DIGITAL TWIN ENABLING TECHNOLOGY CATALOGUE

Deliverable D1.1

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1.0	27-05-2021	Final	Ready for submission

[1] Integers correspond to submitted versions

EXECUTIVE SUMMARY

Digital twins are by nature broad in scope, and thus encompass a wide range of technologies, from the traditional computer aided technologies (CAx) to advanced computational hardware and also more emerging technologies such as the (industrial) internet of things and deep learning. In order for SMEs to get the most out of their Digital Twin implementations, it is important that these technologies are made available and are presented to them in a way that is understandable and relevant to their business.

In this deliverable, we catalogue a number of Digital Twin technologies that are provided by the Change2Twin consortium. The catalogue is the starting point for a taxonomy of Digital Twin solutions, which is ongoing work in Task 1.4 of Change2Twin. We label the catalogue items according to the nine organisational and technological barriers identified in D1.1 and show that the Change2Twin offerings cover all these barriers, at least to some extent. The initial catalogue also has a good coverage in terms of the types of technologies offered, but nevertheless can benefit from including offerings from external providers in the future.

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1 DOCUMENT SCOPE

The introduction of Digital Twins in small and medium sized enterprises (SME) depends on the availability of a wide array of enabling technologies. This report describes an initial version of the Change2Twin enabling technology catalogue and discusses the wider context in terms of the marketplace, and how the planned activities will assist in making the technologies accessible and findable to Digital Innovation Hubs (DIHs) and SMEs.

This work builds on the barriers described in Deliverable 1.1, by tagging each of the technologies according to the barrier(s) it addresses.

According to the Grant Agreement, this report will be input to the marketplace with respect to enabling digital technologies and will prioritise resources for augmentation of selected partner technologies.

2 INTRODUCTION

Emphasising the importance of having a common understanding of Digital Twin (DT) from the Change2Twin *Deliverable 1.1: Digital Twin Barriers*, we briefly recapitulate the conceptual frame supported by the definitions: *A Digital Twin is a digital representation of an artefact, process or service that is sufficiently accurate that it can be the basis for decisions. This digital replica and the real world are often connected by streams of data.*

Change2Twin addresses Digital Twins of artefacts, processes and services associated with manufacturing. In more complex cases, the solution itself is dynamic and involves combining different models, information sources and business processes and purposes, making it a cross-disciplinary challenge.

Complexity increases when the Digital Twin becomes a part of the system it supports. Subsequently, it has its own lifecycle management needs concurrent to that of its real-world counterpart, sometimes called the Physical Twin. The foundation for having an effective and efficient Digital Twin solution that SME companies can adopt, relies on a clear and common understanding of what the Digital Twin is, its capacity for creating value, and how to manage it in the context of an operational system and business process in the Smart Industry setting.

2.1 STORYLINE

To understand the value of technologies that are considered as enabling Digital Twinning for manufacturing SMEs, we need a clear perspective of the use case scenario.

We recognise that there are various Digital Twin use cases that can arise over time as flexibility in manufacturing is achieved, participants are better informed and more familiar with the ecosystem, and new uses and value are explored. However, here we describe the foundational storyline as the original concept in the Change2Twin project. Minor additions are made for completeness and in anticipation of aspects that are arguably essential to completing the picture.

The following figure shows the original concept of the end-to-end service provided by the Digital Innovation Hub (DIH) to the SME using the Marketplace that provides enabling technologies. It is extended to show how the Technology (Tech) provider is involved in making enabling technologies available and accessible through the marketplace. Moreover, the figure mentions the simple steps of engagement for successfully supporting the SME.

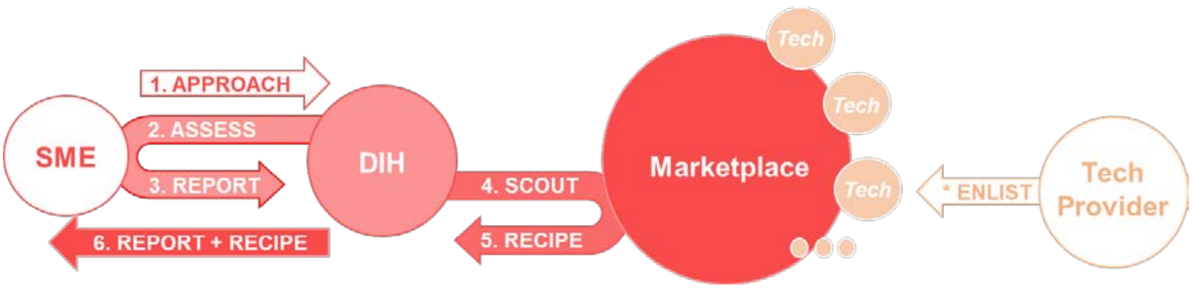

FIGURE 1: HOW SMES, DIHS, AND TECH PROVIDERS INTERACT WITH THE MARKETPLACE

The participants in this scenario are the SME, DIH, Marketplace and Tech provider. Here we have one entry point into this scenario, where the SME approaches the DIH for support. From the perspective of the DIH, the steps are as follows:

1. DIH is approached by the SME for support.

2. DIH assesses the situation of the SME, with the SME. This can be done, for example, by completing the Change2Twin COMPASS assessment and readiness tools.
3. DIH and SME complete the report as to which Digital Twinning purposes are more suitable for the SMEs, with an instruction and agreement as to which should be pursued.
4. DIH assists the SME by scouting the Marketplace in search of enabling technologies suitable for the selected purposes by the SME.
5. The enabling technologies are provided as a recipe to the DIH by the Marketplace.
6. DIH provides the matching recipe to the report with recommendations of enabling technologies, the associated Tech providers, and information about developing and implementing a workable Digital Twin for their designated purpose.

In addition, and in parallel to these steps, the Tech provider is responsible to enlist their enabling technology in the Marketplace, to make it findable by the DIH, and to make it accessible by the SME. It is crucial then that the information is up-to-date, especially with regards to technology revisions or fixes, and changes to Tech provider contact and operating details. To ensure that the DIH activity can deliver the expected value to the SME, it is also crucial that the enlisting is done according to an effective search mechanism built into the Marketplace.

The search mechanism needs to consider the storyline, in that assumptions about the *a priori* knowledge and the frame of mind of the DIH agent will determine how findable technologies are, especially as the Marketplace grows in size and popularity. E.g., if we assume that the SME has been informed of the TNO 7-step method, used as a basis for the Digital Twin readiness assessment, then the jargon and reasoning about the enabling technologies will be specific to this frame of mind. And if the SME or DIH has a very specific criterium due to having a technology expert asking the question, then the question will be more specific.

As we then relax this storyline to allow flexibility of this process, the entry point may not be as Step 1 suggests. We may have the SME accessing the Marketplace directly. However, for the sake of clarity and usability, the focus of this report is only on the original concept with the Tech provider addition described.

