Application of Digital Twins in IoT Platforms

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***Abstract*— Today, the Internet of Things (IoT) has left its infancy. It has become one of the core technologies for the digitalization of various domains. With this transition, IoT platforms have to address new requirements: Rollouts into business operations require professional integrations in legacy environments and usability for users without a technical background. Especially in engineering, digital twins are used to represent physical objects, store related information in one place and perform simulations to simplify complex topics. This paper describes an approach for integrating digital twins in IoT platforms, with a focus on improving usability for non-technical users and IoT integrations.**

Keywords— Internet of Things; IoT-platform; Digital Twin; Rollout

I. INTRODUCTION

A. Market Trends in Internet of Things

In theory, Internet of Things (IoT) describes physical objects connected to the internet to exchange information with each other [1]. Sensors are measuring real-life information, processing them locally or with the help of software services on the internet, and actuators are then performing real-life activities. In practice, IoT has become one of the enabling technologies for the megatrend of digitalization [2]. Through IoT, software services have the opportunity to interact with the physical world without the help of human interaction. Nowadays, technologies like artificial intelligence, augmented reality or autonomous driving rely on IoT.

There are two major patterns to set up IoT solutions: The first one is usually used for market-ready products, especially for end customers. In this pattern, dedicated field devices are only interacting with a dedicated software service. There is no need (and often no intention) that neither the devices nor the software service share data with others. Examples are e. g. smart weights or smartwatches. These IoT solutions are easy to maintain and use, but are not open to being integrated into a broader IoT environment. The second pattern is usually used by organizations fostering a digitalization strategy. Here, the IoT environment is open to be extended and its data to be used by others. The same IoT device or software service can realize many use cases.

In these IoT environments, IoT platforms are software services that allow administrators to manage and monitor a large number of IoT devices in one place. Furthermore, IoT platforms are linking the IoT world to the IT infrastructure. They gather and persist raw data from various IoT devices and protocols as well as process them into a unified and machine-readable format. Besides, they provide various IT interfaces for third-party systems, so that tailored applications for users can be built upon them [3, 4]. Depending on the software vendor, IoT platforms can also take over other tasks and responsibilities besides these core activities. With this broad number of functionalities and a central role in connecting the IoT- with the IT world, IoT platforms have become a crucial part of an IoT environment [5] (fig. 1).

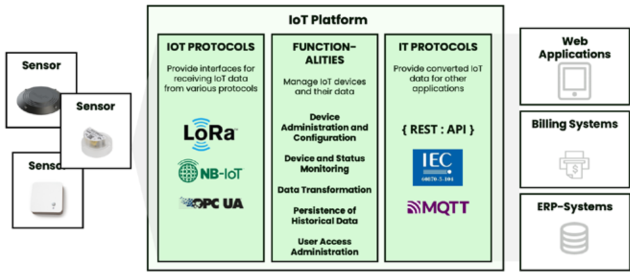

Fig. 1. Central role of an IoT platform and its responsibilities

Nevertheless, over the last couple of years, the requirements towards IoT platforms have changed. Many organizations started with proof-of-concept projects to gather experience with this new technology and evaluate individual benefits and use cases. This led to a strong technology-driven development of IoT platforms covering the needs of IoT administrators. Functionalities within IoT platforms focused on easy maintainability and flexibility to adjust to the changing needs of a proof-of-concept project.

Today, IoT has become more and more mature. In general, the hype in the media is over and many proof-of-concept projects finished. Organizations are convinced of the benefits of IoT and start professional rollouts [6, 7]. With the transition from research into larger applications, a new group of users is using IoT and new requirements towards an IoT platform occur. A broader number of users from various business departments start to use IoT-based solutions. This type of user usually has a little technical background and/ or interest in IoT and needs a simple solution for their daily business processes. Besides, administrators of IoT infrastructures need solutions to integrate the IoT environment into the organization's IT landscape.

Many IoT platforms miss the point to address these changing requirements. In the best case, they address the needs of IoT administrators, as this type of user is already involved in proof of concepts and thus there is a strong involvement yet. But by missing the needs of business users, the full potential of IoT cannot be exploited. Even if IoT platforms provide integrations for IT interfaces, they are lagging functionalities enabling business users to benefit from IoT (see fig. 2). There is even a high risk of failing the transition from proof of concept into rollout [8].

