The First Full-Cloud Design Space Exploration Platform

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1 Introduction

The importance of simulation driven design is already well recognized: since the majority of manufacturing companies have focused on decreasing the time to market due to the shortening of the product life cycle over the last decades, it became arguably the most promising method to reduce lead time and development costs, bringing simulation to the #2 place in recent CAD trends [1]. However it is estimated that currently only less than 5% members of the global engineering population are capable of using the simulation driven design approach [2]. That is, simulations are still mostly used in design validation, but not design space exploration, and rarely affect decision making (which is the meaning of "driving" the design process). Moreover, these 5% members are generally employed by large enterprises which means that usage of simulation driven design is limited not only to the selected experts, but also to a relatively small number of companies.

We consider the situation outlined above to be created by two issues which are further addressed to as the "cost" and "expertise" problems, for brevity. The cost problem includes expenses of assembling and maintaining the hardware and software suite that enables simulation driven design. Large-scale simulations require high computational power as well as owning a variety of CAD and CAE tools. Small and medium businesses may be simply unable to make this process cost-effective, considering the licensing and maintenance costs and the uneven computational load, which can result in unproductive time if owning a HPC system. The expertise problem is a natural consequence of the fact that simulation driven design requires both deep and broad knowledge due to the multidisciplinary nature of the tasks it is meant to solve. In large enterprises adopting this approach, often there are simulation experts working in so-called Methods and Tools departments to support a much greater number of "end users" — less experienced engineers who focus on specific design problems. Many smaller companies will not reach the required level of expertise, making it very hard for them to even begin with simulation driven design. Note that the situation where the majority of company's employees is capable of handling multidisciplinary design problems is so unlikely that we are in fact excluding it from consideration: best realistic option is role differentiation as it is seen in big engineering communities.

Below we shall discuss the recipes to solve the expertise and cost problems as prerequisites of a solution that allows to widen the range of simulation driven design users.

2 Vertically Integrated Applications

Vertically integrated applications are easy-to-use integrated solutions that solve a class of design problems. A typical example is an application integrating some CAD with a CAE tool that provides a number of controllable parameters (part dimensions, load values) and calculates certain performance characteristics (stress distribution, for example). Such application can hide the complexity of the underlying solution from the end user, giving him a limited set of inputs and outputs. The concept of vertically integrated applications easily fits into the "experts and users" scheme mentioned above: relative simplicity of an application allows it to be used effectively by non-experts, while its capabilities depend on the skills of an expert who takes the role of the application developer. In one form or another, this approach is used in many existing design practices in order to share knowledge and expertise between participants.

There are several ways to develop vertically integrated applications — from creating fully custom software using general purpose programming languages, extensive scripting and application-level programming, to utilizing the already available specialized solutions. The latter are meant to simplify development by providing a number of ready to use integration components that can be configured and connected with each other, usually within a graphical user interface. Such a platform is in fact essential for efficient development of integrated applications — otherwise it would require adding production-level programming to the list of necessary expert skills, which works against the purpose.

Speaking of simulation driven design, however, integration alone is not enough: the application must also make the integrated solution available for automated analysis and exploration in order to support decision making — as opposed by using simulation to only validate existing designs. Thus in addition to various integration components the development platform also has to provide data mining components and analysis tools, which finally is the ultimate requirement for any design space exploration platform.

3 Cloud-Enabled Applications

Cloud-enabled applications are a recent CAE trend; without exaggeration, nowadays we witness the emergence of a cloud-based CAx ecosystem, starting with such tools as Onshape, SimScale, or SimForDesign. It is important that these tools conform to the defining properties of the cloud computing model [3]. In particular, they enable on-demand service and rapid elasticity, providing the needed flexibility to become a way of decreasing simulation costs.

Currently members of the cloud ecosystem begin to publish their APIs (which is rather natural for web-based systems) enabling seamless integration of these tools. This makes it possible to develop cloud-based integrated applications, solving both the expertise and cost problems. However, the cloud ecosystem still lacks the key element that allows developing and using vertically integrated applications enabling simulation driven design. As noted above, efficient development of these applications requires a design space exploration platform, such as Isight or modeFRONTIER available in desktop versions. Yet currently there is no such solution designed specifically with cloud-based applications in mind and allowing full-cloud integration.

