Research And Application Of 3D Collaborative Design in Oil and Gas Field Surface Engineering

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Abstract. With the constant development of major oil and gas fields at home and abroad towards the direction of digitalization and intelligent technologies, the traditional surface engineering process has encountered the challenges of limited professional collaborative design and poor data connection, etc. The advanced 3D collaborative design has gradually become the mainstream platform of oil and gas field surface engineering design due to its features of a higher degree of model reduction and its advantages of cross-discipline, cross-platform, and cross-region collaborative design. However, in the course of current station modeling and designing, due to the complexity of engineering and the limits of design software, etc., the problems of mutual transmission failure amongst models and the loss of attribute information are prone to occur, causing a bad impact on the work efficiency of 3D collaborative design. In this paper, the commonly used 3D collaborative design software in oil and gas fields has been systematically discussed along with the common issues and their solutions in aspects of 3D design analyzed. Moreover, the effective application of collaborative design in the stage of procurement and construction, and the stage of the operation and maintenance of the digital station shall be separately discussed. While improving the efficiency of 3D collaborative design, it also plays the role of guidance in strengthening the digital and intelligent construction foundation of oil and gas fields.

Keywords: 3D collaborative design, oil-gas field surface engineering; design software; intelligent construction.

1. Introduction

In terms of the relevant survey of the International Energy Agency [1], from 2011 to 2035, the average annual investment in global oil and gas projects would be around one trillion US dollars. The huge influx of investment funds has resulted in a large number of cost overruns and progress declines existing in numerous large projects of various oil companies. In 2014, according to the survey conducted by Ernst & Young on 365 oil and gas projects around the world, it was found that 73% of the reported project progress delays, and 64% of the project cost overruns. One of the primary factors leading to project delay or failure is the incorrect implementation of project management, contracting, and delivering strategies [2]. In addition, the economic crisis, trade war, and the outbreak of the COVID-19 epidemic have had a significant impact on the construction of relevant projects. In order to deal with the projects delays and cost overruns and to mitigate the negative influence of external environmental uncertainties in the oil and gas industry, some major oil companies have taken strategic measures [3] to cope with the abovesaid situations, such as strengthening project risk assessment, enhancing efficient personnel management, optimizing and upgrading of relevant equipment and facilities, etc. Amongst them, digital and intelligent construction in oil and gas fields has been regarded as one of the most efficient solutions to mitigate the above challenges and improve operation performance [4]. Under such circumstances, various oil companies have sped up the digitalization and deployment of intelligent construction of oil and gas fields. Also, with the advantages such as

decreasing the project construction time, reducing the investment of the project, and rendering technical support in aspects of intelligent operation and maintenance of the plants, 3D Collaborative Design has increasingly become the focus of digital and intelligent construction in various oil and gas companies. Meanwhile, in order to standardize the constructions of the digital plants of the petrochemical companies, the Ministry of Housing and Urban-Rural Development of the People's Republic of China has issued the Standard of Digital Delivery for Oil Refining and Petrochemical Project (GB/T51296-2018) in September 2018, which has accessed technical support and injected strong impetus into the 3D collaborative design and digital delivery in the petrochemical industry of China [5].

With the constant promotion and broad application of 3D collaborative design, numerous issues occurred due to the complexity of the engineering and the limits of the designing software, etc. during the processes of 3D collaborative design, such as designing, plotting, and delivering, making the work at all stages difficult to complete with superior quality. In this context, many scientists carried out a lot of research on how to solve the issues at each stage. Liu Bo et al. [6] analyzed the application status quo and the issues that existed of the professional equipment in collaborative design and 3D automatic plotting and provided three solutions to the issues of the inability to automatic plotting. Pang Liang [7] summarized the practical engineering experiences based on the PDMS platform and analyzed the issues encountered while using the software. Ma Ming et al. [8] discussed the difficulties of implementing the models and documents during digital delivery and proposed relevant technical solutions. Model design is a critical process of station construction, and the design quality has directly impacted the safety and accuracy of the project. Presently, there is no summary and discussion on the common problems and the relevant solutions. Based on this, the most common software used for 3D collaborative design in the oil and gas field has been systematically discussed in this paper with issues encountered during the 3D design of the stations analyzed and the solutions put forward. Also, the intelligent application of collaborative design in terms of efficient procurement and construction as well as the maintenance of the digital stations has been discussed. While realizing the efficient application of 3D collaborative design, it also plays the role of guidance in the matter of consolidating the foundation of digitalization and intelligent construction of oil and gas fields.

