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Digital Twin the next step of tool integration

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ABSTRACT
Digitalization is massively changing and impacting business in general. It increasingly puts data (better the derived information, knowledge) of the core of business decisions, or build new business around data. This trend is pretty obvious with all the "new", digital business. But this trend is very quickly entering the traditional business. The game changer in all this is the ability, to collect data, link this with other data – to derive insight and knowledge. The data collected reflects real world things and its behaviour. The real world things comprise e.g. human beings, systems, or its production / service environments. With the ongoing real world behaviour, or use the digital representation is continuously growing. The digital representation – ***the Digital Twin*** *– is following its real world "twin". The richer the data is, the more powerful the capabilities are, and the more knowledge can be extracted.*

However this requires an environment, enabling the "management" all this data. It is comes to data management PLM or databased come to peoples mind. With all the effort in order to renew the environment, to be ready for the digital era, the key question is to find a good balance allowing to carry-on with well-established processes, but also to benefit of the new capabilities – which will arrive progressively. In all this the effort needed, to set it up, maintain it – and also allow future evolution of it.

For this purpose this white paper has been written in order to clarify scope and purpose of the digital twin, shape the underlying environment, and see what is needed to get there. It is pretty obvious that digital twin in the wider sense, is nothing new. Many capabilities are in place or emerging – mainly in the field of classical authoring capabilities, e.g. classical modelling & simulation techniques. Other requirements will be new, such as collecting data from the "real world" can inject it into the virtual world. This would allow e.g. to inquire, or compare status of operation and service, to quickly investigate in the "as operated" configuration, based on particular event or failure – with conventional analysis / simulation means, or to benefit on continuous services checking, comparing or learning from data in order to trigger actions from it.

Finally all of this has to be considered in the frame of "PLM". Traditional PLM grew out of PDM, as an essential service of configuration control and share some key backbone data – for management along the lifecycle. Though to a large extend the actual core data was not affected integrated by that. It is a key challenge for the new "Shared Enterprise Service" to master all at the same time, succeed with the integration of core data, benefit of new digitalization service – with openness for the future, and an investment that is in relation from the value in return.

DIGITAL REVOLUTION

It is a widely spread view point, that we are in midst an industrial revolution. In the continuation, of machine power, assembly lines and automation, we are now facing the digital revolution. The discussion is not if, but how quickly this revolution will impact industry. Not only industry, this revolution has the potential to impact significantly also the society. But what makes this evolution a revolution?

To answer this question, a brief look to the "new business" will help. The internet we know today, grew out of the opportunity to connect computers to improve the sharing of information, among different work places. Around this basic connectivity and technologies to share information many services did emerge. From the basic start in the 90s, it grew into service to provide digital access to traditional medias (e.g. music), and today, we rely on many services for purchase, renting, sharing or networking. It entered and changed rapidly how we do business.

One of the big differences for new business, relying on digital services is, that the entire process can be digital recorded. Literally every transaction, every click on a link, leaves a digital trace. With all this information related to purchases, rent, or share - or even the interest in it, can be stored.
This recorded – raw – data, turned out to be a treasure. This data can be used in order to observe, or to find pattern in customer behaviour. The derived insight can be used offer tailored services, for different groups of customers, regions or seasons. With the increased use of analytics, the derived knowledge can help to understand user behaviour to an extent, that future behaviour can be predicted.

