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Research Article

3D Point Cloud Data Basis Shape Management for Assembly of Modularized Large and Complicated Marine Structures

Deok-Hyun Yoon,[1,2] Hee Jin Kang,[3] Jin Choi,[3] Deok Eun Kim,[2] and Xin Huang[1]

[1] *College of Civil Engineering, Nanjing Forestry University, Jiangsu, Nanjing 210037, China*
[2] *Samin Information Co., Ltd., Busan 612-020, Republic of Korea*
[3] *Advanced Ship Research Division, Korea Research Institute of Ships & Ocean Engineering, Daejeon 305-343, Republic of Korea*

Correspondence should be addressed to Xin Huang; huangxin@njfu.com.cn

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As global competition heats up, in order to improve the productivity, simulation-based methods are becoming increasingly dominant in shipyards. The advancement of the CAD-based production management process even allows verification of installability and functionality before beginning the actual construction. However, whether the ship has been exactly constructed as designed can still and only be manually verified for a limited area. Therefore, significant interblock and intermodule errors are inevitably present in assembly, resulting in costly, time-consuming inspections and modifications. If the construction errors and defects can be investigated and controlled in each shop before assembly of modules, the productivity will be considerably improved. In the installation simulation of large structures, early detection and correction of the errors in junction allow fast and efficient assembly and provide better quality product development even with distributed construction yards. This technique can promote interindustrial collaboration among companies of different sizes, resulting in a significant improvement in overall productivity. In this paper, 3D point cloud data basis shape management framework has been studied with several case studies in a shipyard.

1. Introduction

Incorporating IT into the design process, 3-dimensional computer aided design (3D CAD) models are rapidly evolving from the "Does it fit?" model, which verifies the geometry and installability of structures, to the "Does it work?" model, which investigates the functionality of the assembled structures [1]. Through the contribution of 3D CAD modeling, the design of complicated structures and shapes has become efficient, and shipbuilding industries are now able to design and construct megablocks at a high preerection rate [2]. Currently 3D product model-based designs and simulation-based process management are implemented in marine plant industries for the design and installation of large structures, such as turrets. Despite advancements in 3D CAD technologies, the industries still rely on limited manual inspections to assess whether the structure has been constructed according to the original design or the 3D CAD product model [3]. The current design and construction process for a block, such as an engine room, in which complicated pipelines and valves are placed is an example. Once it is confirmed that the designed equipment module can function as intended, the module is then configured and constructed. The constructed module needs to be connected to the other blocks. Generally, the specific locations for connection work, such as junctions of pipes, are marked on the panel sides of the adjacent blocks [4]. However, such markings cannot be labeled on an open block, which does not have a connection panel. In such a case, the connection work refers to the installability-verified 3D design drawings. Furthermore, the accuracy control (AC) of the outline and quality control (QC) of the equipment modules are conducted during the construction of each block to allow connectivity to the other blocks.

2. Existing Methodology for Shape Management

The QC for an equipment module in a shipyard is divided into the equipment test, installation test, and module test [5, 6].

