DIGITAL TWIN DESIGN PROCESS FOR EFFICIENT DEVELOPMENT AND OPERATION OF A CUSTOMIZED ROBOT

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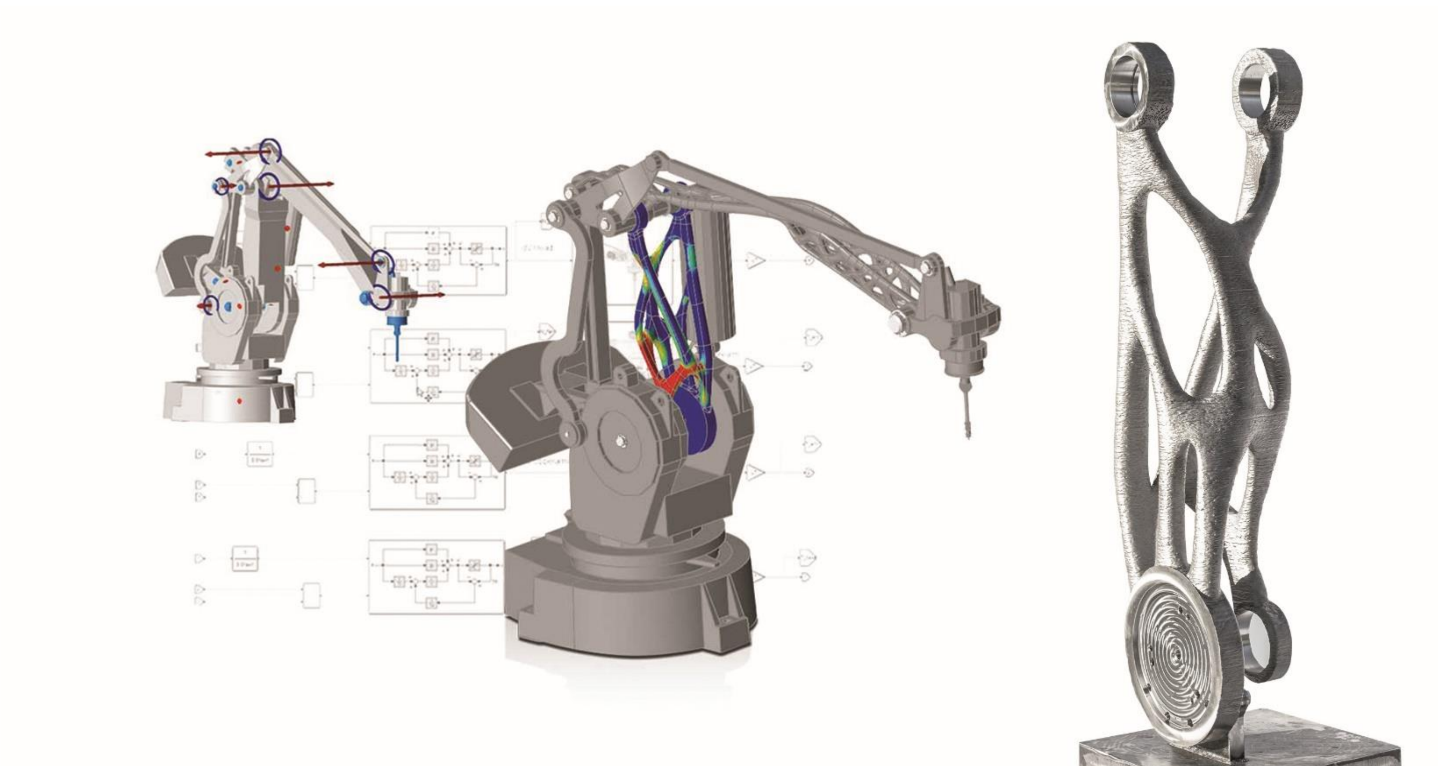

ABB, MX3D and Altair demonstrate how Industry 4.0 will deliver customized manufacturing equipment

As a growing industry with a wide range of application classes, industrial robotics offers a broad array of solutions for individual applications. Nevertheless, there is still a desire for even more customization. Whenever specific needs are identified, these new requirements are intended to optimize the robot's productivity through higher operational precision and custom operating conditions. For some time now, companies have been using digital twins to improve their products and the efficiency of their product development processes. While digital twins, thanks to advanced technologies and modern methods, are becoming increasingly valuable to industry, the way they are used varies significantly from one company to another. Usually the application is tailored to specific objectives, such as reducing maintenance downtime or gaining new insights for future design improvements based on real operating data.

