Towards a Distributed Digital Twin of the Agricultural Landscape

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Abstract: Agricultural landscapes form a complex system of interacting and changing elements and subsystems. They involve stakeholders from varying disciplines each with their own resources and perspectives. Understanding and working with such a complex system requires a comprehensive description of the whole ecosystem and an approach that enables interoperable and cross-scale management of distributed information resources. We introduce a concept that we call the Distributed Digital Twin of the agricultural landscape, which handles the distributed nature of resources over different stakeholders and platforms while providing a basis for integrating both pre-existing, historical and real-time information for physical things such as landscape objects.

Keywords: Agricultural landscape, Distributed Digital Twin, data infrastructure, catalog, IoT

1 Introduction

As a place for agricultural, forestry and industrial production, as a living and recreational area and as a habitat for flora and fauna, the agricultural landscape provides diverse ecosystem services for people. Various stakeholders deal with individual facets of the landscape system. Each has different requirements with regard to the existing resources and the type, content, quality, and spatial and temporal extent of information. At the same time, actors in diverse disciplines provide comprehensive specialized information, which are usually available in domain-specific information systems and scattered over different organizations. The fundamental challenge is therefore to make this information – usually in distributed form – available to the actors in a form that meets their needs and to harmonize it across the various stakeholders such that it helps establish a common and cross-scale understanding of the landscape and its components to facilitate coordinated decision-making (VAN DEN BRINK et al. 2017). Much of the information held by different actors relates to identical real-world objects, which often are represented as independent and autonomous objects. The concept of mapping things – including their (real-time) state and behavior – and processes in the form of Digital Twins (DT) of the real-world phenomena is already practiced in the context of Industry 4.0 (BOSCHERT & ROSEN 2016). A fundamental challenge here is the distributed nature of the available specialist information. To address these challenges, we introduce the notion of distributed DTs of the cultural landscape. Our approach aims at optimizing the data integration process as well as the whole process of stakeholder engagement required in the Geodesign process as described by STEINITZ (2012).

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This paper first reviews related work and explains the background and the requirements in the field of agricultural landscape. Then, the proposed approach in addressing the defined requirements is described. The focus will be on the main elements of the distributed DT. Finally, as a proof of concept, the concept is demonstrated with an example from the agricultural research center associated with the School of Life Sciences of the Technical University of Munich (TUM), where the concept is being implemented. In the conclusions, the contributions of the presented work – especially to the field of modeling and managing the agricultural landscape – are highlighted and future work is discussed.

2 Related Work

2.1 Digital Twins of (Agricultural) Landscapes

The notion of DT was originally defined in product lifecycle management for industrial machines. In industry, the DT is seen as a comprehensive physical and functional description of a component, product or system, which includes useful information for all lifecycle phases of the physical thing. The creation of DTs is purpose-driven and may exist in several levels of detail reflecting the requirements of the purpose (BOSCHERT & ROSEN 2016). Only very recently colleagues from geospatial information science and planning have started to discuss using DTs in the context of urban planning, see (BATTY 2018), although concepts for creating "mirror worlds" date back to the 1990s (DAWKINS et al. 2018). BATTY (2018) describes the DT of a city as a digital representation of a city in terms of its physical assets. Digital twins of real cities often arise in connection with Smart City projects. City administrations that are currently building digital twins of their city, such as Helsinki, Rotterdam and Singapore, usually aim to create a semantic 3D city model and keep it up to date. The objects of the model are usually enriched with real-time information from the Internet of Things (IoT) as well as the results from various simulations such as solar potentials, noise propagation or traffic. The aim is to obtain the most comprehensive and up-to-date information possible on the current state of the city. In industry, the digital twin of a complex system can be seen as an aggregation of digital twins of the components of the system (BOSCHERT & ROSEN 2016). A major problem in setting up and keeping DTs of more complex systems up-to-date is information integration. This is because the information is heterogeneous and distributed among different stakeholders. This is true for large industrial facilities, like production systems consisting of components from different vendors (BOSCHERT & ROSEN 2016) who might own the DTs of their components, and to a greater extent for cities as they are even more complex and involve much more stakeholders and data owners. Therefore, a Digital Twin of a city will have to be a distributed DT.

