6th annual IEEE Conference on Automation Science and Engineering
Marriott Eaton Centre Hotel
Toronto, Ontario, Canada, August 21-24, 2010

Generative CAD and CAE Integration Using Common Data Model

G. P. Gujarathi and Y. –S. Ma*

Abstract— **The proposed method includes generation of a "common data model" (CDM) containing all the required parametric information for both CAD and CAE analysis. CDM stores and supplies the associative data to both CAD and CAE models and thus maintaining the associative dependencies between them. As the common data model gets modified according to designer's intent, the changes in it are consistently reflected in both CAD and CAE models through regeneration and analysis iteration. The same data model can be used to work with different CAD and CAE packages since it is totally independent from the software tools used. The data model is reusable and the whole process can be automated so that the embedded expertise in the cycles of the adaptive design and manufacturing can be consistently applied iteratively during product development processes.**

NOMENCLATURE

API: Application Programming Interface
CAD: Computer Aided Drawing
CAE: Computer Aided Engineering
CDM: Common Data Model
FEA: Finite Element Analysis
GUI: Graphical User Interface
KBE: Knowledge Based Engineering

I. INTRODUCTION

There are number of commercial CAD software tools such as Solid Works, Pro/Engineer, etc., and CAE analysis software tools like Ansys and Nastran which are widely used in the industry. Most of these tools are usually focused on either CAD or CAE application separately and lack the full capability of the other technology. Thus a design engineer has to work with two or more software packages at a time for modelling and analysis and yet keep checking the constraints applied throughout the engineering processes in order to avoid losing model integrity. Ideally, the designer would like to integrate CAD and CAE in order to complete every design cycle effectively. Currently, in most cases, a CAD software tool can provide a exported geometry model in standard formats, such as STL, IGES or STEP which can be used as the input in a CAE analysis package; but before the geometry can be used for CAE purpose, the original design model has to be modified, simplified and enriched with some additional parameters to make it suitable for analysis. Some of the major problems associated in the past with CAD-CAE integration are information losses, compatibility issues between CAD and CAE software [1], breakdown of associations, reusability of knowledge [2], conflict of modelling complex geometry and its analysis simplification requirement [3], loss of design expertise, difficulties in automation of the design process [4], unacceptable time associated with the total design process [2][5], geometry simplification of CAD and its conversion to FEA model for mesh generation and analysis[6][7].

The proposed method suggests using of a *common data model* (CDM) consisting of all the semantic driving parameters for CAD (Siemens NX6), mesh model and CAE (NX Nastran) analysis. CDM can be used to generate all the models and analysis results using software API and the recorded macro commands. Since the common data model can also be managed to keep the dependency constraints among the input parameters for different processes such as CAD and CAE sessions, this method thus assures that all the models use the same shared information model. For a design to be carried out according to a set standards and codes, a parametric product model can be generated automatically using a knowledge base and API. This way the design process can also be controlled according to the well defined engineering concepts and regulations; and hence it will also reduce the need of recalling design expertise implemented in the process. Potentially, all models will be integrated parametrically using knowledge bases and programming logics for setting constraints and making decisions. In case of using different CAD and CAE software tools, then the common data model created can be used as the source of knowledge and its implementation can be achieved by programming those different API functions. Thus this CDM can be used with various software tools regardless of their compatibility with each other.

II. LITERATURE REVIEW

Considerable research has been done on CAD and CAE integration in previous years. Most of the work was focused on mesh compatibility between various CAD and CAE software tools. There was relatively less focus on completing the design loop and the automation of the entire process. Also most of the studies were focused on implanting data model generated from CAD into CAE and then continue the CAE process interactively. As far as the authors' knowledge,

Manuscript received February 28, 2010. This work was supported in part by the NSERC Discovery Grant # 355454-09.

G. P. Gujarathi is a MSc student with the Department of Mechanical Engineering, University of Alberta, AB T6G 2G8, Canada. Tel: 780-248-1727; e-mail: gujarath@ualberta.ca

*Corresponding author. Y.-S. Ma is an Associate Professor with the Department of Mechanical Engineering, University of Alberta, AB T6G 2G8, Canada. Tel: 780-492-4443; Fax: 780-492-2200; e-mail: yongsheng.ma@ualberta.ca

no one uses APIs of both CAD and CAE tools to integrate design and analysis cycles which involve capturing and maintaining the expertise throughout the processes. So far, there is no reported work done on a common data model to keep the integrity of both CAD and CAE models.

