Multi-view Feature Model Representation to Support Integration of Chemical Process and Mechanical Design

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ABSTRACT

Increasingly extensive attentions have been given for the collaboration between chemical process and mechanical design teams, especially for large scale energy industries such as oil sands mining, upgrading and refining. The innovation of this proposed approach is to provide efficient and flexible information share capability between different engineering departments. In this direction for the oil industry, as an example, the information flow between chemical process engineering and mechanical engineering domains is very crucial. Currently the engineers working for these two fields use different engineering platforms whose information are also isolated. In this paper, a system design with the generic data framework is proposed to facilitate the sharing of information and to help the design from different aspects using multi-view feature technology. A preliminary scenario has been implemented with NX™ and SmartPlant™ software tools. It has been proved that under the proposed system design, engineers working on these two domains can integrated their work coherently and share different information and constraints consistently.

Keywords: multiple view, feature-based integration, collaborative engineering.
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1 Introduction

Large scale industry projects require the collaboration of engineers with different disciplinary knowledge and background to work towards the same final goal. For example, many engineering, procurement and construction (EPC) companies that provide engineering services to oil industry face the increasing challenge for the integration of chemical process, mechanical, and electrical and instrumentation designs. However, the semantic differences between engineering domains and engineering entity representations make the design collaboration processes very complex, tedious and

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inefficient if not impossible. This resulted in the acute research demand of concurrent engineering to enhance the sharing of knowledge between engineering domains.

In the chemical process design aspect, a data structure was developed to implement an integrated concurrent engineering environment [9], which is further utilized to implement design information system [2]. Goodwin *et al.* also developed a framework to integrate a current chemical process design with some historical design alternatives [4]. One shortcoming for these integrations is that there are large amount of mechanical components (pipes, tanks, valves), whose details are to be determined by, and hence their semantics are required to be shared with, mechanical engineers. The chemical process design will have significant impact on the mechanical design of equipment, pipe lines, and other components used in the process. Herder *et al.* developed an approach to classify and manage the "external factors" in chemical process design, where most of the "external design factors" are related to detailed mechanical design contents [6].

In terms of mechanical design with attention to details, product design and manufacturing information have been more integrated than the process domain based on the development of computer-aided tools for design (CAD), engineering (CAE), manufacturing (CAM) and process planning (CAPP). Following the concurrent engineering approach, the geometric information features are well defined and can be stored in databases for sharing [1]. Several data models and system frameworks are proposed and developed to implement information sharing. For instance, a common data model is developed by Gujarathi *et al.* to implement the data sharing in CAD and CAE models [5]. In addition, Pullan *et al.* introduced a framework to implement the design information sharing among mechanical design and manufacturing [10]. Xu *et al.* achieved information integration for design, manufacturing, and engineering with a multi-model approach [11]. In another study, the information sharing between mechanical design models is well connected and shared using agent-based and web-oriented techniques [12].

Unfortunately, despite of the previous studies listed, there have been few research developed to "breaking the wall" between the two domains and to enable engineers interact with each other and share information directly. Until now, studies are going on in parallel lines and few of them have been done to connect the information of mechanical design with other engineering domains, such as chemical process design. Thus, there is an urgent need to improve the information sharing, feedback and updating capability in order to eliminate the information boundary restriction which current lies on the piece by piece exchange between different engineering domains.

2 GENERIC DATE STRUCTURE AND SYSTEM ARCHITECTURE

2.1 Multi View Feature Based System

Following the concurrent engineering concept, in mechanical engineering, several information integration methodologies have been developed. One of the most efficient methods is multiple-view feature concept, which is widely used in the design of mechanical feature modeling to facilitate the management of relevant design information [3] and implementation of engineering changes [7]. In addition, it has been utilized for the integration of CAX systems [11]. However, there are few research works reported on the construction of a multi-view data model inter-discipline information sharing, e.g. between mechanical design and chemical process design. In this paper, a generic data structure is proposed using multi-view feature model to integrate process design data, mechanical engineering and detailed equipment design data.