Apart from their own work, the authors of this paper are not aware of any publications specifically on DTs of the agricultural landscape. However, numerous standardized information models and many specific GIS projects deal with the representation of landscapes. Examples of standardized information models include the ISO 19152 standard: Land Administration Domain Model or the OGC standard CityGML (GRÖGER et al. 2012) at international level, the INSPIRE directive at European level or AAA modelling at the national level for Germany (ADV 2015). In addition, there are many mostly independent specialist information models of different domains. With the development of the LandModel^{TUM} a first effort was made to map the complex system of the agricultural landscape in an application-independent, spatio-temporal and expandable information model, which serves as the digital twin (MACHL et al. 2019). The elements represented in the information model provide stable reference objects for the enrichment with interdisciplinary information as well as for the development of analysis methods for the detailed analysis of different aspects of the agricultural landscape. The distributed nature of interdisciplinary information has not yet been fully taken into account in the project. Specifically, data from different sources were integrated into the information system and not mapped just as references to distributed data sources.

2.2 Management of Distributed Geospatial Information

With the advances in technology, businesses and the way organizations and their activities are being operated, a great concern has become the management of distributed information. As more complex systems and their complex inter-connections have evolved, the management of distributed information has turned to a must for almost all domains such as the geospatial domain. In the late 1990s, a group of experts and governments proposed to develop Spatial Data Infrastructures (SDI) in order to regulate and harmonize the flow and exchange of geospatial information. SDIs comprise a set of agreements on organizational level and technology standards together with policies to enable the discovery, sharing and interoperable exchange of spatial data (KRESSE et al. 2012). To ascertain these functionalities, a key component of SDI has been defined which is the metadata registry, the "Catalog". In the context of SDIs, standards for metadata such as ISO 19115 or Dublin Core and for catalog services such as OGC CS/W have been developed. For instance, the OGC Catalog Service is a standard that specifies interfaces, bindings, and a framework for defining application profiles necessary for publishing and discovering digital resources (NEBERT et al. 2016). The metadata is responsible for providing resource properties that can be queried and returned through the catalog.

There are several types of catalog metadata. Some are for specialized domains while some are particular to a specific type of resource. In addition to the well-known metadata standards in the geospatial domain, there exist several standard metadata for describing domain information. W3C's Data Catalog Vocabulary (DCAT) is a standard that enables a publisher to describe the dataset or data service in a catalog. DCAT also facilitates interoperable exchange and consumption of metadata among multiple catalogs. Recently W3C has published DCAT version 2, which provides mechanisms to cover any type of information resource (ALBERTONI et al. 2019). These standards are used worldwide in Open Data portals on national and multi-national scales like, for example, the German Open Government Data portal, INSPIRE geoportal, London Datastore, etc. A common feature of most of these catalogs is that the registry of resources is based on the thematic categories and in the form of a dataset (a collection of data on a specific topic) such as information on protected sites under the thematic category "Environment". Nevertheless, with the emergence of the Internet of Things (IoT) and the ever-increasing usage of sensors and real-time information, the type of resources and information managed in the catalog is changing. Especially in the field of agricultural landscape planning and management, a distinctive temporal and spatial heterogeneity of resources, information and physical things (MINBO et al. 2013), and thereby the management of resource owners remains a challenge.

3 A Data Infrastructure for a Distributed Digital Twin

The complexity of the agricultural landscape as a system requires cross-disciplinary and cross-scale understanding. It is particularly important to create interfaces between the various disciplines involved. To deal with such complex systems while appreciating the role of all involved stakeholders, we need a multidisciplinary information infrastructure that takes into account the heterogeneity and distributed nature of information resources and their interconnections. To address the above mentioned requirements we developed a concept named „Smart Rural Area Data Infrastructure – SRADI" which is inspired by the principles of Spatial Data Infrastructures (SDIs), Geodesign, IoT and DTs.

