

Study on System Support for Offshore Plant Piping Process Using 3D Simulator

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KEY WORDS: Offshore plant, Piping process, 3D simulator 3D, Working efficiency, Installation drawing

ABSTRACT: An offshore plant is an offshore platform that can process oil and gas resources in rough seas with a poor working environment. Moreover, it is a complex structure with different types of offshore facilities and a large amount of outfitting that connects different offshore installations. In particular, an enormous amount of various piping materials is installed in a relatively narrow space, and thus, the difficulty of working is relatively high compared to working in ships or ground plants. Generally, when the 3D detailed design is completed, an offshore plant piping process is carried out at the shipyard with ISO 2D fabrication drawings and ISO 2D installation drawings. If a worker wants to understand the three-dimensional piping composition in the working area, he can only use three-dimensional viewers that provide limited functionality. As offshore plant construction progresses, correlating work with predecessors becomes more complicated and rework occurs because of frequent design changes. This viewer function makes it difficult to identify the 3D piping structure of the urgently needed part. This study deals with the process support method based on a system using a 3D simulator to improve the efficiency of the piping process. The 3D simulator is based on the Unity3D engine and can be simulated by considering the classification and priority of 3D models by the piping process in the system. Further, it makes it possible to visualize progress information of the process. In addition, the punch content can be displayed on the 3D model after the pipe inspection. Finally, in supporting the data in relation to the piping process, it is considered that 3D-simulator-supported piping installing could improve the work efficiency by more than 99% compared to the existing method.

1. Introduction

Pipe installation work in offshore plant construction is a major construction process that accounts for more than 40% of the total construction by work type (Kim and Shin, 2014). Previous studies have continuously minimized the loss and cost of work by efficiently managing the production and installation processes of numerous pipes made of various materials according to the characteristics of work on offshore plants (Ham et al., 2016). To examine the contents of major studies, Ham et al. (2016) attempted to minimize the inefficiency of delayed pipe delivery by designing a regression analysis predictive model for pipe production and installation. This study demonstrated the possibility of more accurate pipe lead time prediction if high-quality data are acquired and appropriate variables are selected as a result of the nature of regression analysis. Wei and Nienhyuis (2012) applied an assembly sequence algorithm for fittings to the pipe installation plan and examined the possibility of interference and

processing. They implemented a system that derives an automatic assembly sequence by reflecting constraints in the actual assembly; however, there were partial limitations in improving the entire piping process. DSME (2015) suggested an automatic method for cross-verification of 2D drawings and 3D models in 2D and 3D pipe systems using the ISO 15926 xml file format. Furthermore, SHI (2015) proposed a piping work management system composed of a unit for pipe information extraction from pipe design information, a work difficulty setting unit, an individual work ratio setting unit, a performance management unit, and a performance database. It manages only the engineering information, excluding the 3D computer-aided design (CAD) model. Park and Woo (2018) proposed a data structure for an integrated piping process management system by defining items that need to be improved for each process of offshore plant piping materials. Oh et al. (2018) presented a method for predicting the required amount of pipe materials for offshore structures based on big data analysis for more accurate material

Received 18 November 2019, revised 8 March 2020, accepted 9 April 2020

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demand planning and purchasing for designers. Park et al. (2019b) addressed a management method based on the connection relationships between installation pipe fitting items acquired from CAD information for prior management of the offshore plant installation readiness. Park et al. (2019a) performed process visualization, bottleneck process analysis, and partner performance analysis-based process mining with log data generated in the pipe materials supply process.

The aforementioned studies focused predominantly on pipe design, process plan, and piping process management system configuration methods. However, incorrect working and reworking occur frequently because workers do not identify the three-dimensional structure of the work area during field piping work, even if the pipe design and process plan and management are performed systematically. Offshore plants undergo frequent design changes during the construction period. To perform field work by accurately reflecting the design intent, we need 3D development information as well as isometric (ISO) 2D installation drawings. Furthermore, the 3D CAD pipe model requires identification of the three-dimensional pipe structure considering relationships with the previous task and the interrelationships of tasks by classifying the tasks by material, spool, and size according to the characteristics of the tasks. However, a process management system without a 3D simulator feature cannot meet these requirements, and a 3D viewer with limited functions is used or an additional 3D CAD pipe simulation work is performed according to the workers' demands.

With this background, our study proposes a system support method using a 3D simulator for easy and efficient identification of the on-site piping process work structure. The implemented 3D simulator can perform 3D simulation for the piping process in the system through a lightweight 3D CAD model based on the Unity3D engine and can visualize the process by interconnecting every process progress information in the system. Furthermore, the post-processing status after the pipe inspection can be referenced by indicating the punch details on the 3D model. In addition, the degree of work efficiency improvement compared to the existing method was examined for a 3D simulator-based system used through three work scenarios.

2. Items Analysis for Supporting Offshore Plant Piping Process

The piping of an offshore plant is arranged and installed considering the relationship with the previous task and the interrelationships of tasks in a limited local space with the components of Architecture; Structure; Equipment; heating, ventilation, and air conditioning (HVAV) system; and Electric as shown in Fig. 1. To perform the pipe installation work efficiently considering these offshore plant components, the following information support is required for the workers in general.

(1) Installation status of components: The piping must be installed

without interferences for connections between different facilities or internal structures. Hence, the worker must be aware of the installation status of components related to the piping.

(2) Pipe installation priorities: The pipe installation priorities are determined according to the physical characteristics such as the spool diameter, thickness, and material; the installed block; and the deadline. Furthermore, in general, the following piping work is performed in consideration of interference with surrounding structures after large pipes are installed on the site. Therefore, the subsequent piping work cannot be performed unless the worker is already aware of the priorities, and the piping must be installed again in serious cases. Hence, the worker must always be aware of the priorities of tasks.

