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FOODIE DATA MODELS FOR PRECISION AGRICULTURE

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Abstract. *The agriculture sector is a unique sector due to its strategic importance for both citizens (consumers) and economy (regional and global), which ideally should make the whole sector a network of interacting organizations. The FOODIE project aims at building an open and interoperable agricultural specialized platform hub on the cloud for the management of spatial and non-spatial data relevant for farming production. The FOODIE service platform deals with including their thematic, spatial, and temporal characteristics as well as their meta-information. Most of current information systems deal with data in the proprietary structure that fits the most to the purposes of each organization or individual. The structure of data itself is commonly proprietary even if there is a standard exchangeable format used by an information system. As a result, many organizations as well as individuals produce massive amounts of information for internal and external purposes. If we would like to integrate data from several sources, we need to establish a unified data model that is capable to include all the nuances of the underlying data models. In this regard, the conceptual model of FOODIE relies upon the following basic pillars: Data and service modelling in the geospatial domain relies upon the series of ISO/OGC geospatial standards and best-practices, Data and service* *modelling in the agriculture domain relies upon specific agriculture standards and best-practices such as the INSPIRE data model for Agricultural and Aquaculture Facilities, Transport and Monitoring Facilities. The paper described data models implemented as part of FOODIE infrastructure. In addition, FOODIE data model specification ensures: unified understanding and concept of agricultural data; interoperability with other similar (sub)systems when using open data in a standardized way; compliance with existing legislative requirements in Europe (especially INSPIRE and LPIS).*

Keywords. *Precision Agriculture, Data Model, FOODIE, INSPIRE, OGC, LPIS*

Introduction

The agriculture sector is a unique sector due to its strategic importance for both citizens (consumers) and economy (regional and global), which ideally should make the whole sector a network of interacting organizations. Rural areas are of particular importance with respect to the agro-food sector and should be specifically addressed within this scope. The FOODIE project aims at building an open and interoperable agricultural specialized platform hub on the cloud for the management of spatial and non-spatial data relevant for farming production; for discovery of spatial and non-spatial agriculture related data from heterogeneous sources; integration of existing and valuable European open datasets related to agriculture; data publication and data linking of external agriculture data sources contributed by different public and private stakeholders allowing to provide specific and high-value applications and services for the support in the planning and decision-making processes of different stakeholders groups related to the agricultural and environmental domains (Charvat, et al., 2014).

The FOODIE service platform deals with thematic, spatial, and temporal characteristics as well as corresponding meta-information. Most of current information systems deal with data in the proprietary structure that fits the most to the purposes of each organization or individual. Any information system in the agricultural, soil, meteorological, etc. domain is not an exception. Most of these information systems deal with data in the proprietary structure that fits the most to the purposes of each organisation or individual. The structure of data itself is commonly proprietary even if there is a standard exchangeable format used by an information system. As a result, many organizations as well as individuals produce massive amounts of information for internal and external purposes. If we would like to integrate data from several sources, we need to establish a unified data model that is capable to include all the nuances of the underlying data models.

In this regard, the conceptual model of the FOODIE platform relies upon the following basic pillars:

- Data and service modelling in the geospatial domain relies upon the series of ISO/OGC geospatial standards and best-practices.
- Data and service modelling in the agriculture domain relies upon specific agriculture standards and best-practices such as the INSPIRE data model for Agricultural and Aquaculture Facilities, Transport, Monitoring Facilities (JRC, 2013).

In addition, FOODIE data model specification is a task that must ensure:

- Unified understanding and concept of agricultural data.
- Interoperability with other similar (sub)systems when using open data in a standardized way.
- Compliance with existing legislative requirements within (and beyond) Europe (especially INSPIRE and Land Parcel Information System (Grandgirard & Zielinski, 2008).

A final evaluation is foreseen for the FOODIE Data model specification in order to fulfil all three above mentioned essential requirements. Therefore, bear in mind that is the third of four approximations to the final data model that may still further evolve in the future.

