8 Reasons why CAD and CAE are outdated, and MAR™ is the future

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Abstract:

For more than half a century now, people thought CAD and CAE were acronyms for Computer-Aided Design and Computer-Aided Engineering. In reality, however, Computer-Aided Documentation and Computer-Aided Examination would be more appropriate. Computers barely aid engineers' design, the design is in their head, they use the computer to document, validate and iteratively refine it. It is like paper, pen and slide-rule have been replaced by powerful machines, but the tasks they are performing are still similar. Operating this way, the outcome of engineers' work will always be restricted by their limitations of time, money, and patience. They're often limited to just one or two choices at a time, and then go for the better one, not the best possible design.

At the Swiss Institute of Technology (EPFL), we have solved the major problem standing in the way of true Computer-Aided Innovation. In the future, engineers will share design goals with the computer, tell it what they want to achieve, as well as the constraints involved. The computer explores the solution space to find and create ideas that nobody would ever think of on their own. Skeleton|CAx™ is an advanced, intelligent system, capable to autonomously create designs, simulate physical behavior and achieve a specific optimization goal at the same time.

We have created SkAD Labs, a company developing the commercial roadmap for this invention. Our Medial Axis Representation™ technology (MAR™) will introduce enormous benefits replacing the previous generation of engineering development tools. Just as in the previous engineering software disruptions, new generations of winners and losers will be created, based on their awareness and will to adapt.

Introduction:

We are at the dawn of a new industrialization wave that is poised to fundamentally transform the way business and society interacts with its environment. Just as previous innovation waves, novel technologies currently developed and introduced will have a pivotal impact on the way we design, build, use and perceive industry products in the future.

In the last century, engineering was permanently disrupted by the modern inventions of industrialization. In particular, the introduction of digital technology generated a first wave of computer tools that changed the way engineers interacted with their products. In the aftermath of the third industrial revolution, software was built simply the way design and calculation engineers were working at that time. There were two different types of jobs, one responsible for the design of a product and one for the analysis of whether the design would sustain the expected loads. Accordingly, two types of engineering tools have emerged,

Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE). Every one of them was created to fit the needs of their respective engineers, CAD for design- and CAE for calculation or "simulation" engineers.

Since the initial introduction of CAD and CAE, many improvements have led to solutions which conveniently support design and simulation engineers in their work. More stable numerical methods and better solvers along with more convenient crafting tools empower users to go beyond what was possible in the past. The introduction and wide spread of computer and CAx technologies starting from the 1960s dramatically increased the industrialization process in many markets. It is widely accepted that modern products, like the complex output of today's Aerospace and Automotive industries would not have been possible without CAx technology. Engineers with these new tools at hand were not only faster, but had to rethink their working methods. As a consequence, the usual product development workflow evolved just as much as the overall job description of an engineer.

Yet, the time of huge leaps in improving engineer's work is over, as it seems. Looking at the number of CAD and CAE users (Figure 1), it becomes very clear that we are currently in a maturity phase of the engineering software market. For the CAD industry, the last big disruption took place beginning of this century, an unusually long time ago. The recent introduction of direct modeling and the cloud infrastructure - which happened many years after other IT markets - did not change this situation substantially.