(3) Isometric 2D drawing by work type: In the piping work and inspection stage, the worker or inspector may need to identify the isometric 2D drawing by material, size, spool, and package, or the 3D piping structure model. In this case, the sorting function of the 3D CAD pipe model needs to be provided in this field work.

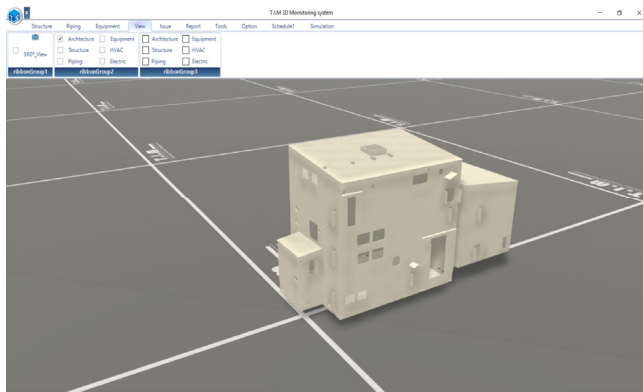
(4) 3D working internal space: To better understand the working internal structure in which components are arranged in a complex manner, we need to identify the 3D piping structure model by combining only the partially required components. In this case, the 3D CAD model must allow disassembly and assembly. In addition, a partial modeling feature should be provided to allow identification of the internal connection status by expanding or shrinking only a part of the workspace.

(5) Punch: Punch refers to the writing of the problems and processing requirements together with the inspection date and location after piping inspection. In general, the site creates isometric 2D drawings or takes pictures and provides them to the shipyard. Therefore, for specific reworks, the 3D CAD model related to the punch must be identified.

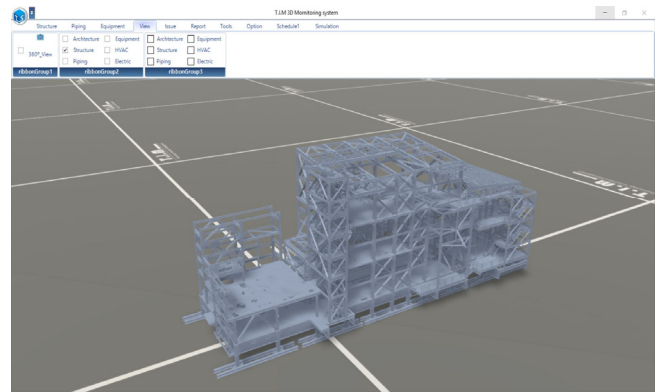
3. Development of Offshore Plant Piping Process Support System Using 3D Simulator

3.1 Composition of 3D-simulator-based System

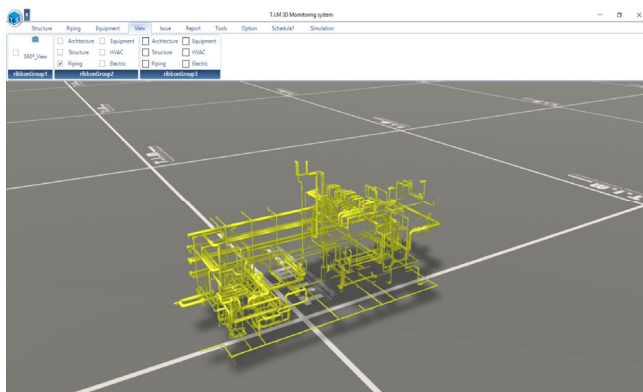
To minimize incorrect working in field work and to improve work efficiency, the worker must be aware of the installation and arrangement of structures and various fittings, including piping, in the workspace during the progress of work in three dimensions. Therefore, in this study, we designed a system to visualize the work situation in three dimensions by connecting the offshore plant process with a 3D CAD model and to enable 3D simulation of the internal structure according to the demands of the worker or inspector. Fig. 2 shows the correlation between the internal information and the system configuration based on the working progress and engineering data of the 3D CAD model shape information and the manufacturing resource planning (MRP) system of an offshore plant production design. The 3D simulator of this system shares and interconnects the process and engineering data in the database and various ISO 2D drawings.