An important note is that the enabling technologies listed in this catalogue are not exclusively provided by the Marketplace. e.g., the COMPASS and readiness assessment tools are not necessarily enlisted in the Marketplace. However, this could be easily done, but as the current storyline describes, the Tech provider would be the DIH itself. This natural extension to the scenario can be made once the flexibility of this ecosystem is encouraged and the storyline elaborated.

2.2 MARKETPLACE

The marketplace consists of a collection of marketplace items, which are divided into two categories: *innovation items* and *offerings*. Innovation items are considered to be at a technology readiness level (TRL) of between 4 and 7 (ec.europa.eu, 2014). TRL 4 is described as "technology validated in lab", whereas TRL 7 is described as "system prototype demonstration in operational environment". Offerings, on the other hand, are items that are considered to be at a TRL of either 8 or 9; that is, either "system complete and qualified" or "actual system proven in operational environment" respectively.

The marketplace includes items that differ in nature, including:

- consulting services,
- information,
- software,
- hardware, or
- complete Digital Twin solutions.

In terms of defining the marketplace items we distinguish between two different concepts: *description* and *context*. The description involves all the fields related to an item that are fixed, such as the name of the item, a description, the owner (both provider organization and contact person) and item logo. It may also include information such as TRL and licencing details. The descriptions are specified by the providers themselves. The *context* of an item is a way to describe the item in order to make it findable and accessible within the marketplace. The context of the items will be defined by the project partners during the ongoing activities in WP1.

The initial work in populating the marketplace has been done by collecting information about the Change2Twin consortium technologies with contributions from WP1, WP2, WP3 and WP6. It has focussed on the collection of item *descriptions*. The work on defining item *context* is currently in its early stages. An outline of the methodology used to define the context (or taxonomy) is provided in the following subsection.

It should be noted that the population of the marketplace is an ongoing process and will continue throughout the project, to eventually include technologies from external providers. In this sense, the description of the items in this deliverable is to be regarded as a snapshot of the initial version of the marketplace.

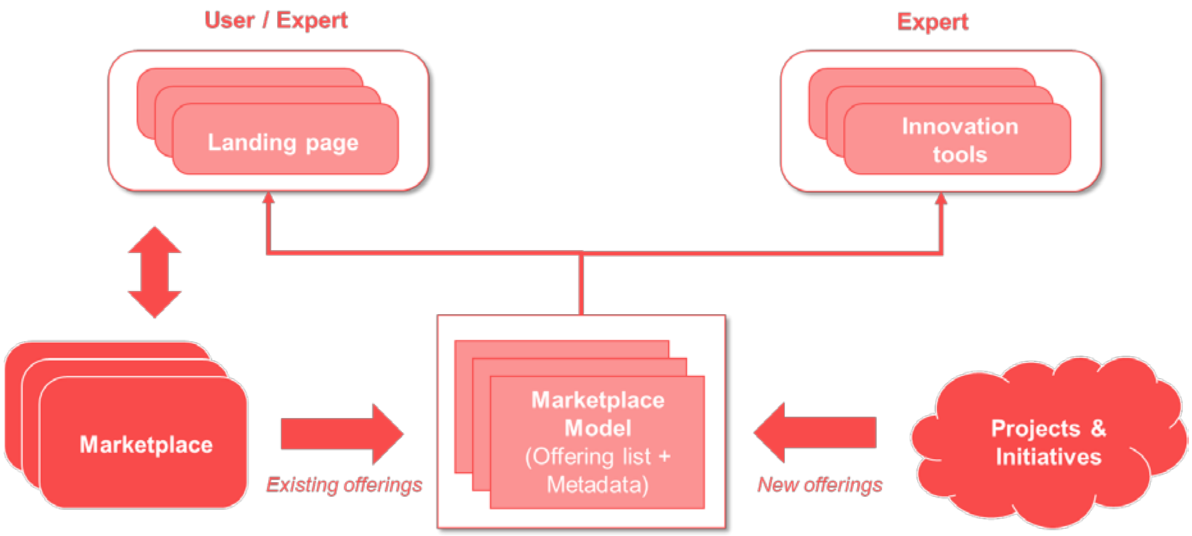

FIGURE 2: HOW THE MARKETPLACE RELATES TO PROJECT AND USERS

2.3 TAXONOMY AND END USER ACCESS

In the presentation of the storyline, above, we highlighted that it must be easy to discover the offerings that contribute to Digital Twin implementations. The catalogue that we establish in this document needs to support this essential requirement independent of the type of organization or person who is searching for a solution. Each offering needs to include a set of metadata or tags that enables it to be found by potential users. The following two aspects are of importance:

a) Which metadata characterise an enabling technology item and are DIHs and SMEs familiar with these terms?
b) How will the marketplace portal help the user to find the best solution to his/her problem?

While a) is of importance in WP1, the actual implementation of user interaction with the marketplace is part of WP2. The metadata that describe functionality and applicability of a technology item are above referred to as the *context* of that item; the context reflects its role in the Digital Twin. Digital Twins are heterogeneous systems consisting of a multitude of components all of which may be regarded as enabling technology items. Task 1.4 in Change2Twin will provide context keywords that characterise “enabling Digital Twin technologies in a way suitable for DIHs in their dialogue with SMEs" (cited from the Grant Agreement). We refer to the collection of context keywords as a Digital Twin taxonomy; it will provide input as to which metadata should be used to characterise a technology item. Some of the intermediate results of this work are collected in this section.

To date, many Digital Twin applications have been successfully implemented in different domains ranging from manufacturing (F. Tao, 2019), logistics (H. Haße, 2019) to smart cities (G. White, 2021) etc. However, currently there is no common understanding of the term Digital Twin and, in this respect, a taxonomy could help provide a valuable contribution to fill the gap, demarcating the concept of Digital Twin (C. Cimino, 2019).

In this context, the authors in (M. Enders, 2019) provide a classification of the individual application areas of Digital Twins. As part of a comprehensive literature review, they develop a taxonomy for classifying the domains of Digital Twin applications, stressing the importance, and prior lack of consideration of Digital Twins in Information Systems research. Building on this, the authors of (H. Valk & H. Haße, 2020) undertake a structured literature review and propose an empirical, multi-dimensional taxonomy of Digital Twin solutions focusing on technical and functional characteristics of the technological solution. As an add-on, the proposal allows for the classification of existing Industry 4.0 standards enabling a particular characteristic.

In Change2Twin our goal is to provide a comprehensive taxonomy encompassing both technical and non-technical aspects of the technology. The objective is to identify common dimensions - entry points in the marketplace - used to describe and classify the technology, facilitating the search of Digital Twin enabling technologies. This activity contributes to on-going efforts in Change2Twin, aiming to design a "journey" for end users in the marketplace, lowering the barrier of entry to Digital Twin technology.