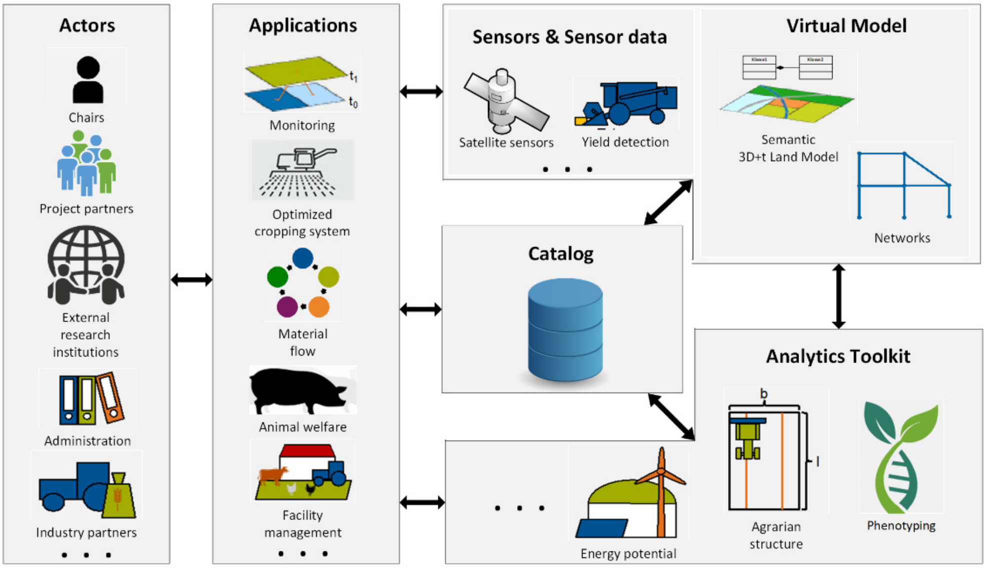

Fig. 1: Smart Rural Area Data Infrastructure – SRADI

As shown in Figure 1, SRADI consists of six core components: "Actors" (stakeholders), "Applications", "Analytics Toolkit", "Virtual Model of Cultural Landscape", "IoT & Sensor data", and "Catalog (Resource registry)". This conceptual model is further developed on the basis of the "Smart District Data Infrastructure (SDDI)" which has been implemented in the context of smart cities (MOSHREFZADEH et al. 2017).

Actors (persons, legal entities) not only provide the resources and data, but also define use cases or applications and accordingly the required functionalities of such tools. Hence, the conception and implementation of SRADI is intended to create an interdisciplinary information infrastructure according to the interests and demands of the diverse actors (e. g. stakeholders).

Applications implement the functionalities required to solve the specific tasks / challenges of the actors. They can be considered as the interfaces between the actors and the distributed DT. The latter consists of the following components:

Virtual Model of the Landscape: a spatio-semantic representation of the landscape as a complex system of interacting and changing elements (e. g. land parcels, hydrologic network, transportation network, vegetation objects). It provides a solid basis for understanding the system of the agricultural landscape as well as for in-depth analyses, e. g. for the recognition, documentation and description of spatio-temporal change processes.

IoT & Sensor data: These comprise all available in-situ and remote sensors including data from third party providers, which are used for enriching the DT with real time information. Examples for in-situ sensors are soil quality sensors, weather stations, GPS trackers on machines and animals. Remotely sensed data comprise satellite and drone imagery and weather data. In general, all kinds of sensors and observation data belong to this group.

Analytics Toolkit: This is a warehouse of existing modelling, analysis and simulation tools that are connected to the other components using standardized service interfaces. Examples of analysis and simulation tools are climate modelling, water source variability, seasonal and storm event simulators, water run-off and soil erosion modelling tools.

The Catalog is the core component of the distributed DT. It not only covers diverse types of distributed resources from projects, software and devices down to the raw data, but also establishes the semantic relations between them. In contrast to existing catalogs as they are used in SDIs, the catalog in our concept is not limited to managing information on the dataset or service level, but functions on the level of individual physical things (like an individual agricultural parcel or machine). Also, the catalog manages not only resources, but also stakeholders and organizations that are involved in the whole process.

In our approach, interoperability is considered as the main aspect for modeling and maintaining the distributed DT of the agricultural landscape. A DT can only be created if the components are able to interoperate. Communication and data modeling is therefore based on open standards such as the ones from ISO (e. g ISO 191xx), OGC (GML, Sensor Web Enablement including the SensorThings API) and W3C (DCAT, DCAT2, RDF). In this paper, we focus on and discuss two main challenges related to creating a DT of the landscape, namely the problem of distributed information resources and the problem of integrating real time information on landscape objects into the DT.

4 Handling the Distributed Nature of Information Resources

In an agricultural landscape system various actors are involved, each with a considerable amount of resources and information. Hence, dealing with distributed information resources is a big challenge. In an on-going project for an agricultural research center of our university, we conducted interviews with many members. The following section highlights some outcomes of these interviews.

4.1 Challenges, Requirements and Approaches

The two main challenges for the integration of information from distributed, heterogeneous resources are a lack of transparency and the multidisciplinary, distributed environment.

Lack of transparency: Different stakeholders have different information about the same real-world object (e. g. the same land parcel, the same road). They typically do not know what data is available from others. Hence, the following questions arise: Who are the actors and what are their responsibilities and contributions? Who is going to be affected by modification of the landscape? What projects have taken place on a particular land parcel before? By whom were they carried out? Who owns which sensor data for a given land parcel? Who has what information about a specific section of a creek?