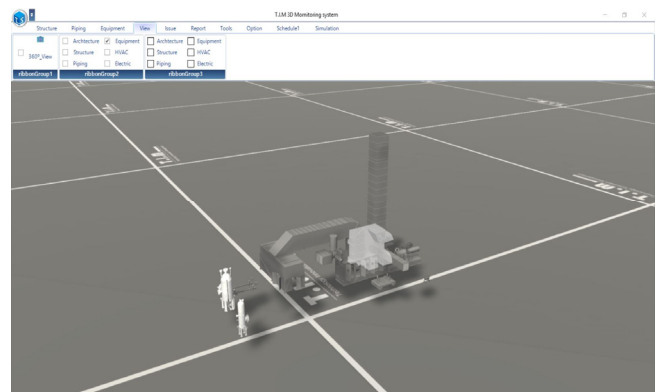
(a) Architecture



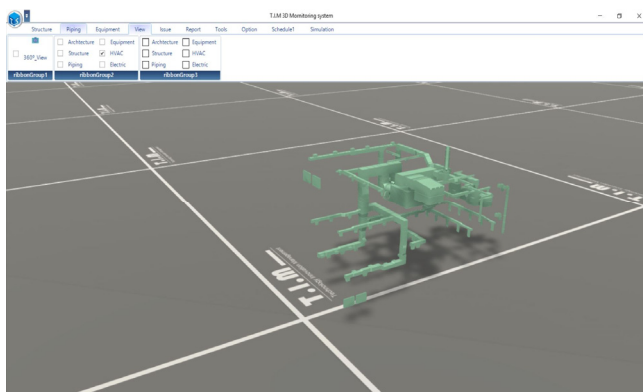
(b) Structure



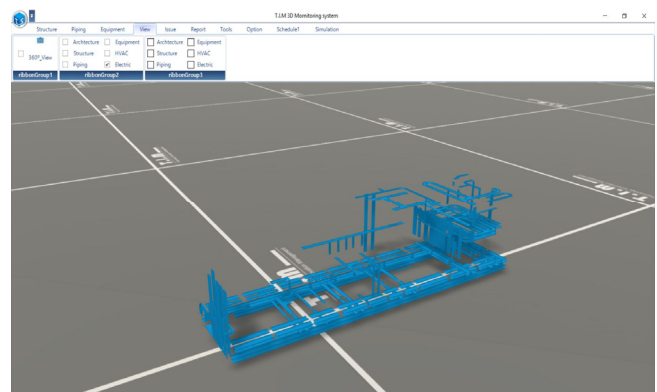
(c) Piping



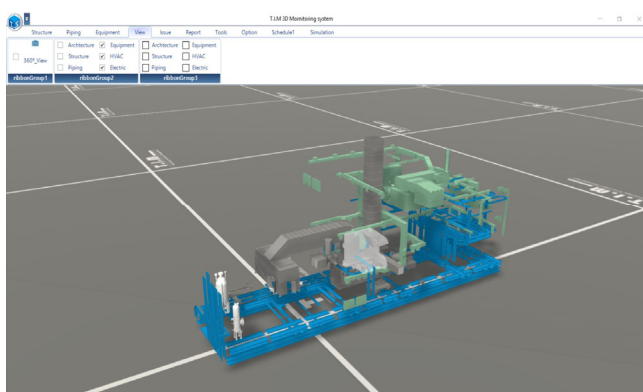
(d) Equipment



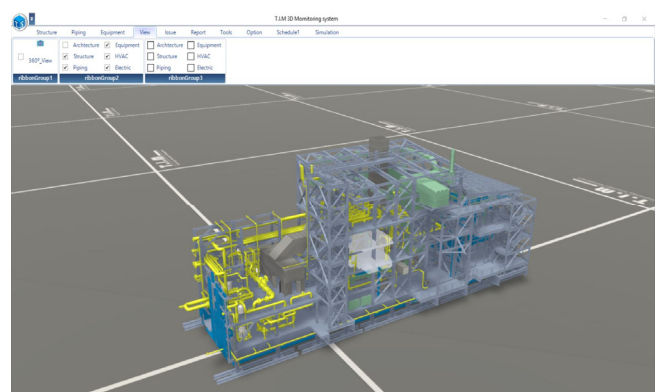
(e) HVAC



(f) Electric



(g) Equipment+HVAC+Electric



(h) Structure+Piping+Equipment+HVAC+Electric

Fig. 1 Constitution of a part in offshore plant: water injection module

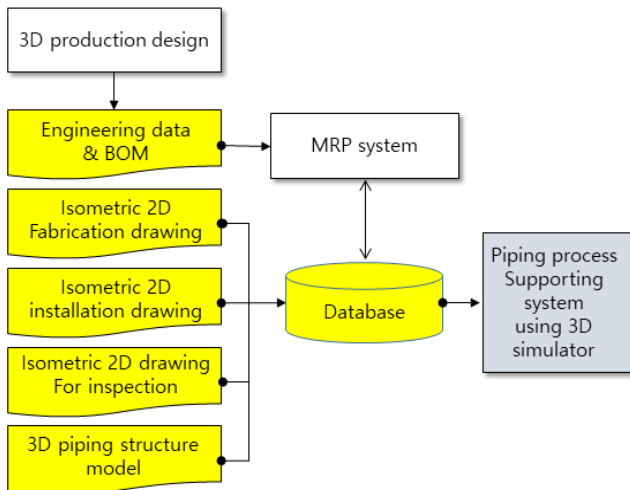


Fig. 2 Correlation between data and system for supporting piping process using 3D simulator

Fig. 3 shows the implemented offshore plant process support system based on the 3D simulator. This system is composed of Calendar, Working Process Summary, manufacturing resource planning (MRP) data, and 3D CAD model, which interact with one another. The Calendar shows the daily work details together with the Working Process Summary. The Working Process Summary includes the total number of pipes, received and installed quantities, current installed quantity, installation completion ratio, and remaining quantity. The progress of the piping work is linked to the 3D CAD model in real time. The MRP data shares the line number, spool number, isometric

drawing number, package number, and BOM information in the database of the existing piping management system, and the related isometric 2D drawings can be seen when necessary. Furthermore, the information required for the pipe installation process, that is, the piping work situation by block, size, material, and system, and piping inspection, that is, the line inspection, flushing, hydro test, pneumatic test, and reinstatement, can be simulated according to the purpose with the spool and package in the 3D CAD model. For the development environment, a standard graphic user interface (GUI) was constructed using Visual Studio C#, and a Unity3D engine was used for 3D modeling; the interface technology for mutual data exchange and interaction was developed and applied independently.

3.2 Simplification of 3D CAD Pipe Model

The 3D simulator for offshore plant piping process support aims for the visualization of the work status and efficient understanding of the 3D pipe structure in the work space associated with the process work. Therefore, the 3D CAD pipe model designed for high-specification computers need to be streamlined for efficient operation in low to intermediate specification computers in production sites. In this study, it was simplified by reducing the number of polygons of the 3D CAD model while maintaining the pipe interfaces. Fig. 4 shows examples of simplifying the number of polygons for piping from (a) 7680 to (b) 3071 and (c) 1957.