In a joint project MX3D, ABB, and Altair demonstrated how a 3D printed robot can be improved by using a digital twin process to achieve more precise positioning. In addition to customer-specific individualization, the goal of the project was to reduce the implementation costs by using a digital twin and, as a result, arrive at a working system faster and more efficiently.

Creating a digital twin

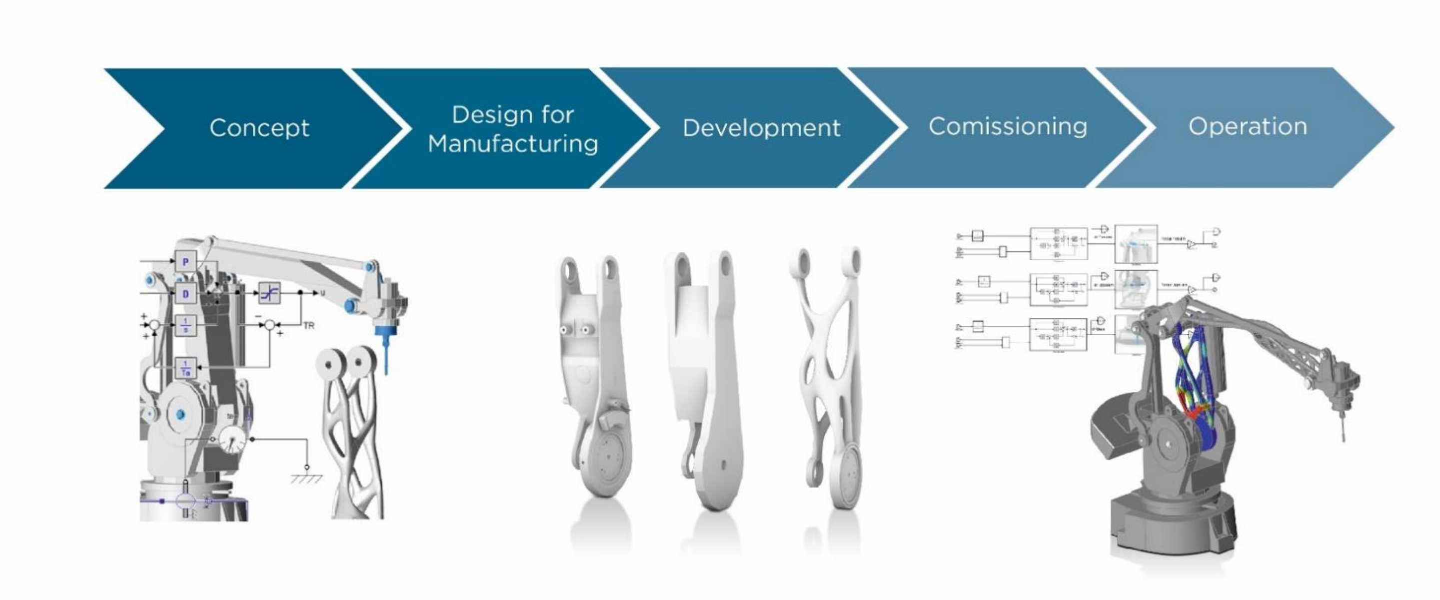

Image Caption Figure 1 – Creating a digital twin: geometric data & trajectory kinematics, controlled system model, individualized arm optimized for production, optimized control parameters

Image Source (MX3D, Altair)

A digital twin is the virtual representation of a product that supports decision-making during development and beyond. It helps to optimize the performance of the finished product and allows important insights to be gained which are useful in the ongoing development of next generation products, following a continuous engineering approach. The digital twin can be simulation or data-driven, each approach has advantages and disadvantages:

- The data-driven twin is accurate, realistic, and specific, but its creation is more expensive and time-consuming. In addition, data-driven twins are not reproducible due to external constraints that cannot be fully controlled.
- The physics-driven twin based on simulation models, on the other hand, is a general representation that is realistic and can be created quickly and cost-effectively. It can also be customized and reproduced at any time.