There is reason to believe that the market is waiting for a novel technology changing the landscape. A situation as now is the perfect bedding ground for disruption. Many times, new technologies have led to incumbents going out of business because they have forgotten how to innovate, trying to ride the wave of success with marginal improvements of their outdated solutions. We believe we have developed such a novel technology, and we would like to introduce to you the main reasons why we believe CAx is entering a new era!
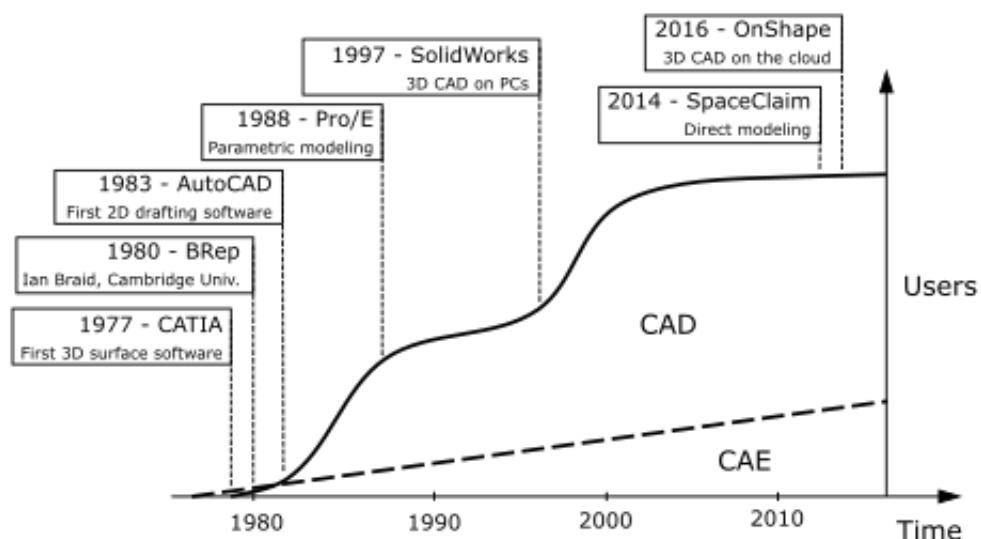

Figure 1: Adoption rate of CAD and CAE software

1. Time-to-market shortens, cost pressure rises

Currently, it takes 4 years to develop a new car model (Tesla Model S [1]), 15 years to develop a new aircraft model (Airbus A380 [2]), and 3 years to develop a new mechanical watch movement (Piaget 900P ultra-thin movement [3]). It comes without saying, that reducing the overall development time of products is paramount to increasing competitiveness and improve efficiency.

Various studies have shown that the duration of product life cycles is steadily decreasing across all industries. Between 1997 and 2012 alone, the average life cycle length across industries fell by 24 percent. The digitalization of almost every business aspect and the resulting efficiency boosts have contributed a big part to this development [4]. A delay in time-to-market is associated with painful cost penalties and jeopardizes the overall financial breakeven of the project (see Figure 2). Competitors might take a substantial share of the market, leaving the delayed product at shortened return on investment.

Although developed for decades, current CAD and CAE software tools are not particularly adapted for modern productivity challenges. Much has been tried to improve usability, reduce irritations and smoothen the workflow within single applications. What the industry just could not improve is the usability throughout the entire spectrum of applications. Yet, utilizing the full range of engineering tools is imperative to developing complex products. From design to numerical simulation to optimization, engineers have to move back and forth between these applications multiple times a day. In times of increasing need for optimization *interoperability* is key to productivity, but weakness of these tools at the same time.

Under increasing competitive pressure, evidence solidifies that engineering companies face inefficient development processes. These processes are based on software products available, which in turn encourages CAx companies to build solutions catering these processes and requested by engineers. As a matter of fact, this situation is perfectly caricatured by Henry Ford's famous quote: *"If I had asked people what they wanted, they would have said faster horses."*

How it will be done tomorrow: We took a step back, analyzed the current engineering practices and identified the weaknesses and bottlenecks. SkAD Labs have achieved what none of the incumbents ever dared to: questioning the fundamental assumptions on how CAx software works and how engineers work.