3.3 3D Simulation Displaying the Piping Process Status

With the progress of the offshore plant process, various fittings are

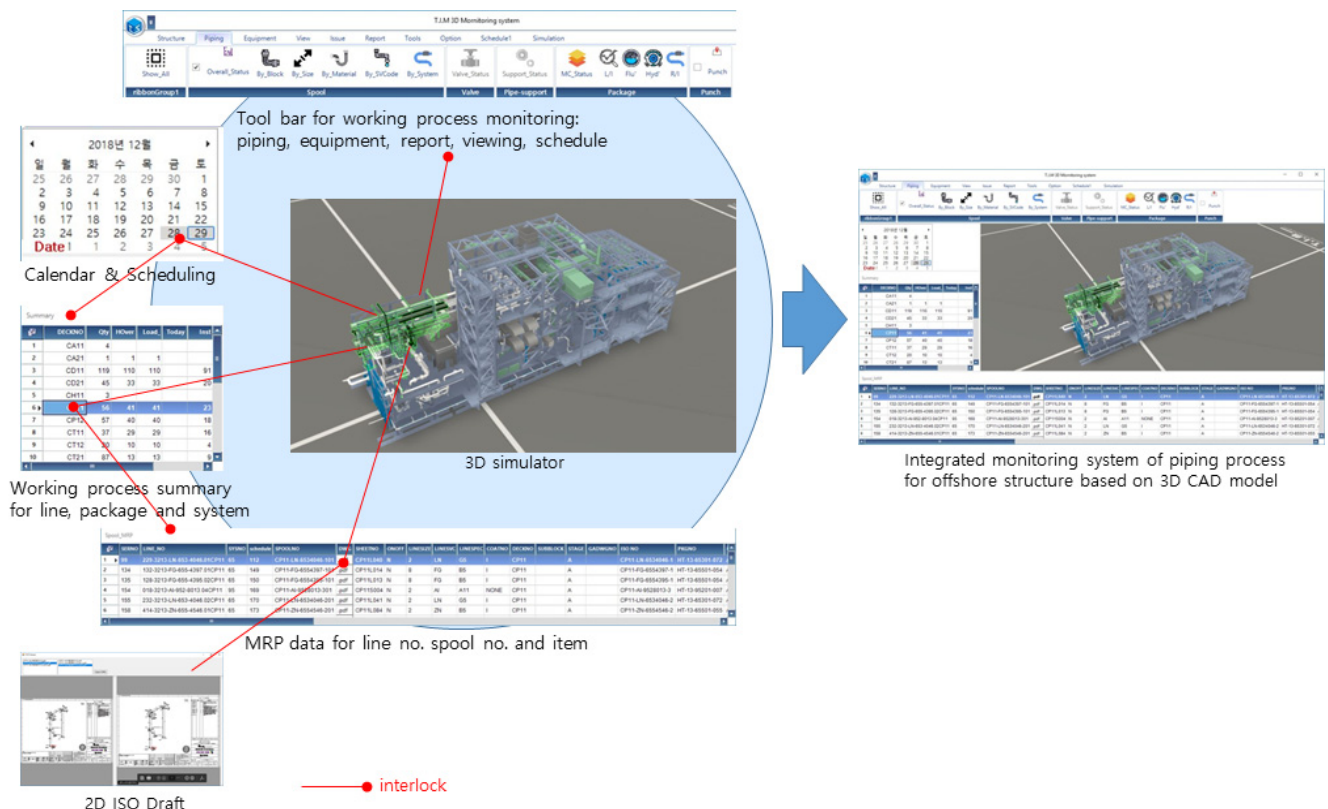


Fig. 3 System structure for supporting piping process using 3D simulator

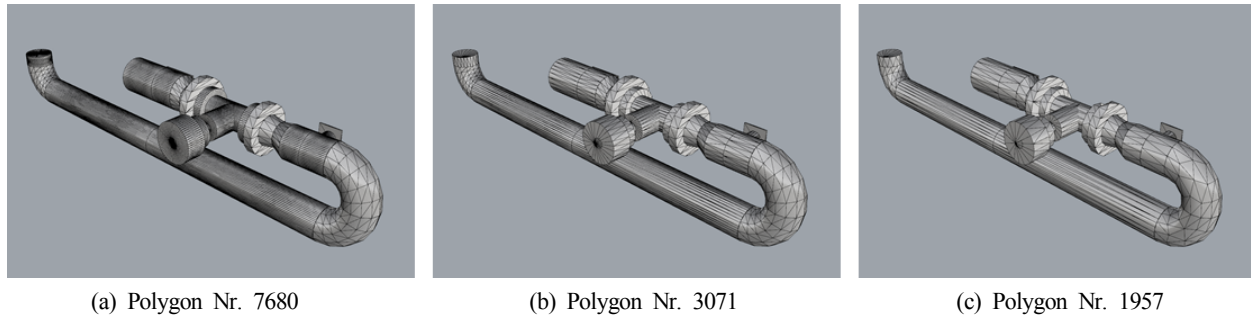


Fig. 4 An example of simplification for 3D CAD pipe model

arranged in a complex manner together with structures and facilities. Thus, the workers and process managers need to visually check the current situation of the process. In particular, it will assist in improving the process work efficiency if the installation of equipment, facilities, and structures, as well as the receipt, installation preparation, and installation completion of the pipes can be checked before, during, and after the work.

