

CAE Data Management Concept

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White Paper

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Executive Summary

The effort required for simulation data management is increasing with the amount and complexity of information that is manipulated in the CAE¹ context. Implementation of Product Data Management (PDM) today is restricted to product design utilizing the large overlap of information content at different locations enabled by the relatively homogeneous CAD tool scenery.

An integration across different domains such as design and simulation where this overlap is rather low opens a completely new level of complexity not addressed today. This is made even more difficult by the fact that little to no PDM is used in the simulation domain and the variety of simulation tools tends to become complex with no common way existing to share CAE information across these tools.

Based on its experiences drawn from many integration and product data management projects, skills competences from various industries, and its vendor-neutral attitude, PROSTEP offers a scalable solution for the management of CAE data that can be implemented step-wise and integrates existing processes and applications using proven and industry strength concepts and tools.

Introduction

The application of methods for the simulation, analysis and testing² of physical phenomena during the product definition phase is today common practice in most industries including automotive, aerospace, plant engineering, and shipbuilding. Software tools are used by engineers to simulate, measure and predict the product's behavior under conditions closely modeling reality and to analyze its response on loads ranging from forces to heat impact.

Thanks principally to advances in computer hardware, the execution of numerical simulations in the last years no longer demands expensive investments in processor power or waiting time for results. Instead, the fact that simulation tools today sometimes tend to be used like "pocket calculators" leads almost inevitably to a situation where their application is restricted by the ability to manage the related data.

The effort required for the management of simulation data is increasing with the amount and complexity of information that is manipulated and produced by the simulation. This seems diametrically opposed to scenarios requiring collaboration between partners in joint projects and processes that are getting more and more complex due to an increasing number of activities handled in parallel.

The cost of changes in the design and planning becomes dramatically higher with progressing maturity of a product definition. The ability to make the right decisions as early as possible is becoming crucial. Analysis and simulation can help to make the right decisions when used efficiently. The ability to manage the data without concessions is the key to this.

¹ CAE: Computer Aided Engineering

² simulation, analysis and testing – referred to as simulation in this paper

State of the Art and Trends for the Future

Managing data is in most cases related to the ability to provide the right information in time at the right place and in the right format. In today's real world scenarios information is distributed across a number of organizations and software systems each of which taking its own perspective on it. The two main characteristics describing such a scenario are location and meaning.

Currently, the integration of the different software systems in the technical product definition area is focused on product design and uses the basic distinction between meta information (product data) which provides a context such as location in space and hierarchical breakdown, and user information (2D/3D geometry). An integration exists at both, the meta information level (allowing PDM systems at different locations to share information) as well as the user information level where – to a large extent – geometry is exchanged as native data and converted to other formats as required.

This is possible because:

- **meta information** is exchanged between different PDM systems but always **remains in the design domain** – thus the meaning of the meta information is retained to a large extent
- there is only one major (type of) **user tool**: the CAD system – even different types/versions of CAD systems have a **high overlap of information content**, so again the meaning of the information remains unchanged.

The limitation is obvious: The meaning of the information is virtually the same to all integrated systems. There is no integration across domains or different kinds of user tools and thus no semantic break. Therefore the integration of design and simulation opens up a completely new level of complexity.

According to DARATECH study³ investment in CAE software and services have reached \$2.1 billion in 2004. This is a disproportionately high rise of +12% compared to 2003 and represents meanwhile about 25% of the overall PLM investments which in total rose by +8% compared to 2003.