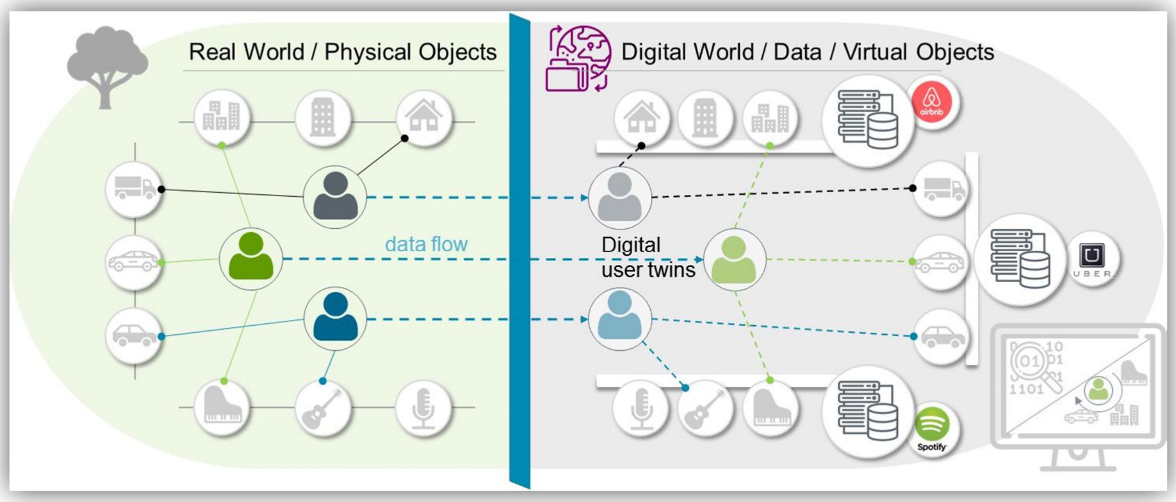

Figure 1 The basic nature of "digital twin"

In Figure 1 this basic relation is illustrated. With the digital economy, the real world items, have a digital reflection – a digital twin. A digital twin in this sense is formed of data, describing its real world item in terms of data properties, basically describing an item, and object properties, capturing the relation to other objects. Basically each purchase, or rental, makes a link between the one renting a car, the rental company and the car – of course with a lot of data more, e.g. locati on or date. Important is in the context, the real world item is first, and each actual transaction is digitally recorded, and the digital twin is continuously fed. Over the time the network of references between objects is growing and growing, and with this growing data, better knowledge can be derived. It is also possible to connect data, where from the recording, no reference is given. For example if someone is often close to a place where a particular football club is playing, there is a certain likelihood that there is a connection. This also explains the trend to connect, or merge different digital service suppliers, to obtain an improved foundation of data.

At the beginning the primary service was share of information, directly followed by sale. Nowadays, many digital services are offered. Common to all those services is that the all have a primary purpose, the e.g. sale, rent or share of media. Those services might be even offered for free. However there is a second, not necessarily obvious business behind, where the data is in the focus. This data might be used to improve the offered services, e.g. to show related items, or personalize the service. However, there might additional use and business cases behind, where the data is quite valuable.

This additional business cases do essentially interfere with the primary use case. In other words the secondary business case can be used to subsidize the primary business case. With this traditional business cases are massively impacted through the backdoor. As a matter of fact, in the last decade many digital services have arrived, where service offer (apartment, taxi, music, video, ..) and consumer is connected through a platform – and the platform is collecting and exploiting the data.

Empowered by this emerging new “gold mine” – the data – new economy is also entering the classical markets. There are many examples where new competitors are entering the field of traditional business. The new competitors approach traditional product development, with the exploitation of “digital business”. The result is in many cases, very interesting products, for an attractive price, with a stunning development life-cycle.

With the arrival of new competitors on the market for cars, aircrafts, spacecraft, the classical industry is massively challenged. There are new competitors on the market, which introduce additional rules in business – “powered by data”. This powered by data, may massively impacting the pricing models, since there are additional parameters to be considered. With this, the classical business models have to be evolved, new ones considered.

This goes along with an ongoing transformation of business, where the whole business process is more and more relying on IT systems. These IT systems introduce new concepts of working together. Concurrent, lean, collaboation are just some of the examples, which are impacting industrial organisations these days. All in common to make the processes, more (cost-) effective, efficient or flexible, to focus more on the main purpose of business.

Last but not least, this also is massively impacting the way of working of individuals. After decades of slowly evolving process, nowadays the way of working is massively impacted. The value proposition of new tools and processes to reduce CNQ, lead time or cost is significant. But also the way of working will be impacted enormous. It is one of the key challenges of this transformation to benefit of the quickly arrving digital services, but at the same time also master to hide the introduced complexity.

This change goes along with the transition from product, to product as a service. Here also data plays a major role, but is obviously also interfered, by the “data as a service. In all the above considerations, data plays a major role, data is in the core of the digital revolution. An efficient, adaptable and flexible way of managing data, together with the timely and tailored offer of access to data will be core to master the digital transformation.