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2.2 System Framework

A schematic system framework is proposed, as shown in Figure 1 for integrating mechanical and process design systems. The system consists of 6 modules, the mechanical and process design environments (2 modules), central feature management system (1 module), product and process feature modules respectively (2 modules), and also data repositories for different domains (1 module). Mechanical and Process design environments provides specified user interfaces to their corresponding domain engineers; while central unified feature management module processes feature information gathered from both domains and facilitate collaborative work across disciplines with an inter-domain feature mapping mechanism and the relevant schemas.

Typical mechanical design system (module 1), such as NX™, contains parametric and feature-based data of the designed assemblies as well as individual parts expressed in detailed 3D solid models. However, in the process design platform (module 2), i.e. SmartPlant™ of Intergraph, the equipment and process data also contains 3D models, as well as schematic diagrams, such as the Piping & Instrumentation Diagram (P&ID) and Process Flow Diagram (PFD) information. Note that in Fig. 1, two domain feature repositories are suggested, i.e. product domain features (module 3) and process domain features (module 4). They are largely classified according to the engineering discipline. For example, if we consider electrical and instrumentation domain, there is a need of specific feature repository for this domain as well. To integrate these specific application modules (e.g. mechanical design and chemical process design), the first module required is a generic data structure to classify the data into three categories, i.e. process, mechanical and equipment designs (module 5).

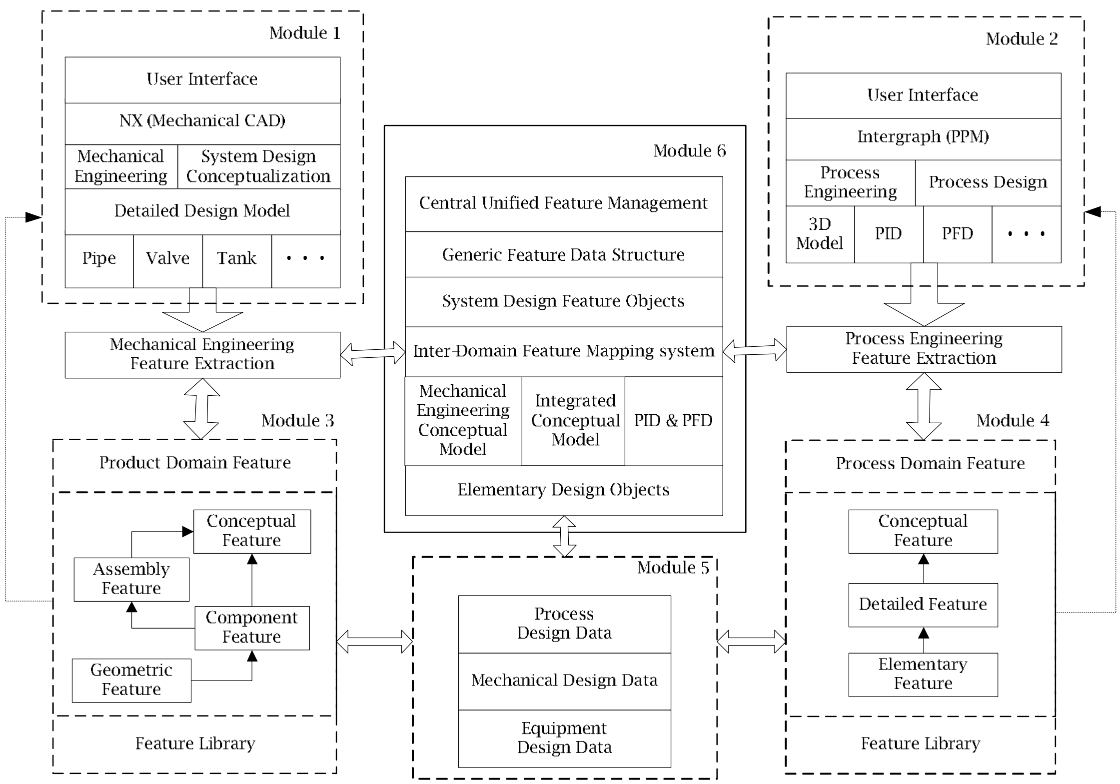

Fig. 1: Illustration of System Framework.