2. Overview of 3D Collaborative Design

2.1. Workflow of 3D Collaborative Design

3D collaborative design refers to an advanced type of collaboration mode in which different designing personnel shall take a unified database as a core, and an integrated designing platform as a carrier based on the overall planning of the same station to complete their design tasks in a consistent coordinate system surrounding the 3D model, all disciplines shall design in parallel and submit their designs according to their authority, which solves the quality control issues caused by poor communication and repeated revisions of the designing conditions, alleviates the stress of construction plot preparing during the later stage of project design, plays a significant role in design quality improvement. 3D collaborative design features 3D model visualization, collaborative design of multi-discipline, intelligent information associating, higher integration of model datum, etc. [9-10] Figure 1 below shows the primary workflow of 3D collaborative design.

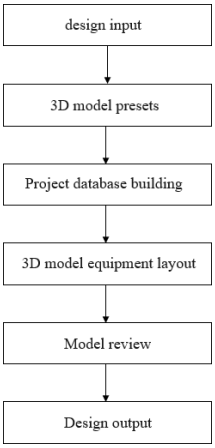


Fig. 1 The main workflow of 3D collaborative design

At the beginning of 3D collaborative design, the project management required inputs for the design, including basic data, quality, materials, information technology, etc. The intelligent design tools and integrated platforms were designed as per the requirements of the Client. Thereafter, the 3D model was preset, including configuring the system environment and project structures, defining the reference database, establishing partitions and models, setting up the users' authorities, testing, and verification, etc. Then, the component library, specification, and reference database, including piping, electrics, instrumentation, etc. were set up via the coding system of the project materials, while completing coding, geometric dimensions, description of the materials, and the inspection of the legend, symbols, and design rules. Once the above processes are completed, the 3D models of each discipline would be established and imported, the data analysis and consistency checking would be conducted by using the characteristics of the structured data while the inspection of the model collision shall be checked via the visualized collaborative platform to validate the accuracy and integrity of the information. During the model reviewing process, it is critical to complete the daily proofreading of the built model, the periodic review of the project (30%, 60%, and 90%), and the review of the model integrity and others. In the end, the designing contents of the project construction-related data, 3D model, and calculation sheet were formulated and output.

2.2. Advantages of the 3D Collaborative Design

2.2.1 Visualized and Refined Design

Compared with the 2D traditional design, the 3D collaborative design presents the project entity as a 3D model. Both the Client and contractor can view the actual scene upon completion of the unit facility and the integral digital plant via the relevant software and platform, enabling professionals from all disciplines to put forward comments and suggestions based on the same model at the design stage. Such practices shall effectively alleviate the issues such as reworking, cost overrun, and slow progress during the construction. However, the refined design shall enable each construction unit of the project to be vividly restored in the model, thus improving the accuracy of the designed products.

2.2.2 Integration of Collaborative Design

In the traditional engineering design, a larger barrier existed amongst all disciplines due to poor communication, which cannot effectively promote the operation of the overall project. After the 3D collaborative design is adopted, each discipline can acquire the design inputs and outputs from the different disciplines online. Effective communication can solve the issues of "errors, omissions and defects" caused by poor communication amongst the different disciplines and within the discipline in order to achieve the target of collaborative modifications, effectively realizing the unified data source for all plots and improving the efficiency and quality of the design.

2.2.3 Lower Safety Risks and Higher Working Efficiency

After the 3D collaborative design has been used in the design stage, the onsite civil construction, process module, and skid fabrication could be carried out simultaneously. The module fabrication can be completed in the plant without any limits of weather and site conditions, which could enhance work efficiency. Meanwhile, with the installation and construction of the relevant onsite facilities simplified, the frequency of work-at-height and hot-work can be reduced onsite, thus mitigating the safety hazards of onsite installations.

2.2.4 Conducive to the Subsequent Management and Maintenance of the Stations

After the stations are constructed with the 3D collaborative design, a detail of the complete model coverage and database is obtained. All this information would be the basis for building digitalized and intelligent stations, which are conducive to the implementation of management, intelligent exploration, and modification throughout the full lifespan of the stations.