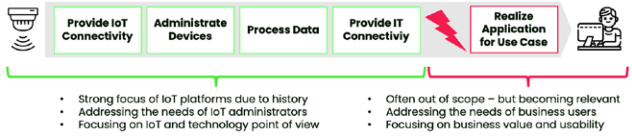

Fig. 2. Lag of business support in usage of IoT data flow

B. Potential of Digital Twins

A digital twin is a virtual representation of a physical object, storing all its information throughout its lifetime. In a shorter description, digital twins can be seen as an avatar of something real. They are the single source of truth for the current as well as past state of a real object. [9]

As the concept of digital twins is an abstract concept and hard to understand, a simple example makes it more tangible: To some extent, a social media profile is a digital twin of a person. It saves master data (such as hometown, date of birth, name, etc.) as well as process data (e. g. posted updates, places visited, images uploaded) of the corresponding person. Besides, the social media profile can save links to other sources (e. g. a personal homepage or LinkedIn profile). The social media profile is a digital avatar of the physical person, uniting information from various sources. It saves all information about a person and becomes the source of truth for others.

Although the digital twin seems to be a rather young concept, it has been known since the beginning of the 21st-century [9]. Originally, NASA used digital twins to save time and money during engineering and testing by using digital twins for material simulations instead of tests on real objects. Besides, digital twins are used for example in constructions. During the planning and construction of a new production plant, many departments work together and need access to information from the same building they are working on. E. g. an architect needs access to 3D models, engineers need access to piping diagrams of the building, etc. In engineering, different standards for digital twins like the building information modeling (BIM) for constructions or AutomationML, a protocol for exchanging plant engineering information in factories, are already well-known.

So far, digital twins are mostly known for being used in the engineering phase. Here, a digital twin represents a type of product that does not necessarily exist yet. With the digital twin prototype, engineers can simulate behaviors like material performances or interference checks. Furthermore, they have all the information for engineering in one place, like the bill of material and CAD drawings.

But the concept of the digital twin is not limited to engineering, it can also be applied in operations during the runtime of a product. Here, digital twins represent a concrete existing object and are linked to its lifetime. It saves the history and current state of this object. With the digital twin instance (see e.g. [10]), users can e. g. see when components have been maintained and when this product was used. Besides, they can remotely see the current state of the real object through the digital twin. [9]

Today, digital twins are getting more and more attention [11, 12]. It is estimated that users benefit from higher efficiency, better satisfaction of customer needs, and maybe even new types of products. Thus, it is no surprise that many companies expect a high impact and are already working with digital twins [13].

In comparison to previous approaches that tried to store all data in one place, digital twins are designed from the users and use case point of view. They represent a physical object, which makes it especially easy for non-technical users to understand what they see. And they group master data as well as process data that is needed to fulfill a use case, e. g. perform a simulation or monitor a real object. Digital twins are not a concrete technology, but more a concept of how to persist and process data. This leads to better support for business processes due to fewer media discontinuity, less search time, and new applications with business value like real-time simulations or condition monitoring.

II. Current Challenges in IoT

IoT is now reaching a new level of maturity and organizations start to use it in professional rollouts. Surprisingly, more than 75% of all proof-of-concept projects in the IoT world fail nowadays [6, 8]. Reasons are — besides others — the new requirements arising from business operations. With the transition from a proof-of-concept into an organization-wide rollout, users from business departments start to work with IoT platforms. IoT platforms need to address the needs of these non-tech-interested users and deliver easy-to-use and tailored solutions to this type of users.

With digital twins, there is a concept available that mostly has been used in engineering. It focuses on visualizing complex technologies and storing all needed information from different sources for certain use cases in one place so that engineers can focus on their working topics. Unfortunately, outside of the engineering domain, and especially in operations and IoT, there are few profound solutions based on digital twins available yet. Existing research focused mainly on technical aspects such as interoperability between IoT and digital twin or data flow and data management (see e.g. [14, 15]).

Although many IoT projects fail during rollout and there is a need for easy-to-use solutions for business users, there is little work on this topic available yet. The question is, how can IoT platforms exploit the benefits of digital twins, to leverage the challenges of IoT during rollouts into business operations.

