturing yield useful results while having no physical output at all. In some of the larger yards it is not uncommon to find a project manager and a systems engineer looking over the CAD/CAM operator's shoulder at a 3-D model on the computer screen. They might be looking for space in the machinery compartment for the refrigeration compressor that doesn't fit where it is shown in the plans, or coming to terms with the fact that there is a hanging knee where the water-lift muffler is supposed to fit. In these cases the information might never leave the screen, but it might identify a problem early in the construction sequence while there is still time and space to do something about it.

Of the many uses for computer modeling that do not lead to a physical output, one of the most compelling is being able to communicate with a client by means of renderings. Three-dimensional rendering is nothing more than a stylized—and sometimes convincingly realistic—presentation of geometry that was prepared while designing the boat. It's rare that 3-D renderings are prepared *exclusively* for presentation purposes; rather, they result from the foundation work done in the laborious design phase. But designers and builders are using the tool more and more to communicate with prospective clients in order to secure work. These renderings are done with software containing libraries of different materials and textures that can be applied to any surface of the model. The software can also create sources of light to simulate the complicated interactions between light and shape.

The cost of a set of renderings can run from several hundred to several thousand dollars. Much depends on how much digitized geometry already exists for the boat in question, and how much detail is required in the images. An experienced operator will know that in order to fit the entire boat in the image, the "camera" will be so far away that it is a waste of time and money to model, say, the seams in teak decking. On the other hand, if close-up shots of certain details are needed, the operator must execute the geometry and apply materials accordingly in order to maintain a convincing level of detail. Once this groundwork has been done, any number of images from various perspectives are possible.

An inexpert rendering can do more harm than good, but a well-prepared one can start you on the path to a successful project. Well-done renderings of wooden boats require familiarity with both the software and the boats themselves; incorrect wood-grain orientation or too thin a coaming can spoil the effect of an otherwise convincingly detailed image. The number of skilled technicians is increasing, and the quality of their renderings is improving. The images accompanying this section are a few of my favorite examples of well-executed marine renderings.

Computer-Aided Design and Manufacturing: A Case Study

In 2010, the restoration of the 83′ Fife schooner ADVENTURESS was nearing completion at Rockport Marine. The majority of the design questions had been answered, but the yard's in-house designer, Sam Chamberlin, faced the formidable challenge of designing the yacht's wood-shelled, bronze-sheaved blocks. The job had to be done quickly and done well, with simple interchangeable parts and minimum size variation among blocks. The blocks also required a high level of finish. Sam and his colleagues decided that the best course of action was to execute a custom design that required hand finishing but would also benefit from the consistency, repeatability, interchangeability, and manufacturing speed of automated computer-numerically controlled (CNC) manufacturing. In other words, the cutting would be done by a robot.

Knowing there could be dramatic repercussions if a block carried away aloft, the design team decided against using castings. It was too difficult to monitor casting quality, given the potential for voids or pockets to form in the molten metal. Fabrication was an option, but it was difficult to obtain high-strength bronze stock of the required thicknesses, and the in-house fabricators and machinists already had more work than they could handle. The designers explored purchasing and subcontracting but could find nothing in the marketplace that met their quality and consistency standards, and there was no one who could commit to the tight schedule. In the end they decided that CNC-milling the blocks' straps from solid billets, or bars, was the best course. On the one hand it was painfully wasteful of material, with a lot of it ending up on the floor as bronze shavings. On the other hand the parts would be identical, interchangeable, of a consistent finish, and ready before launching, with time to spare. In this case, delivery date, quality, and consistency were more critical than cost.

Sam created a comprehensive spreadsheet showing every block, noting its location, function, quantity, shell size, sheave size, number of sheaves, rigging diameter, strap type, and attachment fitting. Working closely with the spar-building crew, he settled on only three different shell sizes. In some cases the turning blocks on deck would be affixed without a shackle and attached directly to an eye-bolt. The strap widths were therefore limited by the inside diameter of the eyebolt. Elsewhere straps would need to protrude beyond the shell far enough to accommodate a ⅝″ shackle. Sam then set to work computer-modeling the three sizes of blocks, using Scan&Solve finite-element analysis software to evaluate the strengths of various pieces. He refined the dimensions in an iterative design process (that is, refinements based upon prototypes) aimed at a final product that would be strong enough for the task without being unnecessarily heavy. When the strap designs were complete he modeled the shells, the sheave pins,