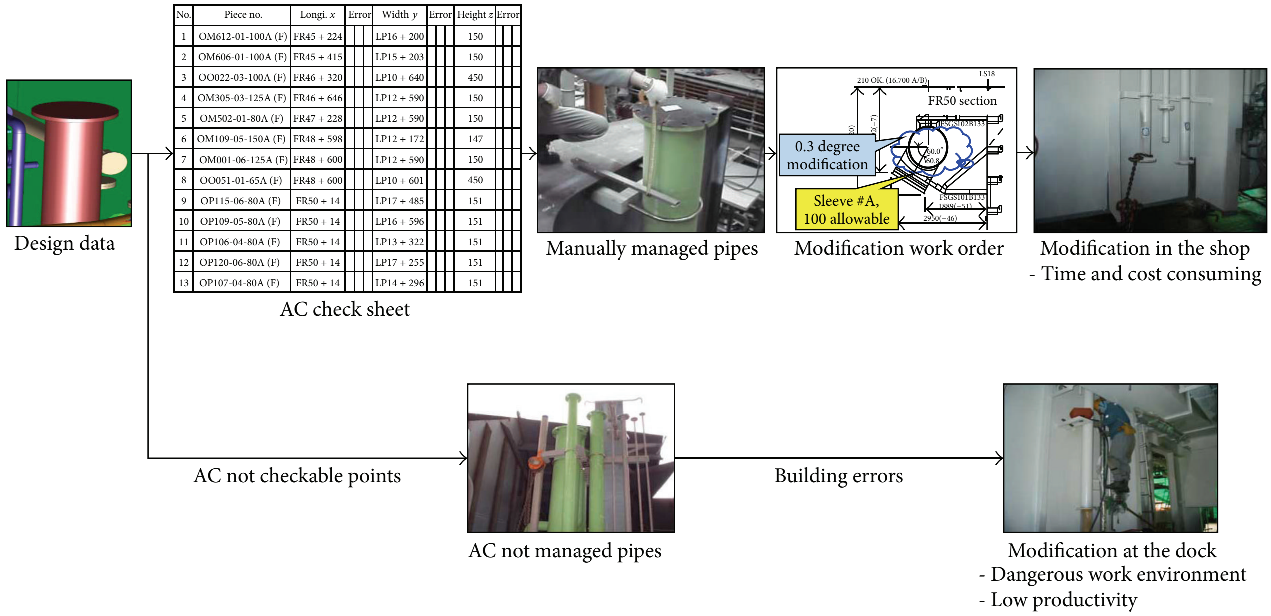


Figure 1: Manual AC check and modification process for preoutfitting.

In each of the tests, the connectivity, such as the location and angle of the pipe terminals, is manually inspected for the adjacent planes before actual assembly [6]. However, as the number of pipe members aligned to the connection plane of the block increases or the architecture of the pipe assembly becomes more complex, the manual inspection and modification will be conducted less accurately and at a slower pace [7, 8]. Furthermore, manual tasks experience additional difficulties due to thermal transformation of engagement surfaces. This is because the expansion or contraction of the engagement surfaces of a module affects the location or shape of the junction. Therefore, this aspect brings efforts to either install complex equipment modules in a single block or simplify the connection architecture between the adjacent blocks. Actually, the percentage of preoutfitting for ships with complicated upper structures, such as the Floating Production Storage and Offloading (FPSO), is about half of that of relatively simple ships [9]. Therefore, when developing high value-added ships, increasing preoutfitting and reducing correction works, which are caused by the mistakes in block assembly at the dock, have significant impacts on cost and time. Table 1 shows some example of QC items for modular building process.

In order to correct the difference in the level of the ship outline or pipelines, which is discovered during the block assembly, additional work, such as hot processing, cutting, bending, or even reinstallation, has to be conducted. This results in delay and degradation in quality. Figure 1 illustrates the present control flow of major shipyards for errors during the block assembly process. In Figure 1, it is shown that the inspection and modification are conducted manually, and the management fails to properly inspect hard-to-detect items, resulting in costly long period modifications in the module assembly site which is the main cause of low dock turnover ratio at the block assembly stage.

Table 1: Example of QC items for equipment modules [6].

Equipment test	Pipe length, pipe bending angle, flange perpendicularity, and so forth.
Installation test	Location of pipe terminal, angle of pipe terminal, and so forth.
Module test	Length of primary panel, level of primary panel, location of internal member, angle of internal member, length, width, level of module, and so forth.

Inconcinnity of engagement surfaces actually happens frequently throughout the preoutfitting and block installation process. As the correction work for the equipment often requires dangerous high place work and welding operations, the inconcinnity is one of the major factors that threaten safety and productivity. Furthermore, because it is difficult in the field process planning to estimate the potential modifications, the experience of field managers generally plays the primary role, resulting in a high level of uncertainty in the process management [10]. In light of this fact, and considering that marine industries practice block and module assemblies, the improvement of construction productivity heavily relies on the effectiveness of error detection and modification for large blocks or equipment modules before actual assembly at the dock. Ultimately, the “Does it work?” and “Does it fit?” simulation concepts that advanced 3D CAD technology brings are concluded in the “Constructed as designed?” concept, which describes whether the outcome of the construction agrees with the designed product. In other words, the agreement of inspection between the constructed product and the designed product completes the 3D CAD product model-based production simulation technology. If fast and accurate inspection can be conducted on the location and shape of the pipeline junctions of the modules between