3.3.1 Representation of piping process status based on 3D CAD model

Most shipyards operate a proprietary system to manage the working process from manufacturing to the receipt and installation of materials. Therefore, the 3D simulator in this system was implemented in association with the database of a process management system. Fig. 5 shows an example of the receipt of piping materials (white), installation preparation (gray), and installation completion (black) in association with the 3D simulator. Fig. 5 (a) numerically shows the receipt, installation completion, and installation completion of the piping materials in Working Process Summary, and the progress of work is displayed in terms of percentage. Furthermore, Fig. 5 (b) displays the status from receipt to installation completion of the piping

materials corresponding to the working process in the 3D CAD pipe model. When a worker registers the work result to the MRP system from the site, the working process situation is expressed in color (white, gray, and black) in the 3D CAD pipe model from the shared database, which allows the worker to intuitively see the working progress.

3.3.2 Identification of 3D pipe location and structure by work type

During pipe installation, it is necessary to identify the piping work status by block, size, material, and system, and to identify the location and structure of the 3D pipe during pipe inspection according to the purpose such as line inspection, flushing, hydro test, pneumatic test, and reinstatement. Fig. 6 (a) indicates a 6-inch-diameter pipe by contour lines in the 3D CAD pipe model. Fig. 6 (b) shows the representation of the pipes with contour lines for pipes in the package—the smallest unit—during pipe flushing using air or water to remove foreign substances from inside the pipes. Besides, the 3D simulator in the system can distinguish a pipe package for line inspection, pipe package for inspection of water pressure of the weld using water pressure, and pipe package indicating completion of reinstatement as shown in Fig. 6.

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3	4	5	6	7	8	9	1	2	3	4	5
10	11	12	13	14	15	16	8	9	10	11	12
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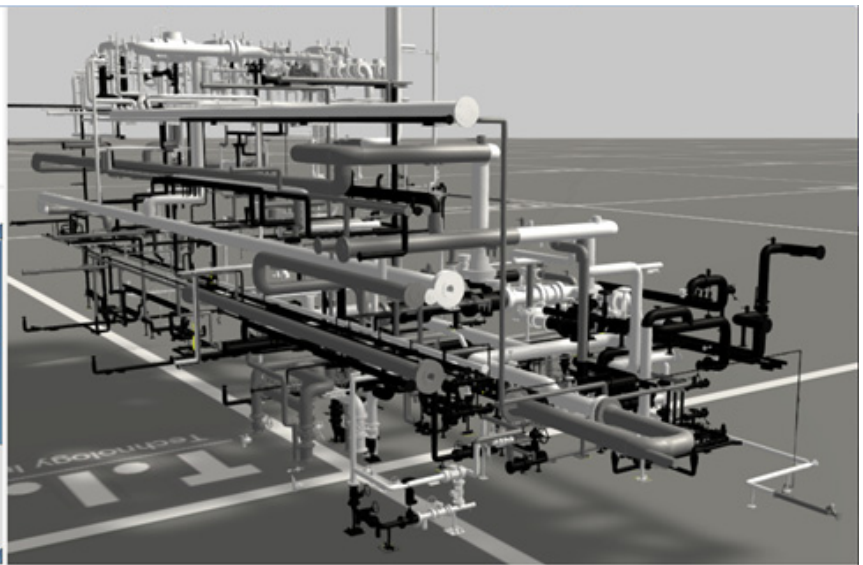
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Summary

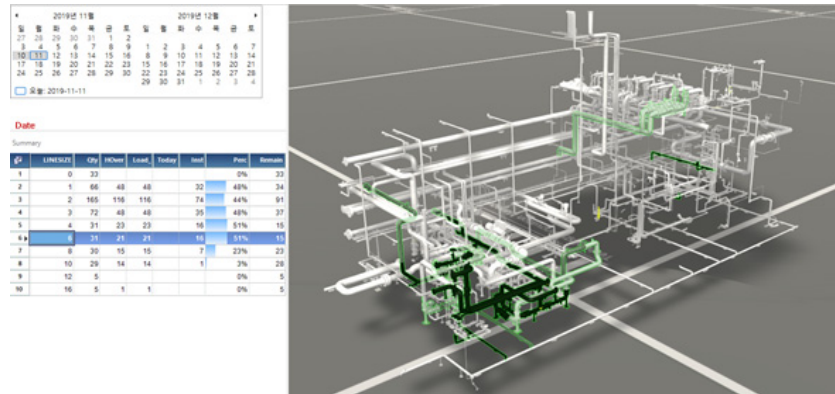
DECKNO	Qty	HOVer	Load	Today	Inst	Perc	Remain
1 CA11	4					0%	4
2 CA21	1	1	1			0%	1
3 CD11	119	110	110		91	75%	28
4 CD21	45	33	33		20	44%	25
5 CH11	3	3	3			0%	3
6 CP11	56	41	41		23	41%	33
7 CP12	57	40	40		18	31%	39
8 CT11	37	29	29		16	43%	21
9 CT12	20	10	10		4	20%	16
10 CT21	87	13	13		9	10%	78
11 CV11	2					0%	2
12 CV21	12	6	6			0%	12
13 CX11	12					0%	12
14 M21A	2					0%	2
15 M21B	2					0%	2

(a) Working process summary



(b) Display of piping installation state on 3D CAD model

Fig. 5 Working process displaying on 3D CAD pipe model



(a) 3D CAD pipe model with identical 6-inch diameter



(b) 3D CAD pipe model with identical package for pipe flushing

Fig. 6 Example of working process state displaying on 3D CAD pipe model

3.3.3 Pipe inspection result displaying in 3D CAD model

Punch means to indicate the pipe inspection date and the details and locations of problems (processing or otherwise), directly in the corresponding work area. In general, the punch details are directly indicated on the ISO 2D installation drawing, or pictures are taken and stored separately in the process management department. Therefore, it

is time-consuming to find and refer to the related information through the package number to check the punch location and processing. The punch function of this system indicates the problems directly in the 3D CAD model, which are linked to the MRP information and are provided to users. Consequently, the worker can identify more accurately the location of the punch and whether or not the punch has