While there are multiple ways to tackle this issue, our exercise is grounded and started from the descriptions of Digital Twin enabling technologies as provided by the consortium partners. This allows us to identify common characteristics, grouping the technologies and relevant characteristics, inferring the dimensions of the taxonomy. In the following, we provide a preliminary overview on two such technical dimensions, namely (i) Building Blocks and (ii) Interoperability. We emphasise that this is an on-going activity, and the following dimensions of the taxonomy may be subject to change. In the upcoming deliverables the study will be further refined and enhanced to also encompass the classification of the enabling technologies provided by the consortium.

2.3.1 Building block dimension

Figure 3, shows the different axes of this dimension, starting with the infrastructure components up to a Management and Control software solution tasked with managing the Digital Twin fabric, both software and hardware, ensuring its operational correctness. The Data Link layer comprises several elements ranging from

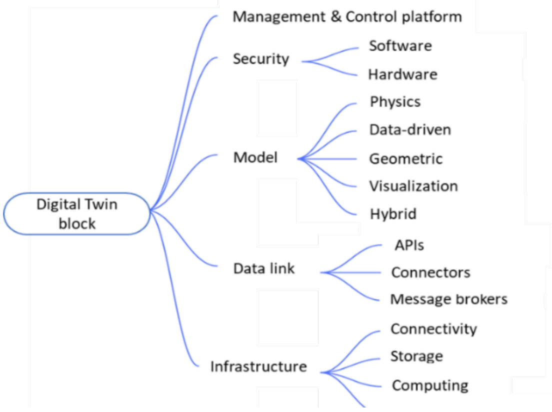

FIGURE 3: DIGITAL TWIN BLOCK DIAGRAM

APIs used to communicate data from/to the Digital Twin, connectors used to extract and fetch data from/to the industrial shopfloor, and message middleware solutions conveying data between interested endpoints. The modelling axis is one core component of the Digital Twin technology and different approaches are possible depending on the context and application domain. Concluding, security is an additional important building block encompassing both software and hardware solutions.

2.3.2 Interoperability block dimension

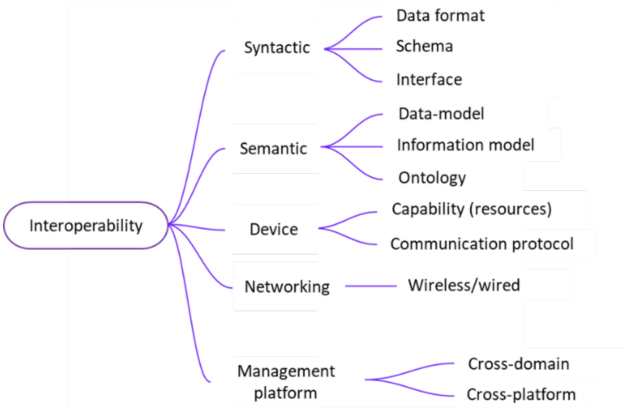

FIGURE 4: INTEROPERABILITY DIAGRAM

Interoperability between industrial platforms, and more generally IIoT technology is of paramount importance, enabling a seamless resource and information sharing between different industrial vendors. To this end, efforts by academia, industry, and standardization bodies have emerged to help address interoperability i.e., the ability for industrial platforms from different vendors to work together and integrate at different layers. The interoperability dimension can be handled from different perspectives such as device interoperability (e.g., ability to integrate heterogeneous devices into any industrial platform), networking interoperability (e.g., seamless message exchange between systems through different networks for end-to-end communication), syntactic interoperability (e.g., interoperation of the format as well as the data structure used in any information exchange), semantic interoperability, and platform interoperability, see Figure 4.

2.4 TECHNOLOGIES NEEDED FOR DIGITAL TWIN IMPLEMENTATION

For the sake of ensuring the completeness of the catalogue, it is of interest to review the existing literature to detail which types of technologies are commonly required for Digital Twin implementations. This will help clarify any gaps in the marketplace that could eventually be filled by external solution providers or by development of existing partner technologies. This categorization may in future be merged with the taxonomy presented above but can for the sake of this deliverable be considered independent of the taxonomy.

There exist several different review articles detailing the types of enabling technologies that are generally encountered in Digital Twin implementations (Fuller, 2020), (Rasheed, San, & Kvamsdal, 2019), (Kritzinger, et al., 2018). In this section we will briefly mention some of the most relevant. The following categorization is inspired by (Rasheed, San, & Kvamsdal, 2019), however, in our summary we also include one additional category on data management and merge the categories on data-driven modelling and big data cybernetics:

- Physics-based modelling
- Data-driven modelling & big data cybernetics
- Infrastructure and platforms
- Human-machine interface

- Data management

It should be noted that Digital Twin is an evolving concept and could in the future come to include other technologies, especially as new ones mature. However, the following can be considered a collection of some of the most important current aspects of Digital Twin implementations.

2.4.1 Physics-based modelling

Digital twinning often begins with a modelling activity. Indeed, many SMEs already have models of their products available in one form or another, which can be an ideal starting point for Digital Twin implementations. In cases where the physical asset does not already have a corresponding 3D model, reverse engineering (RE) can be useful. RE involves converting scans of a physical object (e.g., laser scans) back to a geometric model. Computer aided design (CAD) software is often required both when modelling the object from scratch or via reverse engineering.

Often the interesting aspects of a Digital Twin need to model how the object relates to its environment, for example, modelling how temperatures or stresses vary throughout the object under different conditions. This requires solving mathematical equations related to the physical properties of the model. Standard CAD-type models are, in most cases, not suitable for this as they typically only represent the boundary of an object and do not explicitly represent its interior. The most common approach for making a model suitable for physical simulations is using finite element meshing. This functionality is available in computer aided engineering (CAE) software but is often subject to significant manual intervention. A more modern approach that attempts to unify the design and engineering representations is known as isogeometric analysis (IGA). IGA can be of particular interest in the Digital Twin context as a single representation can be used for multiple purposes.

In the case of twinning manufacturing processes, computer aided manufacturing (CAM) data is also of interest. This is data that comes from CAM software and can include information such as computer numerical control (CNC) information and machine parameters, or in the case of additive processes, slice information and scan vectors.

2.4.2 Data-driven modelling and big data cybernetics

An alternative to modelling physical processes via known mathematical models is to make measurements of actual conditions on the physical twin and apply data-driven modelling methods. One advantage of data-driven modelling is that the data can encompass both known and unknown physics, thus providing a more complete account of the physical processes. However, in order to model physical processes in this way, huge amounts of data are typically required. The internet of things (IoT) is one potential source for such data. The IoT consists of a web of interconnected sensors, instruments and other devices that can gather large amounts of data and continuously stream that data for further processing. In the manufacturing context the industrial internet of things (IIoT) is often more pertinent, where requirements with respect to accuracy and quality of the sensor readings and security of the produced data is typically much higher than in the consumer market.

While the sensor readings from IIoT devices can be interesting in and of themselves, in the Digital Twin context they typically produce too much data to be analysed manually. Recent advances in artificial intelligence have opened new possibilities for generating deeper insights into large amounts of data. While artificial intelligence encompasses a wide variety of computational methods, most of the recent advances have been in machine learning, or more precisely, deep learning. It is now computationally feasible to model high dimensional and highly non-linear phenomena using deep neural networks (DNNs), as is often required in data-driven approaches.