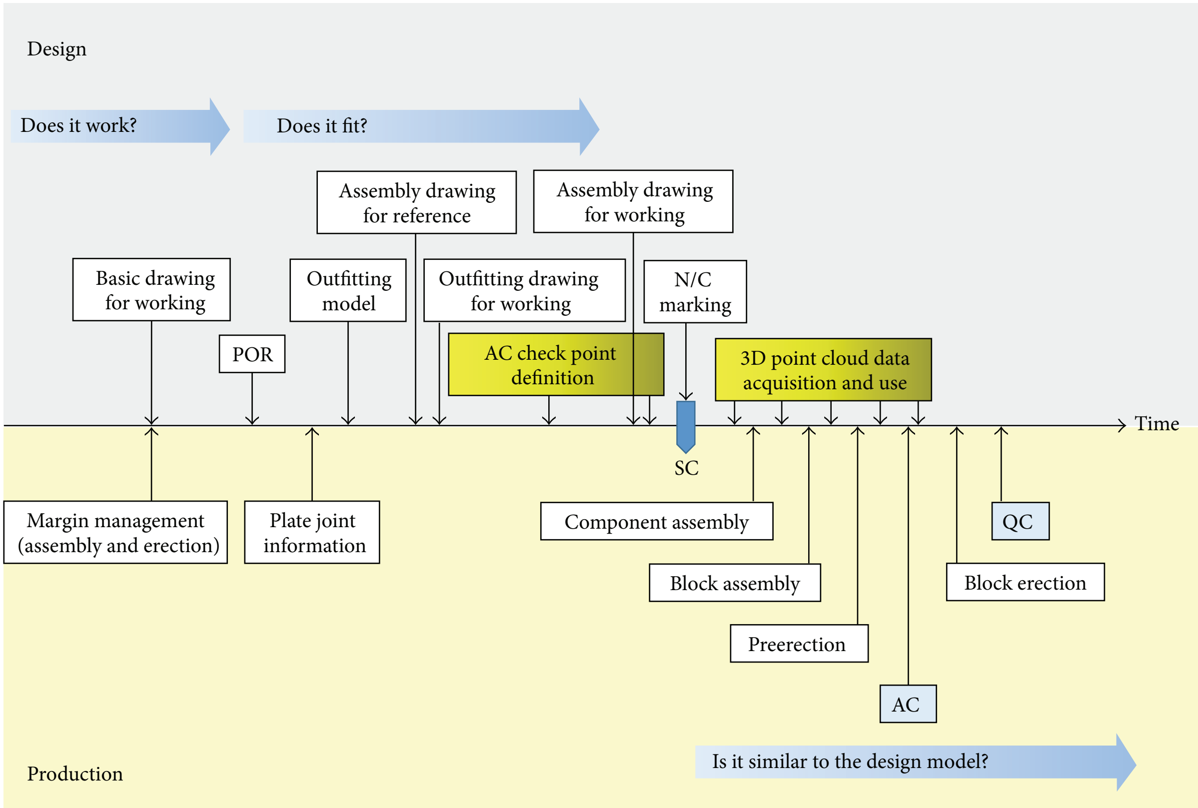


Figure 2: Application of the 3D point cloud data in design and construction process.

the blocks, considers the temperature effects, and perfectly finishes the modifications before the block assembly, the attendant modifications in the block installation and module assembly at dock will be significantly reduced and will ultimately result in a much higher dock turnover.

3. 3D Point Cloud Data Basis Shape Management

A wide variety of commercial 3D laser scanners is utilized in various fields and can be used to generate point cloud data. A point cloud refers to a set of x, y, and z coordinates that are constructed using the phase difference between a laser beam emitted from a laser scanner and the returning beam reflected by an object [11]. Although a diverse array of hardware that is capable of constructing a point cloud is available, the software that is able to utilize and implement them for ships and marine plants is only at the elementary stages of development. In the current marine industries, shape management for product against the design drawings is conducted in two ways: QC and AC of these two inspection options; the point cloud data can be applied to AC experimentally for equipment, pipe, vent, and so forth at the preerection and block erection phases as shown in Figure 2. Through these AC activities at the construction phases, the compliance of the product with the design is inspected. Furthermore, the installability, functionality, and maintainability are investigated under the design phase before the steel cutting process.

The following information from the data generated during the design process is utilized for the automation of panel machining at the construction phase [8]:

(i) panel list of blocks and hull,

(ii) boundary of each block and panel,

(iii) information of equipment pipe pads and angle support models,

(iv) information of hull panel and angle support attachment,

(v) information of pads and angles contained on hull panels.

As shown in Figure 3, this information is utilized through equipment allocation using the hull panel, which is generated in the design process, as the background model. As the 3D point cloud data are available in this task, any structure in 3D space that cannot be marked on hull panels is compared with the design data and modified during the preoutfitting process before block installation [12]. Furthermore, it is possible for the equipment constructed at a distant location to be checked before the delivery. At that point, it can be assessed to verify whether it can be installed to the destination block, whether it causes interference, or how much modification will be required once it is delivered with using attribute data of ship