In order to fully exploit the potential of a digital twin, Altair is pursuing a new approach with a Digital Twin Integration Platform, a combination of data- and simulation-driven twins combining the advantages of both. Simulation-based development, combined with the operation of their own product, opens up countless possibilities to companies, for which various IoT solutions and data analysis can be relied on to help connect these areas.

Virtualization using real data

Beside new product development, system customization and revisions are the most common projects in mechanical engineering. Quite often, engineers face the challenge to map out an entire system without having the required data available.

In the joint ABB, MX3D, and Altair project, a robotic arm was manufactured by a welding based additive manufacturing technique called WAAM (Wire-Arc-Additive-Manufacturing), and structurally optimized per the customer's specific requirements. As a first step, a physics-driven twin was created in order to understand the system's behavior. The data required for the re-design was generated by a 3D scan of the existing system in order to generate a three-dimensional geometry model.

This enabled a multibody dynamics simulation to be performed. The project team worked closely to identify the necessary requirements and load cases of the robot arm. To some extent, parameters from data sheets were used; however, ABB's robot know-how was the critical element. With a system simulation model representing the drives, power electronics and the control system, the functional behavior was modeled. That allowed a holistic system understanding.

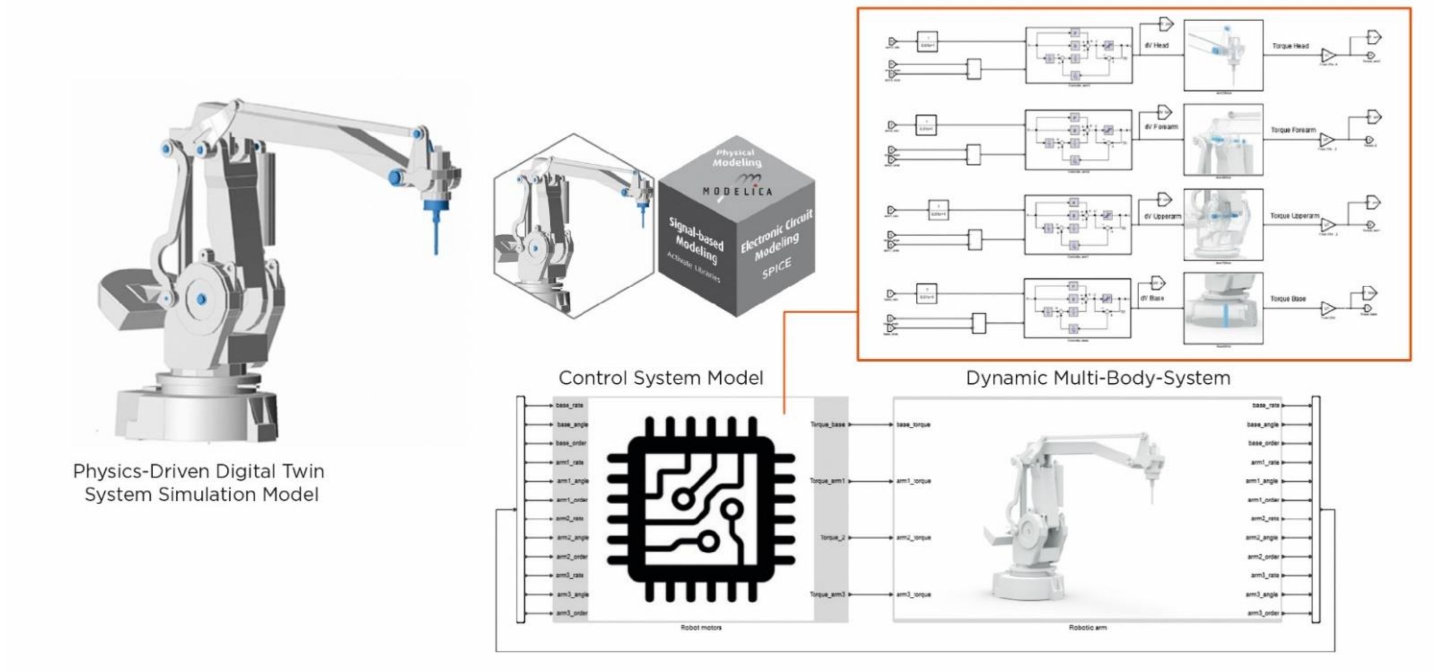

Image Caption Figure 2 – Understanding system behavior using a co-simulation of dynamic MBD model and associated control system
Image Source (Altair)