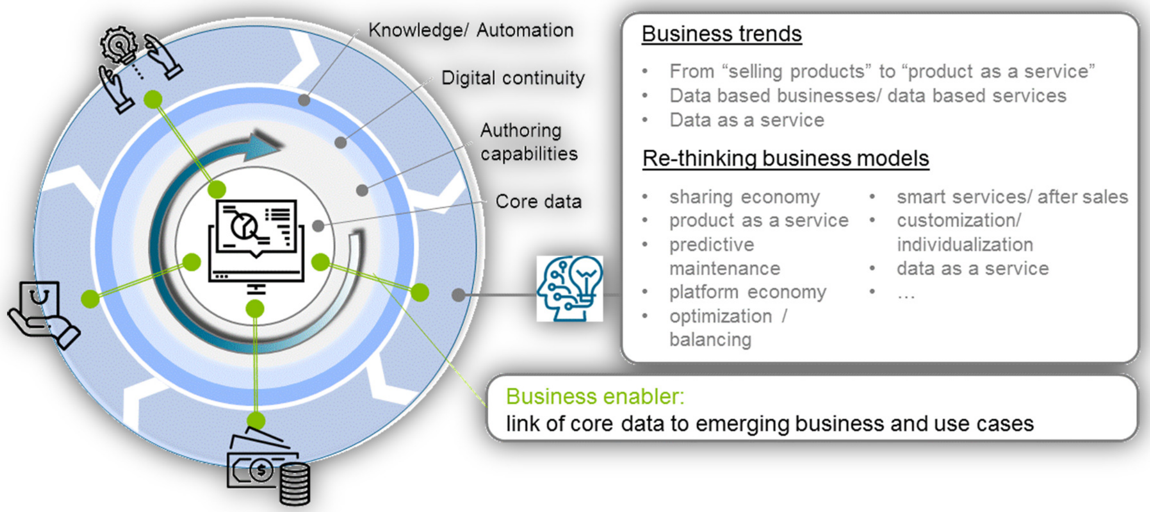

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Figure 2: Data is the core of the business

The big challenge is, how is data “managed” today, and what needs to be done, to evolve the traditional data management such, that the business transformation will be facilitated.

TRANSFORMATION FROM "PLM" – TO SHARED DIGITAL ENTERPRISE SERVICES"

In general PLM is being referred to, if it comes to data management, in product oriented organisations. It ensures the consistent management of data along the life-cycle, from engineering into manufacturing, into service – not to forget the subject of external enterprise with the exchange along the customer supply chain. Consistent management in this context means the consideration of all stakeholders ensuring a correct, complete and up to product data package. The stakeholder involved includes the key business functions, producing the core data engineering, manufacturing and service – but for PLM it is crucial to involve the different transverse functions as e.g. configuration control (including change management), quality or compliance / regulations. With that PLM offers a key shared enterprise function and is the backbone of information, and starting point of all processes.

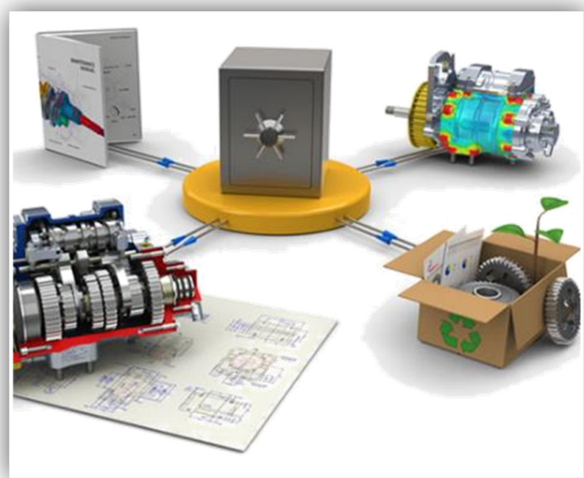

Figure 3 PLM Data Management

PLM systems today grew out of PDM systems – in the core, still many PLM systems are evolved PDM systems. With that PLM systems are quite elaborated to manage configuration of business objects (documents, whole models, result data files), and allow the attachment of further needed meta-data of the different stakeholders – with the associated flow of to ensure reliability of processes. But still in all, for the core functions of PLM systems, looking insight, understand the core data management, is not needed to a large extend. PLM is interested in key principle breakdown structures to manage the information, but the e.g. the diameter of a bolt, or the calibration curve of a parameter, the link between a definition of a data packet, and the I/F where it flows is not necessarily needed.

Still in the discussion, PLM is considered "as the overall environment", this tiny but essential distinction is not made. In the past 10 years attempts have been made to use PLM systems for the detailed data management. With this, use PLM systems to connect the various authoring tools. It is possible, however the costs are significant, and traditional PLM systems will reach its limits.

With digitalization there is an expectation associated, that the environment tomorrow offers additional shared services, which build on top, of the achieved PLM assets, in terms of processes and practices – it might be required to evolve the tools. However in all this the PLM environment tomorrow has to be flexible and adaptable. With the increasing level of integration of the overall environment, also the PLM system underneath, will have much more interfaces. Currently there are many activities in the different domains, to improve their processes; this will also impact also the PLM perimeter.

