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Automation of Simulation Based Design Validation and Reporting of a Valve Family

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Abstract

Valves are mechanical devices for controlling fluid-flow in pipes of different diameter and service pressures used in several industry sectors. Most demanding industry sectors add custom design requirements and require product validation reports many times even before placing valve purchase orders of varying quantities. Therefore, customer and valve developer requirements must be made compatible, design reliably completed and a design validation report created, all as soon as possible. In order to respond to these market constraints, complete valve design process from product planning to product design and validation delivery must be optimized.

This paper reports a 96% time reduction in Simulation Based Design validation and reporting tasks obtained by applying Design Automation in a company that develops valves for this market. Additionally, the architecture and most remarkable features of the Simulation Based Design validation and reporting automation are described.

Keywords: Design Automation (DA), Product Families (PF), Simulation Based Design (SBD), Computer Aided Engineering (CAE)

Nomenclature

API	Application Programming Interface
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
GDA	Geometry Design Automation
DFMA	Design For Manufacturing and Assembly
DFV	Design For Variety
GUI	Graphical User Interface
ICT	Information and Communication Technologies
KBE	Knowledge Based Engineering
MTO	Modify To Order
PF	Product Family
PFBD	Parametric and Feature Based Design
SBD	Simulation Based Design

1. Introduction

Quick design and validation of valves with customer order dependent diameters and service pressures among others requires conscious Design For Variety (DFV) product planning. First of all, new valve development is arranged into valve families. Product Families (PFs) enable commonality standardization of design solutions [1-4] among different members. However, service requirements that a valve family member has to meet, as valve size, specific loading or operating temperature among others, may lead to topological changes in the embodiment design phase. In addition, when valve's service location allows it, customer might be able to select among different actuation modules. Therefore, within valves of the most demanding sectors, valve commonality is restricted to valve architecture, optional actuation modules in some cases and design rules about: component material selection, component dimensioning, candidate component topologies,

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commercial and standard component bill of materials definition, component Design For Manufacturing and Assembly (DFMA) [5], design validation and its reporting. Whereas, optional actuation module selection and detailed design decisions derived from design rule application depend on customer order. Thus, market conditions for valves of the most demanding sectors are equal to those of some mass customization companies [6] following a Modify To Order (MTO) production strategy.

According to MTO production strategy, keys to successfully design a new PF member as soon as possible by modification are: correct architecture selection, optional module complete development and design rule development during product planning, along with standard design rule applicability readiness for customer order fulfilment.

Therefore, after customer order is received, valve family design dimensioning and DFMA rules drive module and component material selection, sizing, topology selection and positioning within its family architecture. Application of design rules must result in the final valve family member geometric design, see Fig. 1.

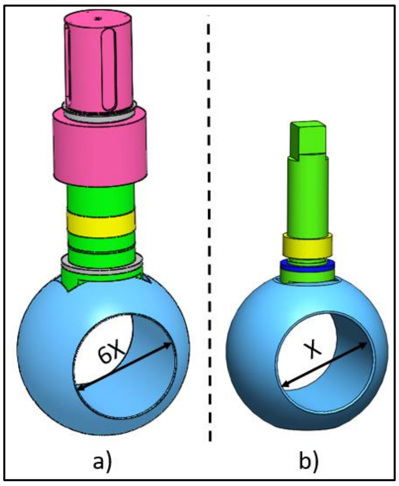


Fig. 1: Geometric design of same sub-system in two sample valve family members: a) Mechanically actuated b) Manual lever. Note also different valve sizes.

Nowadays, in order to manually perform such design geometry modifications as soon as possible, Parametric Feature Based Design [7] - Computer Aided Design (PFBD-CAD) template files are used for Template Based Design (TBD) [8] as they enable Design Automation [9-13]. Furthermore, if complete Geometry Design Automation (GDA) is desired to drastically reduce product design delivery time, case by case analysis and PFBD-CAD customisation through Application Programming Interfaces (API) or Knowledge based Engineering (KBE) frameworks are used.