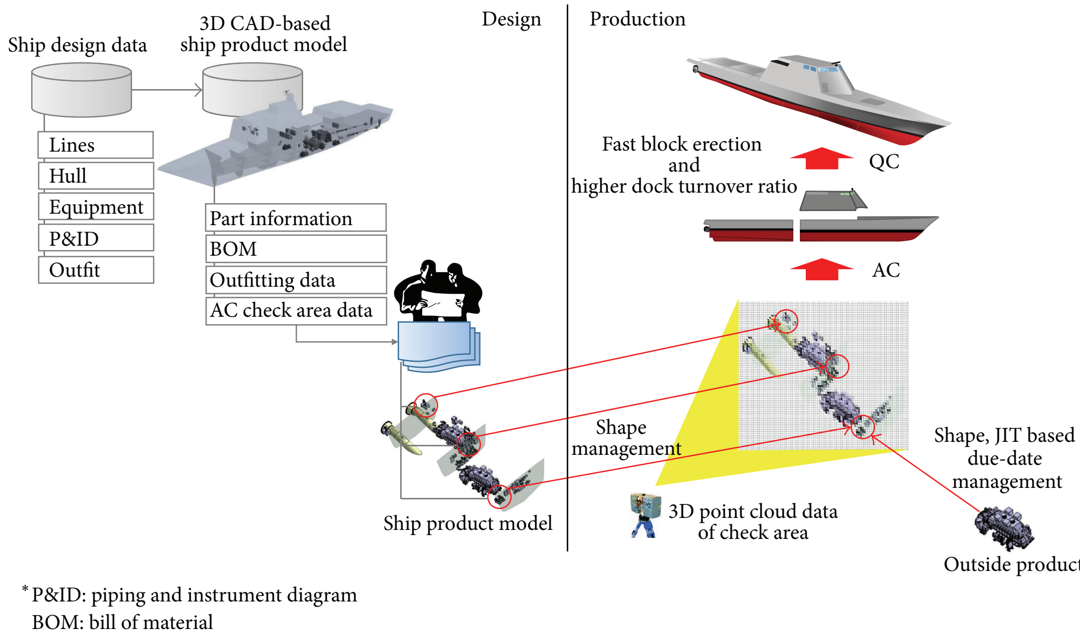


Figure 3: Shape management framework on the basis of the 3D point cloud data.

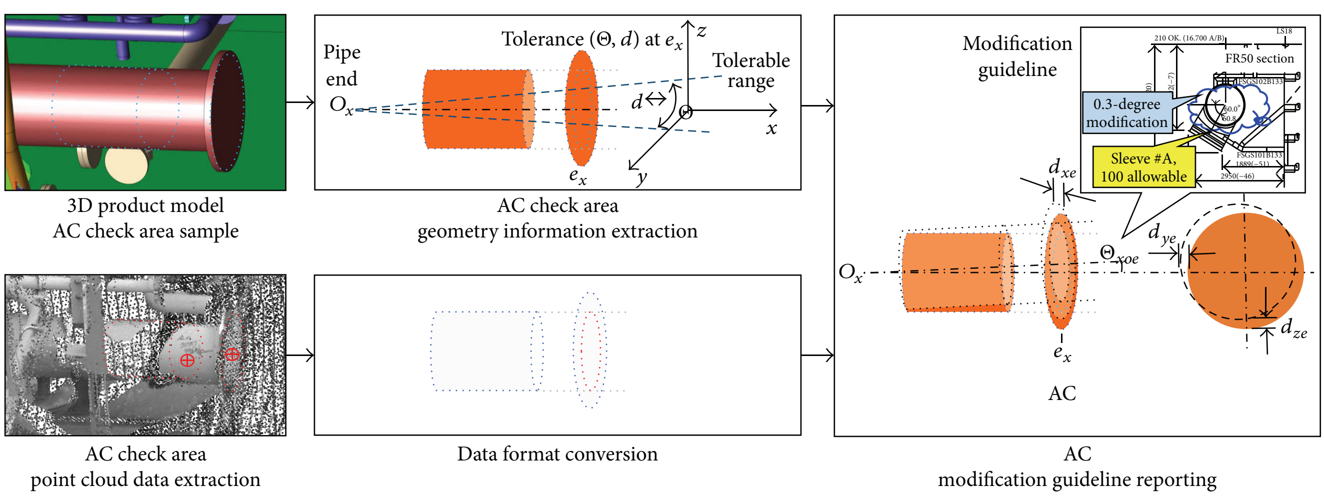


Figure 4: An example of the compliance check and modification order using 3D point cloud data.

product model [12, 13]. Therefore, a higher preoutfitting rate is achievable and the storage period after delivery can be reduced. This results in the implementation of the just in time (JIT) inventory management and provides efficient overall process control.

If the collected 3D point cloud data of the AC check area exhibit disagreement with the design data, considering the interference with surrounding structures, a decision is made to either accept expecting minor modification work at the block installation site or to reject the demand for further modification. In this case the 3D point cloud data becomes a primary basis of the modification job order. Figure 4 illustrates how a modification job order is generated using the 3D point cloud data.