Right now all efforts are deemed to support the downstream processes, to secure the flow of data from engineering into service. However digitalization will come with various individual flows, in various directions. In particular of interest is the flow in the inverse direction, from the "real world" into the virtual world, but also flows across e.g. different projects.

Right now, driven by commercial constraints, there are in the different domains to "digitalize", even automate processes.

SHARED ENTERPRISE SERVICES SCOPE

The scope of functions, ensuring the consistency (PLM) did consistently grow over the past decades, to meet the expectation of the quickly emerging business demands. And overview is shown in Figure 4 .

With the arrival of PDM systems in the industrial practice, 20-30 year ago, the aspect of configuration control has been addressed and solved. The PDM systems have been evolved in the last 10-15 years, to increasingly answer the needs of "life-management" – nowadays PLM systems. The general concept of PLM has also successfully be transferred, into other domains, e.g. ALM (Application Lifecycle Management), or SLM (Simulation Lifecycle Management). But the core concept is always the same. The core data managed as such, is not affected, there will be meta data attached to ensure, consistency of configuration and formal correctness. For example for SLM this addresses the consistency of CAD models, simulation models, result data, and the derived verdict. Important is also, that with the change from PDM to PLM, there was in many cases an expectation, that the authoring tools will be “connected”, which typically was not the case, or turned out difficult to achieve

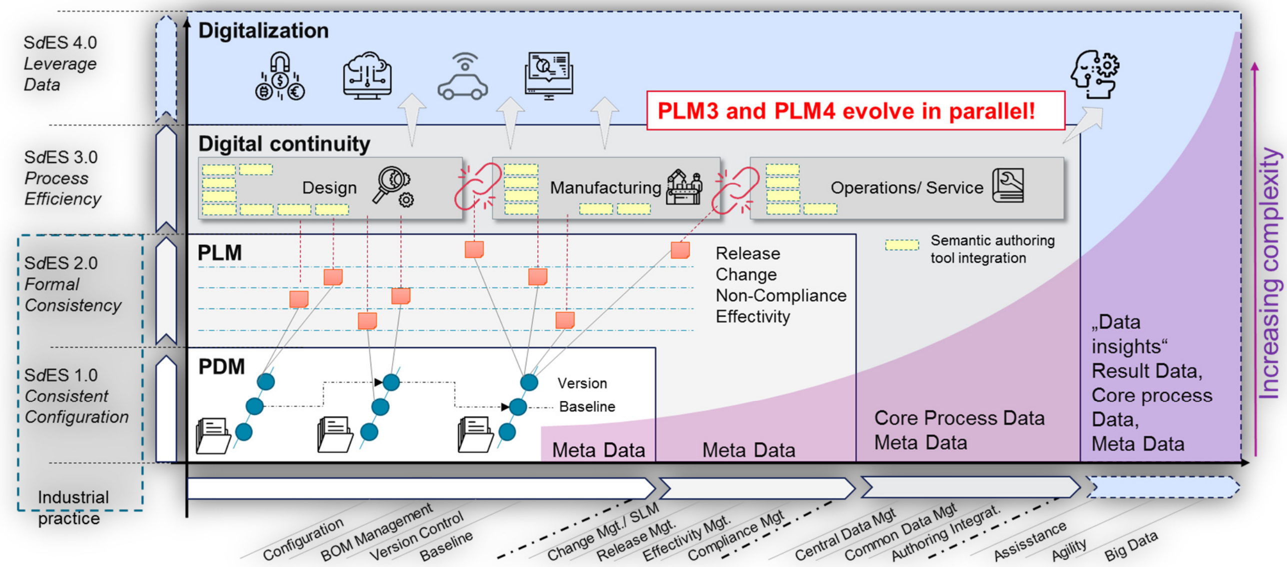

Figure 4 Shared digital Enterprise Services

With that, still right now, in many cases, the practice is that, the authoring tools are in place, supporting the individual processes. The information out of a particular process is provided as document, either written, or generated – from which the information is extracted for the next process.

The need of continuity of data is not new. It is as old as the trend of digitalization as such. Addressing the interoperability between different applications, is a complex topic, and a solution needs to address various constraints, e.g. the good understanding of the managed data, the needed functionality to deal with fine grained data, or the means to extract, but also inject the tools into the authoring tools. This on the technical side, but there are also strategic constraints. Those strategic constraints might include the ability, or aspiration of an organisation to enter the topic – or rather stay back, and subcontract the topic. For some organisations the vendor “lock in” plays a major role. Vendor lock in means that only tools of particular vendors will work in a particular integration platform. Vendor “lock in” is insofar a key topic, as in principle all vendors, where very reluctant to support, more serious approaches for integration.