Following, valve family design must be validated and design validation report written-up. During product planning Simulation Based Design (SBD) [14] helps reducing the number of physical prototypes during valve family design validation and reporting. However, in most demanding sectors each valve family member must be validated as cheap and as quickly as possible. Therefore, each valve must be validated and reported by SBD, as physical prototypes are too expensive and take too long to build. SBD has three main steps: pre-processing, solving and post-processing. First and last by default are manual, whilst solving is automatic. Pre-processing starts with detailed design geometry model preparation: abstraction and/or simplification for simulation performance. Then, loads and constraints are applied over corresponding vertices, edges, faces and/or bodies of the prepared for simulation geometric model. Following, continuum geometry is discretized, loads and constraints are automatically transferred to discretized geometry, and mathematically solved. Solution provides predictions of time-history and spatial field physical variables that must be manually scrutinized for valve design validation and reporting. Several commercial PFBD-CAD systems are progressively acquiring and integrating simulation software (Dassault Systemes' Catia, SolidWorks and, Siemens NX, …) [9] in order to integrate geometry design and design validation. Likewise, simulation software developer Ansys Inc. partnered several years ago with major PFBD-CAD systems in order to develop an associative PFBD-CAD to Ansys Mechanical integration with Ansys Workbench. Therefore, the possibility to use templates for simulation pre-processing, post-processing and reporting automation for product validation is more recent and less used. Complete SBD validation and reporting automation cases that can be found in the literature are even less [15, 16].

Within the application case company, on the one hand, a GDA based on SolidWorks and custom applications is in use for several product lines. On the other hand, SBD validation and reporting was manually performed with Ansys. Therefore, when the development of a new valve family for one of the most demanding sectors was planned, a decision to research whether SBD validation and reporting automation with SolidWorks and Ansys is possible and if it can further reduce MTO's design delivery time was taken. Therefore, this paper researches development feasibility of an Information and Communication Technologies (ICT) for Design, in order to enable research on new product development process improvement.

2. Methodology

In order to verify that SBD Validation and reporting automation improves a Modify To Order new product development process by reducing its design delivery time, an As-Is and To-Be process analysis is followed. As-Is model defines the process tasks and time taken to complete it. Similarly, To-Be model defines how tasks are expected to be completed, once the new execution process is adopted, and time taken to complete it. Process improvement will be measured as the As-Is process execution time percentage that takes to complete the To-Be process.

3. Application case

A complete Modify To Order customer order fulfilment process analysis requires an As-Is model from customer order to physical product delivery. However, as a decision to only vary SBD validation and reporting activities was taken, the rest of tasks have been excluded from following As-Is process model.

Task AI-1: Engineer receives service requirements, and detailed product design geometry generated by the TBD based GDA.

Task AI-1.1: Identify geometric product design architecture and topology, and use valve family planning map to identify necessary simulation graphical picking list.

Task AI-2: According to design rules developed during valve family planning, three sub-model simulations are necessary to validate valve family member design, see Fig. 2.

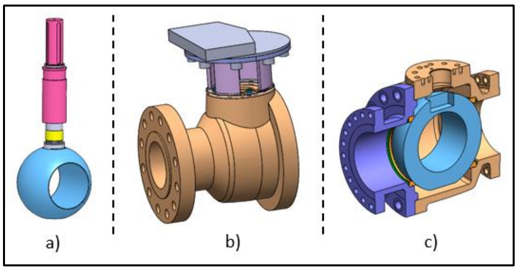


Fig. 2: Prepared for simulation geometry definitions for sub-models defined during valve family planning.

Task AI-2.1: Create Ansys Workbench project.

Task AI-2.2: Sub-model 1 simulation.

Task AI-2.2.1: Create prepared for simulation geometry.

Task AI-2.2.2: Create Ansys Mechanical system.

Task AI-2.2.3: Create material and enter their properties.

Task AI- 2.2.4: Assign prepared for simulation geometry to system

Task AI-2.2.5: Enter Ansys Mechanical and assign materials to bodies.

Task AI-2.2.6: Create auxiliary geometry like remote points and symmetry planes by graphically picking geometry and/or providing values.

Task AI-2.2.7: Define contacts by graphically picking geometry and providing values.

Task AI-2.2.8: Define loads by graphically picking geometry and providing values.

Task AI-2.2.9: Define constraints by graphically picking geometry.

Task AI-2.2.10: Define meshing rules by graphically picking geometry and providing values

Task AI-2.2.11: Define spatial field results for analysis and validation.

