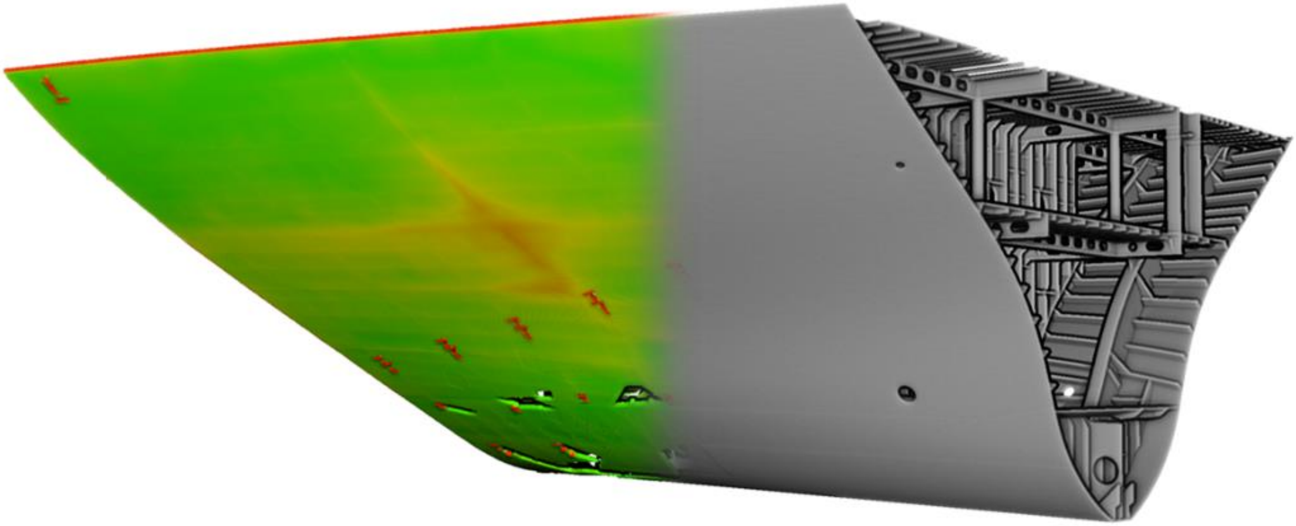
GUIDELINES FOR 3D DOCUMENTATION OF SHIP BLOCK GEOMETRY

A process description



GUIDELINES FOR 3D DOCUMENTATION OF SHIP BLOCK GEOMETRY

A process description

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This guideline has been produced as part of ECOPRODIGI project which has been funded by the EU Interreg Baltic Sea Programme. The objective of the project has been to increase eco-efficiency in the Baltic Sea region maritime sector by creating and piloting digital solutions in close cooperation between industry end-users and research organisations.

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1. Introduction

There is an ongoing digitalisation revolution in all but every industrial sector. The maritime and shipping industry is no exception, and its companies need to implement new technology to strengthen its competitiveness and improve its operational performance. Shipyards are one of the core entities of the maritime industry and produce assets valued up to hundreds of million Euros. While there are already many areas being transformed through digitalisation, oftentimes the sub suppliers located upstream in the value chain are being digitalised to a lesser extent. This guide strives to enabling shipyards and their sub suppliers to utilise spatial digitalisation to make their processes be faster, more transparent, and more effective while simultaneously benefiting the downstream value chain actors.

This document is meant to be used as a supplement when formulate the agreement between a customer shipyard and a manufacturing shipyard. It also acts as a guide for shipyards wanting to utilise spatial digitalisation by detailing the methods and requirements for the implementation of 3D measurements of ship blocks in the manufacturing and assembly phase. 3D documentation can increase transparency between suppliers and customers while providing rigorous quality control and ensuring producibility in the assembly stage. Using the methods and tools in this document allows the manufacturing shipyard to collect and process 3D measurement data of the block in a quality assured and efficient manner. It also details how this data should be formatted and shared with the downstream recipient, the Customer Shipyard, where it can be used for quality assessment and digital planning and verification of subsequent manufacturing stages. This way of working with a digital value chain increases transparency between the stakeholders and generates neutral and objective data on the product that provides a fair and just quantitative measure on the delivered product quality, pertaining to geometry fulfillment.

Figure 1 depicts the value stream and several activities between the shipyard customer and shipyard manufacturer described above.