Any information system gains added value when it is based on the standards used within the particular domain. All sections in this document show that such approach will result in the syntactic interoperability ensuring the data exchange itself through standardized interfaces, services, protocols, formats, coordinate reference systems, etc. The following step may be identified in establishing the semantic interoperability, i.e. the ability of services to exchange data in a meaningful way and with a minimum human intervention (Janowicz, et al.). In other words, we desire that any FOODIE component will share a common understanding of data to produce meaningful results (Esbrí, et al., 2014). The FOODIE data model was transformed from geographic information presented in the form of UML models to OWL ontologies as defined by the ISO 19150-2 standard to support Agricultural Linked Data (Palma, Reznik, Esbrí, Charvat, & Mazurek, 2016) .

Current approaches to data modelling in the agriculture domain

Future Farm (Sorensen, et al.) says that farmer needs to manage a lot of information in order to make economic and environmental sound decisions. Such process is very labour intensive due the facts, that most parts have to be executed manually. The farm activities include tasks of monitoring field operations, manage the finances and application for subsidies depended on different software applications. Farmers need to use different tools to manage monitoring and data acquisition on-line in the field. They need to analyse information related to subsidies, communicate with tax offices, product reseller's etc. (Charvat, et al., 2012). All these needs can be described by the schema in Fig.1.