Skeleton|CAx™ allows a restructuring of the product development process, reducing the overall time to develop a product by 50%. This reduction is the sum of many fundamental changes we have built into our technology. The beauty of it is the full downwards compatibility with respect to legacy models and systems. Skeleton|CAx™ enables a smooth transition into the next generation virtual product development, allowing optional integration with previous tools.
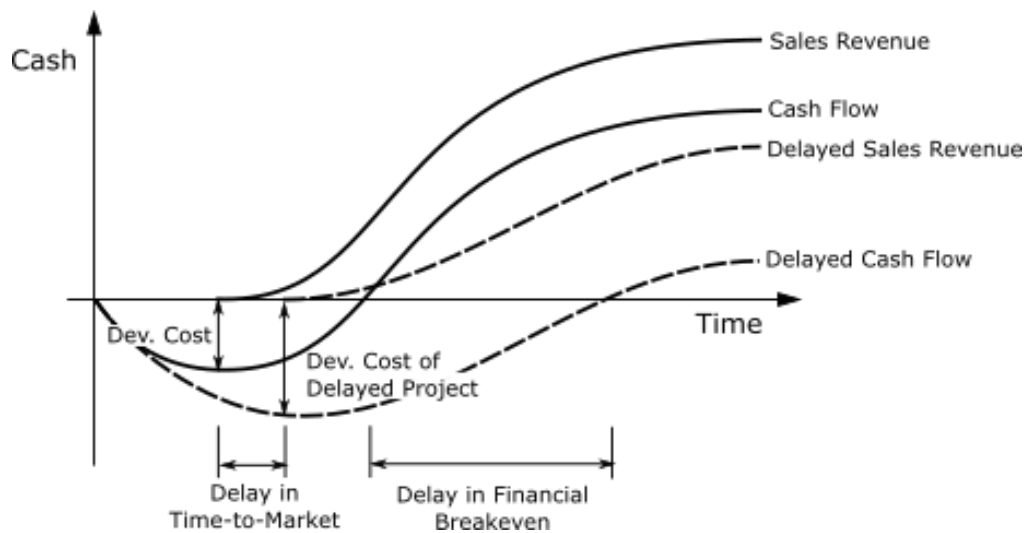
Figure 2: Effect of a delay in time-to-market

2. CAD/CAE integration level: the model data problem

CAD and CAE systems have been developed with the purpose to provide support for engineers in product design and virtual testing. As a matter of fact, to a large degree they managed to improve the development cycle and to allow for more complex designs to be realized. Yet, they are two different platforms, impossible to merge seamlessly. Root cause is the incompatible way their underlying technologies and the science behind them works.

In a conventional CAD environment, a solid object is represented by its boundary (Boundary Representation, or BRep). This technology was specifically developed as an object representation for visualization and easily drafting as well as shape edit functionalities. BRep models are hollow inside their outer shell.

In CAE environments on the other hand, the object's interior needs to be discretized (meshed), so that physical meaning can be associated to the inside. The overall shape of the object, however, cannot be easily edited anymore as of this point. Cell decomposition representations, as employed in simulation environments have a huge amount of associated data points and no practical means to create or modify design features.

The conversion between the two representations is practically 1-way, namely BRep to cell decomposition (CAD to CAE). The reverse transformation cannot be traced back to the original shape after a transformation, like for example due to a body deformation. In the same fashion, there is no way to assign or map physical information like stress fields, kinematic data, and such, on the CAD representation. Regardless of what engineering software providers may advertise, none of them has managed to integrate CAD and CAE beyond a joint user interface. This approach might delude, but is a desperate approach on solving any of the deep-rooted CAD and CAE incompatibilities. As a consequence, shallow user interface solutions critically fail to deliver the benefits of a true native integration of both platforms.

How it will be done tomorrow: Skeleton|CAx™ employs an alternative representation model for both CAD and CAE, fusing both environments in its fundaments. The benefits for the user

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are not only faster product development cycles, but also significantly improved ease of use and extensive Artificial Intelligence support.

What does that mean in concrete? Well, as an illustration consider a virtual model that is both, CAD and CAE model. You could naturally draw, simulate, modify the design as well as the simulation at any time without even noticing that you are working cross disciplines. At the same time, you could just skip this "manual" workflow by defining design goals and constraints and let the computer do the bulk of these tasks.