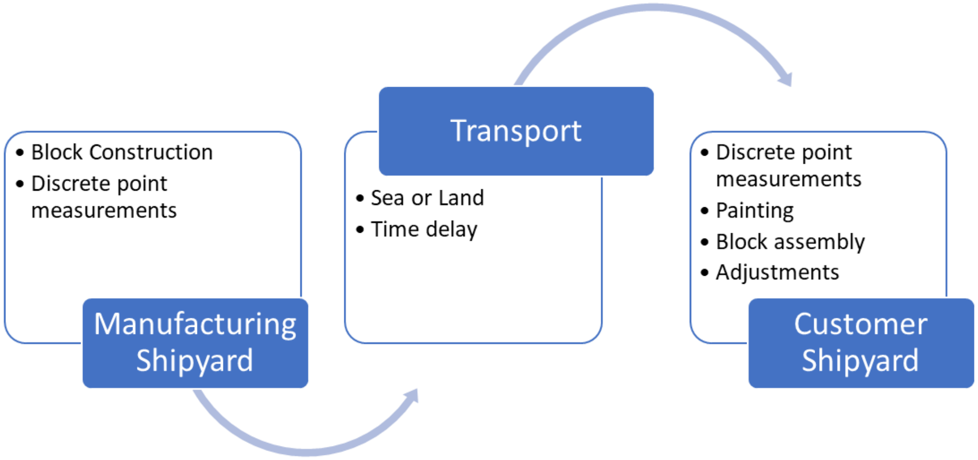

Figure 1 Product flow and activities in the value stream between manufacturing shipyard and customer shipyard for blocks.

At the manufacturing shipyard there is the construction of the blocks and a measurement activity to take some control points. This is reported as a measurement protocol and forwarded to the customer shipyard. The block is then transported to the customer shipyard, typically by sea. Once received, there is another measurement activity using total station to verify the geometry by defining a set of discrete points and planes. The alignment process must be repeated at the start of this measurement process so the measurements are expressed in the ship's coordinate system and can be compared to the nominal values of the master drawing. As there is often time constraints and the block must be moved onwards in the process to carry out for example painting and outfitting activities there is only limited time and resources to redeem any identified defects.

This document proposes the addition of two main components to the existing process described above. These are a) the use of 3D laser scanners to collect more holistic geometry data of the blocks, a geometrical digital twin of sorts, and b) establishing a coordinate system on the block using physical references already at the manufacturing shipyard. The benefits of this workflow would be to reduce time spent on measurements at the customer shipyard along with early detection of defects and creating the heads up in time needed to plan and allocate resources for fixing them before the final assembly stage onto the main hull. Figure 2 shows the intended new value stream that has been expanded to include the digital delivery of the block in parallel with the existing physical value stream.

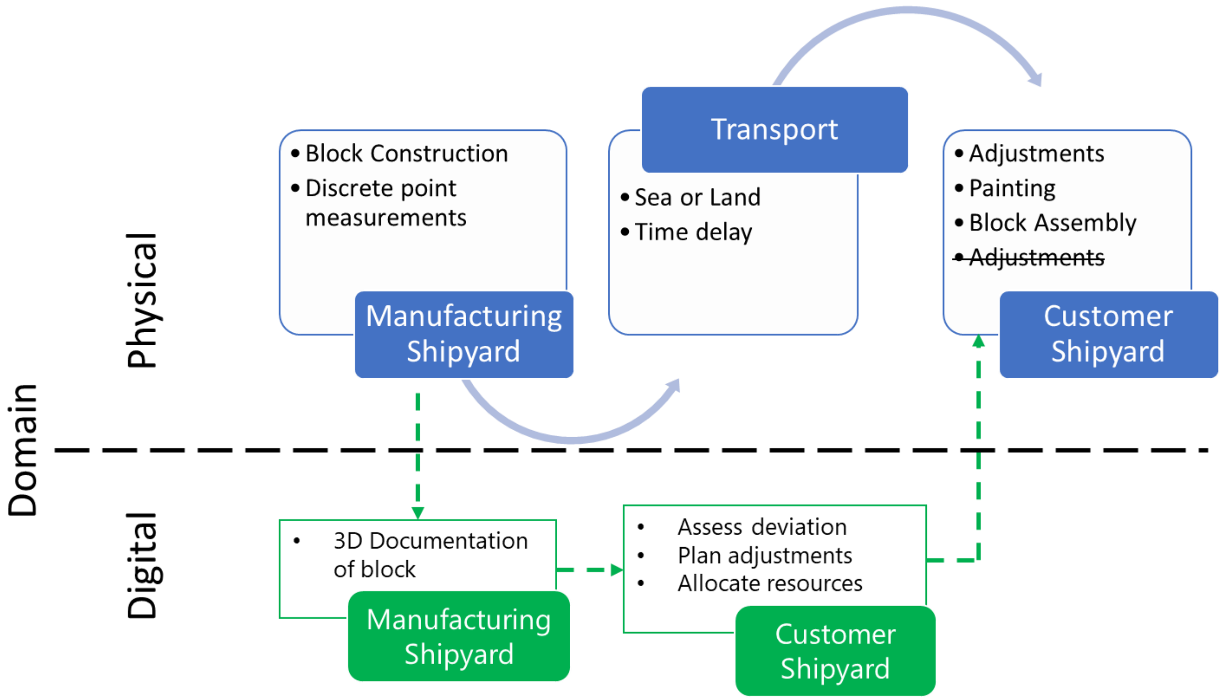

Figure 2 Proposed new workflow including establishment of physical references in ship coordinate system and digital twin delivery ahead of the physical delivery.