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Then the system integration module has to be designed (module 6). This module consists of 6 layers. There is a unified feature management layer which registers, maintains and validates all the features according to a unified scheme and related mechanisms. The feature data structures are defined in the next layer which is to be interfaced with the data module (module 5) to provide feature attributes values, including all the parametersõ values. The third layer is the run-time module that keeps evaluation system for all the features in order to maintain the total system consistency. With the consideration of variations in different feature definitions and associations among them, an òinter-domain feature mapping systemó is suggested in the 4^{th} layer to enable a systematic mapping and evaluation association function. This layer of the module can be used to map both horizontally among different application module features and within the unified feature module itself, among its 5^{th} layer macro data structures, such as the associations between PIDs, PFDs, and integrated conceptual model based on the input of different disciplines. For example, those relationships between the three data categories, i.e. process engineering data, mechanical engineering data and equipment data, can be developed in this layer. Such mapping mechanism is mainly using associative graphs. Ultimately, in the lowest (6^{th}) layer of this module, all the run-time feature constituents are managed as a large set of elementary feature objects; such as PID symbol objects, PFD flow circuits, or a mechanical design pressure vessel.

In real application, a library can be developed based on the relations developed by using the framework of this unified feature module, and identifying input/output data sets by system engineers. Such a library can serve the purpose of ensuring the functionality feature mapping by providing sufficient links between different feature types. Similarly, additional design information from the other disciplinary systems can also be incorporated into the centralized and unified system, such as electrical and instrumentation domain design system. It can be expected that such a systematic integration approach can reduce the design life cycle maintenance hurdles between mechanical and chemical design engineers.

2.3 A Unified Multi-view Engineering Model

To enable interoperability between chemical process engineering and mechanical engineering systems, a modular structural software hierarchy supported with a unified feature modeling method [8] that entails different levels of entities, has to be established. The hierarchy of Unified Engineering Model (UEM) is illustrated in Figure 2. There are 7 layers according to the modularity scopes and information dependencies. The top layer, UEM, assembles all information modules across disciplines. It can be appreciated that a *complete* information navigation scenario would contain certainly too much redundant, irrelevant and tedious information for any user working in an individual specific discipline; and it would be a waste of time and precious manpower to evaluate and enable such òall-in-oneó and òwide-spectrumó information flow. Therefore, certain abstraction and extraction of UEM is needed to generate different views for different purposes, by which each view includes corresponding information for a certain perspective. For example, at the top level, a project management view is designed, which is to be generated for the said specific purpose, which may contain schedules, mile stones, engineering costs, bill of material, suppliers, etc. Similarly, in less comprehensive scopes according to engineering domains, views for process engineering, mechanical engineering, as well as electrical, control and instrumentation are derived from the unified engineering model at a lower level.

More technically, vertical mapping schemas are placed between different layers, which are used for the integration of different information levels. There are 7 layers, i.e. project management, engineering views, configurations, functions, system, features and databases. Note that the project engineering management module is coupled with configuration management in the 3^{rd} level from the top; it is supposed to keep the configuration integrity of each solutions. At the functional layer,

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engineering principles, standards and codes are supposed to be implemented in a plug and play manner and they are dynamically verified so that the design validity is always evaluated in the first time. Further in the same level, equipment view entails mechanical facility/device design and selection that are achieved by interactions with the engineers involved. Also, equipment view will be materialized with various working configurations and serve for different projects.

Features across different domains are grouped together under a unified feature management module. They will be managed, verified by corresponding standards and codes according to function requirements. Each feature is mapped to certain geometrical form; while certain features group together to form a view for a specified area.

Note that in the feature level, feature information also needs to be shared and transferred in the horizontal direction. Considering tanks, reactors, pipelines, pumps, etc. in the process engineering design, they are represented in the form of process domain feature elements. These features need to be mapped into mechanical design conceptual assemblies at different levels to be further materialized into mechanical design items with certain parameter driven geometrical entities. Besides, information sharing between these engineering views is also significant, especially when any change in any domain occurs. For example, in order to keep information consistence, the change of technological features defined in process engineering view needs to be transferred to mechanical design view to trigger the corresponding changes there; the change of mechanical design features also needs to feedback to features associated in the process engineering view. Otherwise, there will be information conflict between the different domain entities.