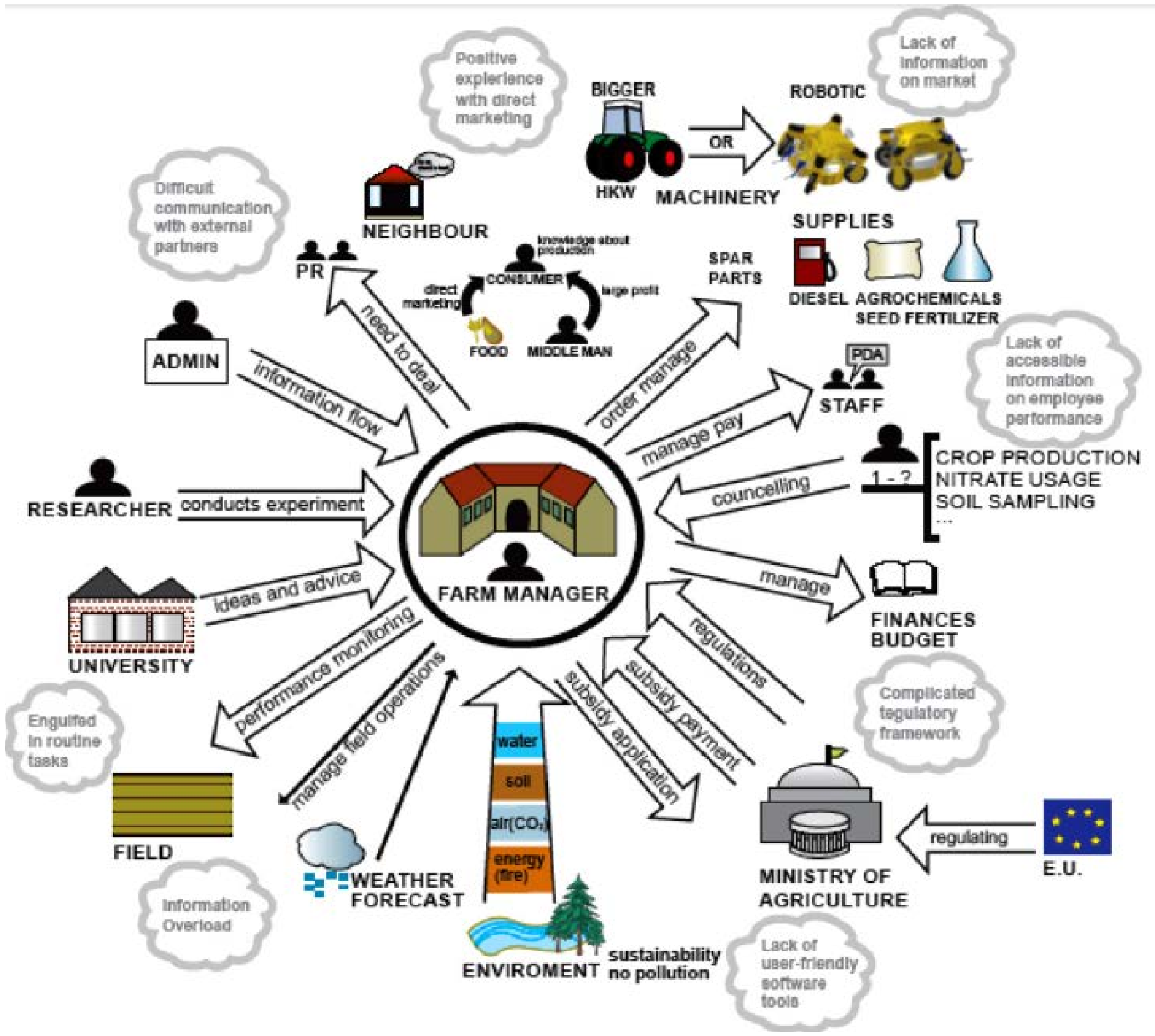

Fig 1. Schematic overview of relationships between farm management and its environment (Sörensen, et al., 2010).

W3C

The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. The W3C mission is to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web. Below we discuss important aspects of this mission, all of which further W3C's vision of One Web (W3C). As mentioned above, Linked Data initiative is one of the examples.

OGC

The Open Geospatial Consortium (OGC) is an international industry consortium, government agencies and universities participating in a consensus process to develop publicly available interface standards. OGC® Standards support interoperable solutions that "geo-enable" the Web, wireless and location-based services and mainstream IT. The standards empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. (OGC)

INSPIRE data model for Agricultural and Aquaculture Facilities

The Agricultural and Aquaculture Facilities (hereinafter AF) model is composed by core information in relation to the geographical description of entities under the Agriculture and Aquaculture scope. Agricultural and aquaculture facilities are in the European INSPIRE Directive (EC, European Commission, 2007) defined as "farming equipment and production facilities (including irrigation systems, greenhouses and stables)".

The AF data model is based on the Activity Complex model (EC JRC, 2013). “Activity Complex” is in INSPIRE a generic name agreed across thematic domains trying to avoid specific thematic connotations such as “Plant”, “Installation”, “Facility”, “Establishment” or “Holding”. Because of this, the Activity Complex model must adhere to the requirements of horizontal datasets in which facilities are considered independently of their thematic scope. Such scope may be for the FOODIE project the Nitrate Directive, Water Framework Directive or Waste Directive.