Task AI-2.2.12: Solve simulation.

Task AI-2.2.13: Orient view, set legend and capture report image for each variable and region of interest.

Task AI-2.3: Sub-model 2 simulation

Task AI-2.4: Sub-model 3 simulation

Task AI-3: Write-up valve SBD validation report combining spatial field variable average values, rotations across several components, figures and text using report template defined during product planning.

Task AI-4: Analyse simulation results and report, and decide whether to validate or not.

Corresponding To-Be process model follows:

Task TB-1: Engineer receives: valve service requirements complementarily defined by customer and valve developer, detailed product design geometry, SBD validation and report generated by SBD and TBD based GDA.

Task TB-2: Analyse simulation results and report, and decide whether to validate or not. Simulation result many times exhibit spurious numerical effects. Therefore, it is important to perform this step with an engineer.

Time to complete tasks grouped by sub-models and report are shown in Results section Table 1.

3.1. Development of SBD validation and reporting automation

Improving SBD validation and reporting from As-Is to To-Be process raised a technical feasibility question. Is it possible to develop a user-free SBD validation and reporting automation in Ansys Mechanical linked to SolidWorks?

Prior to any coding research, a literature review about DA development methodologies was conducted. MOKA [17], KNOMAD [18], etc. are classic KBE references that highlight the importance of documenting design processes before automating them, as Zheng et al. [19]. However, KBE practitioners like La Rocca and Verhagen et al. [20, 21] still highlight the particular importance of creating transparent DA applications with clear knowledge transference to the user in order to avoid the fear to black-box effect. While others like Johansson and Elgh [11] claim that using TBD raises DA user confidence on a DA, as it is more familiar to user.

Therefore, in order to overcome users' likely fear to black box effect when they cannot easily inspect the process, among the three combinable options to automate pre-process, post-process and report Ansys solver solutions: i) custom developments, ii) Macros over classic Ansys Mechanical APDL Graphical User Interface (GUI) and iii) Scripting over Ansys Workbench and Ansys Mechanical GUI, a choice to program over users' current GUI, i.e. Ansys Workbench and Ansys Mechanical was made. Ansys Workbench API is written in IronPython and is recordable. While Ansys Mechanical API is written in JavaScript and is not recordable.

Scrum-like software development methodology was followed to develop the SBD validation and reporting automation with short sprints delivering partial automations between frequent sprint reviews that provided feedback to enable software requirement completion during development. Nonetheless, only final SBD validation and reporting automation workflow is shown in Fig. 3 and described next.

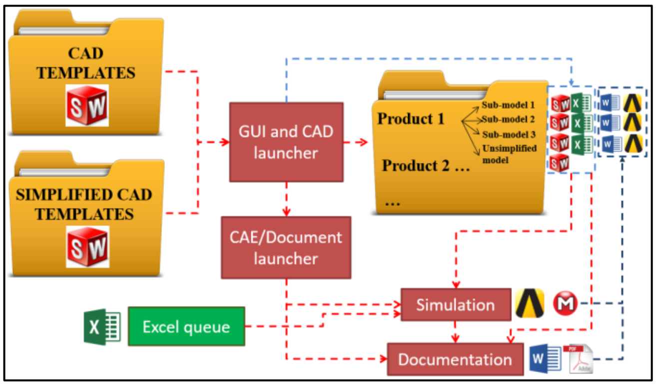
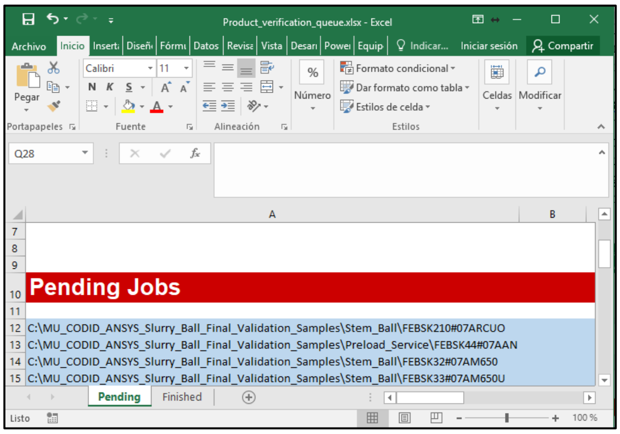


Fig. 3: SBD validation and reporting automation workflow.