How does it work? Skeleton|CAx™ is based on Medial Axis Representation™ (MAR™) technology, meaning that it builds a joint CAD and CAE model directly from its skeleton (Figure 3). MAR™ is superior in grasping topological and geometrical context and allows to automate most manual tasks based on this information.
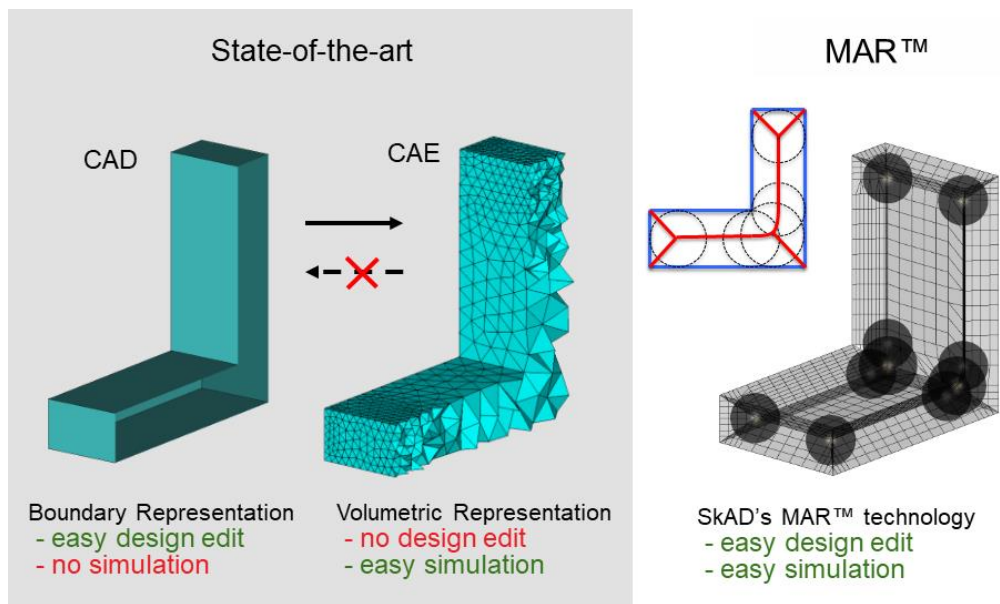

Figure 3: BRep and cell decomposition vs. Medial Axis Representation™

3. The optimization dilemma

It is the dream of every mechanical engineer and manager to develop the perfect product: optimized for weight, cost efficiency, manufacturing, etc. and developed faster than anything else before. Currently, engineers perform manual iterations between CAD and CAE to optimize their products. First, a CAD model is imported into CAE, then a simulation model is created. Once simulated, the CAE results are analyzed, and modifications are manually fed back into the CAD model based on the designer's interpretation and experience. As a matter of fact, this is a broken digital link!

There is currently no way to digitally feedback CAE results into CAD. Modern CAE solutions try their best to offer optimization loops and smooth integration based on the modification of the imported BREP model from CAD. Yet, real usage and convenience is strongly restricted, leaving these solutions far beyond their promises. These methods lack the ability to overcome the BREP. In other words, once a shape is created, optimization can only exist within its original topology.

Structural optimization software packages lack the ability to find original optimal designs because of their deterministic nature (parametrization), while those employing stochastic methods (non-parametric) are not suitable for all types of structures. Yet, no technology has been proposed able to overcome the shortcomings and limitations of BRep based CAD model optimization. This is why non-parametric methods (topological optimization) are used, although lacking convenience and workflow consistency.

How it will be done tomorrow: Since Skeleton|CAx™ is a true, native fusion of the two model representations, there is no restriction in automatic optimization loops. This allows the full availability of finding *original optimized shapes*, a functionality that was feasible only by destroying the BREP model up to now. Never again engineers will be left with an optimized, but non-CAD model of the optimal shape. Skeleton|CAx™ can create and delete new boundaries of a shape, thus optimizing beyond what is possible today with parametric design models.