Peak [2] described problems associated with CAD and CAE interoperability, fine grain associativity gaps and software tools' limitations. Deng et al. [4] incorporated the use of feature based modeling and analysis for CAD and CAE integration where various features associated with both CAD and CAE including all geometric and non-geometric ones. The prototype software for injection molded product design tried a feature mapping method for CAE feature simplification such as ribs. Zeng et al. [5] suggested the use of *ZAP,* a knowledge based FE modeling method, to reduce design time. They suggested CAD- FEA integration at knowledge level and stressed the importance of automation in idealization of CAD and mesh generation. Hamri and Lèon [3] suggested using *polyhedral* model as an intermediate model between CAD and FE model for interoperability. They recognized the need of re-analyzing the same CAD model multiple times with modifications in the evolution of product design phases. Lee [12] focused on creating a single model containing both CAD and CAE features and explored the advantages of a *common modeling environment* and *bidirectional* CAD and CAE integration. This approach involves multiple feature representations and limited automation. Su and Wakelam [9] worked on creating an intelligent hybrid system to integrate various CAD, CAE and CAM tools in design process using a blend of rule-based system, artificial neural networks (ANNs), genetic algorithm (GA) into a single environment using parametric approach for model generation and rule based approach to control the design environment. However, their work did not investigate the automation mechanisms to reapply engineering rules and constraints in the design process.

Some of the limitations associated with CAD and CAE integration approaches can be solved with the help of knowledge based engineering. Cao et al. [1] developed a middleware to transform CAD models into acceptable CAE mesh model, i.e. HEDP (High End Digital Prototyping). It can manage model simplification and defeaturing of CAD models to make it acceptable to FEA meshing and also get quick results; but the integration is one-way traffic and lacks the recursive loop support. Yip et al. [3] focused on a *knowledge-intensive CAD (KIC)* which includes integration of design lifecycle and engineering knowledge with CAD, including CAE results; but they did not show how these two aspects interact automatically. Shephard et al. [10] developed a method to support *Simulation Based Design* via CAD model simplification and data management. It seems the modular design environment works well in a controlled interactive design and analysis setting, but is not clear how the associative design and analysis parameter relations introduced by engineering constraints are maintained consistently. Foucault et al. [6] addressed the mesh quality enhancement in conversion of CAD model to finite element model for analysis. Novak and Dolsak [11] devised a design advising system based on finite element analysis results. Peter Wriggers [8] worked on intelligent support for the FE analysis for automated process of meshing and analysis. All of this work was aimed for improving the performance of existing CAD and CAE software tools but these concepts are not integrated among themselves to take advantage of all of them.

III. Common Data Model

Common Data Model as the name suggests, is a database of all the design semantic parameters required to build CAD, FE models and to conduct engineering analysis with the assistance of knowledge based tools. Figure 1 gives a structure of the proposed design processes in a design cycle.