3. Details of Common Design Software and the Supporting Tools

After decades of development at home and abroad, 3D collaborative design has gradually become a regular design method in aspects of architecture, nuclear power plants, petrochemical plants, etc. and the relevant design software has also been considerably upgraded in terms of the functions and performances with the continuous updating of the versions [11]. For the petrochemical industry, the requirements for the selected design software are more stringent due to the complexity of the process, higher safety risks, and the collaborative design needs of the various disciplines. Currently, the 3D pipeline design software with a larger market share and wider application in oil and gas stations is mostly designed and developed by foreign manufacturers, including PDMS [12-13] and E3D Design [14] of AVEVA, PDS [15] and SP 3D [16] of Intergraph, PLANT 3D [17] of Autodesk, AutoPLANT Piping [18] and OPM software of Bentley, etc. Even though it has a late start in China, superior 3D collaborative design software such as PDSOFT and eZWalker have emerged in the past two decades, amongst which PDSOFT [19] of Fulong Intelligent has gained sound performance in numerous domestic projects, and eZWalker of DMS [20] has been vigorously promoted and adopted in Xinjiang Oilfield. Moreover, the domestic 3D design software with a smaller market share also includes PDMAX of Changsha EW Soft, and ZWPD of Zhongweishutong. Meanwhile, with the rise of digital delivery and full lifespan management of stations, the major software manufacturers have enhanced the establishment and management of the intelligent pipeline & instrumentation diagram (P&ID) designing software and delivery platforms. See Table I for further details.

Tab. 1 Commonly used 3D collaborative design software for oil and gas stations

Software Supplier	Location	3D Design Software	Intelligent P&ID Design Software	Digital Delivery Platform
		PDMS		
AVEVA	UK		AVEVA Diagram	AVEVA NET
		E3D		
		PDS		
INTERGRAPH	USA	SP 3D	SP P&ID	SP Foundation
		CAD Worx		
AUTODESK	USA	PLANT3D	PLANT3D	—
BENTLEY	USA	AutoPLANT Piping	OP P&ID	Bentley MicroStation & Project Wise
		OpenPlant Modeler		
DASSAULT	France	SolidPlant 3D	SolidPlant P&ID	—
SIEMENS	Germany	PipeSpec	COMOS P&ID	COMOS
FULONG AI	China	PDSOFT	PDSOFT P&ID	Open5D
DMS	China	eZWalker	—	PIMCenter

It is also worth noting that even though some of the above software, due to the reasons of modeling accuracy and depth of use, have different 3D design modules in the fields of power, civil engineering, structure, etc., it is usually necessary to integrate other non-piping professional 3D design software[21], such as Tekla Structures, CAESAR II, Revit, Civil 3D, etc., see Table II for additional details. Some of the software was built-in with professional design modules, database, and model libraries embedded for the relevant fields, and they are supportive of rapid plotting and material statistics. In addition, they are compatible with the 3D piping design software.

Tab. 2 Non-piping Professional 3D Design Software

Software Supplier	Auxiliary Software	Feature
Tekla	Tekla Structures	Detailing of steel structures in project engineering [22]
	AutoPIPE	Analysis of pipe stress in the model [23]
Bentley	AutoPIPE Vessel	Design of pressure vessels and heat exchangers
	STAAD	Structural Engineering Design Analysis in 3D Models
	CAESARII	Analysis of Pipe Stresses in the Model [24]
Intergraph		
	SPRD	Unified Coding and Grade Management of Materials [25]
PTC	Pro/Engineer	Refined 3D Design of Process Equipment [26]
	Civil 3D	Design of functional areas and general plan in the factory [27]
	3ds Max	Mostly used for reverse modeling of established stations [28]
Autodesk	Revit	Collaborative design of buildings, structures, and disciplines within buildings
	Navisworks	Model Integration, Project Review, and 3D Walkthrough [29]
	InfraWorks	BIM design of roads and buildings in the factory area
EWSOFT	PWSD	Refinement design of water supply and drainage pipes [30]
HONGYE TECHNOLOGY	HongYe Software	Refinement design of water supply and drainage and HVAC in the project

The packaged digital delivery project has been officially formulated with the inclusion of 3D collaborative design software, intelligent P&ID design software, and a digital delivery platform. At the beginning of the design, the Client shall make a comprehensive choice based on the project needs and the status quo of the contractor's configuration in order to lay a solid foundation for the comparison and selection of 3D collaborative design software and the model file format unification in various fields and disciplines and to ensure a good start of the station material procurement and project construction in all stages.

4. Common Issues and Solutions during the Collaborative Design

4.1. Model Repetition or Omissions

Once the workload of model construction gets too large, even if the work has been divided in terms of professions and personnel at the start of design, there would be problems of unclear modeling

division in case of any major modifications in the process, resulting in modeling repetitions or omissions. With the multi-stage review of the models, collision inspection, and accumulation of the relevant personnel's experiences, the model quality issues caused by such factors shall be fully alleviated.