The Cutting Edge

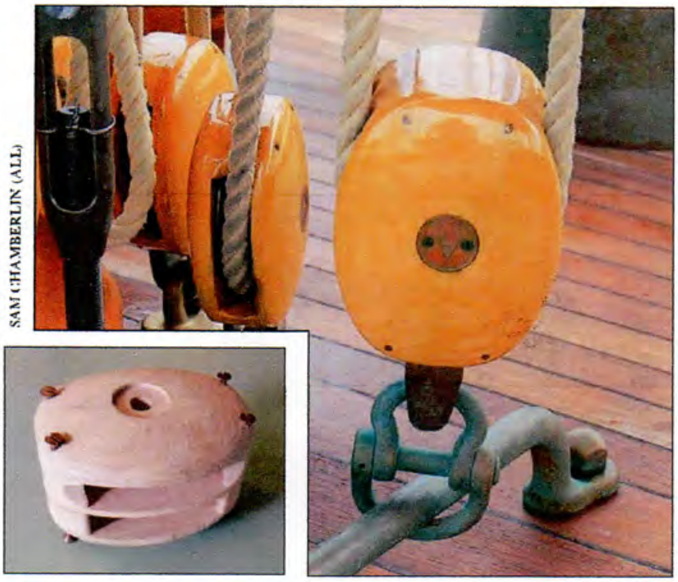
In the early 1960s, a communication studies professor named Everett Rogers published a book called *Diffusion of Innovations* that advanced a new theory about how technology spreads throughout our society. Rogers presented a typical bell curve. On the left he placed the group of people who provide the initial enthusiasm for a new technology and labeled them "innovators."

I was reminded of this study on a recent visit to Brooklin Boat Yard (BBY). After spending more than a decade in the design office at Rockport Marine, I had collaborated, sailed, and shared occasional beers with BBY owner Steve White and project manager Eric Blake. I had always thought of Brooklin and Rockport as similar places and was therefore unprepared for the tour of a recent project here. I had never seen anything like the boat they were building, and was completely floored by the collaborative process among designers, client, and builder.

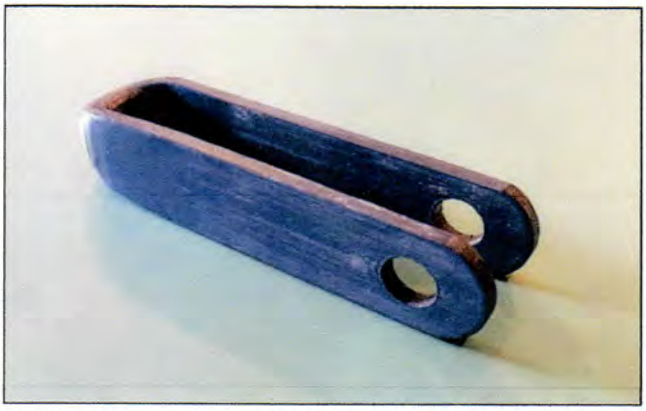
The boat is the product of two architects operating in very different worlds. Frank Gehry, a renowned architect of land-based structures, developed the boat's style—one in which, like the undulating sculptural forms of his buildings, decidedly does not follow function. On the other hand, the boat had to sail well, so its overall shape, rig, and sailing elements were designed by German Frers.

BENJAMIN MENDLOWITZ (BOTH)

The 74′ sloop FOGGY was a design collaboration between naval architect German Frers and building architect Frank Gehry. Computer rendering, 3-D printing, and computer machining made the engineering and construction possible.



SAM CHAMBERLIN (ALL)



The parts for the wood-cheeked blocks of the schooner ADVENTURESS were cut and milled using computer files. 3-D-printed prototypes allowed for a slight adjustment to the design before the identical parts for 100 blocks were manufactured.

and the "coins" let into the sides of the shells to secure the pins.

Anyone who has ever disassembled a half dozen traditional Merriman blocks for maintenance and then tried to put them back together again will understand why, with over two hundred blocks to build in a very short period of time, it was critical that the parts be interchangeable. Straps, pins, shells, and coins had to be tested for fit—and perhaps modified—before committing to an entire production run. Making the prototypes, however, was a challenge: Each machine shop they consulted would have required expensive setup time, and to keep things affordable this would have to be spread across an entire production run.