Machine learning is often categorized into *supervised learning*, *unsupervised learning*, and *reinforcement learning*. Supervised learning can be particularly useful when wanting to embed existing human knowledge in the Digital Twin, as it is based on modelling pairs of input data and labels. The labelling can either be done manually, representing human knowledge, or computationally, as for example in the case of approximating simulation results with DNNs. The result of training a supervised learning model is that the model can then infer labels for new input data, entirely automatically. Unsupervised learning, on the other hand, does not require labelled data. Unsupervised approaches such as clustering can be used to gain new insights on the nature of the data, or to detect anomalies in large bodies of data. Reinforcement learning (RL) is yet another approach where a machine learning model (which we call the agent) learns to take actions based on observations of its environment. The environment may, for example, correspond to the readings from IIoT devices. The agent is then rewarded according to some desired behaviour and learns by trial and error over time to maximise its reward. RL is particularly useful in the context of planning and controlling Digital Twins.

Hybrid modelling approaches aim to combine the physical modelling and data-driven approaches. Hybrid analytics often provides a more flexible and robust approach and has the advantage of preserving the known physics of the model while also dealing with the low quality or quantity of data that plagues data-driven approaches. Nevertheless, the combination is often more complex and requires a more tailored approach.

Big data cybernetics is a term used to describe the application of the above approaches in a cybernetics context (Rasheed, San, & Kvamsdal, 2019). Cybernetics is a cross-disciplinary field where the aim is to steer an arbitrary system towards a certain reference point, by exploiting feedback from chosen actions in order to determine further actions. Some aspects that can be considered enablers for big data cybernetics include:

- Data assimilation, where data is processed and filtered, and
- Reduced order modelling (ROM), where complex high-dimensional problems are approximated by lower dimensional problems.

2.4.3 Infrastructure and platforms

All the models and data involved in a Digital Twin typically require significant computational resources when they are to be processed. One of the major technologies that enables processing in a big data context is cloud computing. Cloud computing offers computational resources from a remote location over a network. One of the key benefits of cloud computing is that it offers flexible scalability of compute resources without SMEs having to invest in their own infrastructure, which can be useful considering the different computational requirements at different stages of Digital Twin implementations (e.g., training DNNs). Cloud computing can be contrasted with edge computing which aims to bring computational resources closer to the source of the data. A major benefit of edge computing is that the data can be processed without ever having to leave the local network, solving issues with latency by avoiding transferring huge amounts of data. An additional benefit of edge computing is that it is easier to ensure the data remains private and secure. However, it often requires a significant investment in local compute hardware. Fog computing automatically combines edge and cloud resources to optimize the processing of the data. Similarly to cloud computing, high performance computing (HPC) is also typically offered from a remote location but in contrast to cloud computing, it targets solving hugely complex problems that cannot typically be solved by a single consumer-grade computer. HPC jobs are normally subject to a queuing system, where jobs are submitted and await the availability of the computational resources.

The IIoT devices that have been discussed previously can also be considered part of the infrastructure of a Digital Twin. Availability of high-speed wireless networks has resulted in it being much easier to integrate IIoT devices that can monitor manufacturing processes. While wired networks have advantages in terms of reliability, they are often more expensive to maintain and less flexible for subsequent augmentation with new devices. The emerging technology of 5G, which brings ultra-low latency together with higher speeds, increased reliability and increased availability will also be a driver for Digital Twin implementations. 5G also addresses issues with the limited number of devices that can share the radio frequency by using a wider bandwidth.

There exist several services that aim to ease the implementation of (I)IoT technologies and Digital Twin as a whole, by offering complete solutions. Such offerings often include aspects of Software-as-a-Service (SaaS) and Platform-as-a-Service (PaaS) covering multiple elements of cloud and edge computing, and relevant communication protocols.

2.4.4 Human machine interface

Digital Twin brings excellent possibilities to exploit advanced visualization methods such as augmented reality (AR) and virtual reality (VR). If a Digital Twin of a physical asset is available, it makes sense, in many settings, to superimpose data extracted from the Digital Twin onto the physical twin. This can be done in a variety of ways, from using AR headsets or other screens to directly projecting the information onto the physical twin. AR and VR provide visual feedback to the user, but there is also the need for passing information from the user to the twin, (e.g., for control). Both AR and VR can be combined with technologies such as natural language processing or gesture control to provide effective environments in which the twin can be controlled either through voice control, or via physical movements.

2.4.5 Data management

As we see from the plethora of enabling technologies, Digital Twin implementations can involve a complex array of software and hardware components and data types. In order to bring the contribution of all the technologies together into something that can be described as a Digital Twin, sophisticated approaches to data management are required.

Digital twinning involves many different model versions that can represent different aspects throughout the lifetime of the twin, from design and simulation to manufacturing and actual use. Product lifecycle management (PLM) provides a platform for integrating, storing and accessing data throughout the lifetime of a product. Key benefits of PLM are that it provides configuration control and traceability. PLM can be used for many different types of data, from product structure data and CAD drawings to documentation and related e-learning information. PLM is also an important driver for the use of standards, which is vital in Digital Twin implementations for ensuring that there is interoperability between the different components, and also interoperability between the Digital Twin and the outside world.

Blockchain is a technology that has in the past few years been popularized through its use in various cryptocurrencies. However, blockchain does have a wider use that can be of interest in Digital Twinning. Blockchains provide a permanent decentralized historical record of information that is secure, traceable, and transparent; all of which are important in the Digital Twin context. There also exist alternatives to blockchain technologies, such as directed acyclical graphs (DAGs), that address some of the issues with scalability.

3 CHANGE2TWIN ENABLING TECHNOLOGY CATALOGUE

Although the focus of this deliverable is on so-called "enabling technologies", we make use of the document to catalogue all the items to be listed in the initial version of the Change2Twin marketplace. This includes items that are not necessarily considered "enabling technologies" themselves but are important in preparing SMEs or DIHs to be able to exploit the technologies, for example, including assessment tools and training workshops. Such offerings are indicated with an asterisk (*) in the following subsection titles.

It is the ambition of Change2Twin to also include offerings from external organizations in the marketplace. However, in this initial version of the catalogue, we consider only items that are internal to the Change2Twin consortium. As such, the marketplace is under continual development, so this document offers a snapshot of the initial version of the catalogue. This deliverable will be followed up in the subsequent deliverables D1.4 in Month 24 and D1.6 in Month 42, both of which will discuss that adaptations made to the technologies to better prepare them for Digital Twin applications.

For each of the enabling technologies in this catalogue, we provide 10 descriptors, as described in the following table. These descriptors may be subject to change in future versions of the catalogue.