Based on empirical data the measurement work at the customer shipyard can be reduced by up to 80% and the possibility to plan ahead for repair work reduces both over time cost and increases the ability of shipyards to detect and handled defects prior to the hull assembly phase. This can significantly improve the working conditions and reduce both the time needed to do the repairs and sometimes eliminate the need to cut open access holes in the outer hull.

1.1. Definitions and Stakeholders

The following lists contain definitions used throughout the guidelines and descriptions of the stakeholders that have been identified in connection to the processes and value streams within the scope of this project.

Definitions

3D documentation	to perform measurements with a 3D laser scanner or total station to digitize the spatial properties of an object (the measurand)
Accuracy	*(of measurement)* closeness of the agreement between the result of a measurement and the value of the measurand, i.e. the real-world artifact
Alignment	transformation of measurement data to a defined coordinate system, here the *ship coordinates* (X, Y, Z)
Level of detail	level of detail (LoD) for digitization, which can be defined per area or feature
Primary grid	set of *surveyed references* in the area surrounding the block or on the block itself that have been defined in *ship coordinates* (X, Y, Z)
Repeatability	closeness of the agreement between the results of successive measurements of the same measurand
Secondary grid	set of temporary references that are used during a measurement job to complement the *surveyed references* in the *primary grid*
Set out	using measurement systems to mark given layout coordinates in the physical environment as references during equipment installation
Ship coordinates	the coordinate system (X, Y, Z) defined in the ship construction drawings
Surveyed reference	artificial reference point for 3D measurement that is permanently mounted in the area surrounding the block or on the block itself and has been defined in the *ship coordinates* (X, Y, Z)

Stakeholders

Manufacturing Shipyard	shipyard that are manufacturing the block steel structures
Customer Shipyard	the downstream shipyard that is ordering blocks
Classification Society	entity responsible for making sure that the ship and its components are fulfilling demands related to safety and seaworthiness
End Customer	ship owner, the end customer who will be operating the vessel. Concerned with all aspects of build quality and cost

1.2. 3D Laser Scanner

A 3D laser scanner, or terrestrial laser scanner, is an active non-tactile measurement instrument used in a wide range of applications. Examples include terrain, infrastructure, buildings, crime scenes, factories, and products. The technology is based on articulating a range laser on a well-defined path around the instrument while recording the direction and distance travelled by measuring the reflected laser light and the position of the articulating mechanism. The most common type of 3D scanner uses a rapidly rotating mirror to direct the laser light on a circular path around the instrument while simultaneously rotating 180 degrees around its vertical axis. Most modern 3D scanners also house an RGB sensor which can provide optional color data for each 3D point measured. The positional accuracy in the collected surface measurements is often ranging from one to a few mm.

To measure an object holistically the instrument must be positioned in a series of locations around the object. This introduces the need for registering, or aligning, different data sets to one common coordinate system. The process of registration can be carried out using overlapping measurement data of static artifacts captured in the different data sets. These artifacts can be already existing in the scene, such as the object itself or its surroundings, or they can be artificial reference objects in the form of checkerboards or spherical targets that are placed strategically in the scene to ensure they are overlapped by measurement from several or all of the data sets. Figure 3 depicts two types of artificial targets used for registration of data sets captured using 3D laser scanners.

Figure 3 Artificial reference targets used when 3D scanning: (left) Spherical target and (right) Checkerboard targets

The data resulting from one or more captures using a 3D laser scanner is often called a point cloud. It is a collection of points, each represented by an X, Y, and Z coordinate, and possibly also color coded as R, G, and B values. Additionally the intensity of the returned laser light can be stored and used for rendering a grey scale if no RGB data was captured, the intensity is a measure of the amount of laser light that was reflected back into the instrument and often correlates with what the human eye sees as dark and light surfaces. The grey scale rendering can be seen in Figure 4 below, exemplified through 3D laser scan data of a bow thruster.

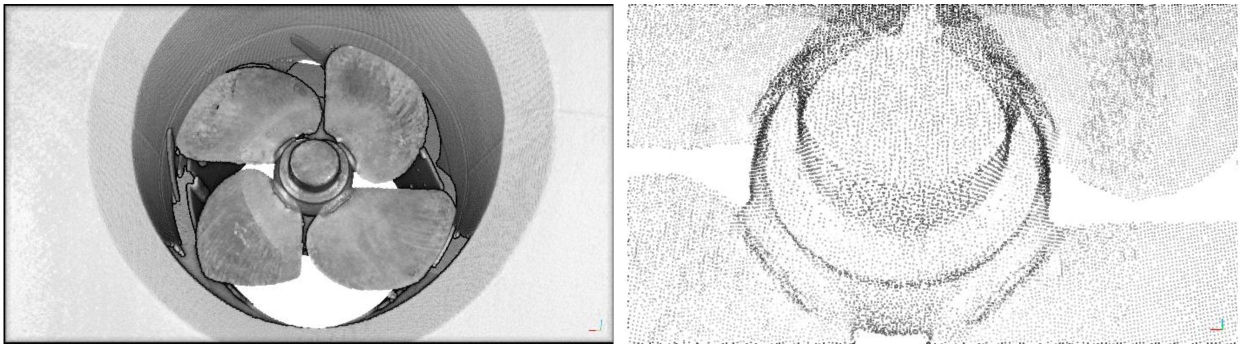

Figure 4 Rendering of point cloud data of a bow thruster captured using a 3D laser scanner: (left) viewed from a distance and (right) close up to show individual surface measurement points