Data integration in a multidisciplinary, distributed environment: Even if the different actors know about data of others on real-world land parcels, the integration of information can be difficult, because the ways they define and refer to that specific real-world object are not necessarily the same. For example, stakeholders have different ways of semantically and geometrically representing a landscape object and they also use different object identifiers. This causes problem when the data of multiple actors should be integrated and linked. Therefore, the questions are how to relate different data about the same real-world things to each other. This is a critical point for the DT of the agricultural landscape because of the nature of continuous spatio-temporal changes of the landscape objects (e. g. land parcels) that directly affect the integration of resources on the basis of those objects. In order to address this challenge, it is beneficial to have a single representation of the real world objects so that each real world object is represented only once with a globally unique identifier. Then, stakeholders can relate their information on real-world objects by linking their information to these reference objects. However, this only works if these landscape objects have stable identifiers, which preserve the link over long-term.

As a response to these challenges, we propose to setup a catalog as a registry for resources of all types as well as their providers (stakeholders). As mentioned above, we have developed a concept that goes beyond the well-known catalog components of SDIs (described in section 2.4). In our approach, the resources which should be covered by the catalog include not only datasets and services that access and process the data, but also entries for all relevant individual physical things (e. g. landscape objects or devices like sensors and farming machines) and the details of involved organizations and stakeholders. Links are established between the virtual landscape model and stakeholders and their information resources. Hence, for a landscape object (e. g. land parcel) a user can retrieve its related resources and the corresponding stakeholders. For the landscape objects, we use data provided by the government (geo base data) where all objects have stable identifiers. This ensures that the created relationships will remain valid during the life cycle of the real-world objects. If other data sources such as Volunteered Geographic Information (VGI) (e. g. OpenStreetMap) would be used, the lack of stable object identifiers would become a problem.

4.2 Metadata Model for the Distributed Digital Twin

In order to model the distributed linked resources, we developed a metadata model based on the DCAT version 2 standard (ALBERTONI et al. 2019). The metadata model designed specifically for the Distributed DT of the agricultural landscape contains the following classes and relations (shown as a UML class diagram in Figure 2):

- The class *InformationResource* represents general information about various types of resources. It also allows to specify whether the information on a specific resource is freely accessible to all (public) or only to members of an organization (private).
- The types of resources are distinguished by introducing nine specific sub classes of the class *InformationResource*. These are *Dataset*, *OnlineService*, *OnlineApplication*, *Software*, *Project*, *Method* and *PhysicalThing,* which is further specialized to *Device*, *Animal* or *LandscapeObject*.