Technology Descriptor	**Detail of descriptor**
Marketplace ID	Unique reference identifier with relation to the marketplace
Description	Brief detail of what the technology is, does and can mean to the user
Partner	Name of the technology provider, currently a member of the Change2Twin project and thus also the marketplace
Type	Classification of technology offering [current categories: software, consulting, community, laboratory, demonstrator, computing infrastructure]
Users	Type or names of specific users as reference for its use
Link	Online reference
TRL	Technology readiness level as currently defined by the European Union (ec.europa.eu, 2014)
Relation to standards / interoperability	Relevant standards used by, or related to, the technology as reported in Deliverable D1.2
Relation to barriers	Organizational and technological barriers defined in Deliverable D1.1 that are addressed by the technology: • [BAR-O1] Lack of visionary leadership • [BAR-O2] Unprepared for change in working practices • [BAR-O3] Many open questions • [BAR-O4] Unclear ecosystem support • [BAR-T1] Keeping it fit for purpose

	• [BAR-T2] Maintaining reliable operation • [BAR-T3] Ensuring effective execution • [BAR-T4] Accounting for uncertainty • [BAR-T5] Bringing it all together
Need for augmentation	Explanation of the degree to which the technology can or needs to be augmented to be useful for digital twinning.

Due to the diversity of items in the catalogue, not all of the above descriptors apply to all items. We indicate such cases with "not applicable" or "not available" (n/a).

3.1 GOTOOLS

Marketplace ID	MI1
Description	A collection of C++ libraries containing mathematical functionality and data structures needed in digital twins using B-rep and V-rep CAD-models for Finite element analysis and isogeometric analysis.
Partner	SINTEF
Type	Software
Users	Programmers of digital twin solutions looking for adaptable CAD modelling functionality.
Link	https://github.com/SINTEF-Geometry/GoTools
TRL	5-8
Relation to standards / interoperability	The formats used are closely related to the resources in Part 42 of ISO 10303 (STEP) but reading to and from STEP is not a part of the library.
Relation to barriers	BAR-T1, BAR-T4
Need for augmentation	Need to improve documentation.

3.2 GOTOOLS - GATEWAY: G22 TO STEP, STEP TO G22

Marketplace ID	MI2
Description	Gateway to translate between STEP (ISO-10303) and g22 to use the GoTools C++ Library.
Partner	SINTEF
Type	Software
Users	Programmers of digital twin solutions looking for adaptable CAD modelling functionality.
Link	n/a
TRL	4
Relation to standards / interoperability	Gateway enables read and write compatibility between GoTools (MI1) and Part 42 of ISO 10303 (STEP).
Relation to barriers	BAR-T1, BAR-T4
Need for augmentation	Need to deploy on cloud server and document the functionality.

3.3 IOT EDGE PLATFORM – NERVE

Marketplace ID	MI3
Description	Open platform to collect, store, visualize and provide real-time data from machinery for use on the edge or transfer to server/cloud solution. The

	platform can host and execute Digital Twin simulation for a faster correction of the process. It can be deployed also in conjunction with solutions from other technology providers contribute to creation of a digital twin for the respective company.
Partner	TTTech
Type	Software
Users	With the extension of the Data Services to Azure IoT HUB, the users can collect the data at high speeds on the node and store or visualize them centrally in the Management System. Integration in the Management System of supported LDAP (Lightweight Directory Access Protocol)/Active Directory allows users to be connected to a diverse collection of IT resources, including: Windows, Mac, and Linux devices, as well as applications located both on-premises and in the cloud.
Link	https://www.tttech-industrial.com/technologies/edge-computing/
TRL	9
Relation to standards / interoperability	The platform datapath provides connectivity to PLCs or remote IO modules via Ethernet fieldbuses such as PROFINET and EtherCAT in order to gather data from machine sensors and actuators. This data is modeled in OPC UA, allowing information to be shared in a standard way with other applications at the edge, be stored as time-series data, and be sent via MQTT to the cloud for further analysis. For low-latency applications such as motion control, the platform enables a CODESYS soft PLC where data can be ingested and used in real-time (<1ms).
Relation to barriers	BAR-T2, BAR-T3
Need for augmentation	Data Services: Upgrade to supported and integration of Azure IoT HUB: • Data Services are a collection of services and interfaces that allow to collect, store, analyze, visualize and distribute data. These services and interfaces are available on the edge node and in the Management System. Data Services have been upgraded from beta status to supported. In addition, it has been established a support for direct connection to Microsoft Azure IoT HUB. Management System: Support of LDAP/Active directory for user management. • The Management System allows the import of users and roles for access management through its LDAP integration. Data is synchronized with an LDAP server and the authentication of users is done against this LDAP server instead of the Management System itself. The user authentication provided is LDAP Simple Authentication (username and password) with the option to enable SSL/TLS for a secure connection between the LDAP server and the Management System. An existing LDAP server is required to enable active directory access management. The configuration of the LDAP synchronization in the Management System required expert knowledge (LDAP admin).

3.4 OPEN CALL MANAGEMENT SYSTEM*

Marketplace ID	MI5
Description	Create your own Champion Call. Hand-pick the most relevant innovators in your field. Selecting startups is one thing, selecting

	champions, with proven product-market fit and promising profitability, is another. FundingBox Enterprise is an end-to-end service, from form creation to assignment to evaluators and final selection, that will guarantee a selection made up of la crème de la crème.
Partner	FBA
Type	Software
Users	n/a
Link	https://fundingbox.com/technology-box/
TRL	9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1
Need for augmentation	n/a

3.5 OPEN INNOVATION SERVICES*

Marketplace ID	MI6
Description	Value for your money and excellence for your innovation processes. Collaborate with startups and scaleups in your industry to multiply your innovation potential and solve specific challenges. 1. We scout relevant companies within our pool of existing champions and ecosystem and through industry-specific open calls. 2. We screen all potential profiles and shortlist the ones that are the most compatible with your challenges. 3. We match them by introducing you to hand-picked innovators eager to partner with you.
Partner	FBA
Type	Consulting
Users	n/a
Link	https://fundingbox.com/scaleup-box/
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1
Need for augmentation	n/a

3.6 ONLINE COMMUNITY*

Marketplace ID	MI7
Description	Create your own Champion Community. Unleash the power of crowd knowledge. How to trigger more personal conversations with your customers and partners? How to understand them better and start establishing more loyal relationships? In FundingBox Spaces, gather all your stakeholders in one community ecosystem, a single place where synergies and sense of purpose are enhanced by in-built networking and content sharing tools.
Partner	FBA
Type	Community
Users	n/a

Link	https://fundingbox.com/communities-box/
TRL	9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1, BAR-O2, BAR-O4
Need for augmentation	n/a