Three-dimensional printing provided the solution. Toby Kenniston of Kenniston Machine in Rockland,

The word spectacular came to mind. Deckbeams having variable camber, curving both athwartships and fore-and-aft, shared space with lattice-like skylights. Similar lattice-like portholes, each one unique, were cut into the hull. Unlike the blocks for the schooner ADVENTURESS described above, nothing in this boat was standard or interchangeable. Some of the metalwork was titanium, executed with a 3-D printer. I imagine many sailors who encounter this boat and the extensive use of advanced technology to achieve its unconventional aesthetics will ask "why?" As a designer, I was more focused on the "how."

During my visit, the Brooklin team was coming to terms with a Gehry-office request that the cabin sole carpet be made of a single piece, bow to stern. There was more than a little head-scratching as to whether the office fully understood the extent to which every cubic inch beneath the sole had already been filled with mechanical systems that would need to be accessed for maintenance and eventual replacement. But that snag highlighted for me the most astonishing part of the project: the information flow that had developed between the design office and the builder. The designers had involved the builder to a degree I had never before encountered. Designer and builder regularly shared renderings for various components, such as the bowsprit and the twin custom helms of Seussian shape and angles. For many of these unique items, the builder was sent only a concept sketch, then left with the responsibility of the engineering and final design. The boat is, indeed, a spectacular showcase of what's possible. Whether you find it odd or beautiful, there's no debating that it is eye-catching and breathtaking.

Over the years, Steve and his crew have acquired a reputation as experimenters and ready partners for clients and designers who would expand our definition of what wooden boats look like. From their experiments in refining cold-molded and wood-composite vacuum-bag laminate construction techniques, to incorporating computer modeling, lofting, and CNC tools into their construction processes, BBY has been an industry leader for a long time. With complicated structures that are precision-cut with high-pressure water jets, and components that are 3-D printed in titanium by The Boeing Company, this latest project places them among Professor Roberts's technology innovators as never before.

If all of this seems irrelevant to the average builder, that's largely because it is. Some of these technologies are still beyond the horizon—but only for now. Small shops and backyard builders may not have the budgets to approach a company such as Boeing. But what happens as these cutting-edge advances end up within our reach? What will we be creating in our garages and basements? I imagine it will be spectacular.

—BR

Maine, said that if Sam and the crew could use 3-D printed parts to evaluate the prototypes, his milling machines, using the same digital files as the 3-D printers, would match the 3-D printed parts exactly—meaning it would be hard to find any deviation even with a dial caliper. So Sam e-mailed the data files for the wooden shells to Tim Marchetti of CNC Routing and Design in nearby Camden. He uploaded a second set of data files to RedEye (www.redeyeondemand.com), a subsidiary of 3-D printing leader Stratasys. Within a week he received prototype parts back from both. Upon evaluation the parts were almost perfect, but once the wood shells received the customary 12 coats of varnish, the fit of the straps was too tight. Sam increased the width and depth of their slot in the shells by a few thousandths of an inch and released the items for production. There was still plenty of work to do. The milling tool finish on the straps was surprisingly smooth, but a few that would clearly be in view on deck would have to be polished. Once the wooden shells arrived they would need sanding and varnishing. Just assembling 200 blocks takes lots of time, but the job would go more easily now because every piece was an interchangeable duplicate, guaranteed to fit.

Cloud Computing

What we call "The Cloud" is nothing more than buildings full of large and powerful computers configured to communicate as much and as fast as possible with the rest of the world. Apple, Microsoft, Google, and Amazon have built such computer banks all over the world, but smaller lesser-known companies are also turning to cloud computing. In some ways cloud computing is a return to the earliest days of corporate computers when entire buildings housed mainframe giants less powerful than today's handheld calculators. Today's number-crunching monsters are available to anyone with an Internet connection and are capable of executing a dizzying array of tasks.

Asking what cloud computing can do for you or your business is a little like asking what you can do with a pattern or jig: With the rapidly growing number of services it's less about what is possible and more about what needs doing. In fact, many readers who might not know it are already cloud users. If you get your e-mail on a smartphone, you're already there. But cloud computing is about much more than e-mail. Let's say you want to store your data files securely, access them easily from anywhere, and easily share them with others. You can do this easily and for free—or for a nominal sum if you need lots of data storage. The companies offering this service may already be familiar to you: Dropbox, Google Drive, iCloud, Cloud Drive, One Drive, and others.