Holistic representation of the system

To determine the loads, forces, and torques occurring during operation, Altair's Inspire software was used to generate a multi-body simulation model based on the scanned geometric data. Thus, by specifying the trajectory curves, the relevant motion characteristics (rotation angle, rotational speed, and the rotational acceleration) as well as the required actuating torques for each of the three actuators could be determined. The high-level control algorithm as well as the mapping of the electrical control system of the actuators was implemented using the hybrid simulation environment Altair ActivateTM. In that environment actuators, kinematics, and controls were transmitted into a co-simulation to show the domain-specific interactions in an overall system view, enabling the analysis of various control strategies – both in terms of the control concept and its parameters. The goal here was to achieve the highest possible degree of precision or a low deviation between the setpoint and actual state of the current rotation angle of the respective actuators. An integrated optimization algorithm was used to adapt the control parameter to the specific geometric boundary conditions, which resulted in reducing the deviation to a minimum.

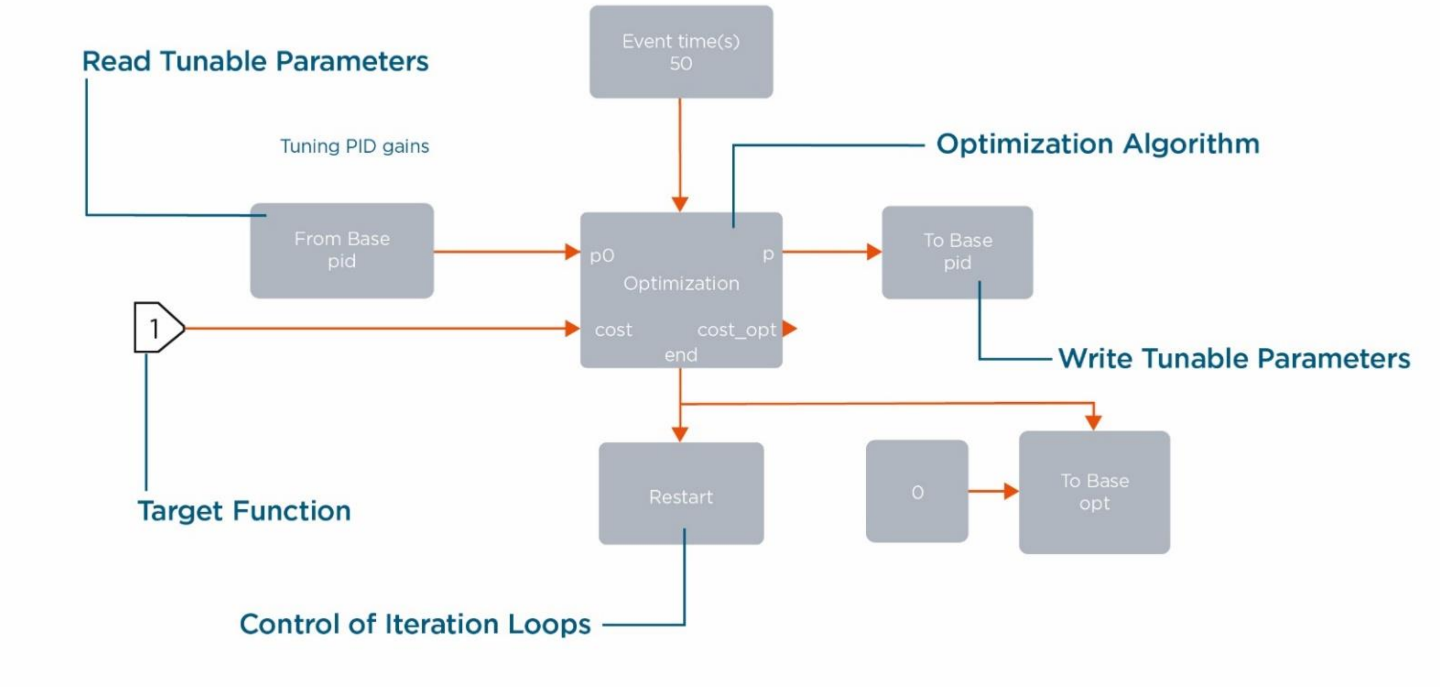

Image Caption Figure 3 – Incorporation of the integrated optimization algorithm for optimizing control parameters to the new geometric constraints

Image Source (Altair)

The optimization method is based on the so-called Trust Region Method, which can change various controls parameters – e.g. the proportional or the differential component – using a derivative-free algorithm. In addition, influences such as the saturation of the voltage applied to the motor and its influence of features such as anti-windup filters can be evaluated.