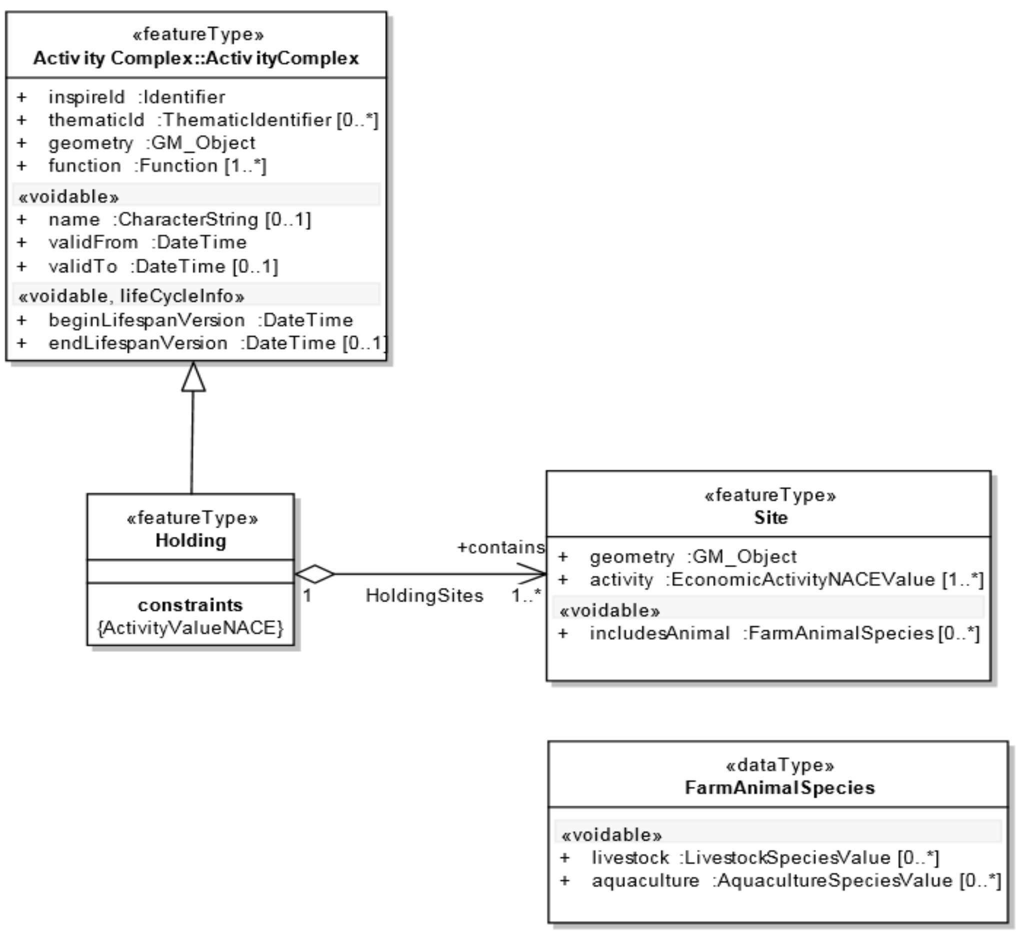

Fig 2. Overview of the feature types and data types of the Agricultural and Aquaculture Facilities Model application schema (EC, 2013).

Please, note that there are also other INSPIRE data specifications within the scope of the FOODIE project, such as for the spatial data themes called “Transport Networks” to support e.g. routing of agricultural vehicles or “Environmental Monitoring Facilities” to support measurements by means of sensor networks.