During the next five years digital simulation is

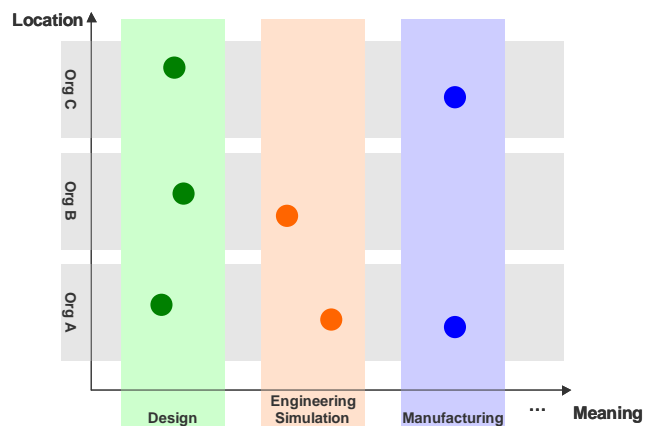


Figure 1: Information – Location vs. Meaning

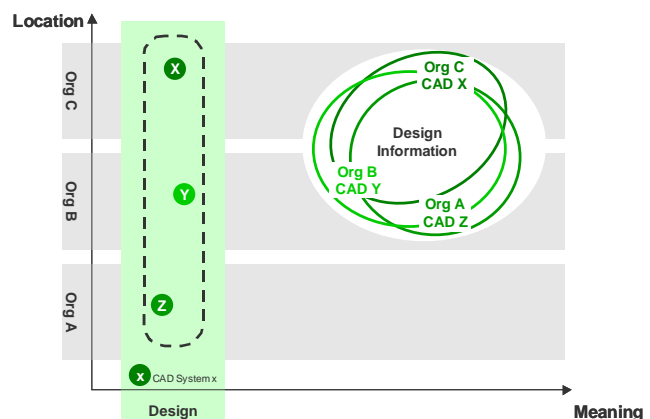


Figure 2 : Design integration over different locations

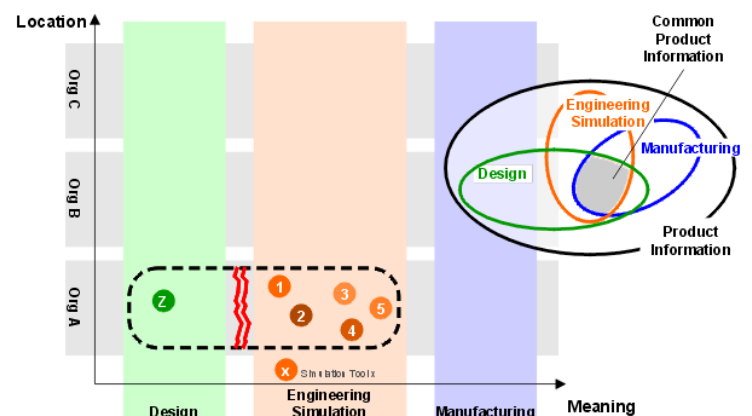


Figure 3 : Domain integration and semantic breaks

³ <http://www.daratech.com/press/2004/040804>

forecasted to be the growth engine of PLM with a conservative annual rise of +12%. The potential of digital simulation to improve productivity is assumed comparable to that of the invention of CAD 35 years ago when drawings boards were replaced by design software running on computers.

In the electronics industry processes are CAE-driven already today, with CAD in the background, although tightly integrated. There are expectations that the same will be true in mechanical engineering soon – simulating a virtual model of the product even before its design is finished.

According to the study advances in high performance computing is an enabler as well as the growing recognition of digital simulation's ability to generate higher quality and more innovative products faster and at lower costs.

The Challenges of CAE Data Management

The CAE domain is probably the domain with the most dependencies into other areas. This is because it aims to simulate real world scenarios using methods of virtual product verification and therefore needs all information necessary to be as close to the real world as required to describe the phenomena under investigation. A strong interlink exists to the design domain due to the iterative processes that are run during the product definition phase.

Results of simulation processes often cause activities in the design domain – being it the release of a design or required changes due to an identified insufficiency or failure. In any case, design information including geometry, connectivity, assembly, etc. is the basis for simulation activities and results are fed back and have influence on the design. As described above design information can be made available in a commonly understood and context oriented way. This is not true for simulation information where little to no PDM is used and the variety of user tools tends to become complex.

The creation of simulation process input from other information such as design or materials causes logical dependencies that cannot be traced later on. Furthermore, design changes and releases but also the study of design alternatives require a consistent management of input and results information and the knowledge of the whereabouts (who, when, what, ...) of the activities carried out. This leads to aspects of versioning and change that are unresolved in CAE today. Once these dependencies are accessible, simulation engineers would be able to directly follow the links to related design information as designers could call up the simulation results they are interested in. This would just correspond to their way of thinking. In addition, design activities could be carried out in parallel to simulation trials without the risk of lacking consistency.

Make CAE Information Referable

Other than design the simulation domain is characterized by a large number of proprietary simulation tools ranging from COTS⁴ tools to in-house solutions. This is mainly driven by the numerous disciplines, each of which using their own specialized software. Aircraft dimensioning and verification, for instance, is done in the areas of global and local static strength, fatigue strength, damage tolerance, composite materials analysis, thermal analysis, etc. This is similar to the automotive industry where simulation tools are in use for the investigation of global (body-in-white) stiffness and operational strength, crash, passenger safety, NVH, air flow, air conditioning, etc.

As a result, the variety of native data formats is of the same order of magnitude as is the number of tools with the consequent high amount of information redundancy. The same information usually has to be held in a number of files in different formats. Central databases for materials or standard component parts cannot be referenced. Instead, data is replicated to several places. It is scarcely possible to re-use information between tools and it requires error-prone manual effort or custom-built solutions.