4 Platform Requirements

To summarize, let us list the requirements to a cloud-based design space exploration platform that can solve the problem of limited availability of simulation driven design.

- The support for cloud-based software integration, which is obviously one of the defining properties.
- The support for desktop software integration and hybrid solutions based on both desktop and cloud applications. This is required for at least two reasons: 1) major desktop CAD tools are not going to be replaced by cloud alternatives in the foreseeable future 2) the solution may include an in-house developed tool that cannot or should not be moved into the cloud. Hence many integration solutions have to be partly based on desktop software.
- Availability of design space exploration components, in particular the components for design optimization and analysis.
- The support for converting a complex solution into a ready tool that can be used by non-experts to solve similar design problems (vertically integrated application).
- The support for the private cloud deployment model, so those companies that meet the expertise requirements of using simulation driven design (the “simulation champions”) can develop integrated applications for in-house usage, keeping the existing practices.
- Finally, the support for the public cloud deployment. A full-cloud solution is required to create widely available vertically integrated applications: both the application and the integrated CAD and CAE tools have to be cloud-based in order to make the solution available as a service. The public deployment model would allow serving integrated applications to companies that lack expertise to develop them, thus lowering the entry level in simulation driven design.

We believe that cloud-based design, in general, will make many practices much simpler — collaboration, sharing, running time-consuming process such as design optimization — and that the design exploration platform meeting the above requirements will provide an increasing number of opportunities to reduce product development costs and time to market as the cloud-based ecosystem of CAx applications evolves further.

5 Our Solution

With the above considerations in mind, we would like to introduce the pSeven design space exploration platform. It is designed for distributed computing, and the platform itself follows the client-server model. pSeven consists of a lightweight backend (the server-side part) and a client-side GUI implemented with modern web technologies (JavaScript, HTML5). Users connect to the pSeven server with a web browser — which loads the GUI and displays it as a web page. The server enables OS-level virtualization: the pSeven backend starts in a Docker container in order to provide an isolated user-space instance to each user. This case does not require any installation on the user's computer, except a generic web browser. However pSeven can run as a desktop application too: in this case it transparently starts a local server on the user's host and loads the GUI in a built-in browser that automatically connects to the local server. pSeven also provides full support for Windows and Linux operating systems: both versions have the same codebase and feature set.

pSeven visualizes design processes using data flow diagrams (workflows) where processing components (blocks) are connected with links showing the data flow. The built-in component library provides various integration and analysis blocks, enabling automation of complex design and simulation processes. Creating a workflow in pSeven consists of adding blocks from the library, applying necessary configuration to them, and linking their inputs and outputs to set up the data flow. In most cases this requires good knowledge of the programs integrated into the workflow, as well as the underlying physical processes, so creating a workflow from scratch is in fact an expert's task. However the author can introduce controllable parameters into the workflow and finalize it by adding a custom interface that provides non-expert users with easy access to important inputs, outputs, and parameters while hiding many configuration details.

pSeven also allows to re-use any workflow as a custom block with its own inputs and outputs. Such blocks are used in the same way as any standard block available from the built-in library. For example, a simulation workflow, once implemented, can be used as a blackbox in various studies — optimization, approximation, automated sampling, and so on.

To collect data from a workflow, pSeven provides the monitoring mechanism that can capture activity of any block and save the data it sends or receives to the internal database. Saved data can then be viewed with a variety of built-in post-processing and visualization tools. These viewers can also be pre-configured by the workflow author in such a way that they are automatically updated with new data when a user runs the workflow.