Customer order and requirements are entered in TBD based GDA. First, design rules are applied to know which modules and component topologies must be selected and their dimensions in the new valve family member. Second, using SolidWorks templates detailed valve design model is created. Third, a valve family member working directory is created which contains a subfolder for each sub-model prepared for simulation geometry and an Excel file specifying sub-model's bill of material's component names, quantities (such as number of bolts), material names and their physical properties, along with load values (working pressure value, bolt's preload value, actuator torque value, internal washer's preload value) derived from valve family planning design rules. If another customer order is received, TBD based GDA queues valve family members in a design geometry queue. In parallel, every time TBD based GDA ends preparing sub-model Excel and prepared for simulation geometries, valve family member is recorded in Fig. 4 Excel file and checks whether the parallel SBD validation and reporting queue is working or stopped.

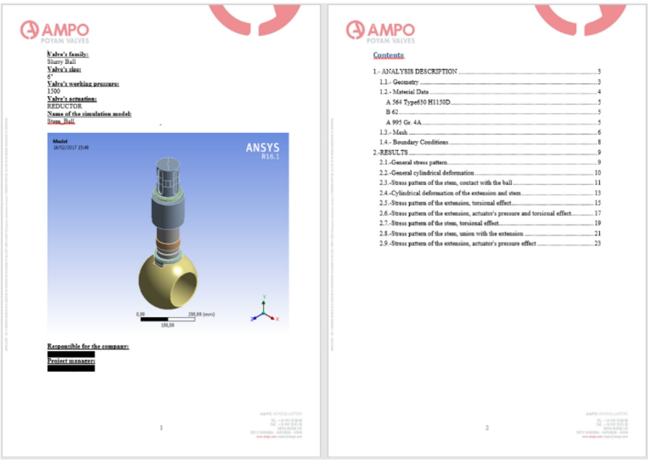


Pending Jobs

C:\MU_CODID_ANSYS_Slurry_Ball_Final_Validation_Samples\Stem_Ball\FEBSK210#07ARCUO
C:\MU_CODID_ANSYS_Slurry_Ball_Final_Validation_Samples\Preload_Service\FEBSK44#07AAN
C:\MU_CODID_ANSYS_Slurry_Ball_Final_Validation_Samples\Stem_Ball\FEBSK32#07AM650
C:\MU_CODID_ANSYS_Slurry_Ball_Final_Validation_Samples\Stem_Ball\FEBSK33#07AM650U

Fig. 4: SBD validation and reporting automation valve queue.

If SBD validation and reporting queue is stopped, TBD based GDA calls a batch file that starts the SBD validation and reporting queue programmed in Ansys Workbench's IronPython. In addition, IronPython scripts basically automate As-Is process model except for Task AI-2.2.1, Task AI-2.3.1 and Task AI-2.4.1 related to prepared for simulation geometry generation which have been moved out of the SBD validation and reporting queue. In order to automate tasks within Ansys Mechanical, IronPython sends JavaScript sentences to its scripting engine. Graphical geometry picking in tasks has been replaced by using Ansys Inc.'s Named Selection Manager add-in for SolidWorks and applying Named Selections on the corresponding prepared for simulation geometries. Finally, to automate report generation Ansys Mechanical has a customizable Report Generator written in XML and JavaScript. Initial Report Generator was finally complemented by calling a MS Word template that on open completes report formatting with VBA Macros (Fig. 5).



Valve's family:
Slurry Ball
Valve's size:
6"
Valve's working pressure:
1500
Valve's actuation:
REDUCTOR
Name of the simulation model:
Stem_Ball

Responsible for the company:
[redacted]
Project manager:
[redacted]

Contents

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A 564 Type630 H1150D 5
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Fig. 5: Sub-Model 1 SBD validation report portrait and table of contents.

With the aim to constrain the amount of Ansys licenses used by SBD validation and reporting automation to one, due to Ansys license cost, sub-models to be simulated for each valve family member are run in a valve level sub-queue.