⁴ Commercial off-the-shelf

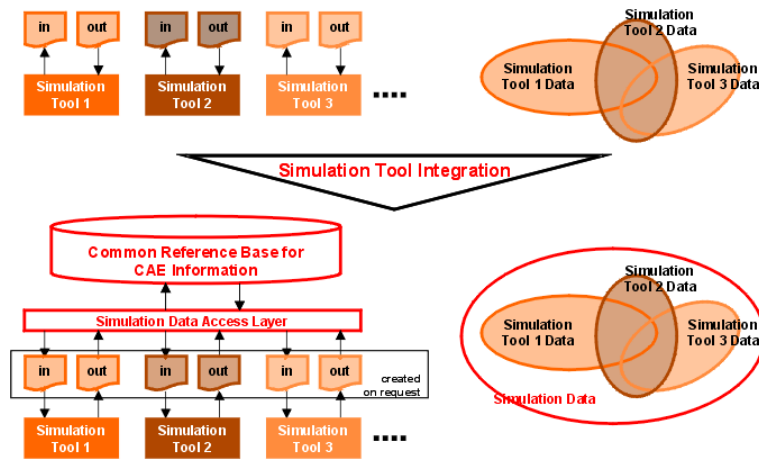


Figure 4: A common basis for simulation information

The way to overcome this situation is the integration of the various tools and formats: the introduction CAE data repository that is simulation tool independent – together with a layer of pre- and post-processors capable of generating native input data and extracting information of common interest from results which is fed back into the repository. This approach can be referred to as “simulation tool integration” – user data is moved into a single domain database and managed at a central location.

Maintain a Product Context for CAE Information

Simulation data today is typically file based. Management of these files is done in file systems having no support to maintain meta-information indicating any “who has done what when, how and why” and “where does this relate to”. This knowledge is kept by people working on the project, encoded in file names or manually updated in spreadsheets. Even if file systems allow for a certain level of structuring there is virtually no way to associate any business process logic with this structure or to implement rules. Version, change or configuration management is completely out-of-reach.

This way of managing data is getting even more difficult by the fact that the structuring and granularity of data files is primarily oriented on tool requirements and not at product related organization principles. In consequence, simulation data simply cannot be referenced from a product component oriented system.

The solution to this is to give the common CAE data repository a product oriented structure. The simulation perspective on the product often is a functional one – function and behavior are the context of simulation. If simulation information is organized according to this scheme, i.e. information related to the simulation of a certain component (single part, any combination of parts, whole systems) is bundled into clusters and associated with that component. Those clusters can be put under product data management. Doing so introduces a simulation view - complementary to the existing design view of the product. These "CAE data clusters" effectively play the role of the CAD files in the database of a PDM system managing the design view.

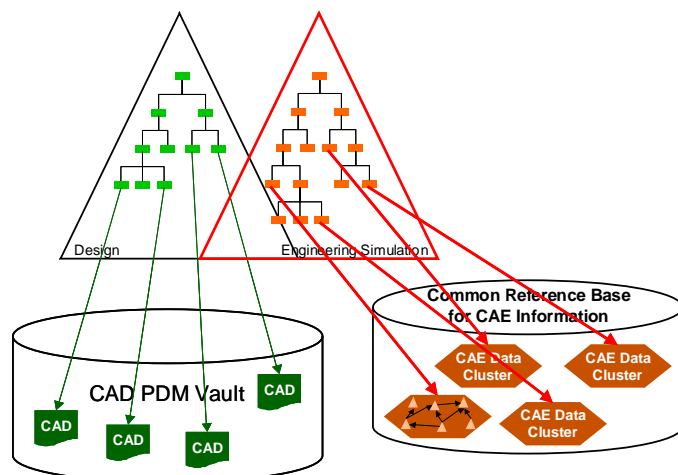


Figure 5: CAE Product data management

Keep Inter-relations of CAE Information with other Domains

Simulation information has strong interrelations with design by nature. This is because simulation seeks to verify product designs. Often, simulation also provides a starting point for the design of the product, e.g. by defining initial conditions that must be met. During the product definition phase design and simulation are interlinked by iterative process loops: Changes on one side cause changes on the other. The same is true of information collected from other domains such as materials.

Relationships describing these dependencies as traces of processes across domain boundaries or as references to the origin of certain information would allow the development history to be tracked independently of where a certain activity was done. They would allow answers to questions like "What was the consequence of this design change on the product's behavior?" or "Why was this material changed in grade?". Today these relationships cannot be kept and managed anywhere.