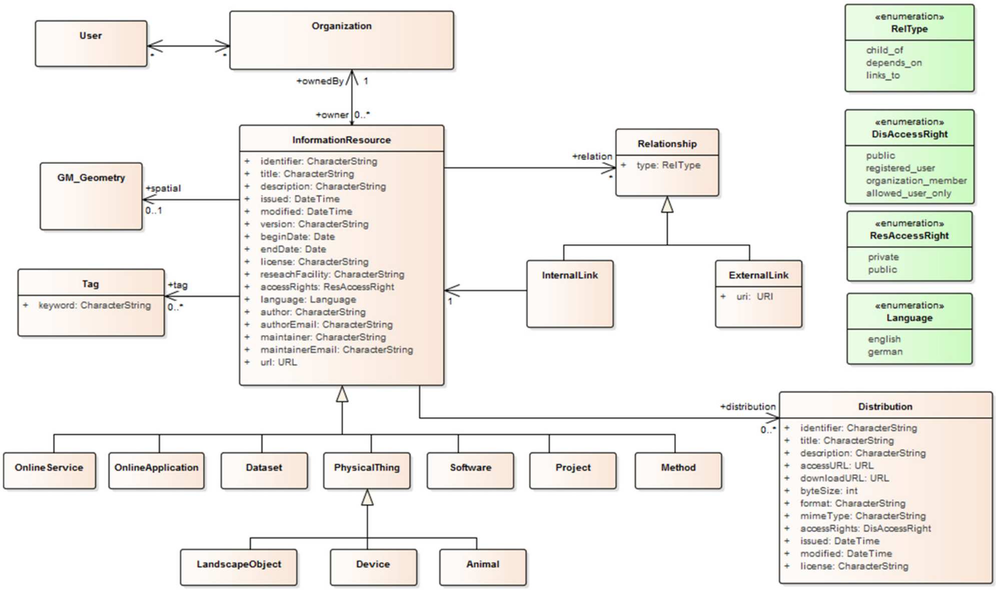

Fig. 2: Generalized overview of the metadata model for the distributed DT

- An *InformationResource* can be represented by an accessible form of a dataset such as a downloadable file or over a web service. This is realized by a relation between the class *InformationResource* and the class *Distribution*. The class *Distribution* again allows the user to control the accessibility of the information. Thus, it is possible to make the metadata open, but to restrict the accessibility of the distributed data.
- The classes *User* and *Organization* are used to manage the stakeholders in the SRADI. Users can be members of multiple organizations and have different types of memberships. Organizations can provide multiple resources, but each resource can only be owned by one organization.
- Relationships between resources of the distributed DT as well as with external resources can be represented by the class *Relationship*. The class *Relationship* is specialized either as *InternalLink* to express a relation to another resource registered in the catalog or as *ExternalLink* to express a relation to an external resource. In general, a relationship is used for linking not only the information resources, but also to show how organizations are connected. With relationships between catalog entries, we create a graph describing the distributed, but interrelated information resources. There are three different types of relations: The type "depends_on" is used to express that an information resource has to be seen in the context of another one. It is used to establish the relationships between information resources from different organizations on a real-world object and the reference object representing the physical object. The "child_of" relationship is used to express part-of-relationships such as projects and subprojects. The relationship type "links_to" is used to link resources that can exist independently of each other. These relationship types are already predefined in the catalog system CKAN being used to implement the concept (c. f. section 6). However, to the best of our knowledge they have not been applied in the described way so far.

Only outgoing links are used for resources. This means that additional resources like subparts or additional information on a physical thing (like a land parcel) provided by the same organization have a reference to their parent (e. g. the *InformationResource* object representing the physical thing). The link belongs to the organization who created that additional dataset (and is only revocable by that owner). The owner of the parent resource does not (and typically cannot) administer those links. Therefore, when linking two resources, the organizations to which the resources belong and their accessibility status must be considered. This is controlled by the accessibility restriction given in the class *InformationResource*. While public resources are freely accessible, private resources can only be seen by their organizations and thus, can only be augmented by additional datasets from the same organizations. The conditions for linking resources with different accessibility restrictions are shown in Table 1.

- The spatial extent of a resource is represented using the class "GM_Geometry" from ISO 19107. This could be, for example, a point, a polygon or a multipolygon.
- In order to model the temporal properties of a resource, a bitemporal approach is used. This is introduced by the attributes "issued" and "modified" (transaction time regarding the catalog), and "startDate" and "endDate" (valid time regarding the existence of the physical thing), respectively.

Table 1: Linking of two resources within the catalog and the restrictions resulting from the accessibility of the resources

Link to (parent) / Link from (part)	Public parent	Private parent
Public part	possible between datasets from different organizations	does not make sense; forbidden
Private part	possible between datasets from different organizations	only possible between datasets from the same organization

A key feature of our metadata model is the specialization of the information resource types. The data catalog and their standards used in SDI and by open data portals mostly refer to (open) governmental data, provided as files or services. Hence, the metadata models are tailored to represent only data catalog entities. However, in our approach we have a catalog that assembles more diverse kinds of resources that are relevant to distributed DTs of agricultural landscapes such as information about physical things or information about projects and methods. This has been done by introducing not only the class *PhysicalThing* with its subclasses *LandscapeObject*, *Device*, and *Animal*, but also other specific classes such as *Method*, *Project*, and *Software*. In addition, we do not only register information resources, but also the physical objects themselves. In fact, by defining explicitly the type of a resource as introduced in our metadata model, we added specific semantics related to the DT of the agricultural landscape. These semantics improve the structuring and retrieval of information in the catalog. For each real world object (e. g. land parcel, sensor, and farming machine) there is an own entry in the catalog. This enhances the applicability and usability of relationship between diverse and multiple resources owned by different organizations. This distinguishes the introduced metadata model from typical geospatial metadata and DCAT data models (e. g. DCAT version 2) and in general from traditional catalogs.

5 Integrating Real-time Information on Landscape Objects

As mentioned above, one of the main characteristics of DTs is that their current state reflects the actual state of their physical counterpart. This is where the capabilities of Internet of Things (IoT) technologies come into play. Through a real-time connection with IoT nodes in the physical world, a DT of the agricultural landscape receives temporally high-resolution information of the real, prevalent condition of each landscape object.