While the digital continuity across the different authoring systems is not solved, there is a new trend emerging quite quickly from the “new economy”. Here the focus is to obtain insights from data. In the new economy the source of information is obvious, it is the internet – all internet operations produce data. This data is collected and subject for further investigations, in order to derive further knowledge from it. And this knowledge is then leveraged, to improve, or focus business – or to set up new business. This derived knowledge might even lead to new business models. For example warehouses, music/movie platforms,

Still the question remains, to which extend traditional PLM services allow the wide, digital exchange of information. This requires a particular granularity if it comes to the data to be exchanged, and the functionality to e.g. exchange, version and ensure the consistency of data. Quite important however, is also the flexibility to allow continuous improvement of the digital continuity. This is very important, since the knowledge on the fine granular linkage of data cannot be considered as available and fixed. Rather the knowledge on it is growing in business, but it is a transformation process. It is important to recognize, and consider in the decision making on tools, that the knowledge on the data model, cannot be considered as exhaustive and fixed. Rather there will be evolution required, since the data model is depending on the process itself (e.g. connection of process silos, automation in the process), and also on particular architectural choices, requiring different data structures. Flexibility on the digital continuity level is not optional, it is a must.

While traditional PLM is challenged to address the need of digital continuity along the authoring tools, there are additional trends observable around PLM, which also might result in different capabilities and functions. A common denominator of the different aspects, is the trend of "digitalization" – inspired by the new economy. One of the prominent examples, where it was raised, was "Industry 4.0", the future intelligent factory. With the trend of automation, the different elements for the production are already connected. From this it is the next logical step, to proceed, and complete the connection among the different involved systems, make the (gathered) data accessible for decision making – and proceed with exploitation of the gathered data.

Obviously there are several technologies involved in Industry 4.0. One of the key enabler for it, is Internet of Things (IoT). The internet we used to know did connect computers. From the very big ones, to the very small ones, people carry in their pockets. IoT allows to bring "all" devices to the internet. Those devices can be e.g. sensor, for machines, previously connected not at all, or tools, allowing tracking location, operation, and performance.

The trend of digitalization did obviously also impact product itself. All systems today are increasingly equipped with sensors of different types. For exploitation purposes, this data is also recorded. As for all digitalization topics, this data allows to better understand the system, use / operation and its behaviour / failure. There are many use cases with this data, technical and non-technical. For the technical aspects, it might include e.g. improved operation, tailored maintenance or the the personalization of the system according operator habits. On the commercial side, it might include the support of additional services; build knowledge for future systems, or to derive further knowledge with the interference with other data.

In recognition that the gathered data is reflecting the system, its status, its location, its previous operation, its current operation, it is just the next logical step to call this information, derived from operational use, Digital Twin. A digital twin in this context could be any real world item: a system / product in operation, or any item of it, the manufacturing environment, used to build and test, or any of the operators in use.