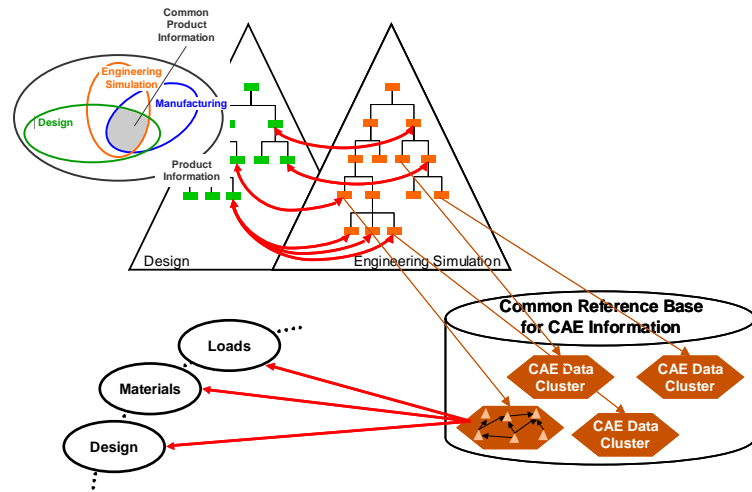


Figure 6: Inter-relating CAE information with other domains

Organizing and managing CAE information in an simulation view

provides the missing anchor points for such references. This allows for integration of the simulation and design domains at the meta-information level. Further, the product oriented structuring of a CAE data repository makes it possible to set simulation information in the context of other domains describing the engineering intent or the activity that was carried out in order to create this information (e.g. for an automatic redo of this activity).

Manage CAE Information during the Product Lifecycle

Product development happens over time. Different domains need to manipulate information concurrently in different views. The absence of product data lifecycle management often puts simulation activities in a position to be satellites of design activities. Otherwise, the overall development process would not be manageable.

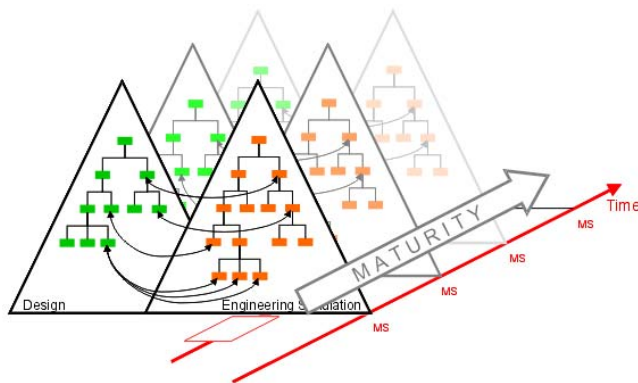


Figure 7: CAE Product data lifecycle management

Managing the lifecycle of product data in design and simulation domain views allows real concurrency. Once PDM is in place for CAE information this can be maintained over time. Information is synchronized at well defined milestones. At these points a snapshot is taken of the current state, recorded and kept for later reference. At specific milestones ("design released", "start of production", "entry into service", ...) the snapshot can be subject to (long-term-) archiving. In between each domain is free to act independently. Roll-back is always possible to the last kept state, and changes since then can be identified for each domain.

Roadmap for the Implementation of CAE Data Management

What has been described above is a scenario that clearly is a vision of how to manage simulation data in a way that would address many obstacles with what is common today. It is understood that requirements differ across industries and companies and that existing processes cannot be simply replaced or broken by a new solution but need to be smoothly migrated in an operating environment.

A company implementing CAE data management needs to have a mid-term and a long-term vision, both with clearly defined requirements and targets. This allows to address the most-pressing aspects as soon as possible but in a long-term context. The road to CAE data management has a number of waypoints that are closely related to the challenges listed above and can be summarized as

1. **Simulation tool integration** – make CAE information referable
2. **PDM for CAE** – maintain a product context for CAE information
3. **Inter-domain integration** – keep inter-relations of CAE information with other domains
4. **PLM for CAE** – managing simulation data during the product lifecycle

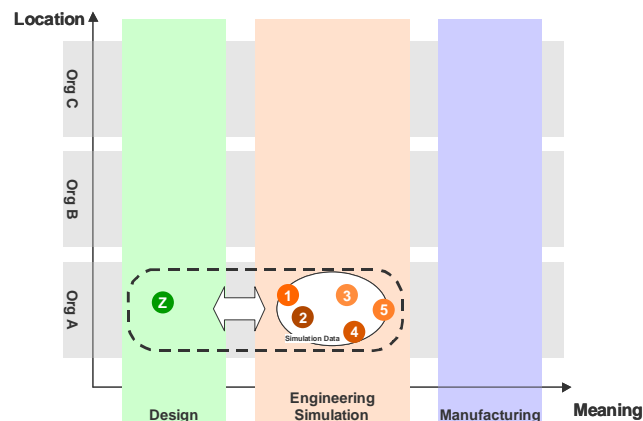


Figure 8: Engineering data integration – the Vision

These steps can be implemented in a successive order – but depending on the requirements any subset of the full scenario could be an applicable solution. It is obvious that the key to achieving simulation data integration is to overcome the heterogeneous world of proprietary CAE tool data by a tool integration approach. The way to integrate the simulation world can be covered in applying off-the-shelf PDM tools and standard EAI technology in conjunction with existing systems and tools.