To put it differently, Skeleton|CAx™ combines all convenience and advantages of a CAD environment with the capabilities of topological optimization methods. The optimization result is a fully editable geometry rather than a density field.
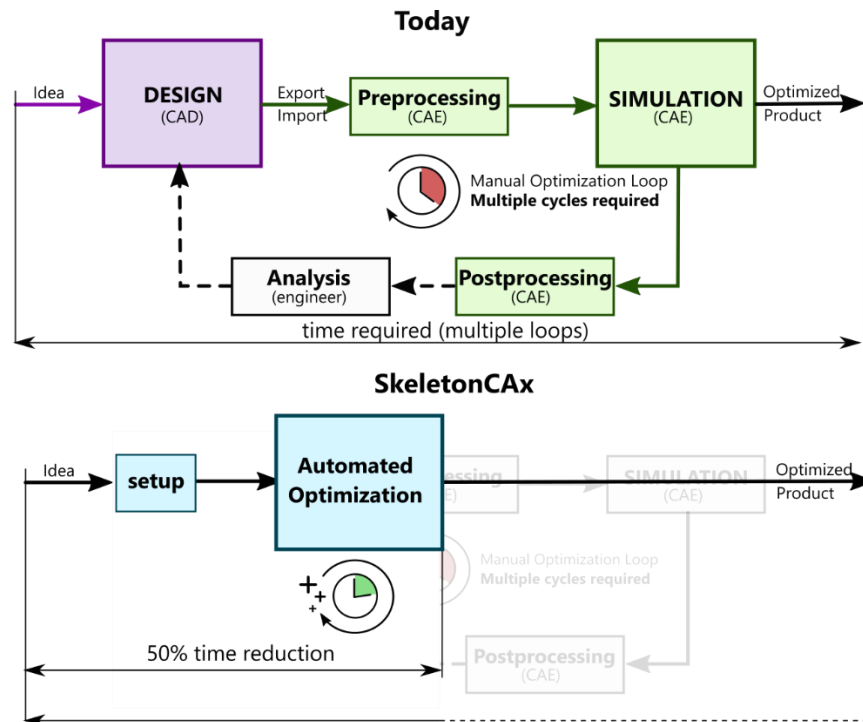

Figure 4: Optimization workflow comparison

4. Feature recognition and topological search

According to industry analysts [5], the annual carrying costs of introducing a new part range between $4,500 and $23,000 per item. Currently, engineers face two undesirable choices when designing a part for a new product: they can either waste valuable time manually trying to find a suitable part in a database —frequently a task that just takes long and is quite cumbersome — or they can give up on the search and create a new part.

The decision to design a new part instead of searching the legacy database and re-use may be the most convenient and fastest decision for an engineer. Yet, it is by far not in the interest of the company, as the implications reach as far as through the entire product development and manufacturing organization. An engineering model database of legacy designs is a real hidden asset. Creating new parts instead of re-using existing ones unnecessarily increase part counts and slow time-to-market. Once a new part leaves product development, it creates additional work and costs for every downstream department, from sourcing, production, inventory, and distribution to sales, marketing, and support.

To eliminate inefficiencies with unnecessary redesigns, engineers must have a well-rounded tool at hand, able to analyze and understand topologies and find similar ones with reasonable abstraction. Currently, technologies for design search are using either keyword-based text search together with part naming conventions, or they are based on a crude geometrical level using minimum distance functions. Both of these cases are unsatisfactory, which is why a vast majority of users do not reuse designs at all.

How it will be done tomorrow: While conventional CAD models do not contain topological information per se, MAR™ models do. Skeleton|CAx™ is able to interpret and search for geometries, going beyond simple minimum distance functions. This feature can be utilized to search for entire parts and assemblies, or for a single feature of a design, may it be deformed or original shape.