The Altair Activate system simulation environment enables the combination of signal-based and physical, noncausal modeling methods based on the tool-independent model description language Modelica®. From an engineering point of view, this way of hybrid modeling is an efficient way to implement the physics-driven twin. Due to the direct coupling with the precise geometry mapping by the multi-body system, variance analysis can be conducted in order to ensure at an early stage that the overall system behaves in the desired manner.

Lightweight structures and accelerated commissioning

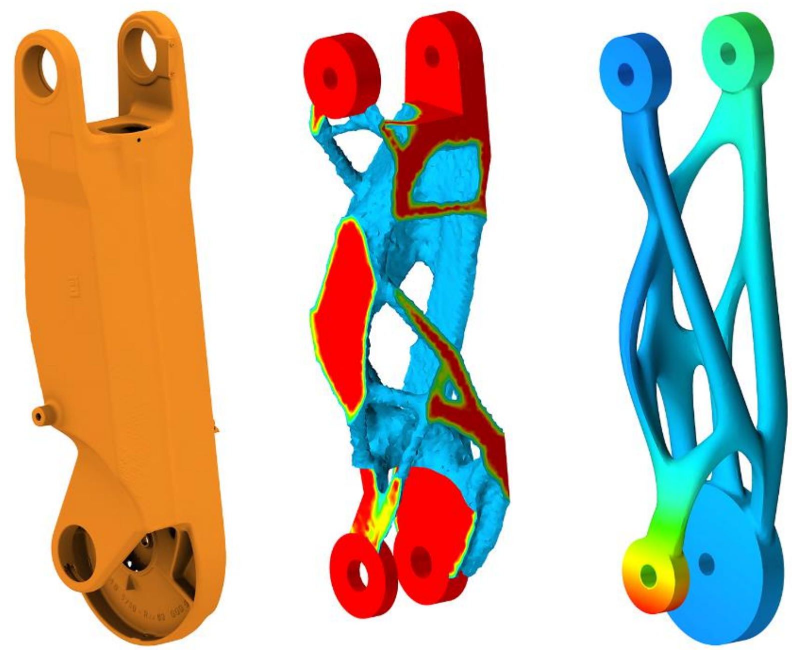

Image Caption Figure 4 – *Original component, topology optimization, realization with manufacturing constraints.*

Image Source (MX3D)

The precise and comprehensive overall system model provides a basis for the loading conditions of a light weighting topology optimization. The new WAAM manufacturable geometry generated using Altair Inspire achieves a weight reduction of over 50% respectively for the lower and upper arms of the robot. Inserting the new lightweight parts into the system simulation realizes a reduction of the required drive torques of the respective electric motors of up to 28% in the peak loads. In a new iteration loop, the control parameters were optimized to the changed geometric constraints (mass, center of gravity).

Subsequently the control parameters were updated, with the simulation achieving optimizations within just a few hours, whereas the same operation with physical testing would take days of iterations.