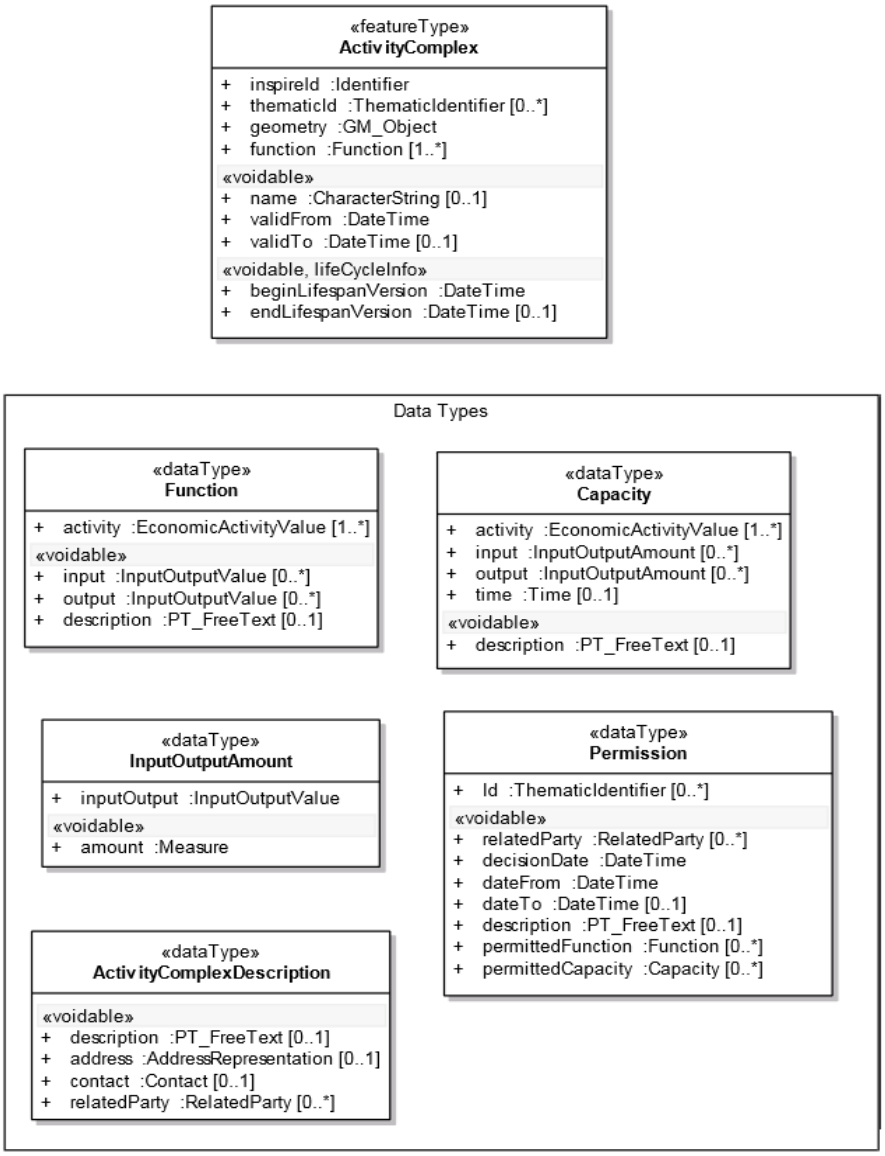

Fig 3. Overview of the feature types and data types of the Agricultural and Aquaculture Facilities Model application schema.

Agro-domain standards

Since 1990, the concept of using spatial data for precision agriculture and food traceability has attracted the attention of the agricultural community (Ehsani & Durairaj). However, the data models were tightly connected to the application. For instance, GPS (Global Positioning System) receivers can relay position data to a PC or other device using the NMEA 0183 protocol (NMEA, 2014), soil information was structured (classified) and expressed according to the traditions of each country, information on fertilizers, pesticides and yield of the crop was stored in a proprietary way etc.

Even now, the tendencies for the unification of the data models mostly follow top-down approach instead of bottom-up. We may see that the standardization started, commonly to other domains, through agreed exchangeable formats and later on also services. On the other hand, it does not influence the underlying data model itself. In general, agricultural data are traditionally closed with limited access and subject of a trade secret.

So far, the most complex approach called “Agricultural Information Management Standards” (AIMS) has been presented by the FAO (FAO, 2014). This initiative, launched in 2006, is a space for accessing and discussing agricultural information management standards, tools and methodologies connecting information workers worldwide to build a global community of practice. Information management standards, tools and good practices can be found on AIMS to:

- support the implementation of structured and linked information and knowledge to enable institutions and individuals from different technical backgrounds to build open and interoperable information systems;
- provide advice on how to best manage, disseminate, share and exchange agricultural scientific information;
- promote good practices widely applicable and easy to implement, and;
- foster communities of practices centred on interoperability, reusability and cooperation.

ISOBUS represents another of the core standardization activities in precision agriculture domain. It is managed by the ISOBUS group in VDMA. The VDMA (VerbandDeutscherMaschinen- und Anlagenbau - German Engineering Federation) is a network of around 3,000 engineering industry companies in Europe and 400 industry experts.