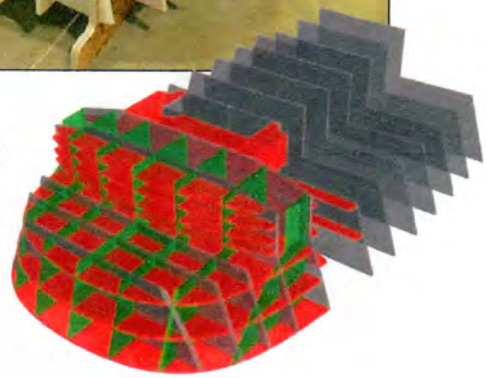
The names I've just listed are the biggest players in the market, but more will come. These folks want your digital data. They want your spreadsheets, your photos, your marketing brochures, your e-mail archives, all of it. It turns out that once you get past the privacy issues—a tough one for a lot of people—there are some compelling reasons to give it to them. Counterintuitively, one of the biggest reasons is data security. The little whirring hard drive or solid-state drive inside the box under your desk is infinitely more likely to burn, flood, be stolen, or otherwise cease to function than the facilities operated and constantly maintained, upgraded, and secured by the world's largest companies. As horrific as a fire would be for most small boatyards, the complete loss of all of your data and records might be the hardest part to deal with. Such a loss is far less likely if you move your data from the server closet in the hallway to a world-class facility run by a multibillion-dollar company bent on keeping your data safe and secure.

The most significant benefit to storing your data in the cloud is that you will have access to it wherever you happen to be. Imagine a potential customer at a boat show stopping to talk with a builder about a particular boat, but the builder didn't bring that boat this year. He brought his iPad, though. With one touch, he can access his Dropbox account and open a whole folder of launching photos. The client explains that she'd love to show these pictures to her husband but he couldn't come to the show this year. So the builder clicks "share folder" and passes her the iPad so she can enter her husband's e-mail address. After the builder adds a brief note of introduction, his new client receives an invitation to join a folder. Seconds later he joins the folder and is reviewing pictures of his next boat. Only a few years ago, the builder would have handed over a business card and asked the customer to visit his website.

Such file sharing is more than a sales tool; it can also ease communication during construction. Imagine this: A project is hitting snags. The clients have multiple change orders. The architect's drawings aren't arriving on time—and when they do they have errors. This flurry of information is arriving by e-mail, and keeping track of it is a nightmare. Dropbox can clarify things immensely. The first step might be to upload all of the architect's plans, the latest versions going into a folder called "Plans Released for Construction" and all the older ones going into another folder called "Plans Archive." The owner and his wife, three subcontractors, and the interior designer are all invited to join the folder, and the architect is

Cloud computing, which gives multiple users access to files, greatly eases communication and organization of product details. The files shown here are shared, via Dropbox, among the builder, designer, interior designer, and owners.

made responsible for moving the old drawings to the archive when a new one is posted. When this happens, everyone in the group gets a notification from Dropbox indicating how the contents of the folder have been modified, when, and by whom. A "Schedule of Finishes" spreadsheet is added, and from now on when a fabric gets changed, the spreadsheet is altered and everyone knows about it. A similar "Interior Examples" folder shared among the group will eliminate a great deal of correspondence and allows the owners and builders to simply pop in and take a look now and then just to make sure that the interior budget is still on track. A "Change Order" folder is likewise shared among the builder, owners, and designer. Now they will be alerted when the project manager uploads the labor and material charges associated with any changes to the contract. There is no longer any confusion about where to go to get the latest information.



Computer lofting and cutting allows for the precise construction of components that can be built off-site and transported to the boat for installation. The jig above is for the cockpit of a 36' sailboat.

Lofting Mylars and Molds

Computer-lofting a boat is quite similar to lofting a boat on the shop floor. If it's an old design, you might assign a point to each position listed in the table of offsets. If the lines plan is available, it's usually easier and quicker to scan the plan and trace the lines in your preferred software program, making note of whether the lines are to the inside or outside of the planking. Once each line on the plan has been traced, the curves are rotated or otherwise manipulated in your preferred 3-D modeling software (Rhino, Multisurf, Maxsurf, Inventor, Fastship Solidworks, Prolines, etc.). The sections are then spaced out at the required interval. The buttocks are rotated to the vertical plane and shifted outboard to the appropriate spacing. The waterlines are located above and below the design waterline to their appropriate positions. You now have a three-dimensional lines plan with no hull skin.