5.1 Characteristics and Requirements

Both the design and operation of IoT applications in the field of agricultural landscape management are challenged by a very specific context compared to other domains. This is due to conditions such as a local absence of electrical power grids and Internet connectivity, and exposure to raw environmental conditions. Both bring along special requirements for hardware and communication design, as well as for their robustness towards disturbances and device blackouts. Within the framework of Wireless Sensor Networks (WSN), the sub-field of Low-Power Wide-Area Networks (LPWAN) offers powerful technological features to meet these requirements. LPWAN-based IoT solutions provide the technical basis to collect data streams from remote and geographically widely dispersed sensors devices through energy-efficient, long-range wireless communication (MINBO et al. 2013). The applied IoT networks and their data streams establish a bridge between the real-world condition of a landscape object and its digital counterpart. IoT networks strongly influence the design of the distributed DT, which should be capable of accounting for flexible numbers and a possibly strong heterogeneity of IoT devices. Real-world landscape objects and their digital equivalent may be related to only one or to several devices, enabling the entire range of 1:1, 1:N and N:M relations between landscape objects and device-related data streams. Further variability in the system can be identified in the heterogeneity of information streams. Devices and data sources comprise the entire range from in-situ sensors and actuators to remote satellite sensing. The number, type, and transmission frequency of provided data streams, their portions of static and dynamic information contents over time as well as their transmission interfaces can differ substantially. Managing the heterogeneity of these interfaces is a major challenge for an efficient and interoperable integration of sensor data.

5.2 Sensor Data Integration into the SRADI

For this purpose, an LPWAN-based WSN for in-situ sensors is established over the entire landscape used and managed by our university. The structural setup and relevant components are shown in Figure 3. Each sensor node within the WSN is responsible for acquiring physical properties of the landscape object to which it is assigned. In-situ sensors are connected to the digital world by means of a sensor network infrastructure via wireless communication technology and respective transceiver gateway stations. For uplink data of the sensor nodes the gateways forward the received data packages to a dedicated sensor management and storage system through respective network processing services. The network processing services connect the gateways, and by that indirectly the sensor nodes, to a common network and ensure secure data transfers and the distribution of data packages to the correct receiver application. The sensor management and data storage component allows for automated processing and storing of incoming and historic data entries. The link between the representation of an object in the virtual model of the cultural landscape and the sensor management and data storage component is established by relations between the corresponding entities in the SRADI catalog.

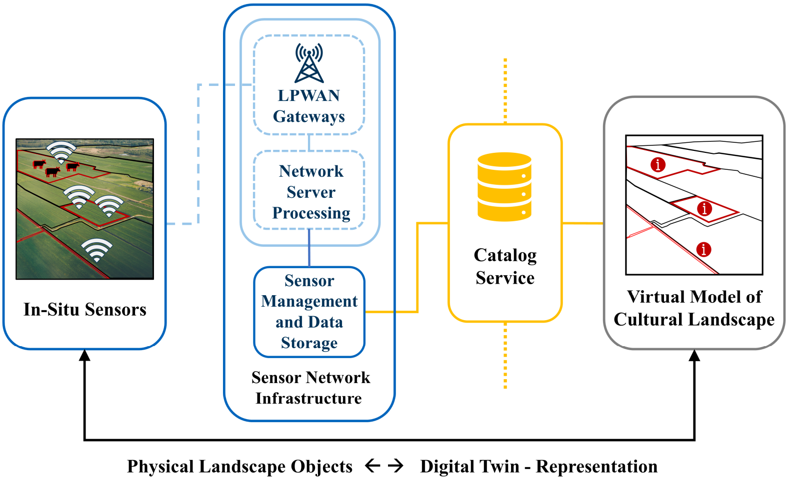

Fig. 3: Integration of real-time sensor data into SRADI

6 Realization and Demonstration of the Distributed Digital Twin in an Agricultural Landscape Research Environment

As a proof of concept for our distributed DT approach, we have set up a data infrastructure for the Agricultural Research Center of the Technical University of Munich (TUM), the "Hans Eisenmann-Forum for Agricultural Sciences", associated with the TUM school of life sciences. The center is promoting and developing digital solutions in the fields of agricultural research and landscape planning, specifically in the fields of agroecology, terrestrial ecology, ecosystem management, environmental monitoring, plant sciences, animal sciences, agricultural and environmental economics and policies. As the main outcome of a baseline study among the 30 chairs that are members of this center, we identified two key points:

First, numerous research activities and experiments are conducted by different teams in multi-disciplinary studies and at cross-scale levels. These activities are carried out in the research facilities owned by the faculty (e. g. fields, stables) both indoors and outdoors. Consequently, huge amounts of data at different time intervals are generated, collected, analysed and archived in different places. At the same time, several stationary equipment (e. g. weather sensors) and mobile devices (e. g. GPS) are used, which are located in different places. The absence of proper management of the existing distributed resources at both the administrative level and at the level of individual research activities is a problem so far.