1.3. Total Station

The total station is perhaps the most common instrument in mapping and measurement work related to infrastructure and buildings. It is a combination of a theodolite for angle measurements and range laser for distance measurements, in combination these make the total station capable of determining the relative positions of discrete points in space with high accuracy.

When conducting measurements using a total station the first step is to establish the instrument’s position in a known coordinate system. An example of a coordinate system is the national grid which exists in most countries to keep an unambiguous positioning system for i.e. property borders and infrastructure. Grids are typically accessed by well-defined reference points positioned throughout the area the grid covers. Establishing the instrument’s position in a known coordinate system can be done by positioning the station on top of a known coordinate reference point, or by placing it within line of sight of three or more known coordinate reference points and measure them to determine the stations position in the coordinate system. The latter option is called free stationing or resection and can be used when working with ship blocks by measuring known geometries on the block and using them to align to the ship coordinate system.

When the object of measure should be measured repeatedly, for example when it is being worked on and adjusted over time, the targets can be used for fast establishment of coordinate system. Then instead of starting over and measuring known features of the block or object and using those to establish the coordinate system, three previously measured targets can be measured and used for free stationing. Examples of targets used with a total station are given in Figure 5.

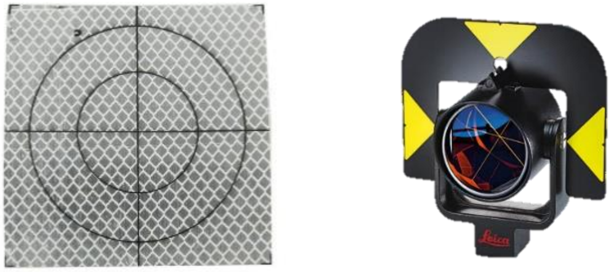

Figure 5 Examples of targets used in total station measurements: (left) Reflective target sticker and (right) Mountable prism target

2. 3D Documentation of Ship Block Geometry

This section details the 3D documentation process step by step. The main process has been divided into four main steps (as seen in

Figure 6); Establish Reference Grid, Perform Measurements, Process Measurements, Deliver Measurement.

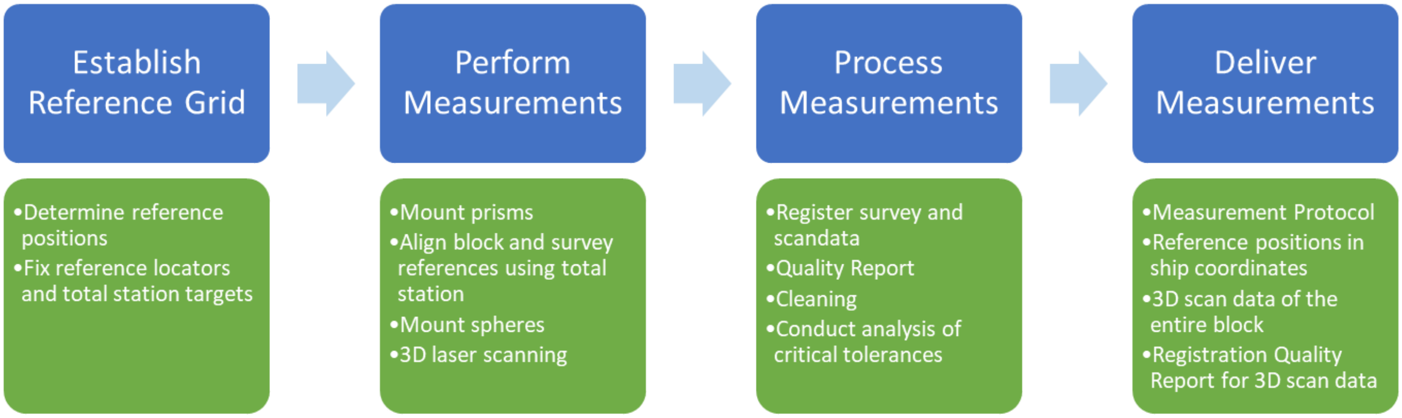

Figure 6 An overview of the Digital Value Stream including activities for each of the steps

These four steps and their contents will be presented in more detail below.