III. Approach for Applying Digital Twins in IoT

The application of digital twins in an IoT platform was driven by an iterative approach, involving concrete customers and their use cases. It was embedded in a general re-design of an existing, market-established IoT platform. According to an agile approach, the research, design, and development went through different stages. It included early prototypes, beta-versions, etc., and took more than one and a half years with continuous user feedback before reaching the final solution.

The objective was to provide practical value for business users by using digital twins in IoT, over theoretical perfection. The starting point for the research, design and development was the existing IoT platform “niota” from DIGIMONDO (see also [16]), which provided typical functionalities many modern IoT platforms cover. This IoT platform was supposed to be extended by the concept of digital twins to increase the coverage of user requirements, especially for users from business departments.

To get a comprehensive set of user requirements, the needs from five types of stakeholders of the system, covering business users and IoT administrators, have been collected (excerpt see fig. 3). From the business users’ perspective, which aims for a high value of IoT solutions with little tech knowledge, users from industries, facility management, and utilities have been considered. From the point of view of IoT administrators that are responsible for the rollout and the IoT operations, the needs of external as well as internal IoT project managers and administrators have been collected. Examples of use cases reviewed are smart metering, fluid level monitoring, leakage detection, asset tracking, and condition monitoring for facilities.

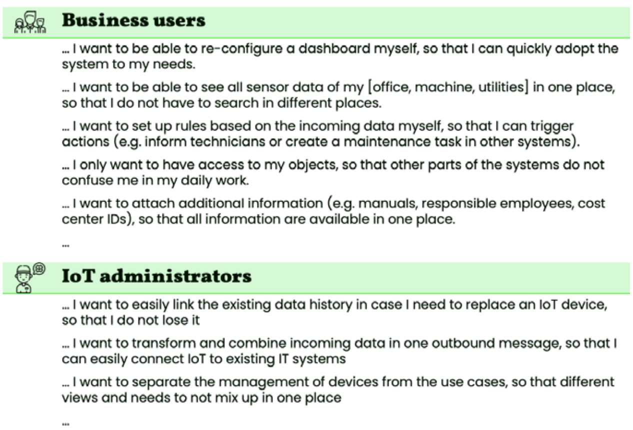

Fig. 3. Requirements of business users and IoT administrators (excerpt)

From the concept of digital twins, three characteristics have been considered. First, it should provide a digital representation of a real object that is intuitive to model and work with for non-technical users. Second, it should be able to provide a single source of truth that collects all relevant information - master data as well as process data - in one place, independent from the source and protocols used. Third, it should support process automation in operations. As IoT platforms are located in operations and not in engineering, the ability of digital twins in engineering to be used for simulations has been discarded.

IV. Result and Discussion

The result was a new generation of IoT platforms that covers the needs of IoT administrators as well as business users (see also [17]). Besides the commonly used and already existing functionalities of IoT platforms, the digital twin became a fully integrated part of the system.

Within the application, a digital twin for IoT can handle master data and process data from various IoT devices as well as IT systems. Examples are interfaces and protocols like MQTT, LoRaWAN, REST-API, or IT systems for meteorological data or maintenance coordination. Besides, each digital twin “owns” a rule system and triggers for process automation. Furthermore, a dedicated visualization with dashboards is part of the digital twin. The digital twin is an independent entity within the system. Its visibility and accessibility can be limited in a way that business users only can access digital twins in the IoT platform without seeing other, IoT-related parts of the system.

From a usability perspective, the digital twin was designed in a way that business users can configure their business solutions themselves through the user interface. The digital twins are organized in a hierarchy in the user interface. Although technically any relation between twins is possible, this reduces complexity when managing many digital twins for users as this structure is already known from Windows and other operating systems. Managing master data such as descriptions, names, responsibilities, or even custom properties are separated in a different view as managing process data and managing process automation. Users can set up custom dashboards with little clicks to monitor the digital twin’s status or realize custom use cases. Besides, all digital twins can be visualized on a map to easily get the connection between the visual representation and the real object.