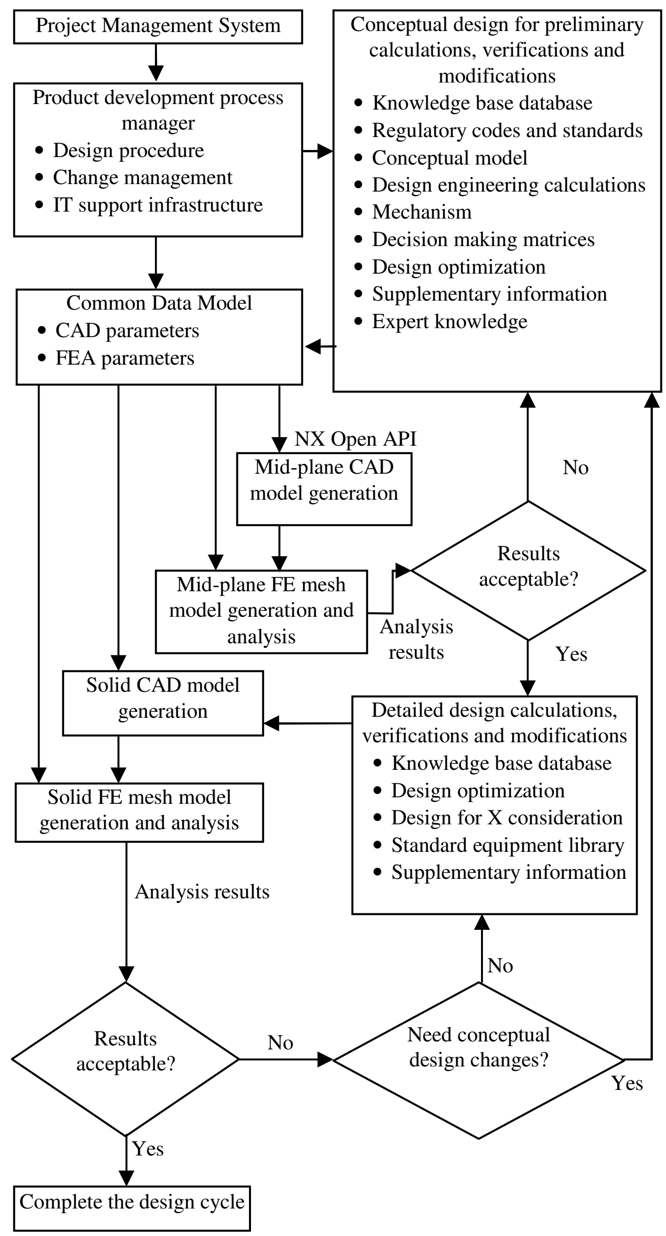


Fig. 1: CDM involving CAD/CAE interactions

The proposed design procedure can be briefly described as follows. After starting the design project, the user is required to input the "*design requirements and specifications*", then based on a knowledge based system, all the design and analysis parameters at the engineering conceptual design level is captured in a data structure and stored in a data file at the same time. The design data model generated this way is referred and used as the Common Data Model (CDM) hereafter. Note that this CDM is a live data file that its contents are increased and the engineering intent embedded is detailed gradually in stages over the period of design consolidation. Figure 2 gives the data structure suggested for the CDM.

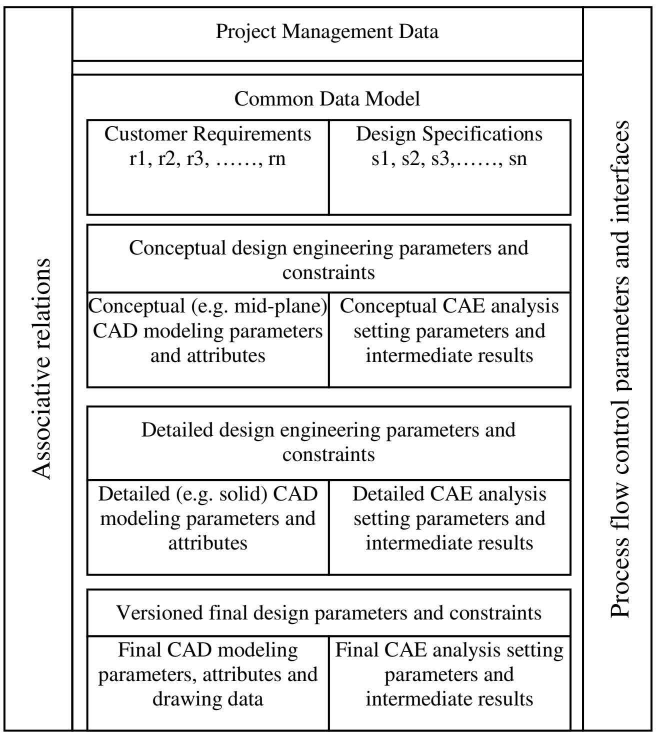


Fig. 2 Common Data Model (CDM) structure

Based on the CDM, a design program further calculates and/or selects all the required geometric and analysis parameters according to the standard industrial design procedures and the regulatory codes. The three basic information sets used in the program to generate the data model are geometric information, engineering rules, regulatory standards [12]. The integration programming tool used for this purpose can be C++, since it is also one of the programming tools for the NX6 API. The parameters generated are further recorded after the application of the industrial standards and design procedure and stored systematically in the CDM. For a particular product design, the user only has to input the customer requirements, specification parameters, engineering conditions, standard requirements, engineering code interpretation factors one time only and they are registered in the CDM. With the integrated intelligent design program for the conceptual design via API and the necessary knowledge database, it is able to generate all the required parameters for modelling and analysis. Complex geometries need automation and design intelligence to build a reliable FE model from CAD [13]. Thus by implement existing design knowledge, standardized procedures and regulatory codes, the reliability and integrity of the model can be assured. Such design loop can be similarly implemented for detailed design stage. Another knowledge based system is used to interface with the CDM to support the design evolvement in the variable levels of details. The CDM records also the factors involved in making decisions corresponding to analysis results and by changing the common data model, different design scenarios and sets of options can be analyzed and recorded. For example, since all the models and analysis are driven by CDM, the knowledge based programs consisting of algorithms can compare simulation results with user requirements and industrial standards. It also uses optimization to change parameters in CDM. This intelligent system reduces requirement of design expertise and can also save time associated with design process.