Finally, thanks to the available integration and analysis blocks, ability to customize the workflow interface and results presentation, and the client-server application architecture, pSeven meets the requirements for a cloud-based design space exploration platform, including:

- Cloud-based software integration: currently integration blocks are available for Onshape and SimForDesign.
- Desktop software integration: direct integration blocks for major desktop CAD tools, such as SolidWorks, PTC Creo, Siemens NX and others.
- Design space exploration: blocks for optimization, training approximation models, sensitivity and reliability analysis, dimension reduction, and design of experiments. These blocks implement a wide range of data analysis and optimization algorithms, supplemented with the SmartSelection technology which automatically chooses the most efficient algorithm for a given problem.
- Vertically integrated applications: a workflow with customized interface can be used as a ready tool that does not require expert skills.
- Private and public deployment models: pSeven can be deployed to a private network, can be used as a public service providing the necessary security thanks to containerization, and can also run on a standalone host.

The combination of these features makes pSeven a powerful platform to develop vertically integrated applications that can be based both on desktop and cloud CAx tools and can work in various deployment models, from full-desktop to full-cloud.

6 Example Use Case

The use case discussed in this section provides an example of a full-cloud integrated application that solves a design optimization problem for any load case specified by user. The problem itself is typical —

there is a parametric CAD model, and some of its parameters (dimensions) can be varied with the aim to improve certain characteristics. The process is iterative: the design space exploration algorithm (optimization component) generates parameter values that have to be sent to a CAD application (Onshape); the CAD application updates the model and exports it to some data translation format; then a CAE application (SimForDesign) receives the exported model, creates a mesh, and runs some pre-configured simulation to get characteristics; their values are sent back to the optimization algorithm which then suggests new parameter values and the next iteration begins.

Example model is a mounting frame (Fig. 1) subject to loads P_1, P_2, P_3 (specified by the end user). Positions of the four crosspieces x_1, x_2, x_3, x_4 can be changed (problem variables). The goal is to find such frame geometry that minimizes the maximum stress under load (the objective).

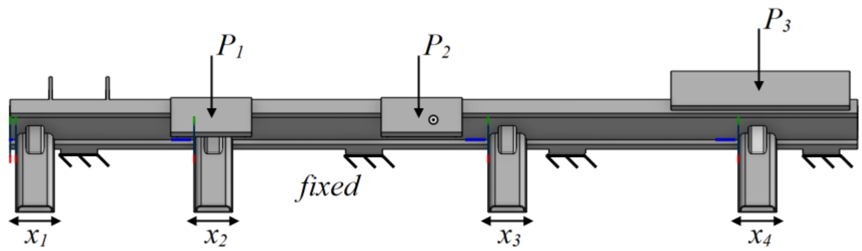

Fig. 1
Example parametric model: a mounting frame with variable positions of crosspieces x_1, x_2, x_3, x_4, subject to loads P_1, P_2, P_3; four points of the frame are fixed

The pSeven workflow for this task (Fig. 2) includes three blocks: the optimization component (problem solver) and two blocks that integrate Onshape and SimForDesign. Blocks can send and receive data, but otherwise they are isolated processes — there is no explicit synchronization or control flow involved.