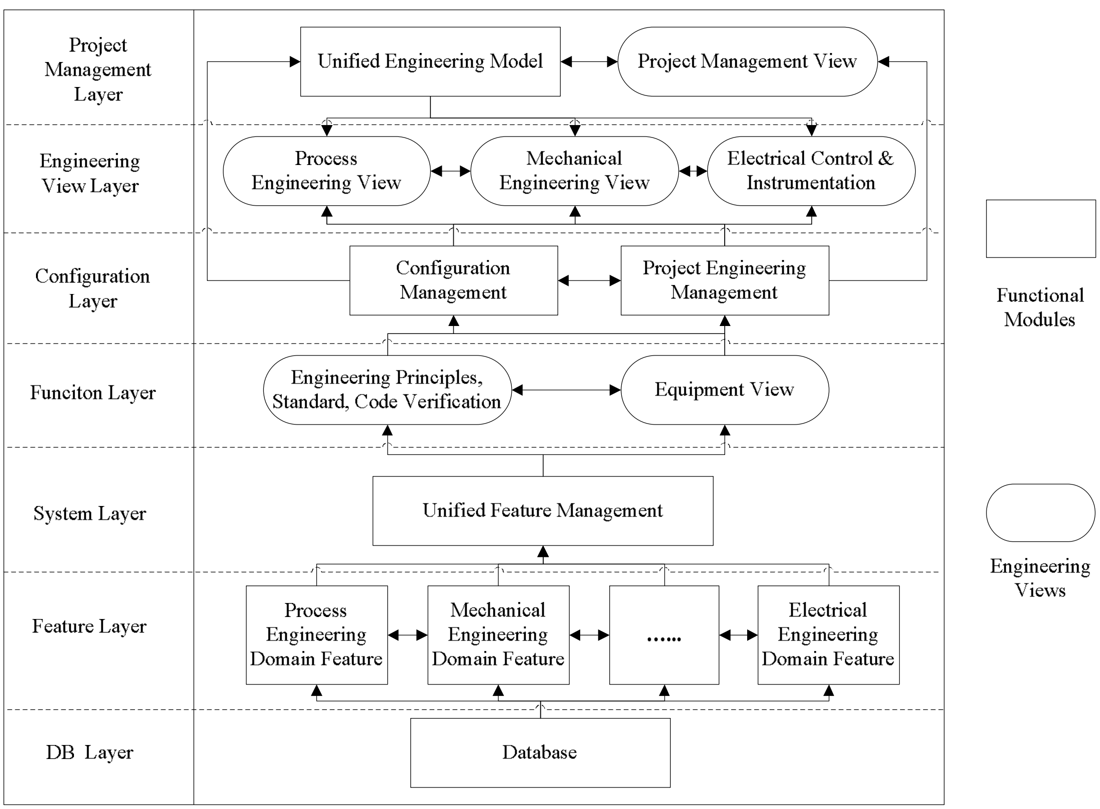

Fig. 2: Hierarchy of Unified Engineering Model.

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3 FEATURE EXTRACTION

Usually, in a project, process engineering design is constituted of extensive mechanical items, such as facilities, modular systems, components and control devices. One problem is that the feature information generated and stored in the process design databases is not compatible with the mechanical design software, such as NX. In terms of mechanical engineering aspect, the most widely used typical components in chemical process engineering are process equipment items, e.g. pipes and valves.

The mapping of mechanical components with process engineering items can be specified by the categories of mechanical units used in chemical process engineering. There are two categories: Standard Component (SC), which can be directly mapped to corresponding process modeling items, such as Intergraph SmartPlant™ model items that have been pre-defined in library; and Non-Standard Component (NSC), whose design information are retrieved from process models and requires mechanical design procedures, process specifications are transferred into the mechanical engineering domain by a common data structure of a neutral format. The design information of the NSCs includes both technological features and geometrical features. Both of them need to be extracted and transferred into a neutral format to facilitate the standard mechanical design. All the above-mentioned features are comprised of the technological/geometrical information and/or the requirements for implementation of these functions assigned.