2.1. Establish Reference Grid

The first step in the process of 3D documentation of a block is to establish a connection between he produced block and the specification that it was built after, most often a 3D drawing. This connection is a spatial alignment of the produced block towards the 3D model coordinates, in essence the ship coordinates. This connection is realized by reference locators that are positioned onto the block and detected using measurement technology, either a total station or a 3D laser scanner.

Determining reference positions
The positions of these reference locators should be decided by the customer shipyard and advised on the block drawings. The locator positions should not interfere with the structural integrity of the block if fastened using a screw or weld seam nor should they be covered by later additions to the structure rendering them inaccessible.

Fix reference locators and optionally total station targets
For the total station purpose the reference locator and target can be one and the same in form of a reflective target sticker, as seen previously in Figure 5. There are also options for reference markers that have interfaces which allow to change targets between the prism used in total station measurements and the spheres used in 3D laser scanning measurements. Figure 7 shows a Traceable3D[1] precision washer reference locator, it is fastened using a 4 mm screw in the center and acts as an interface for mounting either prism or spheres with guaranteed repeatability.

Figure 7 Example of a Traceable3D precision washer, a physical interface to mount reference prism or sphere in the same position with repeatability.

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[1] https://traceable3d.com/

2.2. Perform Measurements

Measurements are performed to create the alignment of the block to ship coordinates, which is a prerequisite to comparing its as-built structure and geometry to that of the ship master drawing. The alignment is done using either a total station or a 3D laser scanner based on the requirements put forth by the customer shipyard. It is recommended that the person or team who is doing the measurements of a ship block should have the possibility to use both a total station and a 3D laser scanner during the same occasion to improve the reliability of the results.

The process is described holistically below but the practical work should be conducted in the following sequence:

1. Mount prisms (if total station is used)
2. Survey locators and align block with total station
3. Mount spheres
4. Perform 3D laser scanning

The alignment is done through 3-2-1 fixing of the block using reliable structures in both the fore and aft sections of the block. The reliable structures are first and foremost the keel, followed by the outer ends of the fore and aft where steel plates join and intersect. These structures are chosen as they are central to both the ship geometry and function. Figure 8 depicts the set of reference points and the block geometry separately. The process of alignment is to reference the block nominal geometry to the set of defined points that have been measured on the physical block.

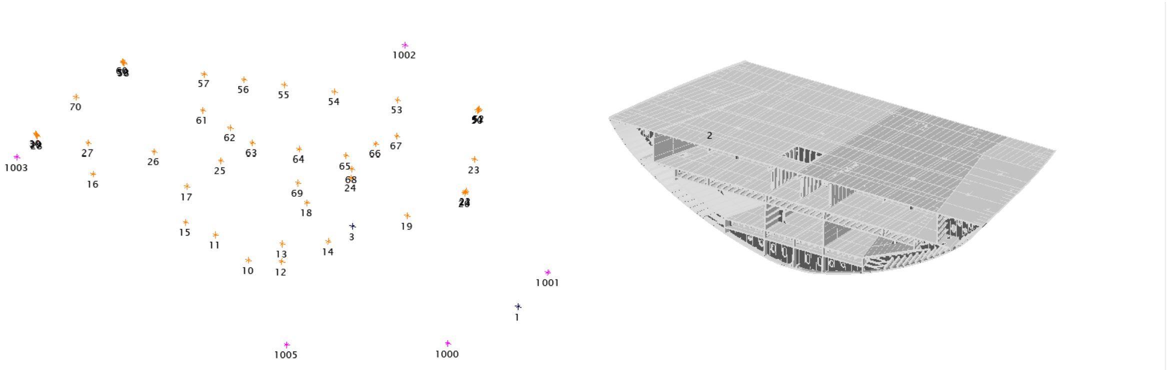

Figure 8 Left: Set of defined points in the block structure that are measured in the block alignment process. Right: Block nominal geometry as designed in CAD software.

As the alignment is done between a nominal model and the manufactured, as-built, version there will inevitably be some level of misalignment. Therefore, the most reliable structures should determine the alignment and the less reliable points are documented for the physical/digital connection and to determine deviations in the manufacturing. Figure 9 depicts an example alignment of reliable structure artefacts and CAD geometry, note the points marked as 1000-1005, these are external references fixed onto the structures surrounding the actual block and are used to improve registration of the data from 3D laser scanning and as known coordinate points to transport the total station between the aft and fore sections.