IV. DESIGN CYCLES

As shown in Figure 1, the design processes are arranged in such a manner that they flexibly follow the conventional as well as advanced, integrated, and parametric product design methodology. The entire design cycle using CAD and CAE integration with the help of common data model takes place in 10 stages

1) Starting the project and establishing a process management system; collecting user input to establish the design requirements and the specifications with a knowledge-based conceptual design system.
2) Generating a CDM and recording the driving design parameters and key constraints with the help conceptual engineering knowledge, standards and codes through programming.
3) To facilitate the quick evaluation of concepts, an abstract CAD model is created automatically by using the necessary API. For example, in designing a pressure vessel like a vertical separator, this step generates a planer (mid-plane) CAD model using parameters from CDM.
4) Using CDM and the CAD model available to build a mid-plane FE model and performing preliminary analysis by applying the required constraints automatically with the CAE software API. The analysis constraints are also recorded in the CDM.
5) Extracting the CAE results and using them to verify whether the model satisfies the design conditions or not with the help of verification programme. The intermediate results as well as the evaluation factors are recorded in the CDM as well.
6) If the model is not acceptable, the user, with the support of the conceptual knowledge base containing decision algorithm and expert knowledge, makes conceptual changes to the CDM accordingly and steps 3 to step 5 are

performed again. This iteration continues until the conceptual design model satisfies all the design requirements at this stage.

7) Once the conceptual design stage is completed, detailed design phase kicks in. Usually, to enable more detailed analysis and finalize the design model, a much more detailed solid (3D) CAD model is generated via a generative program of API functions using the parameters available in the CDM.
8) Similarly, CAE model has to be detailed to fully reflect the features of the new geometry defined. So, next, using software API, a solid (3D) FE model (solid mesh model) is created based on the solid CAD model. This FE model is then used for final numerical analysis in CAE software.
9) The results obtained are again compared with the required specifications and applicable codes and constraints using a knowledge-based program. If the results are not satisfactory changes are made to the design either interactively or automatically and the parameters in CDM are updated. Depending on the intention of design changes, the process can be rolled back to either conceptual design modelling or detailed design modelling stage. Such updated changes can be automatically reflected in both CAD and CAE models by executing the associated generation programs again iteratively.
10) Such iteration continues until satisfactory results are obtained. Final results are extracted from CAE along with CAD model; and they are recorded in the CDM and provided to the user via different required output formats.

V. Automating Design Cycles in the Prototype

For automation of the CAD modeling and CAE analysis process, in our work, the journal application in Siemens NX6 is used. This journal application allows the automation of commonly used routing functions. A journal is recorded in a specified programming language while CAD modeling and CAE analysis process is carried out interactively through software GUIs. Once the process is finished, the journal is stored as a macro program and can be re-run every time to repeat the process again and again automatically exactly like it was performed with the interactive procedure initially. The interesting finding that is important for the proposed method with this journal application is that the new parameter values can be imported into the CAD or CAE model via expression files. Thus as mentioned in the design procedure, this application is used to automatically regenerate the modified CAD and mesh models as well as the CAE analysis steps with the changed CDM data in each design iteration. NX6 gives the option of various journaling languages such as VB, Java, and C++. The process of journaling assures that the same steps of analysis with similar constraints are performed in every iteration of the design cycle.

Journaling is also useful for general file management such as opening, saving or closing a file. Journal thus captures the data of process flow once used and then makes it available for re-use as per requirement. This in turn avoids the repeated user interfaces with the CAD and CAE software and makes automation in the process possible. Future work is considered to couple journaling application with software API in order to automatically trigger the journal process.