Components of a Solution

Simulation Tool Integration - Make CAE Information Referable

Simulation Tool Integration at Application Level

Simulation processes have the general requirement to communicate information between different tools and involved parties within and across domain boundaries. Today this often is a cumbersome and error-prone matter based on manual intervention and specific point-to-point translations of proprietary file formats. But the technology to share and exchange information exists and is ready for application. State-of-the-art development approaches make software independent of IT platforms and data independent of tools.

Practical experiences on the other side show that specific scenarios have specific requirements. Often the scope of standard protocols does not exactly meet these requirements or is not comprehensive enough. This removes flexibility and creates restrictions that do not contribute to the wide acceptance and usability of standards which often leads to decisions not to spend the extra one-time effort to develop independent solutions.

The PROSTEP Simulation Tool Integration approach aims to create a common reference base for CAE information that is independent of specific tools and provides a single data source for all involved simulation methods. It uses existing standard protocols as the basis to configure a simulation data model that exactly fits a specific scenario without creating anything proprietary. The result is a rich data repository that serves as a CAE reference base in a way that is

- Redundancy free, consistent and single source for information of all simulation processes,
- Allowing for centrally manageable data access and administration,
- Enabling decoupling of tools and data / data store,
- Providing a means to couple data from different classes of CAE methods (multi-physics).

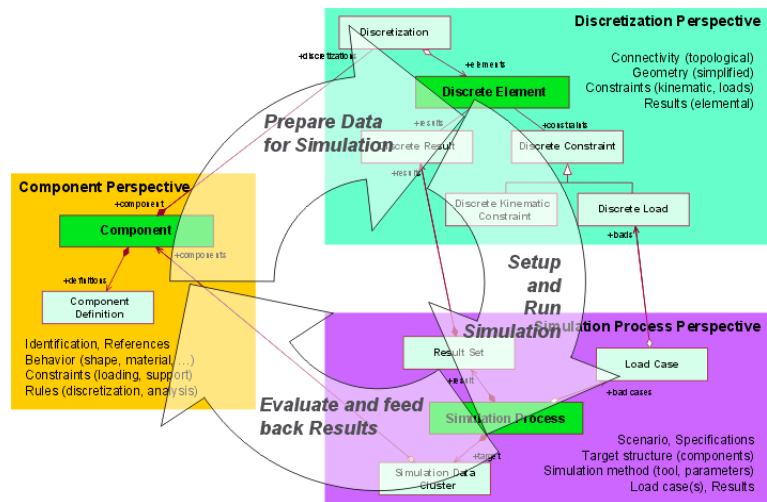


Figure 9: Simulation Integration Framework for Simulation Tool Integration

PDM for CAE - Maintain a Product Context for CAE Information

Application of PDM as a structured Simulation Data File Management Tool

One of the most straightforward steps to establish standard data management methods in simulation is the creation and maintenance of a product context for file-based simulation data. In other words, simulation data shall be organized by a PDM tool capable of managing information about product components (such as documents and geometry models) in a hierarchical structure that reflects the simulation processes.

A specification that describes how to adopt a standard PDM tool to the requirements of simulation is currently developed by the SimPDM working group in the ProSTEP iViP association. PROSTEP is involved in this initiative and actively contributes with its background as a system and tool integration company.

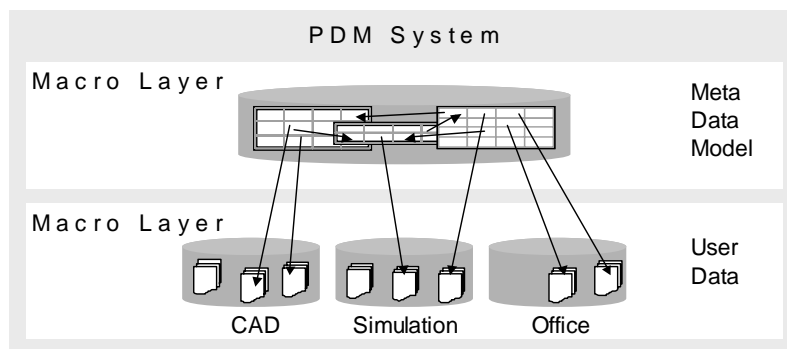


Figure 10: The principle architecture of a PDM system

The principle architecture of a PDM system consists of two layers. Information about the simulation data (files) for administrative purposes is held at the "macro-layer". The user data is stored at the so-called "micro-layer". User data in the simulation domain includes 3D CAD models, specifications, analysis decks, and simulation results.