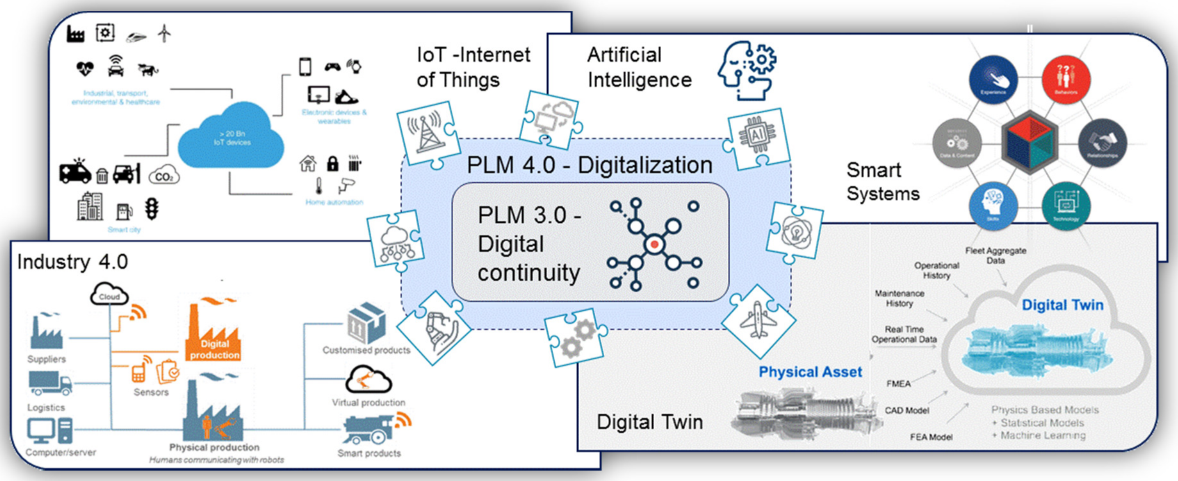

Figure 5: Future trends for PLM

It seems also that digital twin, is the aggregation point of the information collected: IoT, Industry 4.0 or smart system, it all comes down to, what actually is digitally reflected, and this is the digital Twin. From this is not a surprise to see, that digital twin is a major emerging concept, which is currently being discussed in the field of data management or PLM evolution. There are obviously a lot of similarities in the digital twin concepts published, however also some complementary and conflicting aspects. Also there is no direct support of the vendors to do it. For the time being it is commonly agreed that it is the next step, however, not clear, how to realize it.

From what is published the following key findings can be summarized though:

- A digital twin can represent – any – real world item. From very big systems, to very small devices part of it. From the system itself, to the manufacturing environment
- The digital twin is supposed, to provide a clustering of information, in order to obtain a holistic view of information.
- For a given item, there is not only "one" digital twin, rather for technical systems different digital twins have to be considered.
- The are multiple flows needed, to form the digital twin. There is on one hand the field, operation data, which flows in the virtual wold, to feed its digital reflection. But there are specific capabilities needed, for the initial population.

In order to better understand the concept of "digital twin", and consider the implication of the future IT landscape, the Shared *digital* Enterprise Services 4.0 (S*d*ES), a collection and review of internal and external use cases have been performed.

As a starting point the digital twin concept, introduced in Figure 1, has been evolved along the phases of industrial system development. For product development the digital twin is used from the very beginning. Initally with the population of the design of the envisaged system. This is further detailed with the aspects of manufacturing (as planned). Important is, there is no physical twin existing at this stage. Rather the existing capabilites are being used to populate the data forming the digital twin. With the acutal manufacturing the different digital twins come into life, and with that the typical pattern, that the "real twin", is feeding its virtual representation.

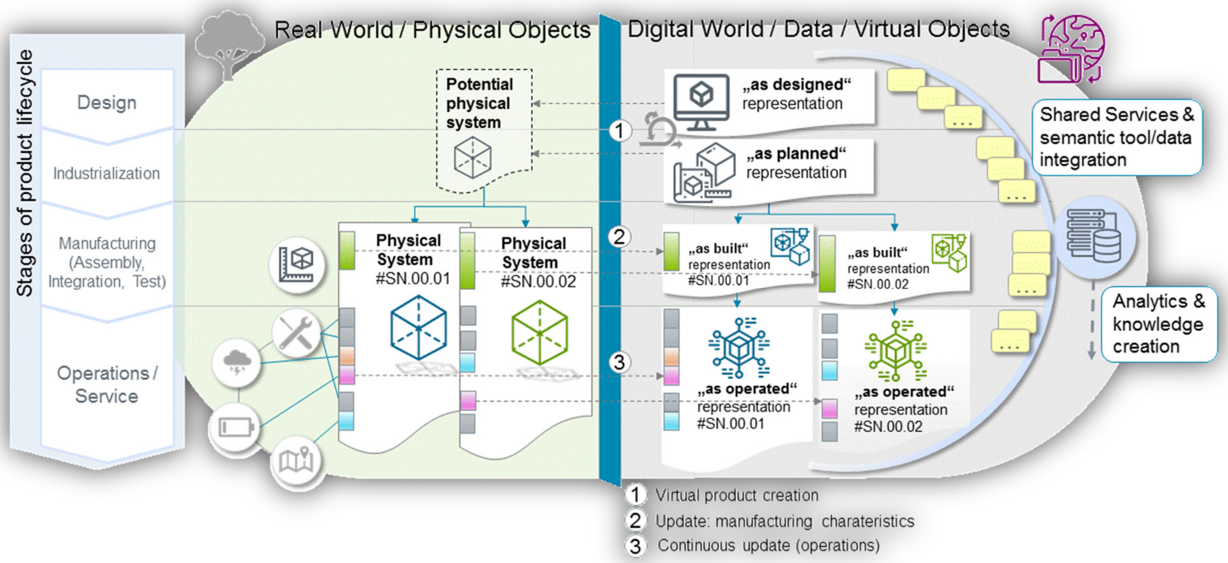

Figure 6: Adaption of the Digital Twin Concept

This evolution of the digital twin concept, has been further evolved, and mapped into the envisaged SdES 4.0. The synthesis of the findings is shown in Figure 7.