4. Data Management for Mobile Device-Basis Site Availability

The point cloud data can be transformed into mesh models or surface models [14–16]. This is so that they can be incorporated into the 3D CAD data that is utilized in the design and construction stages [17]. However, it is important to note that the 3D point cloud data collected at the field occupies anywhere from hundreds of megabytes to dozens of gigabytes, depending on the data usage [17, 18]. Therefore, it is not easy to manage the data on the shipyard network, as the construction fields and design fields are separate from each other. Consequently, a ship manufacturer's design system requires smart data load management to utilize the 3D point cloud data received from laser scanners. In this study, the data

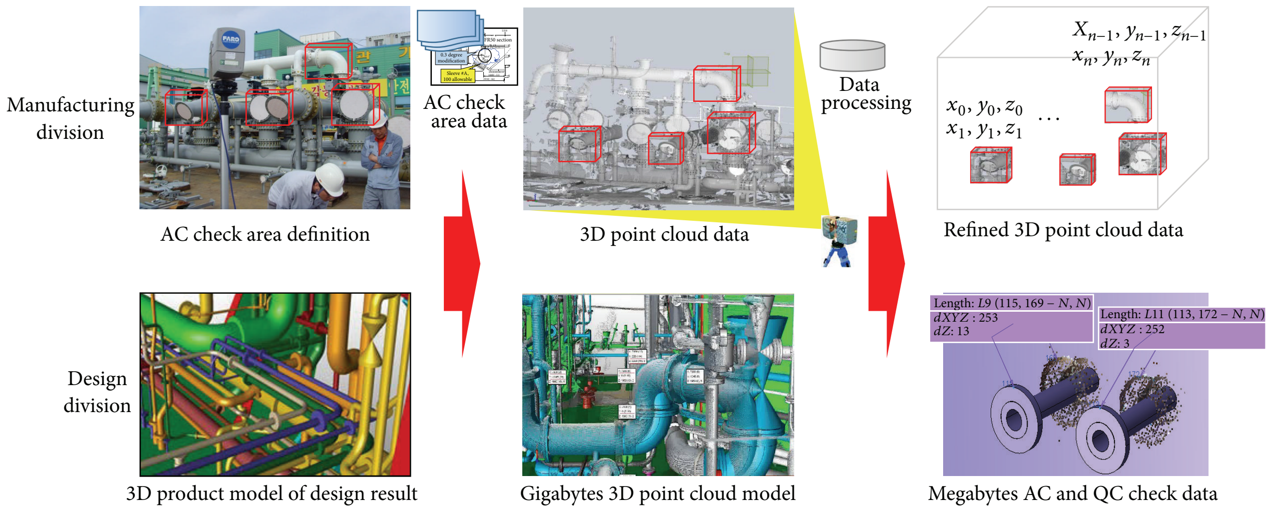


Figure 5: Data processing for online application of 3D point cloud data with small data volume.

load is relieved of dozens of megabytes experimentally as the intensive point data is collected for important regions of machinery room, such as boundaries, pipe couplings, and flanges, with which the design data is compared. Low density or no data is recorded for ignorable regions. In order to implement this method, the data collection boundaries should be predefined based on the AC check items that were identified in the design stages as shown in Figure 5. Furthermore, the collected point data should be refined to better focus on the predefined regions. Furthermore, the quality of the line and surface information can be significantly improved using density functions and thresholds. This can be seen when the point density is increased for high-density regions and decreased for low-density regions with respect to the threshold.

5. Case Study

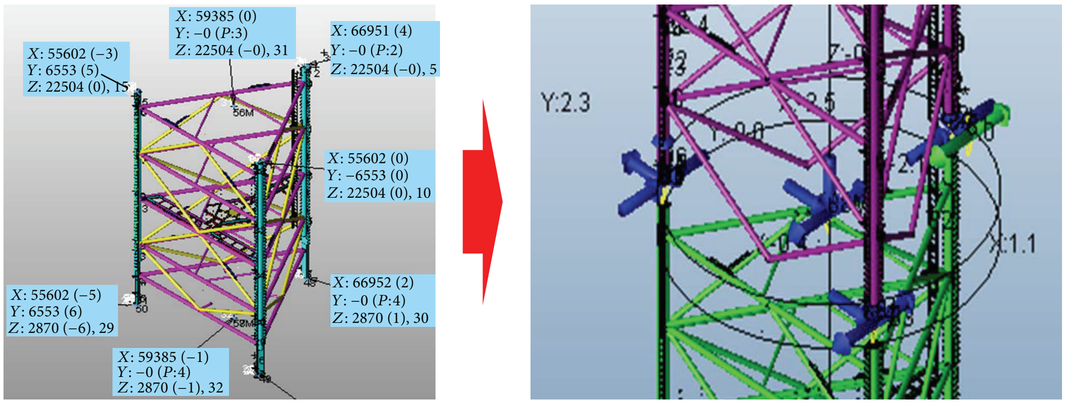
The ability to inspect and modify various assembly methods of 3D point cloud data, including vertically moving assembly, laterally moving assembly, and unit module shapes, is adoptable to various fields of large and complicated marine structures assembly [6, 19]. It is also expected that the cooperation of designers and field mangers at the shop allows the detection and correction of errors of each module before it is delivered to the dock. This results in precise schedule management as shown in Figure 6 and Tables 2 and 3. In the three cases of leg block assembly, point cloud data basis preverified module's assembly shortened installation time in the dock from several days to an hour. Though a couple of days are required for 3D laser scanning, it experimentally does not affect whole process time and cost for delivery.