VI. Advantages and Disadvantages of CDM

As compared to the other methods described in the literature review above, the integration using CDM offers

- Isolation of design data from CAD and CAE
- Ease of separate automation for CAD and CAE
- Easy manipulation of design data, better control over parameters
- Use of engineering knowledge along with CAE for design verification
- Integration of CAD and CAE on parametric level
- Incorporation of rules and standards reducing the dependency for expert user
- Programming allows flexibility of adopting different practice standards used for design
- CDM manipulates data on parametric level thus design changes can be successfully propagated to all the related features in CAD and CAE which in turns eliminates requirement of specific feature manipulation
- The CAD model available can be used for CAM
- Takes into consideration manufacturing effects on design such as welding strength
- Incorporates the use of standard components available as per the inventory for manufacturing
- Use of CDM can incorporate not only operating but also manufacturing and installation constraints

As to the shortcomings, there is a need for the initial CDM parameter and relation identification following the given standards involved which could be difficult to create for the first time; and the programming effort can be a hurdle for the adoption of this method.

VII. Case Study

For proofing the concept, a case study was chosen to design a pressure vessel. The special case was a two phase oil-gas gravity separator [14]. For usual industrial operating conditions, oil-gas separators fall under the category of ASME Division 1 pressure vessels [15]. The case was chosen because it has a generic design procedure thus design knowledge can be embedded into a computer program for reusability. Its design changes depending upon operating requirements so it needs a design process which can adapt for design changes. A sample example for sizing of a vertical separator was taken from a separator handbook [14] for initial study.

In the actual practice, for design of a separator, the operating information is provided to the designer, which includes oil and gas handling capacity, operating pressure and temperatures etc. The designer has to go through standard design procedure and has to calculate required geometric parameters such as shell dimensions, nozzle dimensions, support dimensions, etc., and non-geometric parameters such as design pressure, material properties by following ASME pressure vessel design code

.

Common_data_model - Notepad

File Edit Format View Help

```
[lbf/in^2(psi)]Design_pressure=400
[F]Design_temperature=60
[in]Drain_Nozzle_connector_diameter=30
[in]Drain_Nozzle_connector_thickness=1.5
[in]Drain_Nozzle_inside_projection=5
[in]Drain_Nozzle_outside_projection=10
[in]Drain_diameter=20
[in]Drain_pipe__bolt_circle=25
[in]Drain_pipe__thickness=1.5
[in]Gas_Nozzle_connector_diameter=30
[in]Gas_Nozzle_connector_thickness=1.5
[in]Gas_Nozzle_diameter=20
[in]Gas_Nozzle_inside_projection=5
[in]Gas_Nozzle_outside_projection=10
[in]Gas_diameter=20
[in]Gas_pipe__bolt_circle=25
[in]Gas_pipe__thickness=1.5
[in]Gas_pipe_diameter=30
[in]Head_height=9
[in]Head_thickness=1.51
[in]Inlet_Nozzle_connector_diameter=30
[in]Inlet_Nozzle_connector_thickness=1.5
[in]Inlet_Nozzle_diameter=20
[in]Inlet_Nozzle_inside_projection=5
[in]Inlet_Nozzle_outside_projection=10
[in]Inlet_diameter=20
[in]Inlet_diverter_height=25
[in]Inlet_diverter_length=25
[in]Inlet_diverter_thickness=1.5
[in]Inlet_nozzle_height=66.5
[in]Inlet_pipe__thickness=1.5
[in]Inlet_pipe_bolt_circle=25
```

Fig. 3: A partial list of CDM parameters used in CAD generation and CAE analysis

This process takes a lot of time if it is to be performed manually and involves decision making along with design expertise. However, in most prescribed theoretical design procedures, the parameters such as shell thickness are calculated for the given shell without considering actual nozzle openings, areas of stress concentration, etc. Thus to verify the effect of such added features on the design results, a CAD model has to be constructed by the designer interactively; and it is then used in the following FE analysis. Considering complex geometry of a separator, above process takes a lot of time and efforts. After this one cycle is done, if final design is not according to standards set or client requirement, designer has to go through the entire process again which consumes a lot of time and resources.

In the case study, an algorithm is developed containing standard design procedure and ASME pressure vessel design codes to calculate and select all the required design parameters for given type of separator using input parameters.

Figure 3 shows the partial list of parameters calculated. These parameters include geometric information such as the shell diameter and length along with parameters required for analysis such as material properties, mesh specifications, constraint parameters etc. These parameters are stored in CDM as an ".exp" file. This .exp file is then used as an input to NX6 API. For quick testing purpose, instead of using API to generate, CAD and CAE templates based on parameters defined in CDM are created for CAD and FE models for both solid and mid-plane configurations. Hence, these models can be updated by expressions, and can be automatically regenerated using CDM parameters.