3.2. Geometry and Simulation variants

Correct identification of existing variants is key to any Design Automation development. Thus, in GDA a component has more than one geometry variant, if it is designed with different number of faces or topology. Li et al. [22] stated that CFD simulation variants stem from the need to select different fluid-flow model solvers depending on other inputs. Similarly, throughout SBD validation and reporting automation development the different origin of geometry and Ansys Mechanical simulation variants has been noted. Furthermore, this difference in nature has been exploited in order to minimise the amount of simulation variants to be programmed.

Application case TBD based GDA used 7 different components for sub-model 1. Each component had different amount of geometry variants. Complete theoretical combinations could raise up to 288 sub-model 1 geometry variants. However, as several theoretical combinations do not make sense, summation of different component geometries was used to estimate the amount of geometry variants for sub-model 1. Sub-model 1 components summed up to 27 different geometry variants.

In contrast, Ansys Mechanical simulation variants stem from the amount and semantics of graphical picks necessary to pre-process and post-process a simulation. Actually, the 27 different geometries of sub-model 1, finally resulted in only 6 simulation variants.

A simplified instance of this phenomena can be shown through basic cantilever beam designs. Three different designs are shown in Fig. 6: a) round bar, b) square bar and c) joint split round bar. Three designs can fulfil the same function of withstanding a bending moment. However, round bar and square bar have different amount of faces, hence they are different geometry variants. In contrast, the amount and semantics of graphical picks necessary to define the cantilever beam Ansys Mechanical simulation are the same, so they are a single simulation variant. In contrast, joint split round bar and round bar require different simulation variants. Because, the definition of contact in spatially matching faces, requires more graphical picks with different semantics.

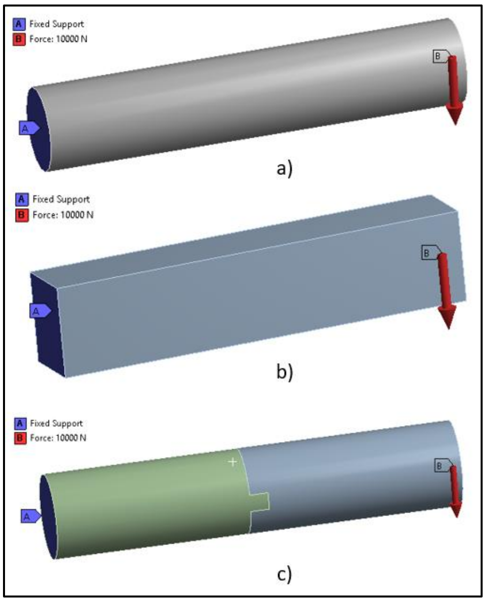

Fig. 6: Different nature of geometry and simulation variants. a) and b) different geometry variant and same simulation variant. a) and c) different geometry and simulation variants.

Furthermore, Ansys Inc.'s Named Selection manager groups picked geometries (bodies, faces, edges or vertices) into a single selection entity. Ansys Mechanical variants stemming from different number of graphical picks with same semantics can be reduced to a single Ansys Mechanical variant. For instance, if contact of a set of pins with their surrounding bodies are going to be defined with the same semantics there are two options: i) model contact of each pin with its surrounding bodies independently (Fig. 7a) ii) model contact of all pins with its surrounding bodies altogether (Fig. 7b). Option i) requires as many Ansys Mechanical simulation variants, as possible different amounts of pins can be. While, option ii) only requires a single Ansys Mechanical simulation variant for any amount of pins.

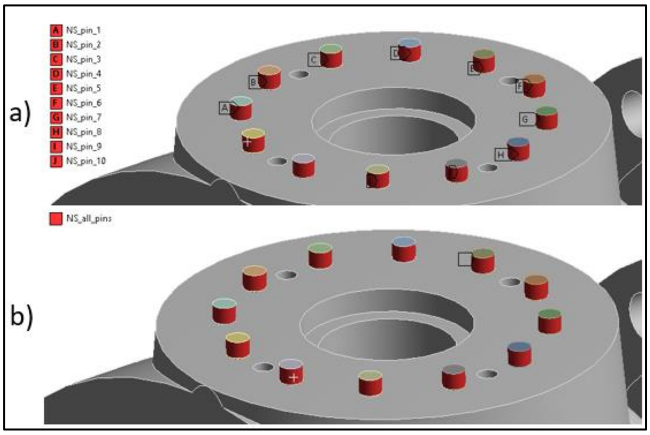

Fig. 7: Representation of a) 12 pins labelled by 12 Named Selections and b) 12 pins labelled by a unique Named Selection

4. Results

Once SBD validation and reporting automation was available, To-Be automated process execution times could be measured. As-Is manual process execution times were also measured to verify if design delivery time can be shortened in a MTO new product development process.