The implications are far reaching. First, large engineering companies do not need rigid naming conventions for parts anymore. They can build up legacy part databases, searchable through a simple sketch or detailed drawing. A huge leap towards better standardization! Second, an autonomous classifier for parts and assemblies can be introduced into such a database. Third, not only search, but also replace functions are possible, allowing the introduction of an exciting model modification and reduction feature as introduced in the following.
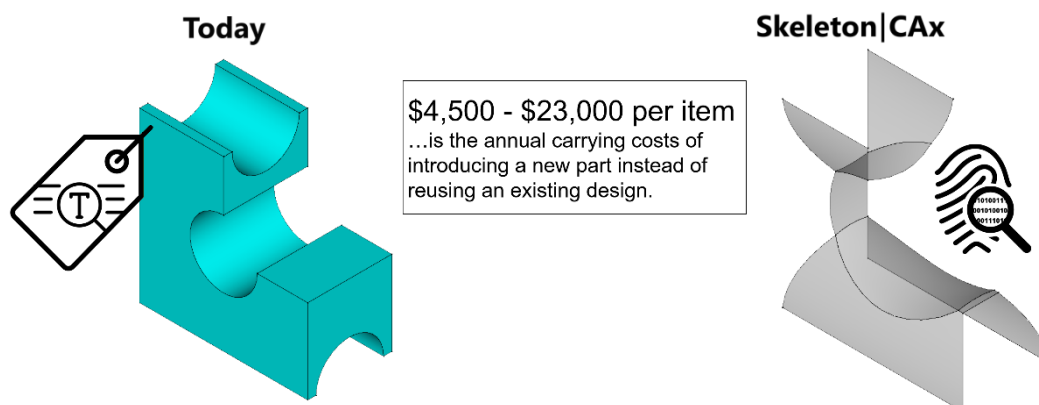

Figure 5: Keyword-based search vs. skeleton (MAR™) based search

5. Model order reduction and speed of early stage design

How to get a first quick understanding of an early stage design under realistic loading? In the initial concept phase, engineers want fast answers with an accuracy level that is adequate to understand basic design flaws and compare different variants. It is well-known, that the cost

of design mistakes is growing exponentially with time (Figure 6). Every engineer should strive to detect and correct design flaws as soon as possible, as later decision will be based on early design choices.

In order to reduce calculation times of early stage simulations, models of low order (reduced number of degrees of freedom) are generated. This routine entails reducing the level of detail in CAD as well as creating a CAE model with reduced, but sufficient degrees of freedom to obtain meaningful results. So far so good, the ultimate problem is that early stage models are completely useless after deriving a CAE result. The time spent in generating them can't be utilized any further, as more accurate models from CAD and CAE have to be generated. Although the learning from reduced degree of freedom models is valuable, the time taken for the process is utterly wasted.

How it will be done tomorrow: As a consequence of MAR™ topological intelligence, Skeleton|CAx™ can automatically decide which parts and features to simplify and which ones to replace with approximations – for both, the design and the simulation.

First, the design is reduced and de-featured and the CAE model, based on the user's accuracy demand, is built appropriately. Second, parts that can be approximated by simple elements like beam, truss or shell elements, etc. will be replaced by such if adequate. All at the fingertips of a user, that simply needs to adjust one accuracy slider. The underlying numerical model remains the same for full accuracy or full reduction. No need to rebuild and redefine it every single time. Simulation and handling times is significantly faster, leaving more time for testing and comparing early stage designs. As a consequence, engineers and designers will be able to identify problems and mistakes earlier, reducing follow-on mistakes and, hence, development cost.
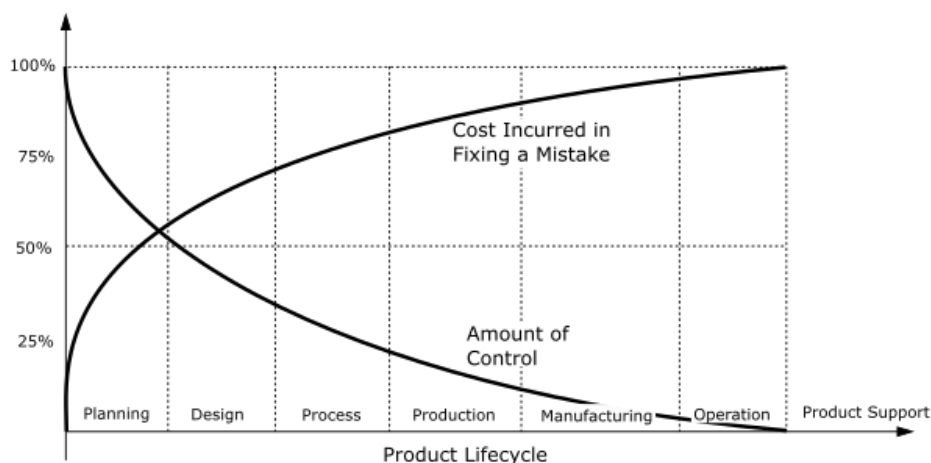