As shown in Figure 7, 3D point cloud data are effective especially for inspection of large and complicated structures' engagement surfaces [19]. The scanned point cloud data are easily transformed into a form that the CAD systems of each shipyard [14–17]. The detected errors are reflected on the modification job order and corrected at the construction site regardless of the distance of each module's work place. As a result, it is acknowledged that the unnecessary risky modifications, which degrade productivity (e.g., dock turnover), can be reduced innovatively. Through a further collaboration with the design data, the modification job order issuance, delivery, and storage can be automated. This results in a significant reduction in demand of modification during the block assembly.

In summary, the use of the 3D point cloud data aids in relieving the limits of the current construction method and allows a higher preoutfitting rate. This ultimately results in precise scheduling of product delivery and is accompanied by the reduction of production time, cost, and risk. Shin et al. [4] reported that the improvements in the construction method resulted in a higher preoutfitting rate followed by a more efficient scheduling and faster production. In their study, the reduction in the FPSO production time only reached 44%. As they achieved a preoutfitting rate of 75%, it was more than doubled compared to what it had been by 32%. This is due to the increase in the collateral modification work at the block installation site for the increased preoutfitting. This result leads to the conclusion that, in order to achieve full reduction in production time, increments in preoutfitting have to be supported by the elimination of the modification work through inspection and verification before the block assembly. Since utilization of the 3D point cloud data enables online remote checkup for installability of long lead time equipment, the construction can have a margin of time for installation and modification, but not for shipping. In addition, the just in time (JIT) management of the material and equipment is possible for the construction process of individual blocks and the installation schedule of blocks and large modules.

6. Conclusions and Future Work

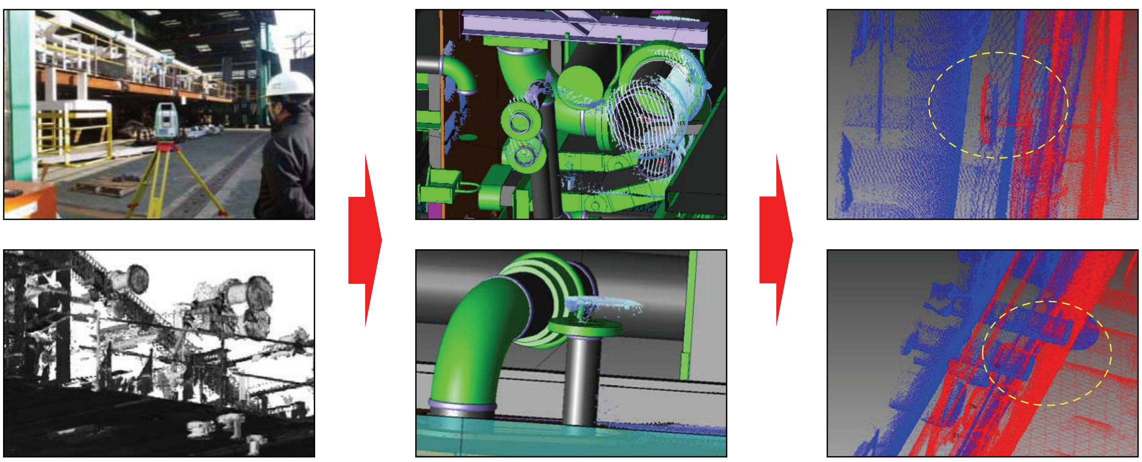
This paper discussed the application method of the 3D point cloud data to investigate whether large and complicated



AC with 3D point cloud data and product model of leg block

Interference check and modification

Figure 6: 3D point cloud data basis simulation for the leg block assembly of a jackup rig.



Scanning and point cloud data generation

AC with 3D point cloud data and product model of leg block

Interference check and modification

Figure 7: 3D point cloud data basis simulation for assembly enables long distance dispersion cooperation.

Table 2: Cost burden examples of existing methods for the leg block assembly.