At this stage the buttocks, waterlines, and sections will not actually touch at every intended intersection because in the process of tracing and then scaling up the architect's curves to full size, inaccuracies that were minor at scale have now, at full size, become noticeable. One of the purposes of lofting is to correct these errors, and the CAD operator may make these corrections (i.e., make the surface fair) now or do it at a later stage in the process.

Modeling software allows the operator to create a hull surface from the traced curves. The actual commands and underlying mathematics of this vary from program to program, but once a preliminary hull skin exists the operator can project onto that skin a grid of lines that corresponds to the spacing of waterlines buttocks and sections. These projected contours may then be compared with the original curves. At this point the operator must go through some trial and error to arrive at a final product that is both fair and faithful to the designer's original plans.

Moving the hull skin to the inside of the planking

HEWES & CO. (THIS PAGE)

Accurate lofting and cutting of molds has eliminated the need for hand lofting in many shops. At left is the entire framework of the 26' powerboat REMBRANDT cut by Hewes & Co. of Blue Hill, Maine.

allows the shapes of molds and permanent bulkheads to be determined, and notches made in them for structural elements. Finally, any notations or indexing lines are added before the pieces are printed full-size on Mylar or sent to the CNC shop for cutting. Experienced shops will be able to work directly with the 3-D data file to cut the bevels on the edges of molds and bulkheads.

The builders and designers I've spoken with say that the biggest difficulty they encountered incorporating computer loftings into their construction programs was convincing the crew to trust the information. When a person works with Mylars it can be tempting to "leave the line" when you cut out molds, and to trim them up by hand. The CNC router exhibits no such timidity. Conversely, the machine does not have a skilled builder's ability to identify obvious errors. Properly prepared, a computer lofting that results in CNC-cut bulkheads and molds represents one of the few technological developments with the potential to improve speed, quality, and cost all at once. Not surprisingly, many leading boatbuilders have been using this technology for several years.

Recording Hull Shape

Whether you are interested in recording the shape of an existing boat for your business or for the benefit of posterity, advancements in photogrammetry and laser metrology (the science of measuring) are rapidly changing the way it is done. Not long ago, the best practice for recording a hull shape was to accomplish the job with strings, levels, rules, and tape measures. Now, the tools of choice are cameras or lasers.

Photogrammetry is the science of making measurements from photographs. Useful for a great many applications, it is exceptionally well suited to the precise recording of surface geometry. While specialized camera equipment was once required, these days most people with a tablet computer or smartphone already have the technology they need to accurately record the shape of a sailboat or powerboat.

I recently watched the process in action as engineer and photogrammetry technician David Cockey recorded the hull of the much-beloved Pulsifer Hampton motor launch. He used a mid-range digital camera on a tripod and chose a wide-angle lens to suit the confined shed. He and several volunteers placed adhesive targets at about 18″ intervals all over the hull before taking the photographs. After transferring the resulting photos to his computer, David employed Photoscan by Agisoft (www.agisoft.com) to develop a dense data set of individual points—a so-called "point cloud." He then used Rhino (www.rhino3d.com) to create 3-D surface geometry corresponding to the point cloud. Once the computer model was complete, David sent the files to Hewes & Co., where a three-axis router milled out a scale half model. A lines plan, table of offsets, Mylar patterns, and CNC molds and bulkheads could have

Laser scanning allows for the accurate measuring of full-sized hulls. It also allows models to be measured and scaled up, for the preparation of construction drawings.

BRENDAN RIORDAN

been produced at this stage, as well.

Autodesk recently launched a free cloud-based "SaaS" (software as a service) called 123d Catch (www.123dapp.com/catch). Users employ a free app to upload photographs from a smartphone or tablet to Autodesk servers, after which the program develops 3-D geometry from the images. For users who require a lines plan or table of offsets, advanced processing is still required by someone familiar with third-party modeling software. Still, small boatyards and backyard builders will soon be able to take a couple of dozen photographs and send them to a subcontractor and request a quote for a lines plan or a CNC-carved half model. Unlike the makers of Photoscan, Autodesk reserves the right to do what they choose with any photos you upload, raising interesting copyright infringement questions. As ever, think carefully about how your information might be used, and by whom, before you upload it in this way.