3.7 ASSESSMENT TOOL

Marketplace ID	MI8
Description	The Assessment tool aims to support companies in finding a solution that is tailored to their specific business needs and ambitions. The assessment is intended to explore these ambitions and evaluate whether and how Digital Twinning can help the company to achieve them. The assessment starts with understanding the SME's current situation and what are their future business ambitions. The key input from the SME are the KPI's that they want to improve on in the future. The assessment links the business needs to the most relevant digital transformations and indicates the relevance of digital twinning as a solution
Partner	TNO
Type	Software, Consulting
Users	DIHs and Manufacturing SMEs
Link	n/a
TRL	8
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1, BAR-O2, BAR-O3, BAR-O4
Need for augmentation	We are considering making an online version of the tool (currently it is in Excel), so that it is easier to update. We expect to receive feedback on the use of it in the first open call, and then modify the questions if needed

3.8 METHODOLOGY FOR DIGITAL TWINNING*

Marketplace ID	MI9
Description	Generating Digital Twins effectively from available engineering and process resources gives you a head start. Similarly, your business case determines the needed abilities and scope of your Digital Twins. Becoming aware of your position, timeline, needs, and goals is thus your first step. As any complex undertaking, they take time to mature in your business, require skilled people, and a reliable infrastructure. We at TNO help you with that using our stepwise approach to digital twins— but it is your journey. Our approach starts with the why, to determine your purpose, and goes across the full lifecycle of the Digital Twin.
Partner	TNO
Type	Consulting
Users	DIHs and Manufacturing SMEs
Link	https://downloads.esi.nl/leaflets/TNO_Digital_Twin_Primer_SMEplus.pdf

TRL	8
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1, BAR-O3
Need for augmentation	n/a

3.9 TRAINING AND WORKSHOPS ON DIGITAL TWINNING*

Marketplace ID	MI10
Description	In a series of workshops, the experts of TNO will help your company deepening understanding, creating vision & implementation plan. With much experience in helping companies form, execute and realize their digital transformation strategies and goals, TNO facilitates, consults and participates in the process to give expert advice and support where innovation challenges require integrated knowledge and expertise.
Partner	TNO
Type	Consulting
Users	Manufacturing SMEs
Link	https://downloads.esi.nl/leaflets/TNO_Digital_Twin_Primer_SMEplus.pdf
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O1, BAR-O2, BAR-O3, BAR-O4
Need for augmentation	n/a

3.10 SMART CONNECTED FACTORY FRAMEWORK

Marketplace ID	MI11
Description	Digital Twins use data from the factory, but how do you obtain this data from your equipment? Smart Connected Factory is the basic infrastructure to collect data from your equipment. The Framework also enables you to gain insight by setting up simple dashboards by yourself. And of course, it is a perfect way to link data, models & business processes together in an easy way that enables real applications
Partner	TNO
Type	Software
Users	Manufacturing SMEs, Solution Providers
Link	https://www.tno.nl/nl/aandachtsgebieden/industrie/roadmaps/smart-industry/projecten/smart-and-connected-factory-data-gebruiken-om-fabriek-te-verbeteren/
TRL	7
Relation to standards / interoperability	OPC-UA, AAS
Relation to barriers	BAR-T1, BAR-T5
Need for augmentation	The roadmap of this Framework comprises a dashboard generator as a next step, then potentially create a connection to an ERP and/or integration of the Asset Administration Shell (AAS).

3.11 MARKETPLACE MODEL

Marketplace ID	MI12
Description	A smart representation of the Marketplace in form of a model enabling the use of intelligent algorithms for selecting the most appropriate marketplace item.
Partner	BOC
Type	Content
Users	DIHs are potential users that might be interested in establishing their own marketplace to better support SMEs in digital twinning and digital transformation.
Link	n/a
TRL	4-6
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O4, BAR-T1
Need for augmentation	The marketplace model is seen as an approach that bridges assessment services and offered solutions. The approach is to continuously integrate concept models and offered solutions in a method and tool independent way. The introduction of an abstraction layer should facilitate functionalities such as search and recommendation mechanisms that are related to a marketplace's behavior.

3.12 ASSESSMENT SERVICE - OMILAB INNOVATION CORNER

Marketplace ID	MI13
Description	The «OMiLAB Innovation Corner» is a laboratory environment reflecting three abstractions layers – business-, concept-, physical abstraction support customers to select the appropriate set of digital twin technology from the marketplace.
Partner	BOC
Type	Laboratory
Users	SMEs that might not be a perfect candidate for digital twinning according to the C2T Compass Assessment require further assessment (eg: Graphenstone).
Link	https://www.omilab.org/
TRL	5-7
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O3, BAR-O4, BAR-T1, BAR-T5
Need for augmentation	The generic OMiLAB Innovation Corner environment allows for the instantiation of concrete physical experiments for specific scenarios. Targeted workshops and consulting services are tightly related to specific problems and therefore result in highly customizable solutions.

3.13 PRODUCTION PROCESS DIGITAL TWIN OF ORGANIZATIONS

Marketplace ID	MI14
Description	The digitizing of production processes is one form of digital twinning. Integrated solution for design, monitor, assess and verify, simulate, execute and mine the production process.

Partner	BOC
Type	Software
Users	SMEs, particularly, SMEs that might not be a perfect candidate for classical digital twinning might want to establish a digital twin of the organization based on their production processes.
Link	Innovation item: Video Download Business item: BOC Group: ADONIS, ADOIT and ADOGRC | Agile. Simple. Smart. (boc-group.com)
TRL	Innovation item: 5-8 Business item: 9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O3, BAR-O4, BAR-T1, BAR-T2
Need for augmentation	Innovation item: Following aspects in need of further augmentation were identified for the innovation item. • Improvement of the knowledge-based simulation • Integration of monitoring and process simulation • Improvement of the (continuous) integration of edge devices and the monitoring environment • Development of concepts and proof of concept experiments for digital twins and digitization challenges, for instance for digitization of raw material, digitization of production processes or digitization of product information Business item: n/a.

3.14 DESIGN OF A HYBRID DIGITAL TWIN SOLUTION*

Marketplace ID	MI16
Description	Design of hybrid DT approaches relying on deterministic, e.g., physics-based, and approximate e.g., ML-based techniques applied to manufacturing in industrial IoT scenarios.
Partner	UNIBO
Type	Software, Consulting
Users	SMEs, DIHs
Link	http://www.middleware.unibo.it/?page_id=103
TRL	5-8
Relation to standards / interoperability	EdgeX IoT edge platform with several connectors.
Relation to barriers	BAR-O4, BAR-T1, BAR-T4
Need for augmentation	Data layer e.g., integrate additional shop floor (data) connectors | domain model depending on the use-case.

3.15 CLOUD-TO-THING MANAGEMENT AND CONTROL PLATFORM IN SUPPORT OF DIGITAL TWINS *

Marketplace ID	MI17
Description	Customize or develop distributed Clout-to-thing software solutions supporting heterogeneous DT scenarios adhering to the applications' Qualify of Service constraints in terms of e.g., privacy/security, real-time response etc.
Partner	UNIBO

Type	Software, Consulting
Users	SMEs, DIHs
Link	http://www.middleware.unibo.it/?page_id=103
TRL	n/a
Relation to standards / interoperability	Bridge telco operator or fog-oriented solutions based on FogOS.
Relation to barriers	BAR-O4, BAR-T2, BAR-T3
Need for augmentation	Data layer e.g., integrate additional shop floor (data) connectors | cross-domain bridging e.g., interoperability with ETSI MEC.