Figure 6: Cost incurred in fixing a mistake

6. Simplicity of use and required expert knowledge

It takes users a long time mastering engineering software to a level that delivers both, satisfying and fast results. As a matter of fact, this particularly applies to CAE and optimization software which feature complex functions and map rather complicated numerical

procedures. Operating these software tools entails numerous decisions, and pulling the right levers in order to crack the case and reach a meaningful simulation result.

In view of different expert knowledge required, design and simulation tasks are typically executed by different departments, involving users with different training and experience level. Passing on information between departments is always a time-consuming task, while prone to communication errors and misunderstandings. To finalize the design of a product, design and simulation departments have to iterate several times and create multiple CAD and CAE models, as described earlier. Not to mention that this even pictures the best case. In the worst case, an R&D simulation engineer is performing both tasks. Under those circumstances, valuable expert time is spent on less sophisticated tasks, that could be performed by someone with a more adequate job function.

To put it differently, there are two approaches how to handle design and simulation currently, and both of them are miserable. The one is to keep them separated with different people performing different tasks. This leads to a lot of back and forth in every iteration step. The other is to let the higher educated person do all, and waste their time with tasks that are not aligned with their skills. Believe it or not, these practices are daily reality in engineering companies and needless to say that they are utterly inefficient and frustrating for employees.

How it will be done tomorrow: Skeleton|CAx™ is developed to be useable by designers and R&D engineers. Due to its built-in intelligence and optional decision layers, it can be an easy to use early stage design- as well as a sharp simulation expert tool. Having said that, Skeleton|CAx™ solves the dilemma by bringing simulation capabilities to the designer's level. Designers are given a mighty tool into their hands, taking most of the expert decisions away from them.
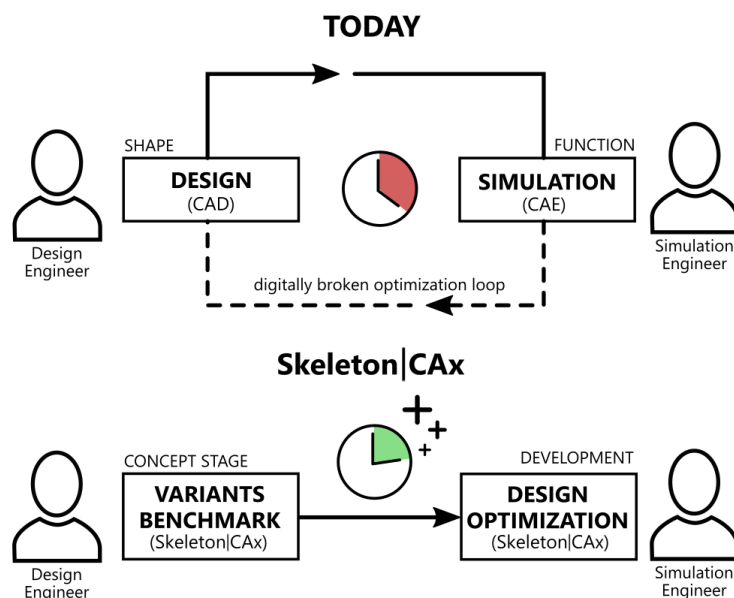

Figure 7: Product development process today vs. Skeleton|CAx™

With this in mind, Skeleton|CAx™ is able to shift workload from the engineer to the designer. The latter will be responsible for obtaining the best possible design concept independently. Once the concept stage is closed, the designer's work will be passed on to the R&D engineer

for last refinements and approval. This way, specialized R&D simulation engineers can be utilized right to the point.