Take a separation tank in oil sand process as an example, the function of it is to store the mixtures of oil sands and transfer separated matters into different pipe routes. To function successfully, the tank needs to sustain certain environmental parameters, such as pressure and temperature. These environmental parameters can be transferred into specific mechanical parameters in the CAD models, such as shell thickness, based on thermodynamic and mechanical relationships.

A set of pre-defined model libraries are to be used in order to facilitate the modeling of standard components. In addition, NSCs, which have been specified and developed in the first time in a project, once fully defined, will be abstracted and put into a few libraries, together with the feature information.

However, these models will not exist in process design model directly and there is no need for a process engineer to know the details. Instead, a process view of this model, which just contains chemical process related feature information, is presented.

As shown in the information flow diagram in Figure 3, whenever the design engineers withdraw data from either of the software platforms, the sub information control will activate the central design control in order to load data from the system. at the same time, the data structure will verify the data classification and pass on several constraints from overall design objectives.

4 PROJECT DEVELOPMENT BASED ON THE FRAMEWORK PROPOSED

Based on the framework proposed in the previous sections, the project development will work in the way as shown in Figure 4, which will be different from conventional project development. First, the project will still start with requirement analysis. Once that is done, the project evaluation will be carried out; in this stage engineering view management agent assigns different views to related engineers across disciplines to facilitate their collaboration effort. After that, it will be checked whether there is any existing similar project template and the working flow will go into two separate routines. If a similar template is found, the corresponding project template will be extracted from a

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library by object database conversion agent. Otherwise, completely new project will be explored and hence a new template is to be developed. Then two flows merge to new project view creation.

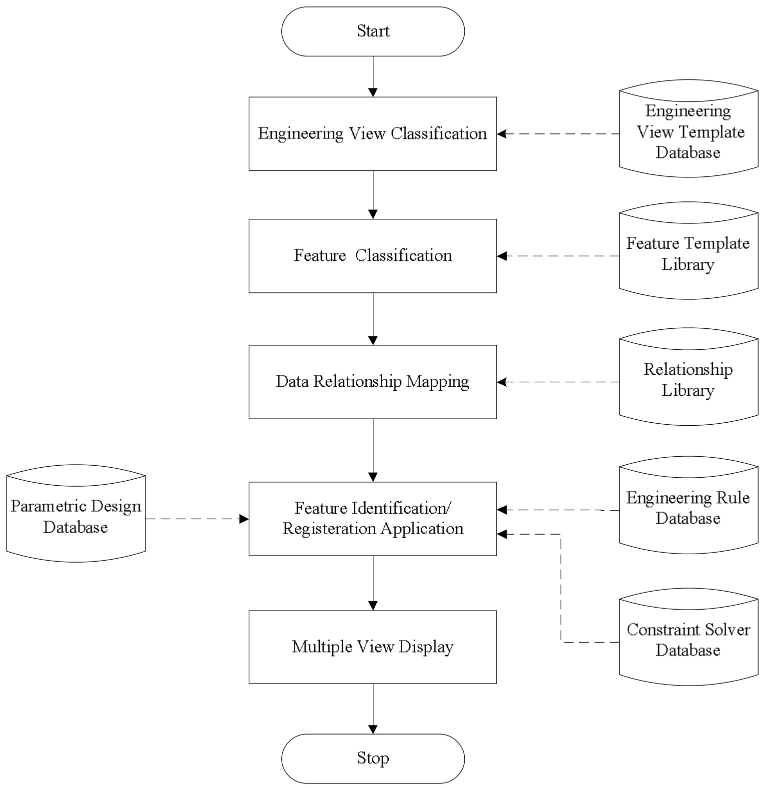

Fig. 3: Data Extraction Information Flow.

Once a project is fully created, it is followed by engineering development, which is aided by Engineering Constraint Check Agent (ECCA). The constraints are a collection of all the domain-specific formulas or relations and they are referenced via a Feature Management Agent (FMA). In this process, FMA will gather feature information from engineering feature library and group them into specific engineering and innovation information and then ECCA is designed to act autonomously on constraint check based on engineering relations. The output of engineering development module will generate project engineering solutions and they are stored in the project engineering database. After iterations of engineering development, project is finally completed; and the final engineering solution is also stored in the previous database. All the project solutions are later converted into project template library items by a Project Database Conversion Agent. Further on, if any new feature type item is created, then it will be converted into a member item of engineering feature library by the object database conversion agent.