The starting point of the system development is the defintion of the Digital Twin in its "as designed" representation. Typically this "as designed" representation is derived from the customer provided requirements. This initial design data, supported with the appropriate analysis activities – forms the first view of the future system. With the consideration of existing platforms, selected suppliers, this preliminary design is further detailed. Significant amount of data is coming from the supplier, which complements the preliminary design with actual data on the equipments. Both the data of the “top-down” derived preliminary design, and the “bottom-up” data provided by the supplier form the system design data. This design data is complemented with the data required to configure analysis tools / simulators and the result of this. All this data together, with potentially derived knowledge from it, form the Digital Twin “as designed”. Needless to mention, that many iterations among the different stakeholders involved are needed to obtain a consistent Digital Twin. Though it is very important to mention, that this Digital Twin, has no “real” counterpart. At this stage in the life-cycle, the “real” twin, does not exist yet. Effectivly this means, that the digital twin, is an assumption, that the Digital Twin “as designed” is representative enough to assume the future appropriate form, fit and function of the “Real” Twin.

For the preparation of the manufacturing the Digital Twin “as designed” will be detailed into the Digital Twin “as planned. For this detailing the design representation will be detailed for manufacturing aspects, the way how the design can be actually produced. At the same time this goes along with the definition of the production means, which are required for the manufacturing Typically this detailing is done per manufacturing discipline, and might require the modification of the system design representation, and requires iterations for the consideration of potentially affected aspects. Typically the update of the system design for manufacturing update comes late, and is quite costly. – so it is a key challenge to anticipate potential constraints, and accommodate those in the initial system design representation. Likewise, to the Digital Twin “as designed”, there is also typically real world counterpart, so this representation is also an assumption.

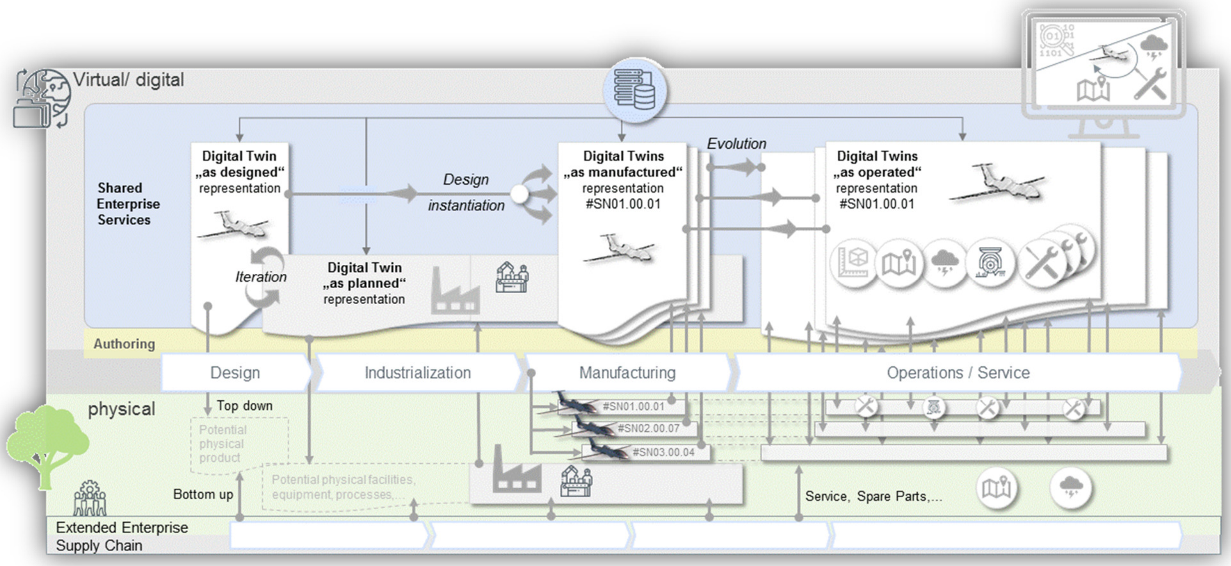

Figure 7: Digital Twin Concept for Products

This real world counterpart will produced in the manufacturing. Here the actual devices, equipment, pre-assembly, and finally the actual system will be produces. From the smallest piece, up to the actual system every item produced is unique. Up to a particular level, all items will be traced with an individual serial number – below that, there is a lot number which can be tracked. In other words in manufacturing the system design will be instantiated, each instance has its own identifier.