	Dimensions	Weight (abt.)	Crane capacity	Additional cost caused by construction delay in the dock			
				Crane	Man-hour	Construction delay	Additional cost
Case 1	65 m × 32 m	7,000 ton	9,000 ton	14 hours	37 m/h × 14 h	1.5 days	268,000 US dollars
Case 2	37 m × 34 m	4,500 ton	9,000 ton	10 hours	37 m/h × 10 h	1 day	250,000 US dollars
Case 3	37 m × 34 m	4,500 ton	9,000 ton	12 hours	37 m/h × 12 h	1 day	223,000 US dollars

Table 3: Application results of 3D point cloud data basis simulation for the leg block assembly.

	Dimensions	Weight (abt.)	Crane capacity	Additional cost caused by construction delay in the dock			
				Crane	Man-hour	Construction delay	Additional cost
Case 1	65 m × 32 m	7,000 ton	9,000 ton	1 hour	37 m/h × 1 h	—	24,000 US dollars
Case 2	37 m × 34 m	4,500 ton	9,000 ton	1 hour	37 m/h × 1 h	—	24,000 US dollars
Case 3	37 m × 34 m	4,500 ton	9,000 ton	1 hour	37 m/h × 1 h	—	24,000 US dollars

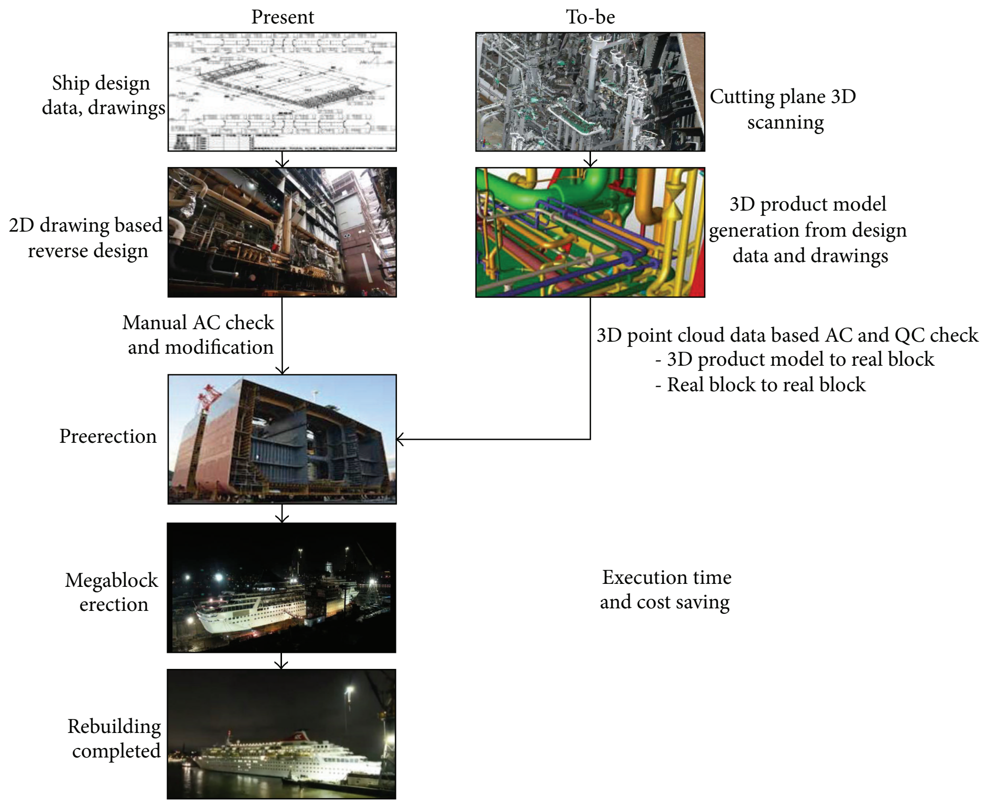


Figure 8: Reverse engineering concept using the proposed method [17, 20].

marine structures such as block modules are constructed as originally designed and to inspect the compatibility with other blocks and installability on the platform. Although the proposed method still contains some technical issues that it must resolve, it will significantly contribute to the increase in the level of productivity in marine industries, where most of the inspections are manually performed. These industries focus on 3D CAD-based design and construction. As the products are compared with the design data and other products in real time and the errors are corrected before installation, the risky, delay-causing modification work can be significantly reduced. Furthermore, the distributed production process can be precisely scheduled for installation of the modular products, and the JIT management of equipment and materials can be possible. Ultimately, this method can lead to stronger interindustrial collaboration within the industry clusters, resulting in higher operation rate of middle class shipbuilders and equipment manufacturers as well as higher dock turnover for major shipbuilders. Further investigation is required in the field of data transfer security during the application of this method.