Information at the macro-layer – the meta-data – carries references to user data and includes type, identification, description, status, and change information about it. The adoption of a PDM system (customization) is done at the macro-layer. The macro-layer specification is referred to as meta data model. It defines the administrative attributes and relationships maintained by the PDM system. This is one of the most-significant advantages of a PDM system compared to a file system based data management solution.

The specification developed by the SimPDM working group reflects the two reference processes for finite element analysis (FEM domain) and multi-body simulation (MBS domain) as well as a combined scenario. In principle this can be extended to other scenarios including CFD, physical tests, electrical systems simulation, etc.

One of the limits of a PDM based simulation file management solution as described here is the virtual inability to cover strongly coupled problems (multi-physical problems) such as the analysis of induced vibrations or heat propagation in a pipeline due to fluid flow. This limitation is caused by the typically tool specific content and granularity of user data files. A simulation scenario involving several analysis tools in parallel would require to overcome this tool oriented-ness.

After all, PDM system based simulation data file management is the application of the well proven design data management approach adopted to the specific requirements of simulation and analysis.

Providing Simulation with non-geometrical Information

In addition to geometrical data (CAD) simulation processes normally need further – non-geometrical information as input. Such information include materials, loads, and support data as well as derived attributes such as center of gravity or moment of inertia. Engineers today are often forced to collect this information manually.

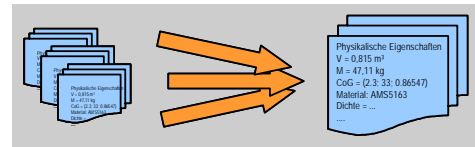


Figure 11: Providing Engineering with non-geometrical Information

Some of the wanted attributes are stored with the CAD models already, but can typically only accessed using the originating CAD tool. In order to optimize the process of data collection and aggregation for CAE these attributes should be made available through a centrally managed repository that is accessible for simulation engineers. The earlier these data can be made available the higher is the benefit for the simulation processes.

The basic idea behind the approach is to avoid multiple external requests for the same piece of information – by this more and more closing the gap between data management in design and simulation. The result is a significant improvement for the simulation engineers to access this information. External sources concerned are – in addition to CAD systems – a number of other databases and files.

The first step to get there is the enumeration of all types and attributes that are needed as input by the different simulation processes. A possible solution where to centrally manage all these attributes is to keep it as meta-data in the simulation domain PDM system (➤ [Application of PDM as a structured Simulation Data File Management Tool](#)) which however is mainly an administration of otherwise disjoint information attributes. A much more powerful approach to manage physical and process-related parameters in a context-oriented way is enabled by the ➤ [Simulation Tool Integration at Application Level](#) approach.

In both cases it is an important requirement to organize the non-geometrical information in a way that can be maintained and accessed by the simulation engineers in an efficient and simple manner.

Inter-domain Integration - Keep Inter-relations of CAE Information with other Domains

Managing Relationships between CAD and CAE – Introduction of a View Concept

To overcome the heterogeneousness between CAD and CAE data, a middleware approach is a promising way. The different manifestations of CAD and CAD data have to be integrated using up to date technologies like EAI and SOA. By implementing such integrations, it is possible to create relations between different systems, different pieces of data and different use cases.

Middleware software enables users to merge information from CAD storage systems together with CAE reference bases, materials databases and so on. To combine the different information pieces, already existing key data can be used. For example, a material number in a PDM record referencing a CAD model can be used to create the conjunction to the material data in an existing database.

For the conception and implementation of those systems, it is necessary to connect the middleware system (normally acting as a central service) to the involved backend systems. It is state of the art for integration platforms in the PDM sector to have a number of turnkey connectors to relevant PDM systems on the market. Using modern middleware technology, the creation of connectors to other systems is efficiently possible and reliable.

With this technology, users can continue working with the CAE tools they already have. The access to the managing systems in the background and the join of the information is realized via the middle-ware components. The integration in the CAE tools can be done using different technologies like XML parsers, API modules or CORBA interfaces.

Providing Simulation with Design Information

Before the simulation of a product can be carried out all necessary input information need to be collected and made available in the necessary format. This includes in the first place geometrical information including:

- Detailed CAD data: Data created by design including design data from previous product versions.
- Approximations: Those parts that don't have a detailed design yet get an approximated geometry from that is sufficient for initial simulation processes.
- Other: Further geometrical data such as cutting geometry, scanned or measured geometry etc. used as the basis for the creation of simulation models.