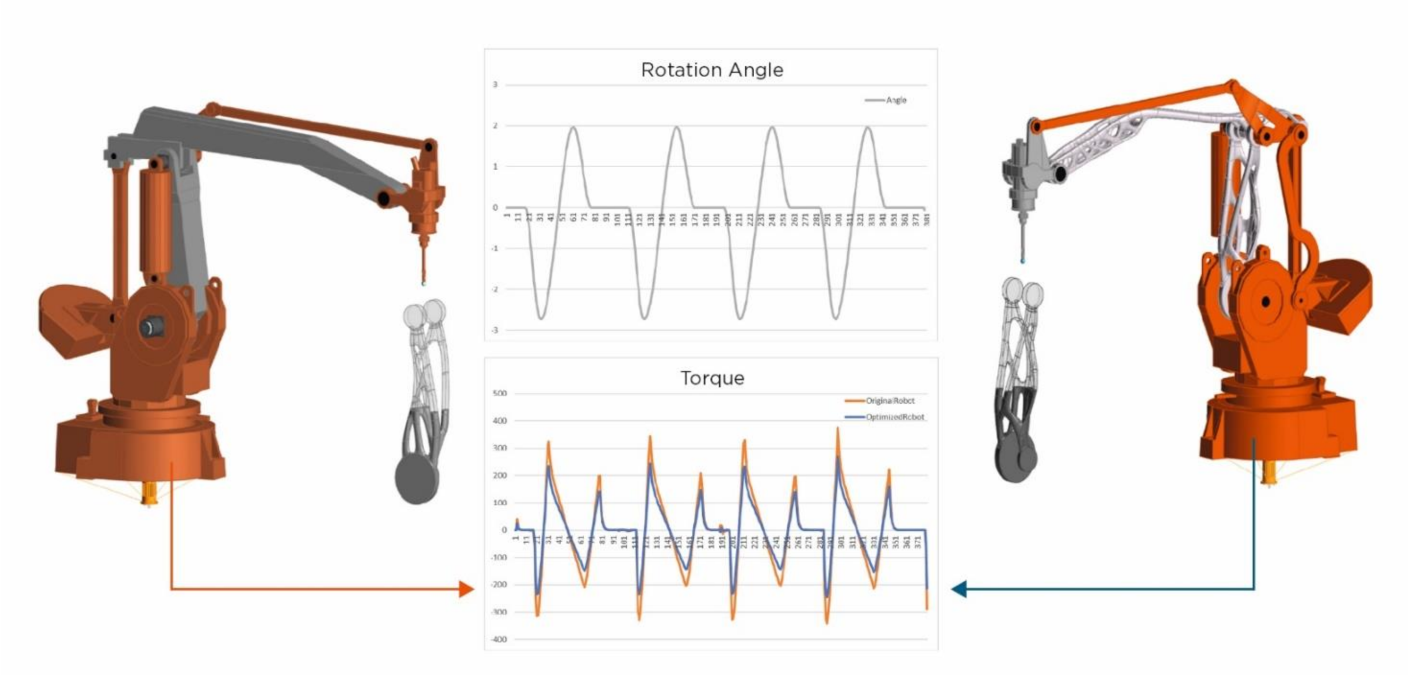

Image Caption Figure 5 – Comparison of the torque curves from the system simulation for the original and the topology-optimized configuration

Image Source (Altair)

The digital twin helps to significantly reduce the time required for commissioning, arriving at a working system faster and more cost-effectively. It is also clear that for a valid simulation model, the combination of closed-loop control and the associated controlled system is essential, because the entire system is required for a new calibration of the control system. It also becomes evident that for a valid simulation model, the combination of control system and associated controlled plant is essential, because the entire system is required for an efficient tuning of the control system parameters.

The value of a digital twin

The results of the project demonstrate increased efficiency through simulation driven optimization, as well as faster operational readiness by virtually commissioning the customized robot. The example of the customized robot project demonstrates how a digital twin can provide the basis for developing customized components and accelerate overall system operation.