7. Automation and Artificial Intelligence

Traditional systems were built for users commanding and executing every single step and every single decision of a development procedure. Many of these steps are just of mechanical nature, and do not require any kind of deep reasoning, while others need further understanding of context, aims, and constraints. What would happen, if an intelligent system could help and sustain a user with their decisions?

Artificial intelligence is already changing the way computer systems work in various industries. It is only a matter of time until it will find its way into engineering computer systems. Potential time savings generated with intelligent development tools are tremendous. A design engineer should not waste any more time importing model data, setting symmetry planes, applying logical boundary conditions or defining the meshing of a simulation model. We believe this outdated. There are two reasons we have not seen it so far. First, contemporary CAx technologies have hard times applying Artificial Intelligence holistically, as they are point products. Second, incumbents have lost the big picture and are just not innovating anymore.

How it will be done tomorrow: Conventional software systems manipulate and handle geometries, Skeleton|CAx™ comprehends geometries. The MAR™ data model structure contains topological information, which enables us to build intelligent agents on top, and automate many simulation and engineering tasks. Assembling, symmetry detection, modeling, intelligent meshing, manufacturing analysis, as well as classifications are only a first glimpse of what can be done with this technology in the future.

We are radically rethinking and inventing a system that is actively supporting an engineer with their task to invent and develop, instead of just executing commands. That is to say, we build intelligent agents that are capable to design, grasp the context of design, perform simulations and analyze results, optimize, and manufacture.

The aim of Skeleton|CAx™ is to free the engineer from process mechanics and transform their job to an overall concept creator. At the moment they are rather detail-oriented and process constrained micro executers. This represents a new vision for the engineering profession, which will not have much in common with engineering jobs we know today.

8. Production and additive manufacturing

A paradigm shift in manufacturing with the introduction of 3D printing, and other disruptive production technologies will inevitably trigger a transformation of product design. Manufacturing is on the cusp of being digitally disrupted and what is needed are fresh solutions that comply with the new ideas. While existing software environments are struggling to find ways of adapting their base technology to challenges like additive

manufacturing, Skeleton|CAx™ is based on MAR™ and will be able to deliver such functionalities with comparably low effort.

Today's workflow is old and outdated, and it's based on the traditional linear path: the engineer is doing design while the software documents and analyzes. The 3D-printing workflow doesn't sufficiently take advantage of generative design or other design breakthroughs.

How it will be done tomorrow: Skeleton|CAx™ will be metamorphic and instrumental in this technological leap. It will take a leadership position as a next generation manufacturing tool.

An exciting example is to accelerate prototyping and manufacturing capabilities through a 3D printable "skeletonization" of parts instead of printing full material models. The speed problem in 3D printing is increasingly evident, and any decrease of production time in this field is eagerly sought-for. Printing functional, reduced mechanical parts with adequate structural integrity is a problem that has not been adequately solved up to now. Skeleton|CAx™ will be able to reduce the time taken to print such parts by more than 80% while reducing material input.

Another example is using MAR™ for advanced thermal control of Selective Laser Sintering (SLS). In rapid tooling MAR™ should be useful for optimizing the design of conformal cooling channels. For milling, MAR™ will be a big leap for planning and optimizing 5-axis machining, which is traditionally a difficult field with many challenges.

Summary:

Altogether, there are many indications that a revolution in the CAD and CAE software industries is imminent and much needed. Several of the most salient ones have been mentioned in this article, but there are more reasonable causes for such a metamorphosis.

It comes without saying that a fundamental transformation of the bread and butter engineering software tools will not happen overnight. It takes foresight to understand the need to act and the grit to be a first mover deploying a novel technology. If you consider yourself a leader in the upcoming transformation or not, one thing is for sure: it will pay off and give early adopters a significant competitive edge.

Skeleton|CAx™ allows fast concepts development, detailed design, virtual testing and fast prototyping using additive manufacturing technology in the hands of only one skilled engineer. The most important feature, however, is that it is a modern data driven platform, prepared and well featured for the next revolution of intelligence in engineering software.

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