4.2. Loss of Model Attribute Information

So far, the 3D design platforms and the related software used by different design institutes and engineering units at home and abroad are fairly different. In case of any disagreements on the unified design tool and the integration platforms at the start of the design, there would be a data file format conversion and mutual model transmission. In such a process, some of the model attribute information might be lost. Taking the Mongolian OYU TOLGOI Central Heating Plant Expansion Project [31] as an example, due to the time wasted on software repurchasing and learning, increasing the project costs, the Australian company decided to use the Smart plant 3D design platform and the Chinese company used the AVEVA E3D design platform. Moreover, incomplete data association between the engineering design software and some processing and manufacturing software is another critical factor that causes the loss of model attribute information. For example, the software of AutoPIPE Vessel could provide refined design for pressure vessels, but due to the interfacing failure with software vendors of PDMS, Smart Plant 3D, resulting in the loss of some attribute information such as flange ratings and types of seal face, etc. When Bab Oilfield in UAE conducted the 3D collaborative design of the stations [32], in addition to the model files of the professional manufacturer models processed by the design institute based on the Intergraph PDS platform, the equipment supplier and the Client also provided the equipment model files, the finished construction documents in various formats. In case of any mishandling, quality defects would be caused, such as loss of model attribute information.

At present, the solution to this problem primarily depends on whether there is proper software interfacing for all software. If there are both proper software interfacing and a unified component library amongst software, then the existing model file format could be converted into the input format that can be easily recognized by the other software, and the interfacing information of both component libraries shall be corresponded, thus achieving the goal of successful mutual transmission of different software models. For example, Daqing Oilfield [33] used the method of converting the model file format to achieve the success of the new station model results transmission from the PDMS platform to the Skyline 3D platform (Figure 2). However, in case of poor software interfacing compatibility, the software with better compatibility shall play the role of the intermediate platform, or the secondary development shall be carried out based on the software performance so that the models and data from different software can be effectively integrated and inspected for collisions. In the Mongolian OYU TOLGOI Central Heating Plant Expansion Project, due to the poor interfacing compatibility between AVEVA E3D and other software, the platform Navisworks was utilized to achieve the integration of multi-professional models. After PDMS passes through the technologies of PML, DAR, .NET, etc. for secondary development, it could enable the developers to communicate with additional engineering design software and platforms [34]. During the construction of the Abadan Refinery in Iran [35], Nasirifar R. et al. realized editing and converting from the Navisworks 3D model to the PDMS model with a comprehensive conversion error of less than 1% by developing the converting code.

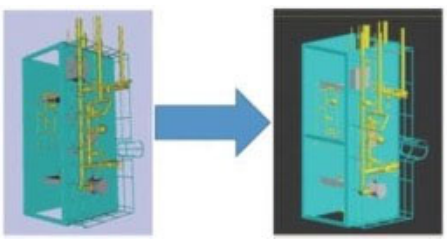


Fig. 2 The sketch after conversion between PDMS results and other 3D models.

4.3. Deviation Between Design Documents and Onsite Construction Drawings

The root cause of such problems is that all relevant parties have misunderstandings about the content and methods of the current 3D collaborative design and digital delivery. On the one hand, no software can achieve the complete modeling and automatic plotting of stations for all disciplines only based on the built-in modules, and the overall design of the stations has been carried out by different disciplines based on their 3D software modeling, and the design result shall be imported to the integrated platform. In the process of importing, some professional 3D models are reversely modeled based on the planar drawing after finishing the design, all this only plays a role of easy visualization. When the planar drawing is modified according to the construction progress while the 3D model is not changed synchronously, then the model files and the construction drawings will deviate. On the other hand, some design results cannot be synchronized between the 2D plots and 3D models, such as the details of the structural framework in PDMS, the gradient information of water supply and drainage pipes, etc. which leads to some differences between the design files and the model itself.

At this stage, most of the solutions to this problem are to rely on the digital delivery platform for data validation and manual review. Also, the manufacturers and vendors are continuously innovating their software and making them more collaborative amongst multiple disciplines, thus improving the compatibility of software interfacing, achieving more professional integration of the collaborative design, and reducing design deviations. For example, software like SP 3D, PDS, and PDMS is also built-in with professional modules like equipment, structures, and HVAC except for the professional design of piping. However, for the E3D Design of AVEVA, the functions of automatic wiring, cable rack modeling, and underground wiring are added [36], setting up a platform for wider use of the same 3D design software.