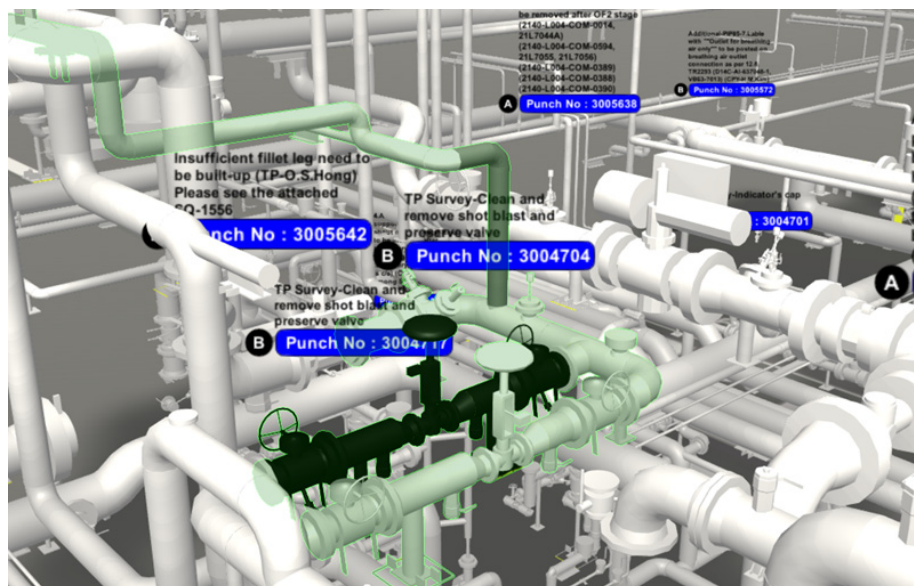


Fig. 7 Example of punch displaying on 3D CAD pipe model

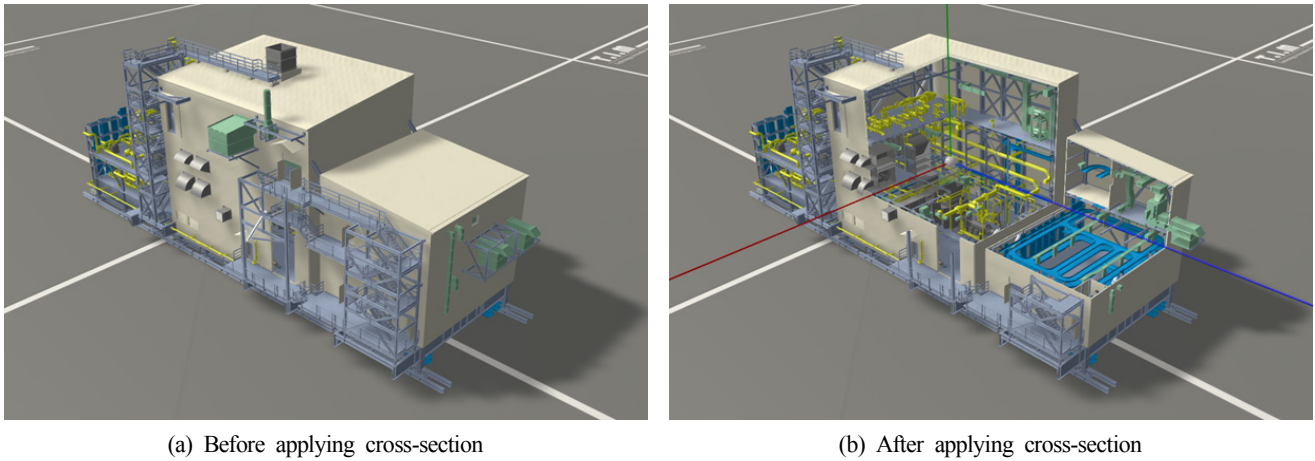


Fig. 8 Example of cross section function on 3D CAD structure model

been processed. Fig. 7 shows an example of a punch indicating a problem together with an expression of the corresponding package in the 3D CAD model.

3.3.4 3D simulation displaying the internal plant structure

The offshore plant piping process is performed considering the interferences between related structures and various facilities and fittings. Therefore, if a worker has identified the relevant 3D work structure in the workspace together with the ISO 2D installation drawing, it can assist in not only preventing incorrect working but also improving work efficiency. To this end, this system enables partial visualization of the disassembly and assembly between offshore plant structures and the internal structure. Fig. 1 (a)–(f) show simulation examples of each component of the offshore plant module. Fig. 1 (g) and (h) show simulation examples that combine only the necessary components. Furthermore, Fig. 8 shows cross-sections of partial simulation examples of the arrangements of structures, facilities, pipes, and other fittings to be installed inside the relevant work space. Fig. 8 (a) shows the 3D CAD model of the entire offshore plant modules before applying the cross-section. Fig. 8 (b) shows the internal structure of an offshore plant by removing the necessary parts by applying the cross-section feature.

4. Work Efficiency Analysis

To examine the work efficiency of the offshore plant process support system based on the 3D simulator, we composed three simulation work scenarios for the water injection module in Fig. 1.

Table 1 Piping components applied to offshore plant module of Fig. 1

Item	Symbol	Unit	Value
Spool	SPL	EA	434
Package	PKG	EA	85
Punch	-	EA	21

Table 1 lists the pipe spool, package, and number of punches used in the offshore plant. Here, spool is the smallest unit of pipe work, package refers to the minimum unit of piping structure, and punch denotes the recording of modifications or problems in work finishing after piping inspection.