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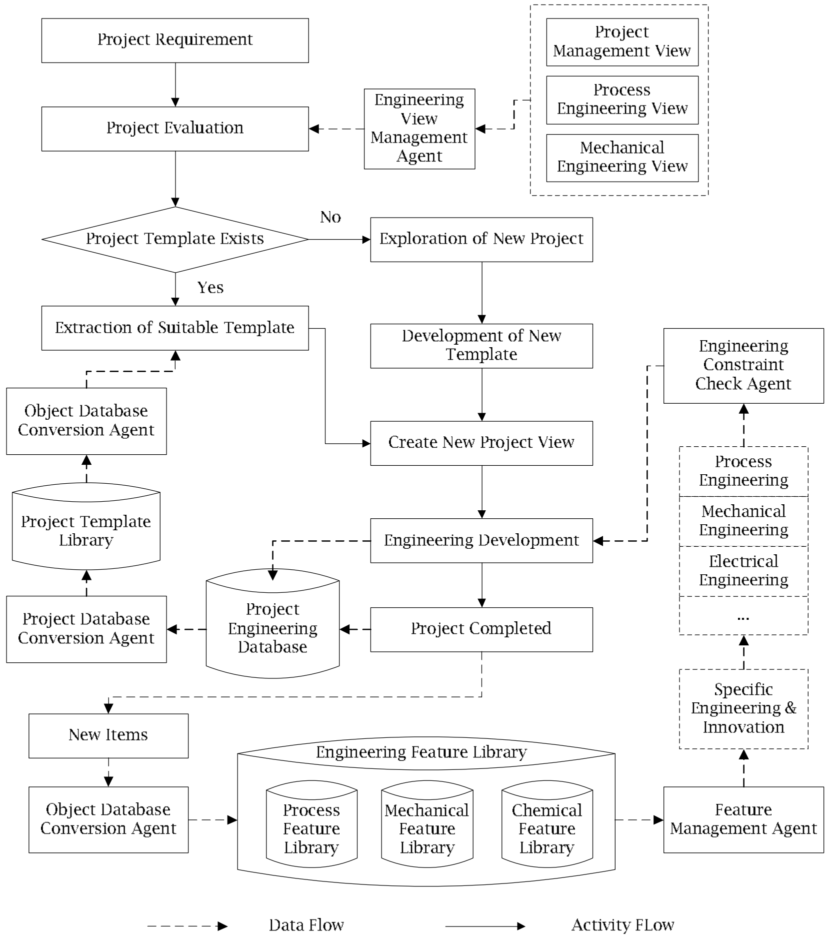

Fig. 4: Project Development Process Flow.

5 CASE STUDY

The information flow and design process of a storage tank involved in a drilling mud farm project, which is designed as an NSC, is illustrated in Figure 5 to show how the proposed framework works. The process engineering view consists of commonly used process features and their editing user interfaces (UIs). One of the output results by chemical process engineers working with the process view is the PID. Once the PID is established, the *Central Unified Feature Management System* will start to extract process requirement feature information, such as pressure, temperature, capacity, etc. The process requirement feature information of the storage tank will be then translated into mechanical features in a mechanical model description in a computer interpretable language, and the detailed model elements, such as nozzles geometric definitions and attributes, which can be generated automatically according to design standards, such as engineering design codes. Engineering constraints for attributes of mechanical engineering features are resolved subsequently and propagated throughout the associated design feature models across different domains, e.g. determination of shell thickness of the storage tank. The mechanical engineering related information is organized in the form of features and managed via a set of dynamic user interfaces (UIs). Then these mechanical features and

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run-time UIs all together are integrated as a functional module, i.e. the mechanical view for mechanical engineers, which provides a basis for further detailed mechanical design.