3.16 CLOUDBROKER PLATFORM

Marketplace ID	MI19
Description	Change2Twin Marketplace for Pilots, Application experiments and different solutions to enable and to maintain digital twinning are to be deployed through the CloudBroker platform.
Partner	CloudBroker
Type	Software
Users	DIH, commercial customers, SMEs, project pilot partners
Link	http://cloudbroker.com/
TRL	n/a
Relation to standards / interoperability	Micado, Docker, API
Relation to barriers	BAR-T3
Need for augmentation	To extend the possibilities of using one single mechanism to operate with different cloud providers. Make sure that necessary technologies are fit the main ambition: to ensure that users have of 100% Digital Twin technologies platform can provide them with.

3.17 CLOUD RELATED CONSULTING SERVICES*

Marketplace ID	MI21
Description	Consultancy for cloud-related deployment.
Partner	CloudBroker
Type	Consulting
Users	DIH, commercial customers, SMEs, project pilot partners
Link	http://cloudbroker.com/
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O2, BAR-O4
Need for augmentation	To extend possible users who would like to use cloud solutions and provide them with detailed information/advice with respect to their business/digital twin case.

3.18 HPC INFRASTRUCTURE

Marketplace ID	MI23
Description	Computing power (HPC, cloud, server virtualisation), data storage and management for scalable services including cloud services, on-demand

	applications, data archiving and synchronisation, digital repositories, or education platforms. Individual consultancy how to levarage your service with cloud or HPC solutions.
Partner	PSNC
Type	Computing infrastructure
Users	C2T pilots, service/applications providers (or users) who want to offer/run them in cloud environment, using computational power (also at HPC-scale) and large storage.
Link	http://uslugi.pcss.pl/uslugi/
TRL	9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O4, BAR-T3
Need for augmentation	Additional features may be provided upon receiving further requirements from pilots/users/customers.

3.19 DEVELOPMENT OF DIGITAL TWINS TO SIMULATE PHYSICAL PRODUCTS

Marketplace ID	MI24
Description	Simulation and testing are key in the development of complex products such as mechanical parts and systems. The finite element method (FEM) is the most widely used method for solving such problems of engineering and mathematical models. Space Structures GmbH offers the development of digital twins for structural and thermal purposes.
Partner	SPS
Type	Consulting
Users	Product owners of physical hardware
Link	https://spacestructures.de/
TRL	9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O3, BAR-T1
Need for augmentation	n/a

3.20 LOW-CODE PLATFORM FOR MACHINE-CONTROL APPLICATIONS

Marketplace ID	MI25
Description	Low-Code software development platform for machine-control applications, based on graphical model-driven software engineering. It is a cross-platform solution, supporting multi-vendor PLC-controllers from e.g. Siemens, Bosch-Rexroth, Beckhoff, Lenze and also Embedded-controllers running on C# / .NET Core (Linux &Windows)
Partner	CORDIS
Type	Software
Users	Machine-control application developers, who also need design documentation (e.g. PDF) that is always up-to-date with the design models and the running software on the machine.
Link	https://cordis.nl/
TRL	n/a

Relation to standards / interoperability	n/a
Relation to barriers	BAR-T1, BAR-T2
Need for augmentation	In the low-code platform, the graphical machine-control models can now be enriched with documentation content and has the extra functionality to generate complete design documentation in different formats. This is realized by integration of the Author-e documentation platform in the Cordis SUITE low-code development platform.

3.21 PRESPECTIVE

Marketplace ID	MI26
Description	Prespective is a software platform. It's an interactive virtual test environment built on top of Unity, in which users continuously test their systems. Not just visually, but also mechanically, connect to their logic control software, human interface and IoT.
Partner	Unit-040
Type	Software
Users	Manufacturing companies, logistics, high tech industry
Link	https://prespective-software.com
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-T1, BAR-T2
Need for augmentation	• Make adjustments in the importer software code to solve issues with off-axis orientation in the original 3D file. • Develop a printjob file reader/importer for the 3D digital twin to be able to re-create (or pre-create) the virtual print process, generating each line and layer of the 3D print object in the digital twin. • Develop user interface to select a specific print layer of a 3D object, with time-scaling, time-control and focus-selection. • Reduce the complexity for new companies (especially SME's) to start working with Digital Twin technology by introducing Prespective "essential". This version has a library of standard industrial assets (like robots, belts, machine cabinets and AGVs) that can be drag & dropped into the Prespective environment.

3.22 AUTHOR-E

Marketplace ID	MI27
Description	Author-e is excellently suited for documentation and specification of digital twinning processes.
Partner	Author-e
Type	Software
Users	Cordis suite users that need to create updated documentation potential benefit from this augmentation.
Link	https://www.authore.com
TRL	n/a
Relation to standards / interoperability	Input: Low code model entered by API (in JSON); adding text as OEM in low-code application.

	Output: Word, Excel, PDF, HTML, XML, ePub Standards: OpenXML, Scorm
Relation to barriers	BAR-T1, BAR-T5
Need for augmentation	The Author-e tool needs to be integrated with the Cordis suite in order to automate documentation of the low-code models. Therefore, an API is developed to generate the initial documentation of Cordis low-code models, and to synchronise this documentation with updates of the models.

3.23 CT-I*

Marketplace ID	MI29
Description	Consultancy and Integrators of new digital enabling technologies deployment. (IIoT)
Partner	CT-I
Type	Consulting
Users	SMEs
Link	https://www.ctingenieros.es
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O4, BAR-T2
Need for augmentation	n/a

3.24 PALLET WRAPPER DT

Marketplace ID	MI30
Description	Digital twin of the pallet wrapped with film, which can be used to forecast the behaviour of the load and the stability of the pallet under the dynamic and static stresses generated during a specific transportation route, from the production company to the final destination.
Partner	AETNA-Group
Type	Laboratory
Users	Manufacturing companies, logistics, research centers, packaging industries
Link	www.techlabtest.com
TRL	9
Relation to standards / interoperability	n/a
Relation to barriers	BAR-T1
Need for augmentation	n/a

3.25 IMPROVE AND OPTIMIZE OUR PRODUCTION CHAIN*

Marketplace ID	MI31
Description	Transforming the processes that use communication chains on paper and non-essential manual work, into digital processes that produce data that can be studied and analyzed in the future, to improve the production chain and the life of the product during its manufacture.
Partner	Graphenstone

Type	Demonstration
Users	n/a
Link	n/a
TRL	n/a
Relation to standards / interoperability	n/a
Relation to barriers	BAR-O2
Need for augmentation	n/a

3.26 SINTEF SPLINE LIBRARY (SISL)

Marketplace ID	MI32
Description	SISL is a mathematical library implemented in C providing a large set of the mathematical functions needed in Computer Aided Design systems (CAD), with a focus of spline technology. Data structures for CAD-models are not a part of SISL. Consequently, targeted applications can be made with simpler data structures than standard boundary representation CAD requires.
Partner	SINTEF
Type	Software
Users	Software developers
Link	https://github.com/SINTEF-Geometry/SISL
TRL	8
Relation to standards / interoperability	The formats used are closely related to the resources in Part 42 of ISO 10303 (STEP) but reading to and from STEP is not a part of the library.
Relation to barriers	BAR-T1, BAR-T4
Need for augmentation	Need to improve documentation.