The ISOBUS standard specifies a serial data network for control and communications on forestry or agricultural tractors. It consists of several parts: General standard for mobile data communication, Physical layer, Data link layer, Network layer, Network management, Virtual terminal, Implement messages applications layer, Power train messages, Tractor ECU, Task controller and management information system data interchange, Mobile data element dictionary, Diagnostic, File Server. The work for further parts is ongoing. Moreover, it was approved as ISO 11783 standard. (Wiki)

agroXML is a standard facilitating data exchange in agriculture and other sectors in contact with agriculture. agroXML is developed by the KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft; German Association for Technology and Structures in Agriculture) and partners among developers of agricultural software systems, machinery companies and service providers. agroXML is based on the internationally standardised eXtensibleMarkup Language (XML). It consists of schemas complemented by content lists. The schema is designed in a modular way. The English language is used for data type and element names and the documentation. Essential modules with definitions concerning the farm and plant production are currently available, modules for livestock farming are in development (agroXML).

Land Parcel Information Systems

Land Parcel Information Systems (LPIS) represent the reaction to the Common Agricultural Policy (CAP) in Europe. They were designed as the main instrument for the implementation of the CAP first pillar – direct payments to the farmer, i.e. to identify and quantify the land eligible for payments. Moreover, additional spatial data are used in the Land Parcel Information Systems as well to effort on sustainable rural development.

Land Parcel Information Systems are operated in each European Member State with various underlying data model. Therefore, we may talk about interoperability only partially. The main reason lies in the different approach to the granularity of agriculture land. On the other hand, the Institute for Environment and Sustainability of the Joint Research Centre of the European Commission (JRC-IES) is continuously working to adapt the newly developed methodologies, practices and templates in order to improve the LPIS and IACS-GIS applications. At the moment, the 45 land parcel information systems across the EU hold more than 135 million detailed land parcels, annually declared by 8 million farmers in the EU (according to http://ies.jrc.ec.europa.eu).

A Spatial Data Interest Community called “Integrated Administration and Control System – Common Agricultural Policy” (IACS-CAP) was established to enable LPIS systems to comply with the developing INSPIRE requirements on Geographic Information.