4.4. Model Browser Freezing

Compared with the traditional 2D models, the 3D models have higher demands for computer hardware and take up extra storage space. When the 3D models take up larger storage and the 3D model browser will freeze, the users can communicate with the software vendors in this regard to reduce the storage required for the model and to improve the model browsing experiences by providing lightweight models, deleting some calculations or plotting, etc.

5. The Application of Collaborative Design in the stage of Station Procurement and Construction

Upon the approval of each process scheme in the preliminary design stage of the stations, it is necessary to confirm the relevant data and technical requirements of the equipment and facilities, have them written into the procurement documents, and submit them to the Client for starting up the procurement and the subsequent constructions. The introduction of 3D collaborative design has achieved the goal of refining and digital managing resource allocation. On one hand, it has improved the accuracy of material procurement, effectively solving the errors of manual material statistics. On the other hand, it is helpful to formulate an accurate cost estimate for the project, reducing the non-standardized operations of material procurement and expenditure. Also, the collaborative design of various disciplines of 3D models as well as the model review and collision inspection in three stages of 30%, 60%, and 90% can effectively alleviate the issues of design modification, the reworking of module fabrication, and delays of construction progress, etc. caused by the disagreements during the construction process, thus shortening the construction time and improving the work efficiency. Furthermore, all the oil and gas fields, combined with their engineering practices and the project construction requirements, have conducted function upgrading and scheme customization for 3D collaborative design in the stage of procurement and construction. During the surface construction of Anyue Gas Field [37], the technical personnel used 3D design to change the overall project from the planar layout to a multi-layer stacking and set up a safe passage (the green part of Figure 3) in the 3D model to ensure the personal safety under the compact layout of the station. During the construction

phase of the Dabei Gas Transmission Station and Aksu Terminal Station in Tarim Oilfield [38], the technicians used 3D collaborative design to generate the 4D BIM model, realizing the dynamic optimization of the construction scheme. Meanwhile, given the situation of poor wireless communication in some stations in Xinjiang, they have customized and developed an offline BIM browser based on the portable working platform of the mobile terminal. In the digital delivery process of one natural gas cryogenic device in Daqing Oilfield, a QR code has been used as the carrier to integrate and display the data of equipment design, procurement, supplier manufacturing, and installation, etc. establishing a tracking system of material status and the entire construction process [39]. Additionally, the 3D collaborative design has been applied in the stage of engineering, procurement, and construction in Xinjiang Oilfield, Shunbei Oil and Gas Field in China, and Bab Oilfield in UAE [40-41].



Fig. 3 Layout of safe passage in multi-layer space stacking design

6. Intelligent Application of Digital Stations in the Stage of Operation and Maintenance

After the digital handover of the project, the Client can make excellent use of the 3D model and the relevant data according to the actual situation and operation needs of the stations. By correlating the model data to the station entities, with the help of digital twins, VR, and AR, the intelligent applications of the visualized operation and maintenance, operator training simulator (OTS), and remote fault diagnosis can be finally realized (Figure 4).

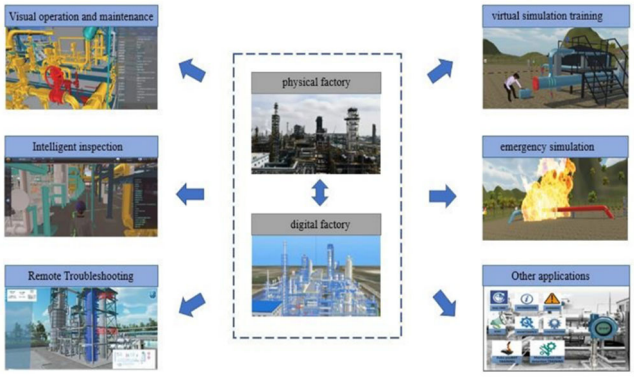


Fig. 4 Examples of extended functions that can be achieved in the operation and maintenance phase of a digital factory.

6.1. Model Data Visualization and Remote Faults Diagnosis

In 2017, the British oil giant 'BP' [42] used Fieldbit Hero smart glasses of Fieldbit Company (an AR startup) to enable the experts in the control room to complete the fault diagnosis of the station facility process from the perspective of the station worker, and to superimpose the simple visual instructions and real-time data of relevant equipment on the worker's vision, helping workers to realize the equipment repair. In 2018, Chevron [43] also helped relevant station personnel to conduct

the station model visualization and remote instructing by supplying Microsoft HoloLens goggles to the on-station technicians, as shown in Figure 5. In 2020, N. Koteleva et al. [44] took the Grundfos vertical electric centrifugal pump as the experimental object to study the maintenance efficiency of AR technology for the oil pump maintenance system. By comparing the experimental and the related data, it is proved that VR technology could significantly reduce the time of fault diagnosis and maintenance. However, since this comparative experiment and the related devices are indoors, the actual industrial application effect needs further validation.