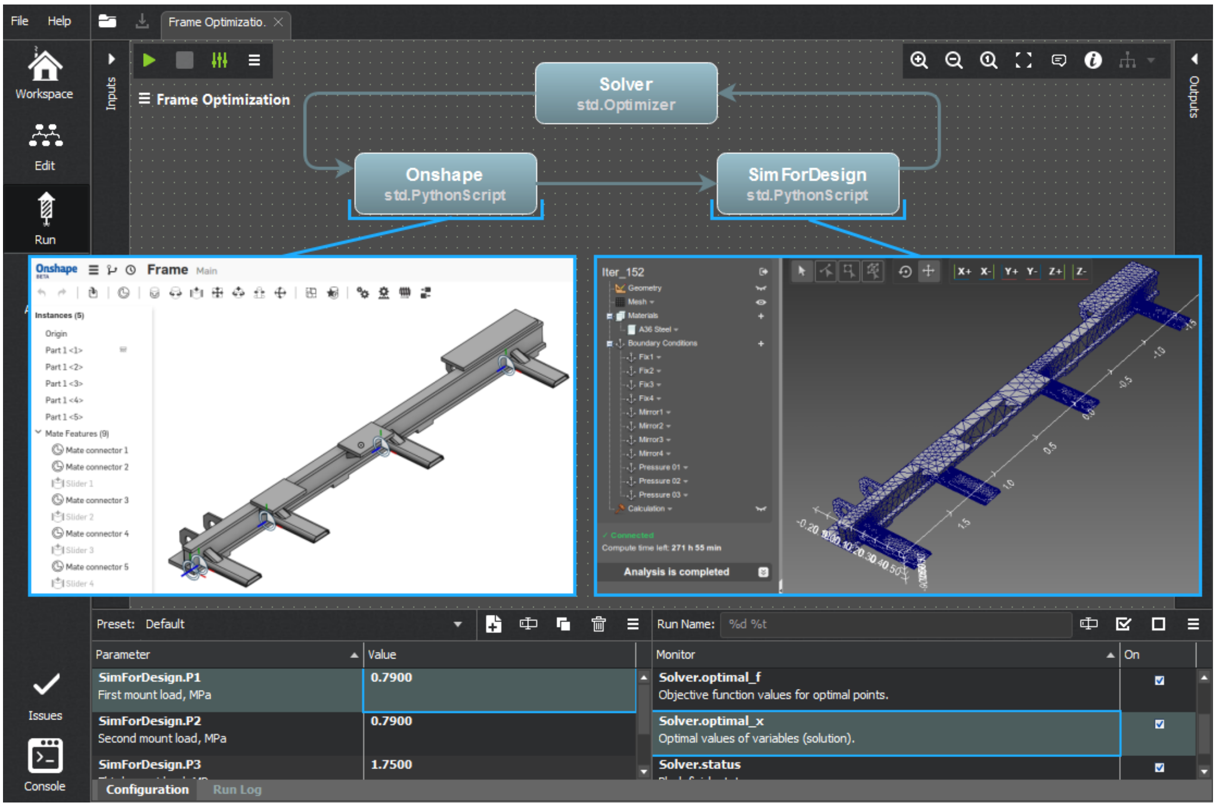

Fig. 2
pSeven optimization workflow with user-controlled parameters — the loads P_1, P_2, P_3 (bottom left) — and a several data monitors (bottom right)

When the workflow runs, the solver generates new parameter values on each iteration and waits until the objective value is received. pSeven sends generated parameter values to the Onshape integration block which has four inputs, mapped to model's parameters. This mapping (as well as the number of inputs) is defined by the workflow author when configuring the block. Other functions do not require author's attention: once this block receives an input from solver, it automatically connects to Onshape and uses API commands to rebuild the model with new parameters and export it to the STEP format. The exported model is sent to the next block that connects to SimForDesign and runs simulation.

The SimForDesign integration block has a default input that receives the model and three additional inputs that set boundary conditions (loads). Again, the number of additional inputs and their mapping to simulation settings are defined by the workflow author, who had also selected these inputs to be shown to the end user as controllable workflow parameters (seen on the bottom left pane of the workflow interface on Fig. 2). Thanks to this, the user can change load conditions without reconfiguring the SimForDesign integration block.