A complete valve SBD validation and reporting process (with its 3 sub-model simulation pre-processing, post-processing and reporting) execution times were measured with As-Is manual and To-Be automated processes. Both are performed on the same computer and Ansys solving times are excluded from both results, as they are not subject of research.

Manual process execution times are measured taking a designer with Ansys Mechanical SBD validation and reporting experience with this valve family. Designer starts the process with: i) Ansys Mechanical simulation models and reports of another member of the same valve family and ii) prepared for simulation geometry models of the new valve family member. During the process, designer manually creates a new Ansys Workbench project and each sub-model simulation starting from each prepared for simulation geometry. Manual process execution time ends when the last sub-model report file is finished and closed. External disruptions and breaks are prevented to keep designer concentrated on this single process.

In order to measure automated process execution times, time starts with: i) new valve family member recorded in the SBD validation and reporting queue, ii) sub-model folders with prepared for simulation geometry models and sub-model Excel files ready and iii) call to the batch file that starts SBD validation and reporting automation. Automated process execution ends, when SBD validation and reporting automation closed its process in the task manager.

As-Is manual and To-Be automated SBD validation and reporting process execution times are shown in Table 1.

Table 1: Manual and automated SBD validation and reporting task execution times

	Manual (min)	Automated (min)	Difference (min)	 (%)
Sub-model 1 simulation	29´	2´	-27’	-93%
Sub-model 2 simulation	63´	3´	-60’	-95%
Sub-model 3 simulation	73´	2´	-71’	-97%
Report Generation	156´	5´	-151’	-96%
Total time	321´	12´	-309’	-96%

5. Limitations

Such 96% time reduction is only achievable if during product planning the correct architecture is selected and, optional modules and standard design rules have been completely and correctly developed. Otherwise, DAs deliver preliminary designs that have to be manually reworked.

From time results measurement point of view, prepared for simulation geometry model generation has been excluded from results. As prepared for simulation geometry model generation is a special purpose GDA, and application case Innovation and Technology Development Department already had experienced MTO improvements with TBD based GDA for detailed design geometry models, similar improvements were expected. Thus, prepared for simulation geometry model generation was considered of no interest and excluded from results.

From SBD validation and reporting point of view, Ansys Workbench, Ansys Mechanical and reporting have all been developed by pure coding. In the future, it could be interesting to research whether they could be automated in Template Based Simulation and Template Based Simulation Reporting approach similar to Template Based Design for GDA.

6. Conclusions

From a MTO design delivery time point of view, SBD validation and reporting automation shows a time reduction of 5 hours, i.e. 96% reduction, in comparison with a fully concentrated engineer with predefined data and process. Therefore, it is considered valuable, during the strategic process of acquiring customer orders from the most demanding sectors.

In addition, engineers are freed-up of long time consuming, low-added-value and repetitive tasks. Enabling engineers to do higher added value, or daily management activities.

From a Design Automation perspective, technical feasibility of developing a SBD validation and reporting automation has been demonstrated. Furthermore, it has been integrated with an existing TBD based GDA, which now additionally generates prepared for simulation geometry models and then runs SBD validation and reporting automation. The latter automatically creates, pre-processes, solves and post-processes 6 Ansys Mechanical simulation variants of sub-model 1, 1 Ansys Mechanical simulation variant of sub-model 2 and 2 Ansys Mechanical simulation variants of sub-model 3, and generates reports for them in English and Spanish, in Microsoft Word and PDF formats.

In addition, how the different nature of geometry and simulation variants, and Ansys Inc. Named Selection Manager can be used to reduce Ansys Mechanical simulation variants has been described.

Finally, since Ansys Workbench 14.5, Ansys Inc. releases a licensed API named Ansys Customization Toolkit (ACT). ACT covers Ansys Mechanical and like Ansys Workbench's API is written in IronPython. Although, initially it was limited to Ansys Mechanical GUI customization. Over the last releases is progressively gaining more functionality and currently is marketed with automation capabilities, too. Despite license cost barrier, it would be interesting to research whether ACT covers everything covered by the JavaScript API, so that a single programming language can be used to develop the SBD validation and reporting automation.