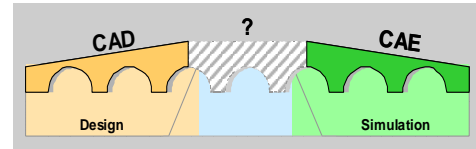


Figure 12: Providing Engineering with Design Information

During the early development stages, approximations and design data from previous product versions are often the only available information. With growing maturity of the product development this is more and more replaced by detailed CAD geometry.

While approximations are typically created in the required formats, detailed CAD models often need to be prepared before they can be used by simulation. This includes simplification of geometry (3D to 2D, de-featuring, ...), the decomposition of large models into smaller ones and format conversions. These processes require a close collaboration of designers and engineers.

It proves reasonable to persistently store the steps performed when preparing design geometry for simulation purposes, being it the documentation of what was done to get from CAD to CAE or the recording of the carried out activities in terms of an re-executable macro. Data management tools applied today are typically not capable of representing relationships between data resulting from such preparation processes nor information about the processes itself in terms of engineering intent (what was done ...). Such a functionality needs to be part of the integration solution between design and simulation as described in [➤Managing Relationships between CAD and CAE – Introduction of a View Concept](#).

It renders more and more important in this respect to consider status information of design data. Version information can not only be used to ensure only released design data is used by simulation but – more advanced – allows to knowingly use design geometry that is not released yet thus enabling a higher concurrency between design and simulation. Such an approach requires that not-yet-released data is marked accordingly to ensure it can be identified and updated later-on ([➤Documenting Design Reference States for Simulation](#)). Using this approach the amount of reference information available for simulation can be significantly increased especially in the early development stage which significantly improves the data provision and certainty of analysis results.

Another important aspect of data provision relates to data quality. Quality problems arising when design geometry is prepared for simulation include

- Redundancies in geometric models (coinciding points or curves, closed curves or surfaces or not topologically closed)
- Holes in surfaces, inaccurate surface transitions, discontinuities
- Decreased CAD geometry through tessellation

Sometimes, the described problems even arise from the conversion process itself. This makes it difficult to use such geometry without additional effort to e.g. close holes or remove redundancies. In many cases this requires the application of so-called healing-tools. Combined with tools to check data quality these tools enable an (partial) automation of the geometry conversion processes.

Administration and Provision of Analysis Results

Analysis results are primarily available as native data and are kept in different proprietary environments depending on the simulation discipline. The major distinction that can be made is between the detailed output of a simulation tool requiring special knowledge for its interpretation and derived reports presenting these results in a clear and understandable form.

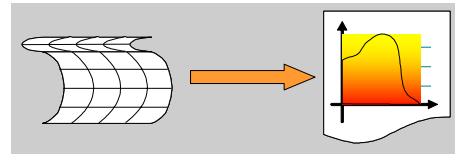


Figure 13: Administration and Provision of Analysis Results

At least the reports should be made available at a central location providing access for the designer of the analyzed part of system. In this way the loop between design and simulation is closed making the synchronization between the two domains actually possible at all.

Independent from the simulation tool its is important to consider the structuring of results in such a central location. In any case it shall be possible for the designer to access simulation results through the part or system in context. This often renders a 1:1-relationship between input data and results of a simulation impossible because

- Information about single parts is usually used in multiple simulations
- Analysis models are often at granularity levels that are not represented by assemblies in the design product structure

The second point defines a requirement to [➤Managing Relationships between CAD and CAE – Introduction of a View Concept](#) to accommodate non-trivial relationships between product structures at design and simulation whereas the first point provides an argument for the realization of a [➤Simulation Tool Integration at Application Level](#) that allows to make this information available independent of tools providers and free of redundancies. This is especially meaningful if simulation results are at the same time input for down-stream analysis processes.

Due to the significant overlap of the requirements on solutions for the [➤Provision of Simulation with Design Information](#) (main distinction is the direction of the information flow) and for the [➤Provision of Simulation with non-geometrical Information](#) (main distinction is the data source) it turns out meaningful to approach these three areas in a common way and to aim for a similar – if not integrated – solution for the management of reference data and results.

PLM for CAE - Managing Simulation Data during the Product Life-cycle

Documenting Design Reference States for Simulation

Simulation processes run concurrently to development from the begin of early design to manufacturing. This implies that the design reference data is continuously changing during this time and new states are released in a timely manner.

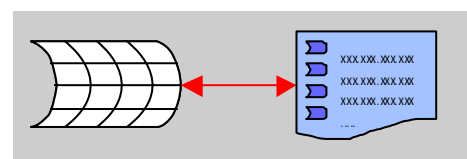


Figure 14: Documenting Design Reference States for Simulation

To allow judgments regarding the validity of simulation results with respect to a certain design state it is required to document referenced design states. The reason is to enable the unique identification of the release status of the reference design data independently of the source system. In addition a reference state forms the basis for the execution of change management (see [➤Change Management for the Design Reference Basis](#)).