From a data management perspective, each digital twin owns its data history to cope with the requirement to provide a long-term availability of historical data in rollouts. The independent data management decouples the hardware from the digital twin and makes business use cases independent from the underlying IoT devices. By this, field devices can be exchanged for other types and vendors without laborious matching of historical data or even losing it. Besides, each digital twin provides flexible possibilities to transform and aggregate data, even across many digital twins. For process automation, each digital twin can manage rules to be applied for incoming data to trigger e. g. third-party systems.

From a conceptual point of view, the digital twin became a dedicated layer within the IoT platform. Typical functionalities in IoT platforms, e. g. device management and device monitoring, are focusing on the IoT world and technical criteria. Complementary, the digital twin is focusing on the IT world and business process criteria. This reduces the chasm between the IoT world and existing IT landscapes because connecting both worlds becomes easier for business users as well as for IoT administrators (fig. 4). Through this, the digital twin became the binding element between the IoT world and the IT world to connect different protocols, technologies, and systems with each other.

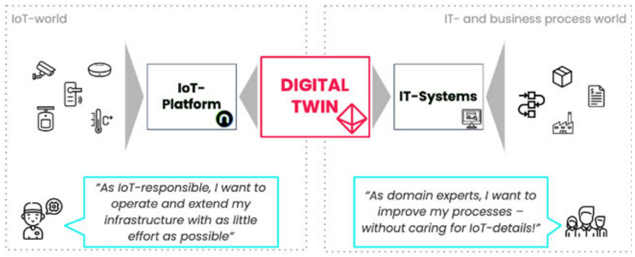

Fig. 4. Digital twin as the binding element between IoT- and IT-world

As a result, after approximately one year of usage, the users created more than 3500 digital twins. With short training, users with little IoT background have been enabled to set up their applications based on IoT. Especially for quick prototyping and proof of concepts, the digital twin was very helpful to demonstrate and evaluate the business impact of IoT use cases. One of the highlights was the feedback of a manager who used the digital twin for a demonstration in a keynote: “With the digital twin, I could set up my IoT demonstration within less than 30 minutes”. Due to the focused representation of real objects, intuitive ways of organizing and grouping IoT devices are possible. Examples are the multiple linkages of an IoT device to many digital twins or a vendor-independent exchangeability of IoT devices without losing data history.

Fig. 5 and 6 give examples of the digital twin used to represent DIGIMONDO’s headquarter. Each room is fully equipped with various IoT devices from various vendors to measure temperature, CO2 level, light intensity, the status of doors and windows, etc. The visual representation of the real office makes it easy for everyone to orientate where the measured data belongs. The possibility to set up hierarchies and unite and aggregate data supports gaining knowledge from the measurements and monitoring the office facilities. Each user with access to this digital twin can easily set up custom rules, e. g. to get notified if the CO2 level is too high or trigger actions in other IT systems if windows are still open in the evening.

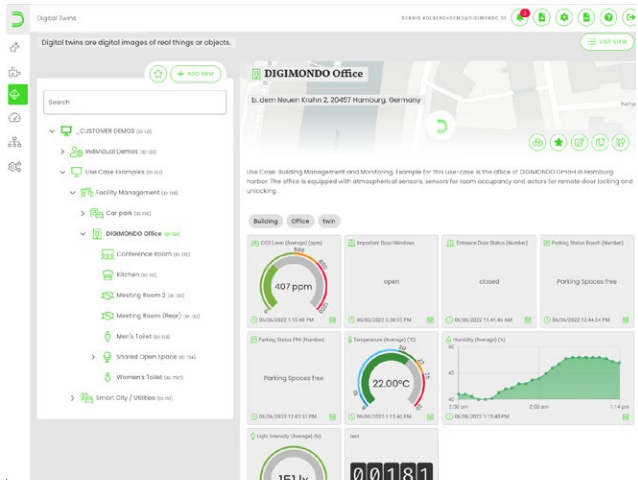

Fig. 5. Digital twin hierarchy and dashboard of example use case

With the application of digital twins in an IoT platform, the complexity of the system itself significantly increases. This refers on the one hand to the technical point of view, where the increase of major features obviously leads to an increase of software code to maintain in the future. But on the other hand, also from the product management point of view, a new type of user with different needs has to be considered. In the first version, a stand-alone software product for the digital twin was considered, which was rejected due to the deep integration with the IoT platform.