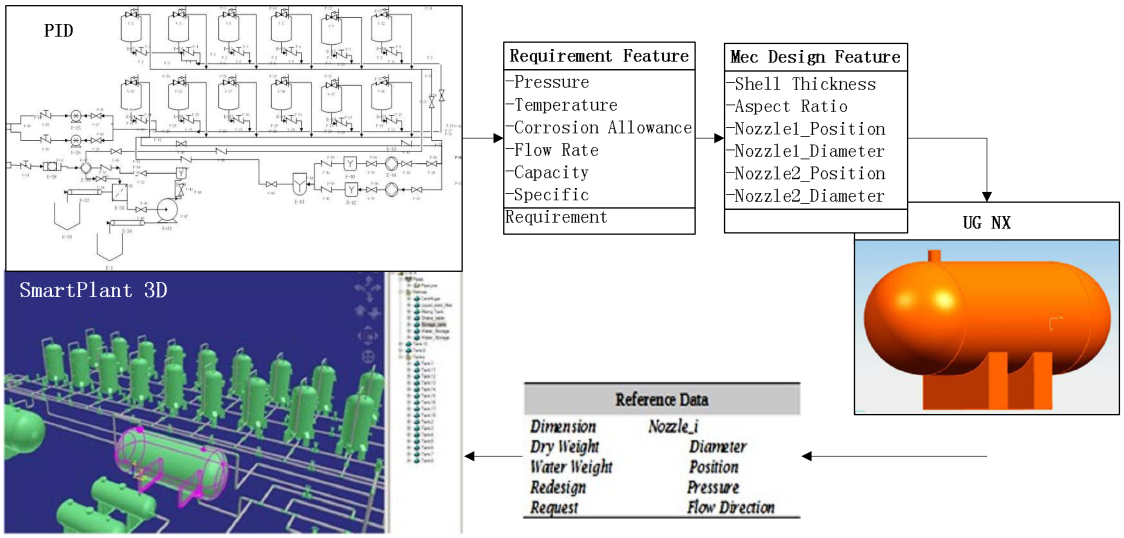

Fig. 5: Case Study System Diagram.

Thereafter, within the mechanical domain, 3D models will be built with CAD applications, such as NX™, based on design requirement features, as shown in Figure 5. Once this model is successfully finished, the product information can be checked by process engineers. However, note that the fully detailed mechanical model will not be presented to process engineers on top of their process design model directly because the combined model includes too much detailed mechanical information, which is not necessary for process engineering and will become a burden for data transfer between applications. Instead, a specifically configured process design view, with updated process feature information of this tank, is generated. Only process related data, such as flow rate, pressure rating and nozzle nominal diameter are updated and associated with the process model entities as reference data. Those local detailed mechanical parameters, such as the rounding corner radii, are filtered off. Based on the process engineering view information, a 3D process view of the project design model is generated in SmartPlant 3D™, which is used to facilitate 3D process modeling and interference check in process domain. As is shown in Figure 5, the tank in NX™ is mapped to the storage tank with pink wire frame in SmartPlant 3D. Those 3D models in the software have embedded relations with PID. Hence all the models included in both the process and mechanical engineering domains are consistently connected.

6 CONCLUSIONS

In many industries, such as energy production, advanced engineering design technologies across disciplinary domains need to be developed in order to support end users in global competition. However, developing a coherent engineering system supporting concurrent and collaborative engineering remains a problem. Currently, those domain-based design processes cause project delays and lose their engineering optimality without considering certain constraints from other domains. This paper addressed an approach to implement collaborative design between mechanical and chemical engineering domains; a multiple engineering view system framework is proposed. These associated, enriched but specifically configured domain *views* can help domain engineers observe other domains'

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factors and constraints that will affect their final design. Besides, a generic data structure is also proposed to store and manage the information flows between the two large scale engineering domains and their systems. However, the authors admit that feature extraction methods are to be further developed, such as extracting mechanical features from process engineering models and vice versa as the current feature extraction technology is very limited and mainly applicable in mechanical engineering domain. For further research, one direction is to enrich the view categories which contain other design aspects, such as analysis and simulation. In addition, the data structure and related system framework can also be further developed and extended to support information flows between design systems and enterprise business resource planning, such as Product Data Management (PDM), supply chain management and Enterprise Resource Planning (ERP) systems.

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