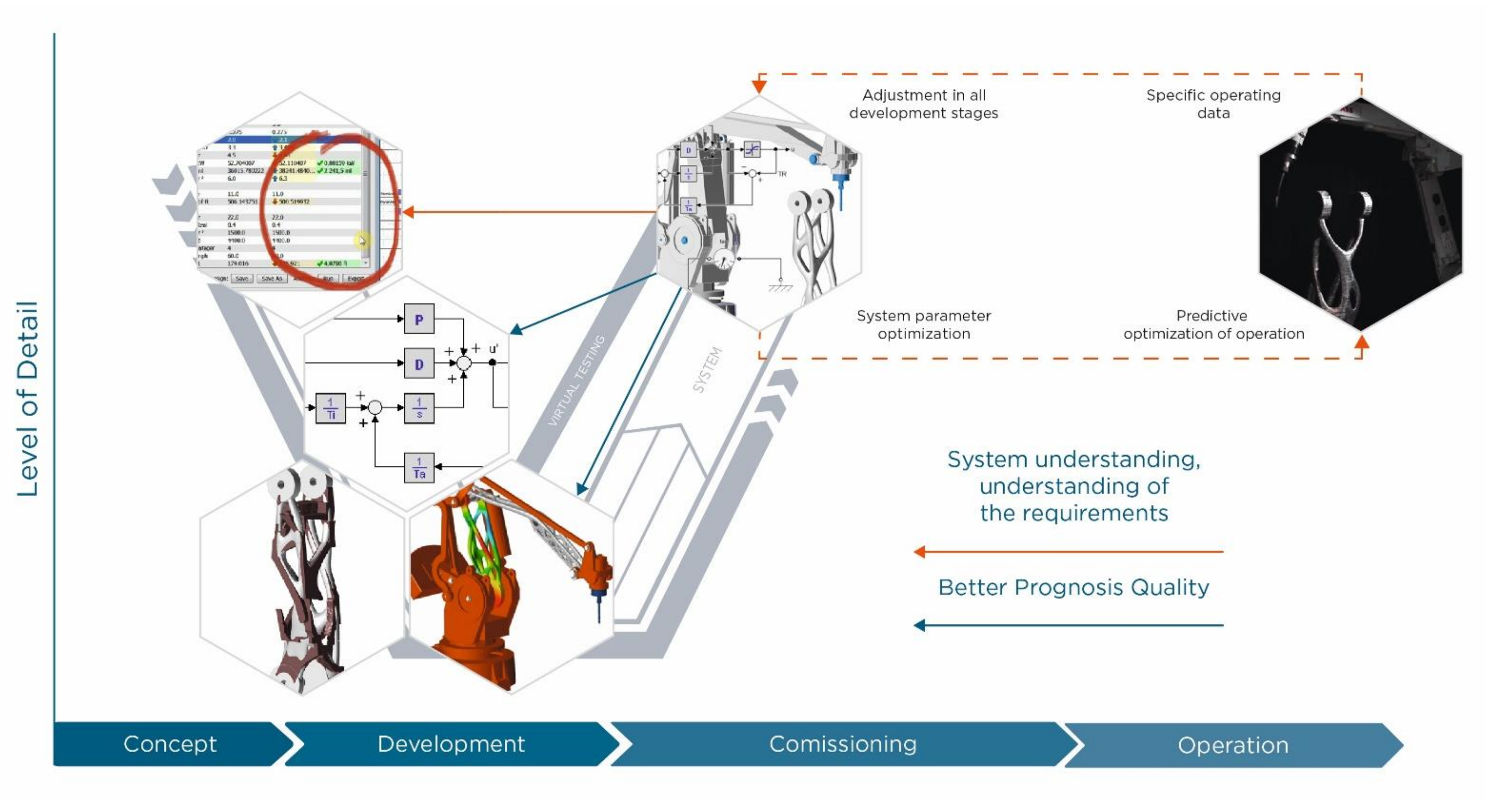

Image Caption Figure 6 – By combining simulation and real data in a closed loop, the greatest possible added value of the digital twin is generated. Extended system understanding leads to more precise requirements and better forecasting quality

Regarding the in-service operation, a digital twin has additional advantages: A physics driven twin can act as an observing instance parallel to the real-time operation, enabling permanent synchronization with the real system. It is possible to determine what needs to be considered in the model in order to iteratively improve the simulation. It is also possible to link the collected operational data of this prototype to the system simulation model via an IoT platform to gain additional insights, such as:

- Calculating additional values that are difficult to record using conventional measurement technology, a virtual sensor, and providing them in a common dashboard
- Comparing ideal and in-service behavior for the detection of ageing phenomena with the aim of "prescriptive" maintenance, this includes not only predicting when, but also what and how maintenance is required

Furthermore, the boundary conditions of the simulation can be adapted to the operational data with the help of the digital twin. In this sense, different instances of the digital twin can be created for a robot to map different installations of the actual robots with varying tasks and user profiles.

Thanks to the virtual approach, the required accuracy of the robot for new boundary conditions could be ensured. The first functional 3D printed prototype type of the robot arm was created without physical tests, it was "Built right first time".

Outlook:

Looking toward the task of bringing the robot back to operation, this approach of virtual parameter optimization promises a considerable efficiency benefit during the commissioning phases for companies that must adapt their control systems. The commissioning can be accelerated and the risk for prolonged deployment gets minimized.

A further outlook of the project is the realization of significant energy saving potentials, when the methodology described above is applied to other robotic applications, or handling and production systems with high dynamics and heavy loads.

Integrated virtual development methods serve the individualization trend.

They help to realize complex batch size 1 products and improve their profitability.

Image Caption Figure 7 – Customized Robot Arm
Image Source (MX3D)