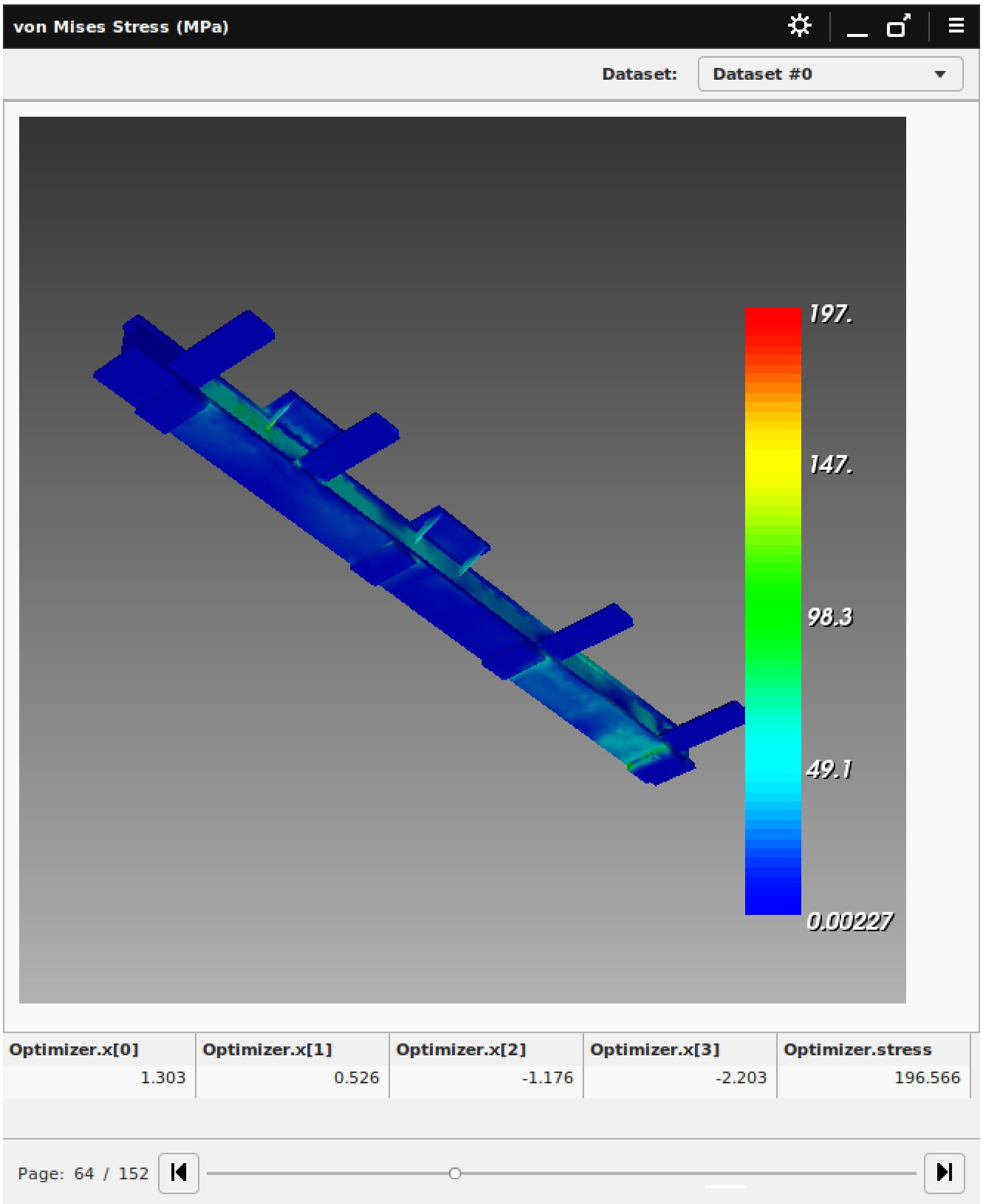

Fig. 3
Simulation data management in pSeven: optimization history shown in a data viewer

The main result of running the workflow is the optimal solution — coordinates of the cross-bars that minimize the stress. In addition to this, pSeven monitors block inputs and outputs and saves simulation data generated on each iteration. This data can then be easily loaded into a data viewer (Fig. 3), allowing the user to study the optimization history and providing a lightweight simulation data management system.

7 Conclusions

We have discussed the importance of simulation driven design and what limits the spread of this approach. Issues arise from the cost and complexity of integrated solutions essential for solving multidisciplinary design problems. These issues can be solved in a new cloud-based environment that allows to develop, publish and run integrated applications solving classes of design problems. Recently released cloud-based design tools provide the basis for such environment, and what is yet missing is an integration-enabling solution. Additional requirements to this solution appear as a consequence of the demand for simulation driven design. We have formulated these requirements and shown that our solution, pSeven, meets the requirements for a cloud-based design exploration and integration platform, enabling simulation driven design in the cloud.

8 References

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