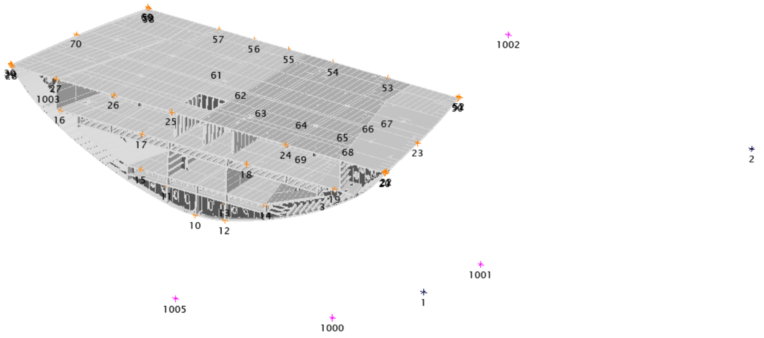

Figure 9 Virtually aligned reference points and nominal CAD geometry

The recommended alignment sequence of a ship block and its reference markers is as follows:

1. The intersection of the center of the vertical keel plate and outer surface facing down is used to define X-axis position and the Y-axis zero.
2. The aft side plate edges are measured at several places, spread over the aft to determine the rotation around Z-axis and lock the X-axis orientation.
3. The X-axis value is shifted to match the block location in the ship coordinate system.

The above sequence assumes that the block is leveled horizontally along the keels outer surface, the bottom of the block geometry. This is the case both at the build site and at the assembly site. If the block geometry is measured anywhere else, for example in buffer storage during transportation, extra care needs to be taken to ensure levelness of the data. The underside of the keel can then be measured both aft and fore to provide a correct rotation around Y-axis and the horizontal structures of the interior can be used to provide a correct rotation around X-axis. This should be considered a special instance of the procedure, to be used only when the block is temporarily stored before, during, or after transportation.

The main benefit of working with reference locators is the ability to have repeatability in measurements over time. Once the references have been defined, they can be re-used to position measurements into the ship coordinates instantly. The references, regardless of type, should be possible to mount interchangeably in the same position using a fixed interface which is fastened onto the block geometry. One solution for this is using the round washers shown previously in Figure 7 with magnetic connectors. The washer is fastened onto the block or surrounding structures and the reference object is then fastened onto the washers using the magnetic connector.

Mount prisms and spheres

The prism and spheres are mounted on the same reference locators and thus cannot be mounted simultaneously. Figure 10 and Figure 11 show suggested mounting schemes for first the prisms and then the spheres using the same reference locators.

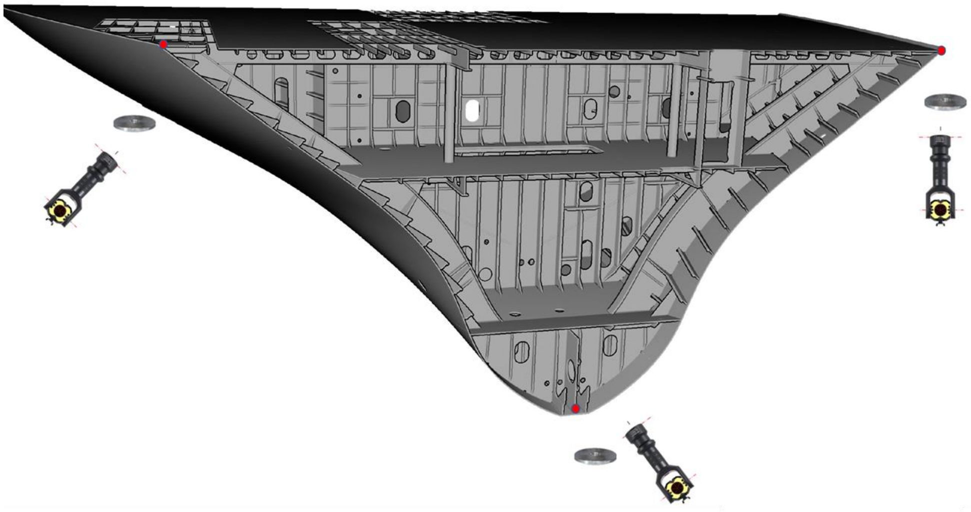

Figure 10 Visualization of suggested reference mounting positions. Prisms are fixed onto reference washers to support surveying of reference positions in ship coordinates using total station

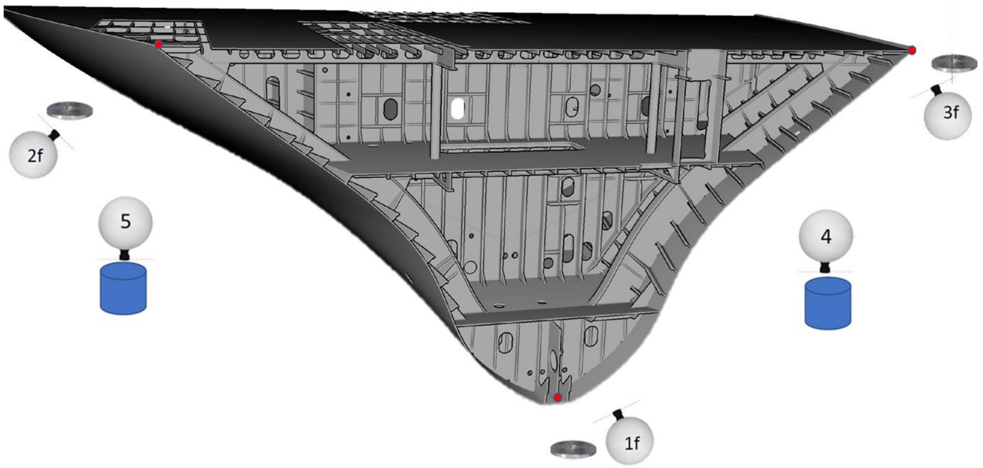

Figure 11 Suggestion for reference locating scheme viewed from fore of block. 1-3 are fixed references on block, part of the primary grid. 4 and 5 are external references used in the secondary grid to traverse the instrument between fore and aft and improve quality of registration

While the reference locator positions, especially those fastened on the actual block are decided by the customer shipyard, below are a list of best practices to keep in mind when selecting the locator positions.