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References

[1] X. Du, J. Jiao, and M. M. Tseng. Architecture of product family: fundamentals and methodology. *Concurrent Engineering*, 9(4):309–325, 2001.

[2] J. R. Jiao, T. W. Simpson, and Z. Siddique. Product family design and platform-based product development: a state-of-the-art review. *Journal of intelligent Manufacturing*, 18(1):5–29, 2007.

[3] T. W. Simpson, Z. Siddique, and R. J. Jiao. *Product platform and product family design: methods and applications*. Springer Science & Business Media, 2006.

[4] T. W. Simpson, J. Jiao, Z. Siddique, and K. Hölttä-Otto. Advances in product family and product platform design. *New York: Springer*, 2014.

[5] K. G. Swift and J. D. Booker. *Process selection: from design to manufacture*. Elsevier, 2003.

[6] M. M. Tseng and S. J. Hu. Mass customization. In *CIRP Encyclopedia of Production Engineering*, pages 836–843. Springer, 2014.

[7] J. J. Shah and M. Mäntylä. *Parametric and feature-based CAD/CAM: concepts, techniques, and applications*. John Wiley & Sons, 1995.

[8] A. Katzenbach, W. Bergholz, and A. Rolinger. Knowledge-based design-An integrated approach. In *The Future of Product Development*, pages 13–22. Springer, 2007.

[9] S. K. Chandrasegaran, K. Ramani, R. D. Sriram, I. Horváth, A. Bernard, R. F. Harik, and W. Gao. The evolution, challenges, and future of knowledge representation in product design systems. *Computer-aided design*, 45(2):204–228, 2013.

[10] S. Sunnersjö. *Intelligent computer systems in engineering design: principles and applications*, volume 51. Springer, 2016.

[11] J. Johansson, F. Elgh, et al. How to successfully implement automated engineering design systems: Reviewing four case studies. In *20th ISPE International Conference on Concurrent Engineering: Proceedings*, page 172. IOS Press, 2013.

[12] K. Amadori. *Geometry based design automation: applied to aircraft modelling and optimization*. PhD thesis, Linköping University Electronic Press, 2012.

[13] M. Tarkian. *Design Automation for Multidisciplinary Optimization: A High Level CAD Template Approach*. PhD thesis, Linköping University Electronic Press, 2012.

[14] M. S. Shephard, M. W. Beall, R. M. O'bara, and B. E. Webster. Toward simulation-based design. *Finite Elements in Analysis and Design*, 40(12):1575–1598, 2004.

[15] J. Johansson. *Automated computer systems for manufacturability analyses and tooling design: applied to the rotary draw bending process*. PhD thesis, Chalmers Reproservice, 2011.

[16] G. La Rocca. *Knowledge based engineering techniques to support aircraft design and optimization*. PhD thesis, TU Delft, Delft University of Technology, 2011.

[17] M. Stokes. *Managing engineering knowledge: MOKA: methodology for knowledge based engineering applications*. American Society of Mechanical Engineers, 2001.

[18] R. Curran, W. Verhagen, and M. van Tooren. The KNOMAD methodology for integration of multidisciplinary engineering knowledge within aerospace production. In *48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*, page 1315, 2010.

[19] P. Zheng, G. Zhao, V. H. Torres, and J. Ríos. A knowledge-based approach to integrate fuzzy conceptual design tools and MOKA into a cad system. In *2012 7th International Conference on Computing and Convergence Technology (ICCCT)*, pages 1285–1291. IEEE, 2012.

[20] G. La Rocca. Knowledge based engineering: Between AI and CAD. review of a language based technology to support engineering design. *Advanced engineering informatics*, 26(2):159–179, 2012.

[21] W. J. Verhagen, P. Bermell-Garcia, R. E. van Dijk, and R. Curran. A critical review of Knowledge-Based Engineering: An identification of research challenges. *Advanced Engineering Informatics*, 26(1):5–15, 2012.

[22] L. Li, Y. Ma, and C. F. Lange. Association of design and simulation intent in CAD/CFD integration. *Procedia CIRP*, 56:1–6, 2016.

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