The first work scenario represents a case where the worker demands the simulation result of an installed 3D pipe structure in order to identify the working progress status. To verify efficiency, we compared the time required for the 3D spool simulation until 434 spools by using the MRP system and the 3D simulation-based system, which are currently used. The MRP system does not include ISO 2D installation drawing and the 3D CAD model. Hence, the 3D CAD pipe model must be found and simulated from the pipe spool number in the MRP system, and the higher the number of spools, the longer the simulation time. However, the 3D-simulation-based system is linked to the database of the MRP system, and this is directly reflected in the 3D CAD model; the installed piping work status can be simulated in real time. Therefore, as shown in Fig. 9, an approximately 99% or higher work efficiency improvement can be expected.

The second work scenario requires the simulation result of the 3D pipe structure by package for the pipe-inspection status, which is required to intuitively identify the inspection report preparation or progress status. Fig. 10 compares the time required for 3D pipe simulation until 85 packages using the MRP system and 3D simulation-based system. The 3D-simulation-based system allows real-time simulation because it can reflect the process working status in the 3D CAD model by package. However, the MRP system must perform simulation by finding the individual 3D CAD pipe model corresponding to the package number. Hence, as shown in Fig. 9, the simulation time increases in proportion to the number of packages and there is a difference in work efficiency of approximately 99% or higher.

The third work scenario is the case in which the punch details are indicated in the 3D CAD model after piping inspection. With the existing method, when the punch details are prepared in an isometric 2D drawing and then submitted, and the process manager or designer finds the relevant 3D CAD model and enters the punch details to

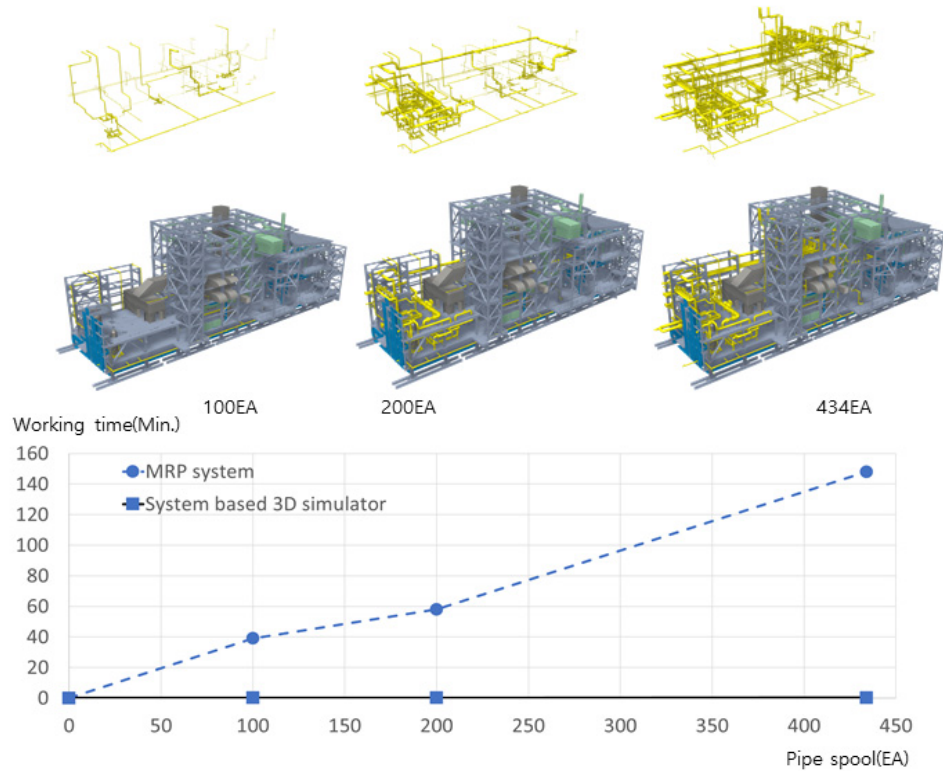


Fig. 9 Comparison of 3D simulation on the installed pipe spools between MRP system and system in this study