This instantiation has quite some consequences on the digital twin representation: Each real world system has its own properties. While in the design representation there are the assumed “designed” properties, now with the production, there are actual properties “as build” – and they will differ. Also there might be some small deviation, modification in the manufacturing which also is different from the Digital Twin “as designed”. As a consequence, with the actual “instantiation of the Digital Twin “as designed, into a real world system, the likewise instantiation has to be done on the virtual side. So in manufacturing the instantiation takes place twice, in real world and in the digital world. This effectively means, that for each system produced, a dedicated footprint in memory for the Digital Twin “as manufactured” has to be created. This disjoint representation for each real world item allows, the capture and representation of the “as manufactured” properties per real physical instance.

This feedback link from "real world" into digital world, is similar to the digital twin in new business. The real world system with its specific properties is driving the digital twin. The sources for this data, which will fed the feedback link is very heterogeneous. This includes data from actual testing, specific measurements e.g. 3-D scans, to data which is provided by the system itself (smart systems). In the same way, the data can be provided the system integrator, or by the supplier.

For the digital twin concept it is important to mention, that along with the manufacturing, a change of control is taking place. During design and industrialization, the digital representation forms the best knowledge on the future system, and with that drives the real system – which does not exist yet, so it is entirely virtual. With the production, the actual real world instantiation the real world takes the control, and drives the properties of the digital twin.

With the manufacturing each Digital Twin "as manufactured" will be updated, with the individual properties. In the simplest case, this is done with a simple update, of properties. But this might also include more complex updates, if specific events require some work around. This might require the "as manufactured" system, will have to be investigated, whether from, fit or function are affected. For this the required capabilities from authoring are used, to investigate in it.

With the start of the operation, the Digital Twin "as manufactured" will be evolved into the Digital Twin " as operated" individually per each system. With every operational use, every MRO activities the digital twin, will be continuously update, to reflect the actual system status and behaviour. This will also include specific events in operation.

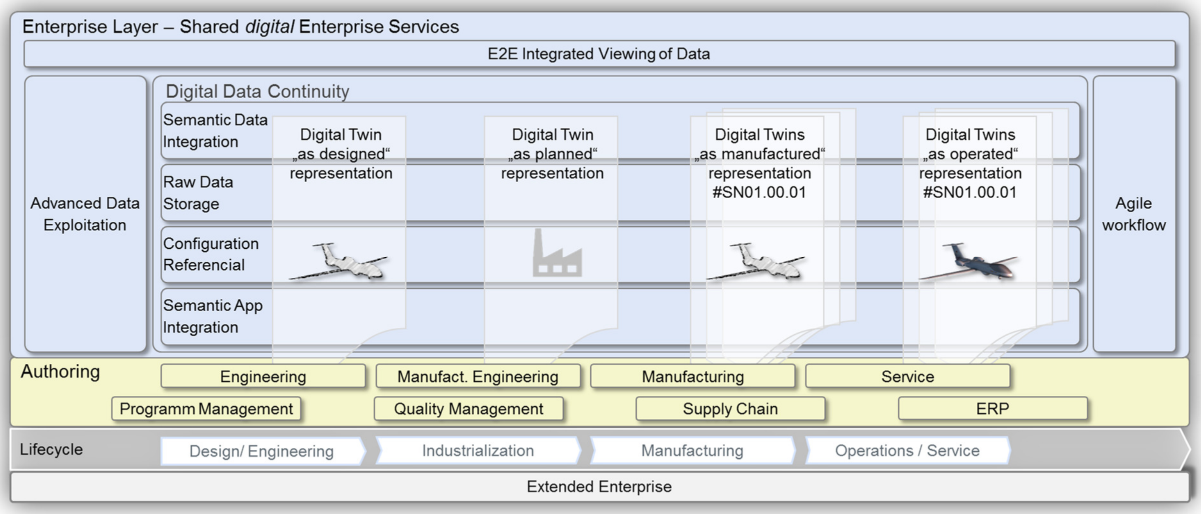

Figure 8: Updated Reference capabilities

CONCLUSION

For realizing the digital twin concept, will require the next level of tool integration. This will consist of succeeding with the authoring tool integration, across the whole life-cycle – relying on the existing PLM backbone as configuration control. This has to be complemented with the capabilities from "digitalization", allowing gathering data throughout the entire life-cycle, simulation / analysis result, testing result, and from operation. This data, can be actually update, the design representation, with respect to actual real world properties, behavior and anomalies. This requires however, that each manufactured system has its own dedicate area in the overall data management framework. One key topic, to keep in mind however is, to keep an eye on usability aspect.