Laser scanning technology is expensive relative to photogrammetry. It is also more accurate, with varying levels of precisions—and price. I have yet to come across a marine application that requires the $^{6}/_{10,000}$"

precision achieved by the high-end devices. Even the $\frac{1}{100}$" accuracy of an average laser scanner is more than adequate for every application I can think of, and the $\frac{5}{64}$" tolerance achieved with the comparatively crude hand-held versions is probably sufficiently precise for most small shops.

Unlike photogrammetry, laser imaging is not sensitive to texture, color, or reflectivity of the surface, so there is no need to paste little paper targets all over the hull—a part of the previously described photogrammetry process that is comparatively low-tech and labor-intensive—and thus, expensive if a crew of volunteers isn't available to apply and remove the targets. Photogrammetry is a relative measurement system open to the potential for

Photogrammetry has been in use for years, and the basic technique predates computers. But powerful computing capacity has increased both the speed and precision of this hull-recording technique.

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Bill, fourth from right, with his classmates and the whaleboat they built for the Charles W. Morgan whaling ship.

Pictured here at Ashmar Boat Works, Bill has made his dream come true. A US Army veteran of the Iraq war, after graduating from GLBBS he apprenticed at Chesapeake Maritime Museum before joining Ashmar.

"GLBBS gave me what I needed to finally do something every day that I love doing, building wooden boats. The staff is the best group of people I've ever known. Though there is always room for learning, they ensure that when you graduate you will have a solid foundation on which to build and grow. I've never been happier." **Bill Bronaugh, Class of 2013**

"Bill is a real credit to GLBBS, both staff and instructors. He is proof that the program they have developed works by providing the industry quality people to carry us forward." **Mike Amory - Ashmar Boats, Cambridge, Maryland**

CLASSIC WOODWORKING

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LES CHENEAUX ISLANDS, MICHIGAN 906.484.1081 WWW.GLBBS.ORG operator error when scaling the measured geometry in the modeling software. Laser scanning records true distance and scale as part of the measurement process.

If accuracy within 2mm will suffice, compact tripod-mount and even handheld laser-imaging scanners are available for indoor or outdoor target-free measurement. At just over 10 lbs the tripod-mount version is almost as compact as a transit level. The unit must be at least 2′ from the object, but accurate measurements up to 1,000′ away are possible. For small boats or in confined spaces, a handheld scanner, though slower than tripod-mount models, can be used with or without applied targets for an accuracy of plus or minus 1⁄16″. This all comes at a price: Handheld models cost $14,000 or more, which is outside the budget of most small boatyards, but there are companies that can measure a hull and produce a 3-D model for a reasonable fee; the resulting data can serve as the basis for the development of a lines plan, a table of offsets, CNC-cut files, or a half-hull model.

Boats and models can also be taken to the laser. For example, the University of Maine's Advanced Manufacturing Center (umaine.edu/amc) recently used a Faro laser arm scanner to record a model carved by Peter Kass of Johns Bay Boat (see WB No. 227). Their goal was to create a computer model to inform a decision about potential hull modifications that might be required as structural and mechanical-system weights were altered. The Faro Edge Portable measurement arm with laser line scanning probe can be used for documentation of as-built geometry, quality control, or reverse engineering (aka "lines taking"). The technology is not sensitive to surface texture so no target placements are required, although there are size limits to what the unit can scan. Accuracy to within 25um is possible (a piece of Scotch tape is about 38um thick). The probe has to be perpendicular to the surface for best results, which can be tricky with large objects.

We are only just beginning to understand the many ways we will use these various technologies. When I was learning about boatbuilding years ago, it took me a while to realize that there was an awful lot I couldn't learn from books and how-to articles. I had to pick up the tools and start using them. That was when things started to make sense. So it is with the technologies I've described here. As we learn to use them, and push their boundaries, we will, in the process, redefine what it means to be builders of wooden boats (see sidebar, page 78).

Brendan Riordan spent a decade in the design office at Rockport Marine. A frequent WoodenBoat *contributor, he is currently pursuing his technology interests in the world of biotech device development.*