Furthermore, the digital twin in IoT reaches its limit when it comes to very specific use cases and the need for custom logic. Obviously, the more generic a solution is, the more it can be applied to a broad number of use cases, but the less specific and tailored it can be for a single problem. The same applies to the concept of digital twins here. It is tailored to IoT use cases, but generic for the domain where it is used. When it comes to e. g. organization-specific processes with the need for special dashboards, the digital twin implementation reaches its limit. Over time, these limitations will be solved by further extension of the digital twin functionalities. The same challenge applies when custom logics and algorithms need to be implemented, e. g. for complex analytics solutions. The digital twin is a (almost) no-code approach that makes IoT accessible for business users. It is not designed for custom software code implementations besides data transformation. Nevertheless, the concept of the digital twin became a fundament for further developments within the given IoT platform. Based on the digital twin and its flexibility, domain- and use-case-tailored IoT modules can be developed on top.

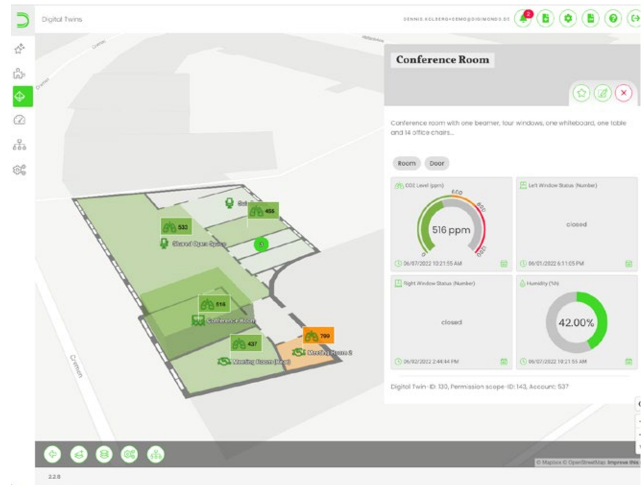

Fig. 6. Visual representation of real objects as digital twins in maps

In general, there is a good match between IoT as a technology and the digital twin as a concept. IoT benefits from the digital twin due to the focus on users’ needs and the combination of various data in one object. But the digital twin benefits from IoT as well because digital twins in operations heavily rely on information from field devices [18]. Without IoT, a digital twin would just be a collection of static data. IoT delivers information about the physical condition in real-time to turn a digital twin into an alive avatar of the physical object.

In comparison to other existing solutions for digital twins in IoT, this solution does not require any additional software development. It can be set up by non-technical users. This approach also exists in other software like ERP-system or asset management solutions, but here the number of use cases covered is very limited.

V. Summary, Outlook and further Research

This paper describes how digital twins have been used in IoT platforms, especially to support business users' needs. Major characteristics of the digital twin in operations have been used to be integrated into an existing IoT platform. The digital representation of physical objects, a collection of all information in one place, and the possibility of process automation have been used to increase the usability of IoT and leverage its potential for non-technical users. The methodology was driven by practice with an interactive, agile approach and involvement of different users and their use cases from industries, facility management, and utilities.

The result is a new level of IoT platform where business users can easily configure their solutions without having any knowledge of IoT. In contrast to digital twins in engineering, this solution is not focusing on using 3D models for simulations. It focuses on persisting meta data, processing technology-independent data in one place and providing functionalities for easy visualization of real objects. Due to the generic concept of digital twins, limitations are in realizing very specific use cases. Nevertheless, the digital twin became a major concept in the given IoT platform. It can also be used to represent devices and build tailored applications based on the digital twin.

As digital twins in operations are not yet very much examined, further research needs to be done to sharpen the definition and gather more requirements on generic functionalities. Besides, due to the increased maturity of the IoT market and more and more large-scale IoT rollouts, further evaluations of business users' needs in various domains have to be done to increase the value added by IoT for organizations.

To sum it up, the combination of digital twins and IoT was successful. It increased the usability of IoT for non-technical users. With this approach, before mentioned limitations of IoT and new challenges during rollouts could be coped. The combination of IoT and digital twins can be seen as a crucial step to fostering the digitalization strategy in organizations and making IoT accessible to everyone [19].

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