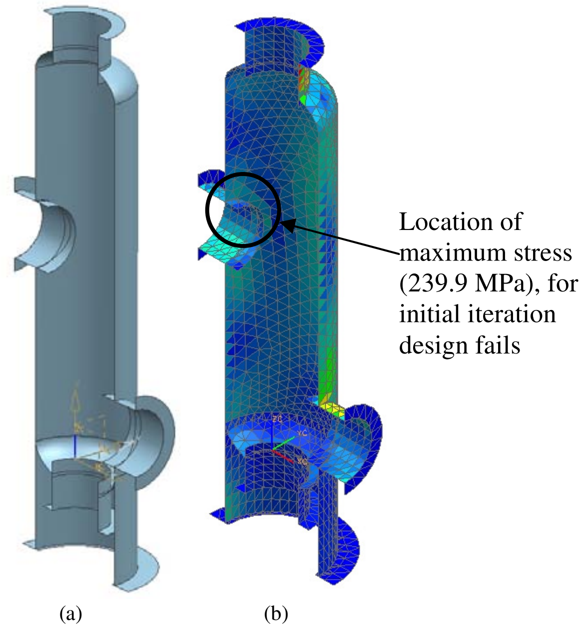
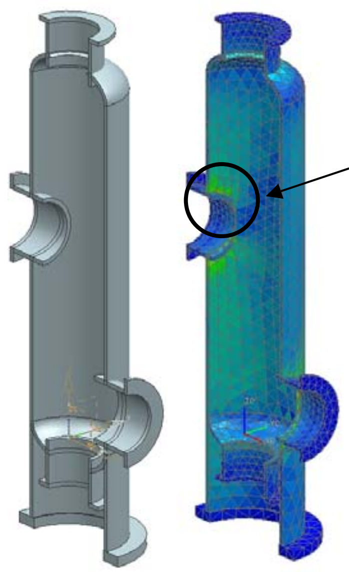


Fig. 4: Conceptual mid-plane CAD model and corresponding preliminary CAE analysis result

Figure 4(a) shows a CAD mid-plane model and Figure 4(b) shows the results of preliminary FE analysis using the mesh model exported from the mid-plane CAD model. This case actually is a sample example from the separator design handbook [14]. As observed in Figure 4(b) during design iteration with mid-plane FE analysis, calculated shell thickness is inadequate to deal with given pressure at nozzle connection and maximum stress (239.9 MPa) is above the stress limit (120.66 MPa) for material chosen, thus thickness gets modified accordingly (from 1.51 in to 2.1 in) and then new analysis shows that the maximum stress (118.3 MPa) is below acceptable level. Similar verification is done for all design requirements and model gets updated accordingly.

Once the conceptual model is fully acceptable at mid-plane level then a 3D FE analysis is performed on a 3D CAD model generated using this revised CDM to do the final analysis iterations. CAD and CAE models are updated using the verification algorithm through common data model to get analysis results. This iterative process continues till satisfactory results are obtained. Figure 5(a) shows the solid CAD model generated while Figure 5(b) shows the final CAE result.

The final result based on the 3D FE model shows the maximum stress (85.86 MPa), the location of it (near nozzle opening). So is true for the maximum deformation. Along with the Common Data Model, the final CAD and CAE models are stored separately for versioning, reference and further development cycles.



(a) (b)

Fig. 5: Solid CAD model generated and the final FE analysis result

VIII. Conclusion

Using a common data model (CDM) to integrate CAD and CAE parametrically, it is feasible to associate design and analysis processes via the associative relations and the built-in interfaces with the CAD and CAE models. This generative approach for design automation can solve the problem of integration of feature-based semantic knowledge and the iterations of CAD and CAE interactions. Design cycles can be coherently modelled with a systematic updating mechanism and the design expertise can be reused. This method does not have the necessary limitation on the software tools used. With a neutral data structure, the common data model (CDM) gives the flexibility of using various CAD and CAE software tools. It can be easily used to automate the entire process thus potentially saves a significant amount of time associated with design process. As it can also connect the design models and expert knowledge with any KBE implementation, it eliminates the need of design expertise to be built into CAD or CAE separately and ensures reusability of those models once they are created in a computerised design format. As all the information is stored and updated systematically, the information lost during CAD model simplification and geometry changes can be retraced from the common data model. The key characteristic of this approach is that the design parameters are stored parametrically in the CDM; CAD and FE model and analysis are generated using templates or API programs. Hence there is no need for the user to input them interactively and repetitively during the design iterative cycles. This method can potentially save lots of time. Also once given all the parameters, it can handle complex geometries as well. In addition, with the inclusion of more design knowledge along with corresponding API programs or model templates, this systematic CAD and CAE integration approach is highly flexible in handling various types of design problems.