The reference locators should be:

- Distributed well in X, Y, Z and preferably close to the perimeter of the block
- Include one position deeper into block, positioned:
    - in a wide-open section and
    - visible from base line level where the measurement instruments are placed
- Placed in the range of 0-400 mm from the edge of the section plates (this is left un-painted) except the markers intended to be positioned on a deep X location
- Positioned so that they can remain in place indefinitely, also after assembly onto the complete vessel
- Positioned on plates thicker than 7 mm for stability reasons
- Fastened using screw, weld seam or adhesive depending on the customer shipyard preference, using adhesive would ensure no permanent altering of the block structure

Align block and survey references using total station

The correct alignment is one key aspect of creating an operational digital value stream and should be conducted by trained crafts people. Total station measurements can be done either before or after the 3D-scanning, but the same scan targets should be included in both measurements.

Mount spheres and 3D laser scanning

Scan around the entire block with as few scans as possible (around 15 meters between every scan position in an evenly distributed grid). See suggested base positions in Figure 12 below.

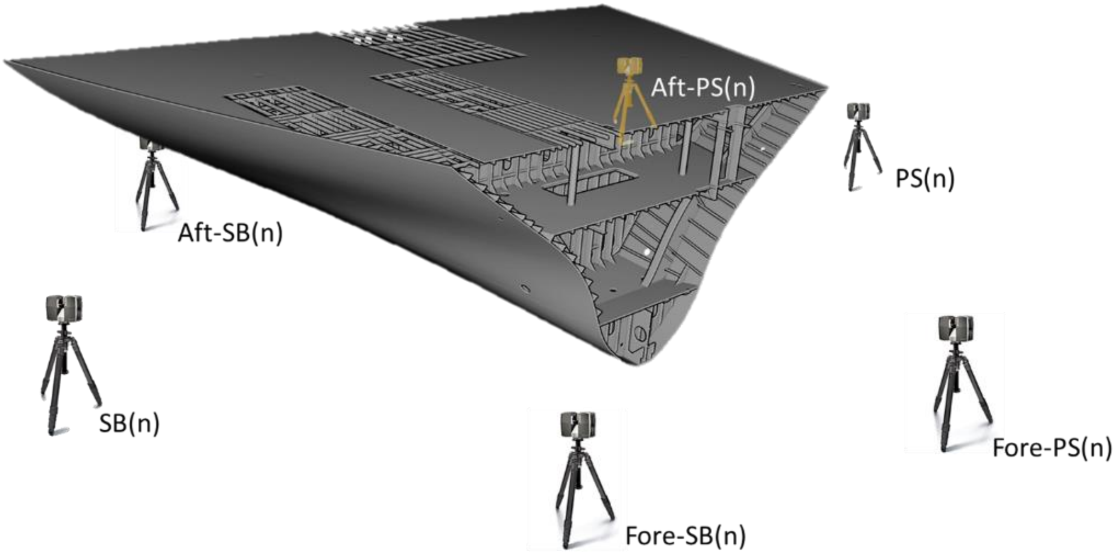

Figure 12 3D scanner base positions, P for Port side and S for Starboard side

Use temporary references outside of the block when there are no surveyed reference points available along the sides of the block. The temporary spheres should be positioned away from the block to provide a good distribution of targets in all four quadrants around the 3D laser scanner.

2.3. Process Measurements

Registration of the data sets collected is necessary to make use of the results. This process is critical and can be the source of data errors if done incorrectly. Therefore, it is important to introduce a quality report or assessment function. There will most certainly also be need for cleaning of the data from support structures or other external objects before it can be said to accurately represent the as-built physical block.

Registration

There are several different software available for registration purposes, often supplied with the total station and 3D laser scanner that is in use. If a total station is used, that should be considered the most accurate data and the alignment and subsequent definition of reference positions in ship coordinate system should be used in 3D scanning registration as surveyed references. This minimizes the introduction of uncertainty in the workflow.

Quality report

The software used for registration should provide the possibility of having a quantitative assessment of the registration results. This is to ensure objectivity in the data and the report should always be presented to the customer shipyard as part of the delivery of the digital block.

Cleaning

The user can manually cut out any external objects that do not belong to the block geometry from the registered data set, such as supports. This can also be achieved using comparison algorithms that check the overlap between CAD and scan data[2].