Fig. 5 Technician using Microsoft goggle.

6.2. Intelligent Inspection

In 2018, Naranjo et al. [45] combined the technologies of AR, VR, and high-DOF (degree of freedom) robots with robotic hands in the pilot block of Ecuadorian Amazon Petroleum Corporation. After the robot transmits the live information of the stations to the remote worker via cameras, positioning sensors, and speed sensors, etc., the workers can feedback the relevant instructions to the onsite robot by the means of tactile sensations so that the function of the remote station inspection, equipment maintenance, and personnel training could be conducted under the low latency network. In 2019, Wang Chuanping et al. [46] achieved the integrated application of station video and access control system by utilizing the 3D Kanban System in Xinjiang Oilfield, and personal safety while inspecting dangerous areas could be effectively guaranteed via the intelligent inspection model (Figure 6). In 2020, Dong Hongjun et al. [47] achieved the intelligent identification of unsafe events in the Heihe Initial Station of the China-Russian East Route and the automatic routes inspection by setting up a 3D model station and developing the video intelligent identification algorithms.



Fig. 6 Virtual intelligent inspections at the station

6.3. OTS and Emergency Simulation

In 2018, Andaluz et al. [48] achieved the Operator Training Simulator for the pig launching and receiving process by using VR technology (Figure 7) and carried out emergency simulations and drills for station emergencies. In 2019, Shi Zhuochan et al. [49] built a virtual simulation training system for an emergency response to crude oil leaks and fire emergencies in the valve-holding chamber in front of the storage tank by using VR technology. It has not only reduced the training costs and increased the training time, but also improved the workers' technical skills. In the same year, Garcia et al. [50] developed training software for instrument technicians in the oil and gas field based on the technology of VR. Utilizing the virtual environment of this software can help the relevant

personnel learn the skills during the installation and commissioning process of intelligent instruments in the stations, saving a substantial amount of costs and time. In 2021, Liu Xianmei et al. [51] developed a virtual simulation training system for multiple job posts collaborative operation by using the 3D modeling tools of 3DS Max and Poser, which is used for visualized simulation training of workers from different places, multiple job posts, and multiple work groups.



Fig. 7 Collaborative operation interface for virtual simulation training

6.4. Other Intelligent Technologies

In 2021, Audrain et al. [52] proposed a 3D collaborative model to optimize the station maintenance processes and reduce the project maintenance time. With the 3D digital collaborative platform built, the engineers can quickly identify the potential bottlenecks and access the facility specification, historic maintenance records, and reports of the relevant supplier in order to closely link the maintenance processes and reduce the overall maintenance time. In the same year, with the Holographic Laser Projection of the 3D design model into the conference room in Malo Oilfield, Gulf of Mexico [53], Chevron could enable the relevant personnel to view the onsite model in a 3D and immersive manner while testing the spacing, assessing the safety and verifying the other design issues before components installation.

7. Conclusion

At present, there are numerous 3D collaborative design software and supporting tools available at home and abroad. On the basis of meeting the project construction needs, the relevant software from the foreign vendors is superior to the domestic software with regard to market share and multi-discipline collaboration.

In the course of station modeling and designing, due to the complexity of engineering and the limits of design software, it is easy to have issues of mutual transmission failure amongst models, loss of attribute information, and deviation between design files and the onsite construction drawings. In this work, all the root causes of the issues have been discussed with corresponding optimized solutions proposed to provide experiences and references for the successful execution of the subsequent projects.

In the procurement and execution stage, 3D collaborative design can effectively alleviate the construction delays caused by design variation, and reworking module fabrication in the traditional design mode, playing a critical role in improving design quality and reducing project costs.

Although the 3D station model has been widely combined with the intelligent technologies of digital twins, AR, VR, etc., and applied to the fields of remote fault diagnosis and virtual simulation training, there is still a long way from the completion of the integrated digital and intelligent stations, and the output of the relevant achievements still needs additional improvement. To conclude, it is suggested that the station information model shall be thoroughly integrated with intelligent technologies to dig up the great potential, thus empowering the development of oil and gas fields.

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