Despite the limited usage of the current 3D point cloud data method, its capability of operating with 3D information of complicated shapes makes the method extremely valuable for large-scale applications, such as open-space remodeling shown in Figure 8. “Present” of the figure is a scene of remodeling that was disclosed in 2014 for the Norwegian Crown from Blohm + Voss, Hamburg, Germany [20]. This remodeling process includes cutting the body into two pieces and then filling in a new block to elongate the ship with many additional features. If the 3D point cloud data were utilized for this remodeling, the design information of the complicated cut section would be more easily achievable. Furthermore, reverse engineering-based rebuilding can be feasible for not only the middle of the ship, but also any complex portion of the ship.

Even the concurrent distributed work can yield a high preoutfitting rate and requires less modification work when the 3D point cloud data is utilized for the shape management of the remote construction of complicated structures. Because the productivity of the distributed collaboration is improved, the operation rate of the small and middle scale shipyards and equipment manufacturers can be effectively maintained, resulting in higher productivity for all. To realize this concept before long, further investigation and discussion are needed for some issues, such as security, to prevent leakage of design knowledge, know-how, data, and other information.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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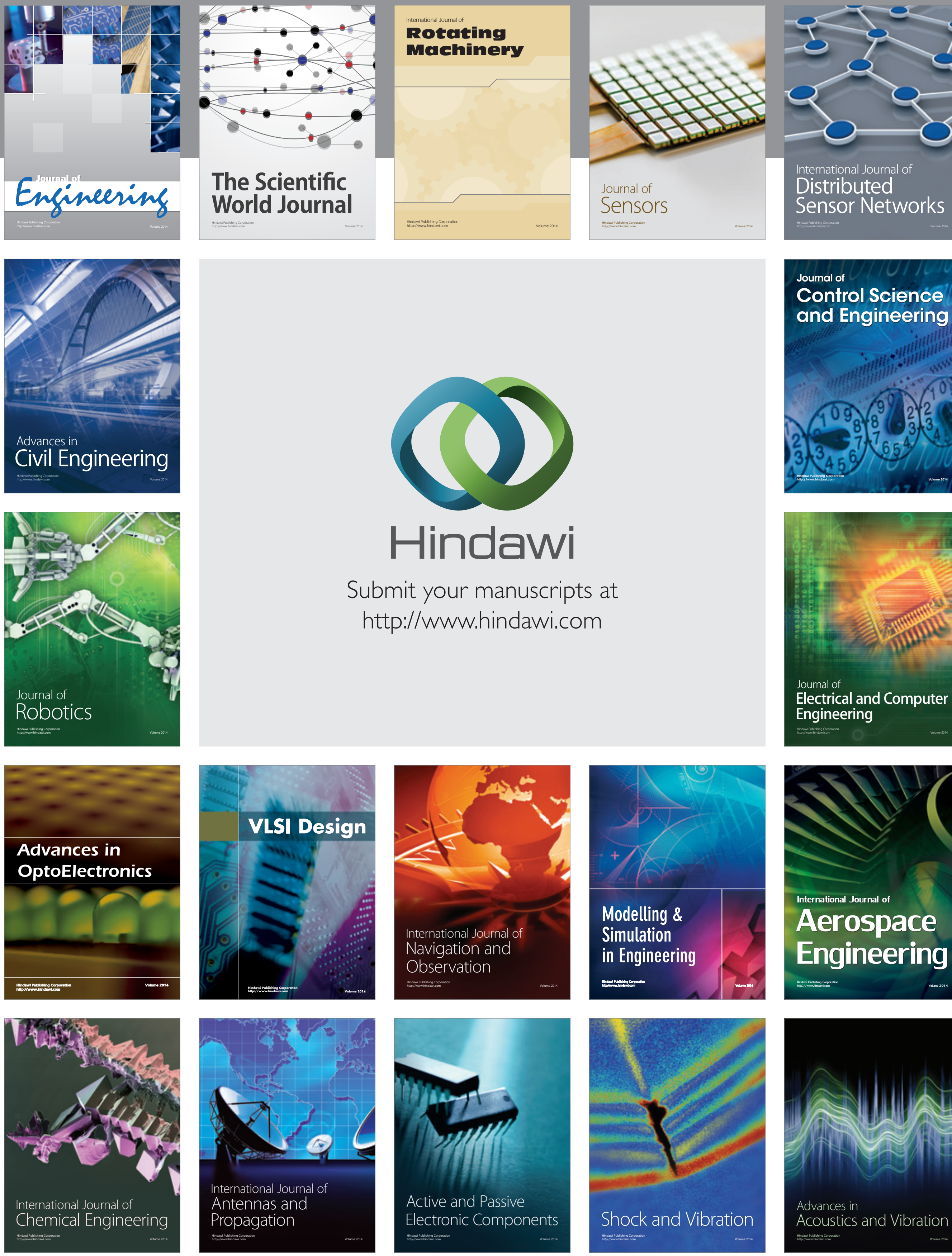

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