Sometimes subsampling the resulting data to a defined level of detail, point-to-point distance can be good to reduce data size. For example, 10 or 15 mm will greatly reduce the size but this must first be agreed upon with the customer shipyard.

Conduct analysis of critical tolerances

One use of the measurement data is to compare its correspondence with the nominal master drawings to assess the result of the manufacturing process. Contractually agreed tolerance levels for the acceptable amount of deviation can be evaluated using this method. Traditionally this is done on a fixed number of discrete points or surfaces using total station or other measurement technology. The Customer Shipyard should provide a format for reporting these measurements and their deviation from the nominal master drawing.

The introduction of 3D laser scanning allows for an, additional, more complete comparison, not only on a set of discrete functional points. As the 3D scanner samples data from the entire surface of the hull there is a possibility to make global assessments of geometry conformance of the block. This can for example lead to identification of outer hull undulations caused by the inner structure and assembly process, see Figure 13 for an example illustration.

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[2] For example, the Cloud2Mesh algorithm in the open source software Cloud Compare by EDF.

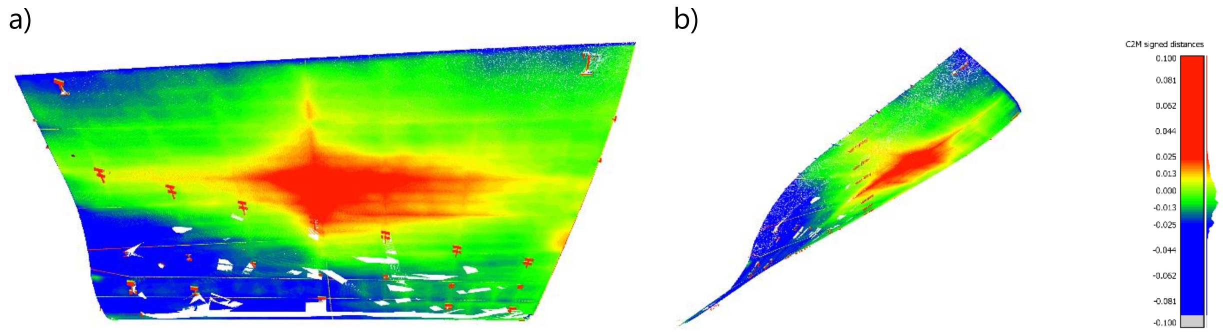

Figure 13 Illustration of heatmap from comparison of the measured manufactured block with Nominal CAD: as viewed from a) Portside and b) Aft. Red values denote hull protrusion >2 cm and blue values denote hull indentions >2cm. Red double-crossed T's are artefacts from digitally removed support structure holding the block upright.

When comparing the entire structure's conformance to the nominal structure, all, if any, deviations can be detected.

The comparison is done using the measurement data aligned in ship coordinates and the CAD master drawing. Each measurement point is then evaluated to find the distance to the nearest CAD surface, the distance is stored along with the measurement point and can be used to illustrate the amount of deviation. Several software exist that can carry out this calculation and subsequent visualization. The example in Figure 13 has been created using the C2M (cloud to mesh) algorithm in the software Cloud Compare[3].

2.4. Deliver Measurements

The measurement data and the comparisons done are intended to give a fair and unbiased data set that represent the manufactured block's geometrical properties. To do so they should be reported in an objective an unbiased way. These are the data that should be delivered:

- Measurement protocol
- Reference positions in ship coordinates
- 3D scan data of the entire block
- Registration Quality Report for 3D scan data

The measurement protocol should contain results for all the control measurement points required by the customer shipyard.

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[3] www.CloudCompare.org

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The positions of the reference locators and their values in ship coordinates should be delivered as a .csv file. This can be utilized by the Customer Shipyard to verify measurements and to save setup time for any downstream measurement activities.

The 3D scan data should be cleaned, and if agreed upon, subsampled to advised density. It should be delivered in the neutral standardized format E57. The comparison with the nominal CAD can be included in the data set as a scalar value of the signed measured deviation for each data point.

The registration quality report is important to ensure transparency and objectivity in the data. It also gives a quantitative assessment of the data reliability. Most 3D scanning software packages that are used to register data sets provide functionality for generating reports of the registration outcome. The Customer Shipyard should provide approval of the software in use by the manufacturing shipyard in the contracting phase.

3. Conclusions

This guideline document introduces the necessary measurement technologies and presents a workflow for how Manufacturing Shipyards and Customer Shipyards can implement 3D documentation technology to create a digital value stream supplementing the existing physical value stream. The main benefits of working in this manner is the reduction of risk of poor quality and final assembly issues causing delays in ship building projects. The use of measurement technology also promotes transparency between the actors that limit the room for disagreements regarding product quality and function fulfillment.

The guide is a first version that can be expanded with practical examples and software guides to better support implementation of these technologies and work methods. As the measurement technologies and software applications continue to evolve the guide will need to be revised.