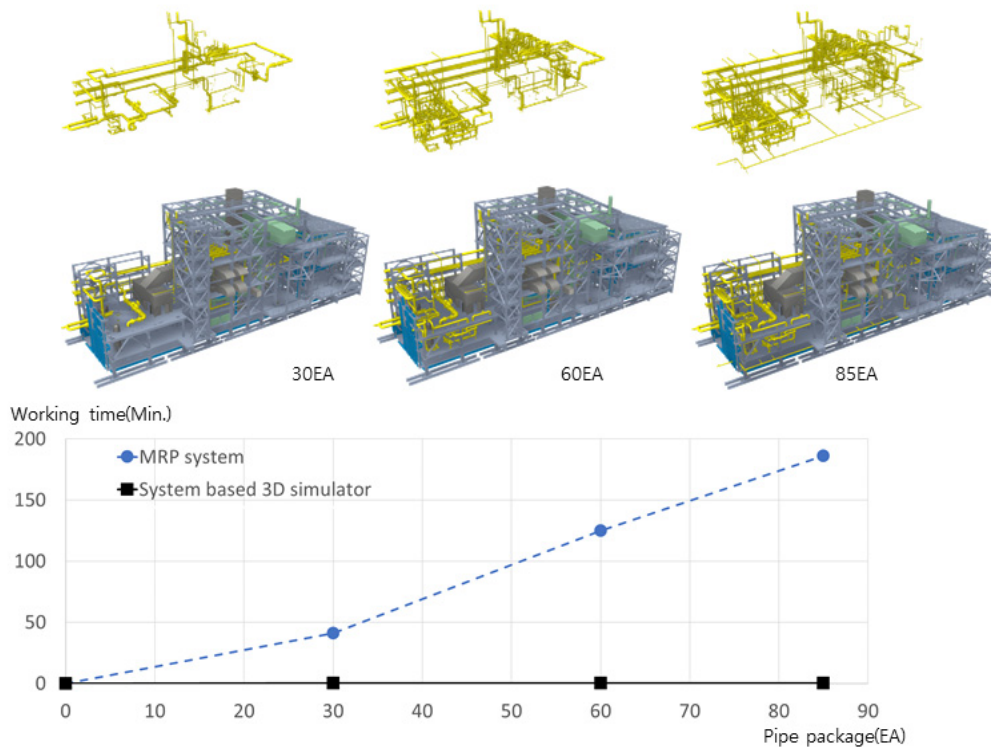


Fig. 10 Comparison of 3D simulation on the inspected pipe packages between MRP system and system in this paper

provide the 3D CAD information to the workers. Therefore, it takes some time to acquire information for rework. As shown in Table 1, it took 56 min to input the details of 21 punches in the 3D CAD model. However, in our system, the punch details are input to the 3D CAD

model in real time; hence, the punch details in the 3D CAD model can be directly output and used. Fig. 11 shows an example of inputting the 21 punch details in Table 1 in the 3D CAD model. As with the previous results, the work efficiency is approximately 99% or higher.

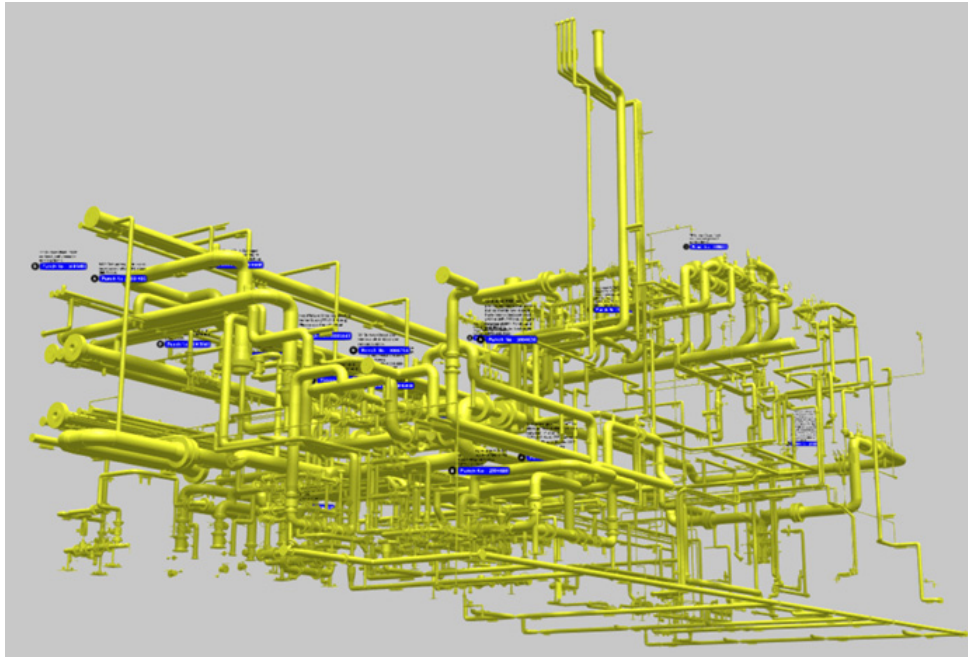


Fig. 11 Example of punch comments registered on 3D CAD pipe model

5. Conclusion

The 3D simulator enables a virtual simulation test of a real offshore plant in which offshore structures, facilities, and various fittings are arranged in a complex manner for easy and accurate identification of workspace information prior to actual work. In the present study, we introduced a method of linking this 3D simulator with the offshore plant piping process for system support. We compared the work efficiency improvement of the proposed system through three simulation-related work scenarios with the existing method.

The results of this study can be summarized as follows.

First, the offshore plant model designed with 3D CAD was simplified while maintaining the 3D shape and was implemented in the system—including the boundary curve—through the simplification process of the offshore plant model designed with 3D CAD.

Second, the offshore plant working process was visualized in a 3D CAD model by linking the process work result to the 3D simulator in real time.

Third, the 3D CAD pipe model corresponding to the same work type was distinguished by spool and package to allow the worker and inspector to check the work status in 3D pipe structure model.

Fourth, the cross-section feature can be used to divide or combine only the work areas for simulation to identify the complex internal and external structures of the offshore plant.

Fifth, the punch details can be directly input to the 3D CAD model after piping inspection, thus allowing the simultaneous visualization of the rework and working progress of the punch details.

Sixth, it was verified using work scenarios that the 3D-simulator-based support system for offshore plant process management can contribute toward the improvement of work efficiency.

The 3D-simulator-based process support system introduced in this paper was developed so that a systematically designed 3D CAD model can provide 3D shape information that meets the requirements of the production site while contributing to an improvement in efficiency of the process work. If the worker can intuitively and easily recognize 3D shapes together with isometric 2D drawings in the field with frequent design changes, it can minimize incorrect working and greatly contribute to an improvement in work efficiency. In this vein, the offshore plant process support system based on the 3D simulator is a critical research field that should be developed continuously with keen interest in the future.

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 ② Carried out the experiment or collected the data
 ③ Performed the analytic calculations or numerical simulations
 ④ Wrote the manuscript
 ⑤ Supervised the findings of this study