Precondition is a complete reference base sufficient for the requirements of the current simulation tasks. Such a reference base can consist of

- CAD models from the current development project
- CAD models from one of the previous development projects
- Geometrical approximations created by simulation (e.g. based on sections)

- Scanned or measured geometry from physical models
- Other, non-geometrical parameters

It is important for the acceptance of the approach that the creation of a reference basis does not imply significant extra effort for the engineers. The creation process should therefore be a highly automated one. This motivates the provision of the functionality to export data for simulation in the originating system. Reference states could then be created "at the push of a button". If the system creating the reference state would further be also the tool to control the entire process of [➤ Providing Simulation with Design Information](#), the documentation of the reference state could be possibly integrated directly into the respective methods.

Change Management for the Design Reference Basis

Simulation processes often result in change requests for the reference data to feed back findings and optimizations. The respective communication with the designer is nowadays usually based on email and telephone. For a later reconciliation of the simulation reference base with the current design state it is therefore required to document the anticipated design changes on the simulation side.

The intention of the change management is to track information changes caused by the simulation processes. Changed information is marked accordingly in the simulation reference basis. The change management thereby covers only the fact that an information has been changed, not including the nature of the change at this point. Information identified this way forms part of the input for a subsequent [➤ Reconciliation of Simulation Results and Design Reference Basis](#). A thinkable extension to this change list would be the capability for a documentation of the change by the engineer including a human readable description of the change or an indication of its relevance for the overall result.

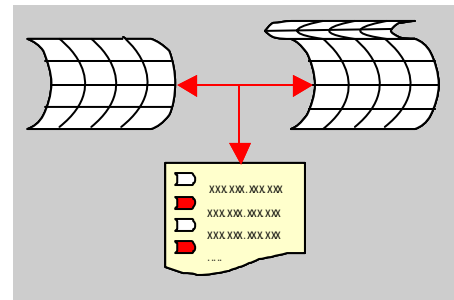


Figure 15: Change Management for the Design Reference Basis

One of the most basic issues in this respect is the existence of ways to assign simulation data and (design) reference data. The structuring of the simulation information can be significantly different from the structuring of the reference information (such as design assembly structure). This requires means and methods to support a mapping between the two sides. Possible approaches for a solution are described in [➤ Managing Relationships between CAD and CAE – Introduction of a View Concept](#).

The result is a list of changed data – related to the information held in the design reference basis – that contains all information affected by changes caused by simulation. The creation and maintenance of the change list should – similar to the administration of the reference basis – not cause significant extra effort for the engineer. The benefit of the unavoidable amount of effort that is inherent to these processes is the smaller amount of data that needs to be taken into account of the reconciliation process itself.

Reconciliation of Simulation Results and Design Reference Basis

The reconciliation of simulation results and design reference basis provides the necessary feedback from simulation to design and thereby closes the iteration loop. A reconciliation is required for all information objects that have undergone changes in the simulation domain. The final target is to identify all information that is either marked by change management, or whose known design state has become obsolete in the meantime. In the first step all affected parts are collected disregarding the actual change which results in the set of data that is subject of reconciliation.

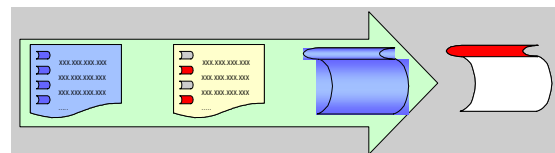


Figure 16: Reconciliation of Simulation Results and Design Reference Basis

The reconciliation process should to a large extent be automated and user interaction kept to a minimum. Its functionality is therefore best placed with the system maintaining the reference state which

should be identical with the system providing the design data for simulation. This also holds for information regarding new design states which should directly be available through the design PDM environment ensuring the necessary access and consistency for all information involved in the process.

Two options exist for the place to compare data marked for reconciliation between the reference state and the simulation results:

- at the simulation side, and
- at the design side

If carried out at the simulation side all design data to be compared needs first to be converted – with all the complexity as described in [➤ *Providing Simulation with Design Information*](#) – which would be an extra effort that should better not be spent if avoidable. This motivates to perform the comparison at the design side – requiring the conversion of simulation data to design – which renders most efficient since this is the direction for the propagation of simulation changes anyway reducing the number of necessary conversions to one per changed data object.

PROSTEP

integrate the future

Dolivostraße 11
64293 Darmstadt

Tel.: 0 61 51 - 92 87 0
Fax: 0 61 51 - 92 87 3 26

info@prostep.com
www.prostep.com