3.27 JOTNE: EDMOPENSIMDM

Marketplace ID	MI33
Description	ISO 10303 repository and application for multidisciplinary analysis, design and test data (AP209) (Lanza, 2019). Comes with a rich desktop client and a lean web-client. Imports from AP242, NASTRAN, Abaqus, Ansys and csv (test data). Enables cross domain correlations. Uses VCollab viewer (separate license).
Partner	Jotne
Type	Software
Users	Simulation (FEM) engineers, Analytics, Test engineers
Link	https://jotneit.no/products/edmopensimdm
TRL	6
Relation to standards / interoperability	EDMopenSimDM: ISO 10303-209 repository. AP209 converters for data from simulation pre-processors and solvers (NASTRAN, Abaqus, Ansys). Visualization support for standard formats (AP209, AP242) and native formats (NASTRAN bdf, op2, ...). Import of design data via AP242. Import of physical test data from native csv and uff type files.
Relation to barriers	BAR-O3, BAR-T1, BAR-T2, BAR-T5
Need for augmentation	Year 1: • Improved interoperability with more CAE data formats

	• Improved managed of cross-domain (analysis, CAD, testing) data models
	• Import, management and visualization of sensor result data (multiple types of sensors)
	• Additional features for cross-domain (analysis, CAD, testing) data comparison and correlation
	    o Compare 3D models (CAD, CAE, Cloud of points)
	    o Sensor results vs analysis results (strain gauges / strain tensors)
	    o Comparison and correlation of thermal raster images and thermal analysis results
	Future:
	• Further improvements for interoperability with additional CAE data formats
	• Support for representation of manufacturing specific data and processes
	• Support for representation of test facility information and data
	• Generation of thermal analysis loads based on thermal raster images
	• Dynamic/live connection to sensor data stream for near real-time visualization and correlation with analysis results
	• Comparison and correlation of data from additional sensor and analysis types

3.28 JOTNE: EDMTRUEPLM

Marketplace ID	MI34
Description	End-user application for Product Lifecycle Management (PLM). Structures a product or project by breakdown elements. These are assigned documents and properties. Rich capability for adaptation to different use cases via a Reference Data Library (RDL), no hard-coding of detailed semantics. Interoperability via STEP AP239 and AP242.
Partner	Jotne
Type	Software
Users	Engineers, Project Managers, Technical Document Management, IoT
Link	https://jotneit.no/products/edmtrueplm
TRL	6
Relation to standards / interoperability	EDMtruePLM: ISO 10303-239 repository and AHT framework integration.
Relation to barriers	BAR-T2, BAR-T5
Need for augmentation	Year 1: • Relationships between the breakdown structure • Breakdown element Change log • Export & Import via STEP Pack • Import data via PDM step file, Dex to the project • Import breakdown structure to a node via .csv file • Breakdown user properties for the Formatted and counter type • Organization • Products • Generate document • Quick search

	Future: • Change management • Visualization

3.29 JOTNE: EDMSDK

Marketplace ID	MI35
Description	Toolkit for developing converters between legacy data formats and STEP (any Application Protocol (AP)). Bindings in C, C++, .NET, Java and EXPRESS-X. Available for Windows and Linux/Redhat.
Partner	Jotne
Type	Software
Users	Translator development, IT integrators
Link	https://jotneit.no/
TRL	8
Relation to standards / interoperability	EDMsdk for converter development.
Relation to barriers	BAR-T2, BAR-T5
Need for augmentation	General performance improvements

4 CONCLUSIONS

Our initial labelling of the items according to the organizational and technological barriers outlined in D1.1 "Digital Twin Barriers" indicates that the items offered by the Change2Twin have sufficient coverage of all the barriers. We have not analysed the extent to which the barriers are addressed but note that all of the barriers are covered by four or more different items indicating that most will be addressed to a large extent. This can be clearly seen in the table presented in Figure 3.

	MI1	MI2	MI3	MI5	MI6	MI7	MI8	MI9	MI10	MI11	MI12	MI13	MI14	MI16	MI17	MI19	MI21	MI23	MI24	MI25	MI26	MI27	MI29	MI30	MI31	MI32	MI33	MI34	MI35
BAR-O1				●	●	●	●	●	●																				
BAR-O2						●	●		●								●								●				
BAR-O3							●	●	●			●	●						●								●		
BAR-O4						●	●		●		●	●	●	●	●		●	●					●						
BAR-T1	●	●								●	●	●	●	●					●	●	●	●		●		●	●		
BAR-T2			●										●		●					●	●		●				●	●	●
BAR-T3			●												●	●		●											
BAR-T4	●	●												●												●			
BAR-T5										●		●										●					●	●	●

FIGURE 3: COVERAGE OF BARRIERS BY THE ENABLING TECHNOLOGIES

In addition to the barriers being addressed to a large extent by the marketplace offerings, the catalogue also has a good coverage in terms of the types of technology available including items covering CAD and CAE, (I)IoT, HPC, Cloud-, Edge- and Fog-computing, documentation software, low-code programming platforms, visualisation, ML/AI, and PLM, in addition to a wide range of consultancy services related to Digital Twin. Nevertheless, in order to comprehensively cover all the potential needs of SMEs in their Digital Twin implementations, the marketplace does require more items to be added in the future. However, as mentioned previously, the marketplace is continually developing, and it is the intention to also onboard offerings from external providers; an activity ongoing in WP2.

Despite the clear need for onboarding of new, external offerings in the marketplace, the current catalogue provides a firm foundation on which to build a successful Digital Twin marketplace. It is also the foundation for ongoing activities in WP1, including:

- How to describe the enabling technologies in such a way as to make them findable and accessible on the marketplace. This will involve annotating the offerings with tags, which may evolve throughout the project, in order to best serve the purposes of findability and accessibility.
- How to ensure the SMEs can integrate the technologies into their Digital Twin solutions. This will involve, for example, the deployment of relevant technologies on cloud infrastructure to enable seamless interaction from the marketplace.
- How to adapt the technologies to increase their TRL level and to ensure their relevance for Digital Twin applications. This will involve changes to the technologies required to make them usable for the pilots and experiments.
- How to ensure interoperability between the technologies by use of standards.

This report has provided a snapshot of the status of the enabling technology catalogue at Month 12 of the project and will be followed up by Deliverable D1.4 in Month 24 and Deliverable D1.6 in Month 42 of Change2Twin.

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