Future work involves creating a knowledge based software tool for automatic assembly coupled with part template library to deal with more diverse design problems. Also this initial study only involves the preliminary design of a pressure vessel type limited to sizing; further work will be included for refining the model with more features to prepare a complete drawing ready for automatic manufacturing.

References

[1] B.-W. Cao, J.-J. Chen, Z.-G. Huang and Y. Zheng, “CAD/CAE integration framework with layered software architecture”, in *Proc. of 11th IEEE International Conference on Computer-Aided Design and Computer Graphics*, Huangshan, China, 2009, pp. 410-415.

[2] R.S. Peak, “Characterizing fine-grained associativity gaps: a preliminary study of CAD-CAE model interoperability”, in *Proc. of the ASME Design Engineering Technical Conference*, vol. 1A, 2003, pp. 573-580.

[3] D.C.Y. Yip, M.C. Law, K.P. Cheng, K.H. Lau and S. Barnes, “Knowledge intensive CAD in product design validation”, *International Journal of Knowledge-based and Intelligent Engineering Systems*, vol. 9, no. 2, pp 45–61, Nov. 2005.

[4] Y.-M. Deng, G.A. Britton, Y.C. Lam, S.B. Tor and Y.-S. Ma, “A feature-based CAD-CAE integration model for injection molded product design”, *International Journal of Production Research*, vol. 40, no. 15, pp. 3737-3750, Oct 2002.

[5] S. Zeng, R.S. Peak, A. Xiao and S. Sitaraman, “ZAP: a knowledge-based FEA modeling method for highly coupled variable topology multi-body problems”, *Engineering with Computers*, vol. 24, no. 4, pp. 359-381, Oct. 2008.

[6] G. Foucault, J.-C. Cuillière, V. Francois, J.-C. Lèon and R. Maranzana, “Adaptation of CAD model topology for finite element analysis”, *Computer-Aided Design*, vol. 40, no. 2, pp. 176–196, Feb. 2008.

[7] S. H. Lee, “A CAD–CAE integration approach using feature-based multi-resolution and multi-abstraction modeling techniques”, *Computer-Aided Design*, vol. 37, no. 9, pp. 941-55, Aug. 2005.

[8] O. Hamri and L.-C. Lèon, “Interoperability between CAD and CAE models for cooperative design”, *Methods and Tools for Co-operative and Integrated Design*, Kluwer, 2004, pp. 451-462.

[9] D.Z. Su and M. Wakelam, “Intelligent hybrid system for integration in design and manufacture”, *Journal of Materials Processing Technology*, vol. 76, no. 1-3, pp. 23-28, Apr. 1998.

[10] M.S. Shephard, M.W. Beall, R.M. O’Bara and B.E. Webster, “Toward simulation-based design”, *Finite Elements in Analysis and Design*, vol. 40, no. 12, pp. 1575–1598, July 2004.

[11] M. Novak and B. Dolsak, “Intelligent FEA-based design improvement”, *Engineering Applications of Artificial Intelligence*, vol. 21, no. 8, pp. 1239– 1254, Dec. 2008.

[12] G. Colombo, A. Mosca and F. Sartori, “Towards the design of intelligent CAD systems an ontological approach”, *Advanced Engineering Informatics*, vol. 21, no. 2, pp. 153–168, April 2007.

[13] P. Wriggers, M. Siplivaya, I. Joukova and R. Slivin, “Intelligent support of engineering analysis using ontology and case-based reasoning”, *Engineering Applications of Artificial Intelligence*, vol. 20, no. 5, pp. 709-720, Aug. 2007.

[14] M. Stewart and K. Arnold, *Gas-Liquid and Liquid-Liquid Separators*, Gulf Professional Publishing, 2009, Ch. 3.

[15] American Society of Mechanical Engineers Boilers and pressure vessel codes, ASME, New York.