Second, many researchers are doing experiments in and with the landscape. We model the whole processes happening during a certain time interval at a specific landscape object. For example, we digitally represent the research parcels in the landscape as well as the laboratories, or objects such as devices with specific location characteristics (stationary and mobile objects). We can consider each of these landscape objects and devices as physical things that can be virtually modelled, according to the DT approach.

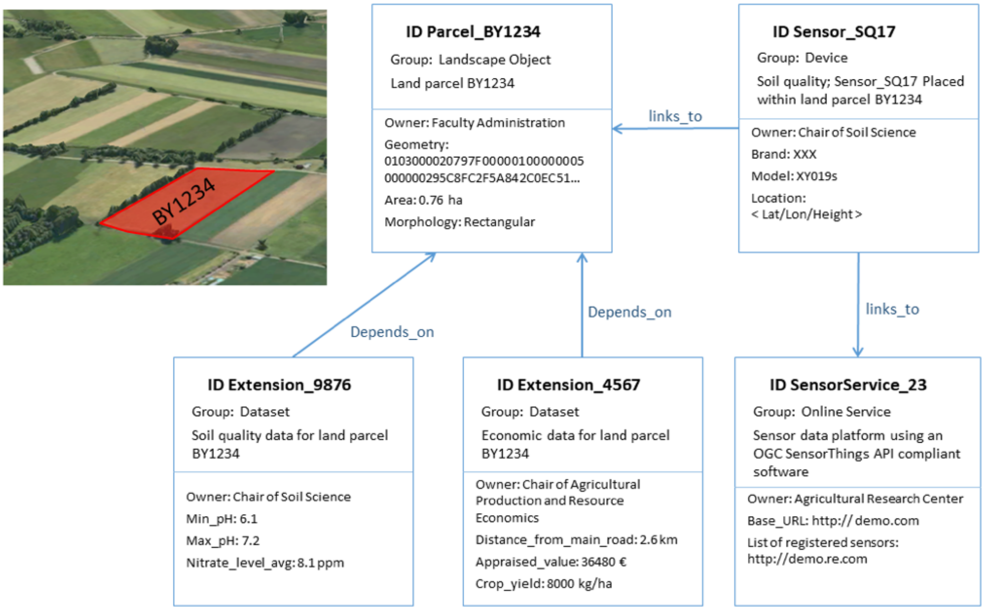

Fig. 4: Example for a Distributed DT of a Land Parcel. Each box represents an information resource in the catalog

To illustrate the situation, an example of the distributed DT of a landscape object is given in Figure 4. In this example, five resources from four organizations are linked. The resource with the identifier "Parcel_BY1234" and resource type "LandscapeObject" represents an agricultural parcel owned by the faculty administration. The basic information of this object (identifier, geometry, area) is stored in a database system implementing the virtual landscape model. An analytics tool has been applied on the geometry of the object in order to classify the morphology as being rectangular. This basic information has been extracted from the database and has automatically been registered as an "InformationResource" in the catalog. For the same parcel, two datasets owned by two different chairs exist. They are represented by two additional catalog entries of type "Dataset" which have been manually entered by the corresponding chairs. They are linked to the catalog entry of the land parcel using outgoing relationships of type "Depends_on". In addition, there is a soil quality sensor installed on the land parcel that belongs to another chair. This resource has a catalog entry type "Device". The sensor data are stored in a sensor data platform (an OGC compliant SensorThings API) operated by the Agricultural Research Center. The resource representing the sensor device is linked both to the land parcel and sensor data platform. This example demonstrates:

1) the management of distributed data on landscape objects owned by different organizations,
2) the connection between real-world objects and sensors providing real-time information,
3) the relationship between sensors (Device) and the sensor data platform (OnlineService); the latter being able to manage the data of several sensors,
4) the relationship between resources and organizations / people / stakeholders such as the ownership of each resource and its connection to the resources of other organizations

To demonstrate the capabilities of the distributed DT with regard to the requirements of our cultural landscape research environment, the following components were implemented:

Catalog: Comprehensive Knowledge Archive Network (CKAN) has been choosen as the resource catalog in our project, due to several advantages (https://ckan.org/). CKAN is an Open Source Software with an active community that constantly improves and upgrades the software and supports users worldwide. It is widely used by many national governments and international bodies such as in Australia, USA, Germany, etc. In addition to the core CKAN, a large number of extensions exist which further extend the capabilities of CKAN as a data portal. In our project, we set up an instance of the core CKAN and adopted its functionalities according to our concept of distributed DT for the cultural landscape. We added some already developed extensions to cover, for example, spatial and temporal attributes of resources. In addition, own extensions for required extra functionalities have been developed. This specifically includes the mapping of the metadata model to the CKAN data model. Moreover, to enable sharing and exchanging of the metadata to other catalogs, the CKAN extension DCAT is used which allows CKAN to expose and consume metadata from other catalogs using RDF documents serialized using DCAT. We further configured it in order to map the developed metadata model to DCAT. Mapping of this metadata model to DCAT version 2 and implementing it in CKAN will be part of the future work.

IoT and Sensor data: The LPWAN-standard LoRaWAN was chosen as transmission technology due to several advantages such as low-power transceivers that can run on battery power for long periods (up to 5 years), long-range transmission coverage ranges from 2 kilometers in urban areas to more than 40 kilometers in rural environments, fewer required gateways in comparison with other types of radio networks due to long-range transmission coverage, communication operates on license-free frequency bands like 868 MHz (Europe) in contrast to 3/4/5G networks, and inexpensive equipment (20 € for a sensor node with LoRa module) (LoRa Alliance 2015). The intended sensor network infrastructure is designed to be exclusively based on open and international standards, including standards from the OGC Sensor Web Enablement (SWE) (Open Geospatial Consortium 2020) and the messaging protocol Message Queuing Telemetry Transport (MQTT). From the scope of SWE standards, the SensorThings API is chosen as an elementary basis for the management of data streams of this sensor network infrastructure. It provides an open and unified framework for the interconnection of IoT devices, data and web applications (Liang et al. 2016).

Virtual Model of agricultural Landscape: The developed spatio-temporal information model of the landscape is based on international standards of the ISO 191xx family of standards and describes fundamental components of the agricultural landscape (Machl et al. 2019). The information system is implemented using the object-relational database management system PostgreSQL (https://www.postgresql.org/), including several extensions like PostGIS (http://postgis.net/) or pgrouting (http://pgrouting.org/). As of 31.12.2018, the information system covers more than 26 million objects representing the state of the agricultural landscape of our entire federal state at that time. In addition to agricultural land use, the objects represented in the information system also cover vegetation, settlement, traffic and water areas as well as property boundaries.

7 Conclusions and Outlook

In this paper we described our concept of a distributed DT of the cultural landscape. The concept has been developed in the context of agricultural science and landscape research and is based on the requirements of a multidisciplinary agricultural research center. The main contributions are:

1) Development of a metadata model which supports the management of distributed information resources with different kinds of data (file, web service), format and data model, ownership, privacy level and license. This metadata model is the basis of a catalog, which promotes transparency and information integration. 2) Due to its unique ability to link landscape objects and owners of information on these objects, the DT of the agricultural landscape can also improve data preparation and stakeholder engagement within Geodesign processes. This is because the information owners can be assumed to be a subset of the "people of the place" (STEINITZ 2012). By querying the catalog, the persons/organizations who own data related to a specific landscape object can be identified immediately. It can be assumed that these persons / organizations are among the stakeholders who should be involved in a process that evaluates and changes the landscape. 3) The link between real-world objects and real time information from different sources. 4) An implementation of the distributed DT, which relies on well-known open international standards, Open Source Software, and demonstrates the capabilities of the DT in agricultural landscape research.

A challenge we face during the operation of our concept in our faculty, and beyond, is that for the catalog, organizations as the owners of their resources should fill in the catalog metadata. However, it is difficult to convince people to do this, as it requires time and understanding of the catalog. In addition, translating the value of our approach into diverse user interests requires clear understanding of the user domains and their limitations.

In order to complete the distributed DT of the landscape, our future research will focus on linking the calculation and simulation models of the stakeholders with the SRADI. Thus, it will be possible to assess the impact of changes to the landscape and to perform what-if scenario modelling on the distributed DT of the cultivated landscape. Currently the metadata model does not support version management, which would be required for studying the history and alternative futures of the DT. It is necessary to ensure the interoperability and transferability of our concept to other implementations used in the agricultural landscape domain or even implementations for other domains like forestry. Additional research will also be required regarding the identification of proper "root objects". These are stable reference objects (in our implementation the land parcels and sensor devices) that are a suitable basis for linking further information.

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