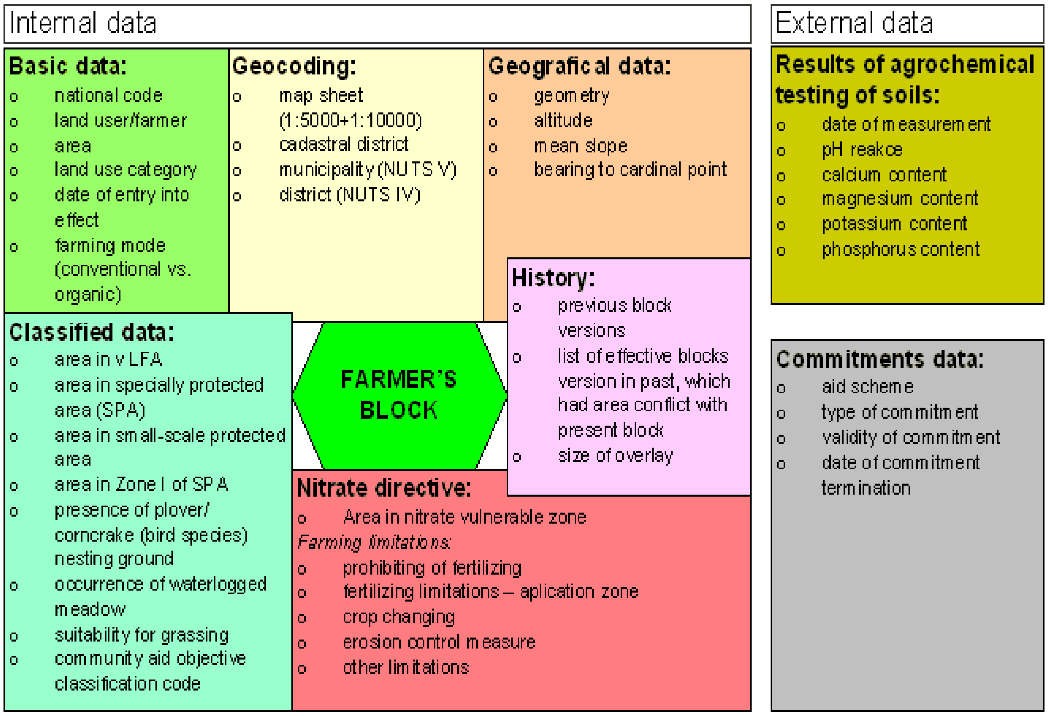

Fig 4. Data structure of the Czech LPIS (adopted from http://www.lpis.cz/en/).

FOODIE Data Model

Compliance with data related standards and information models in the geospatial and environmental domains

There is an extensive set of geospatial and environmental (open) standards that cover data models and metadata specifications. The main standardization bodies in the geospatial domain are ISO, OGC and CEN. All of these work on wider community standards, some also on domain specific models. Besides, these have certainly high relevance for the agricultural domain and accordingly, we use their standards as a baseline – but by far not as the only source – for developing FOODIE service platform architecture. On the other hand, FOODIE follows a brokering approach for data discovery and access, which allows us to account for a diversity of data models and to translate available information in the desired data model(s), in particular, the FOODIE data model.

The FOODIE consortium has found a consensus on the content and structure of the FOODIE Data Model. The resulting FOODIE Data Model has also been consulted with several experts from various institutions like the Directorate General Joint Research Centre (DG JRC) of the European Commission, the European Global Navigation Satellite Systems Agency (GSA), Czech Ministry of Agriculture, Global Earth Observation System of Systems (GEOSS), or the German Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL). The developed FODIE Data Model has also been revised for its semantic and implementation preparedness.

In order to ensure the maximum degree of data interoperability, FOODIE data model follows INSPIRE generic data models, in particular the aforementioned INSPIRE data model for Agricultural and Aquaculture Facilities, by extending and specializing them (see Figure 2).

FOODIE Core Data Model

When taking the Figure 4 into consideration, we may further specialize the data model for provided in the INSPIRE data specification for Agricultural and Aquaculture Facilities. For the FOODIE purposes, there should be a feature on a more detailed level than "Site" that is already a part of the INSPIRE data model. The main motivation is to represent a continuous area of agricultural land with one type of crop species, cultivated by one user in one farming mode (conventional vs. transitional vs. organic farming). Such feature is called “Plot” in the FOODIE core data model specification, being its elementary reference item in the data model.

The term “Plot” originates from concept presented in the INSPIRE data specification on Agricultural and Aquaculture Facilities. FOODIE data model also contains “ManagementZone” feature type that is one lower level than the “Plot“. In other words, a “ManagementZone” is a spatial subset of a “Plot” that has specific properties like electric conductivity, organic matter, pH, soil texture, soil type or soil nutrients.

An example of a “Plot” is depicted in Fig 6, where each “Plot” has a unique identifier to distinguish a “Plot” from any other “Plot”. Please, note that a “Plot” does not imply any explicit relation to the cadastre. For instance, a “Plot” may be only a part of a cadastral parcel. In other words, a cadastral parcel may contain from zero to many (0..N) “Plots”. Furthermore, a “Plot” may have attributes like fertilizer that may appear as “zero to many” with a date stamp to support the history of fertilizers on a Plot.

The parent entities named “Site” and “Holding” remain the same as defined in the INSPIRE data model. The only one exception is the *userId* attribute of the *ActivityComplex* feature type that has been added into the FOODIE core data model in comparison to the underlying INSPIRE data model. The *userId* attribute is a unique identification of an owner of the “Holding”, i.e. “farm” in the real life. Such attribute is crucial for commercial applications.

FOODIE core data model specification has been designed to be an open data model, thus allowing extending it through associations and/or attributes that further specialize the “Plot” feature. The aim of this extension is to provide modularity and enable any farmer/external service provider using FOODIE platform to extend the data model according to his/her needs.

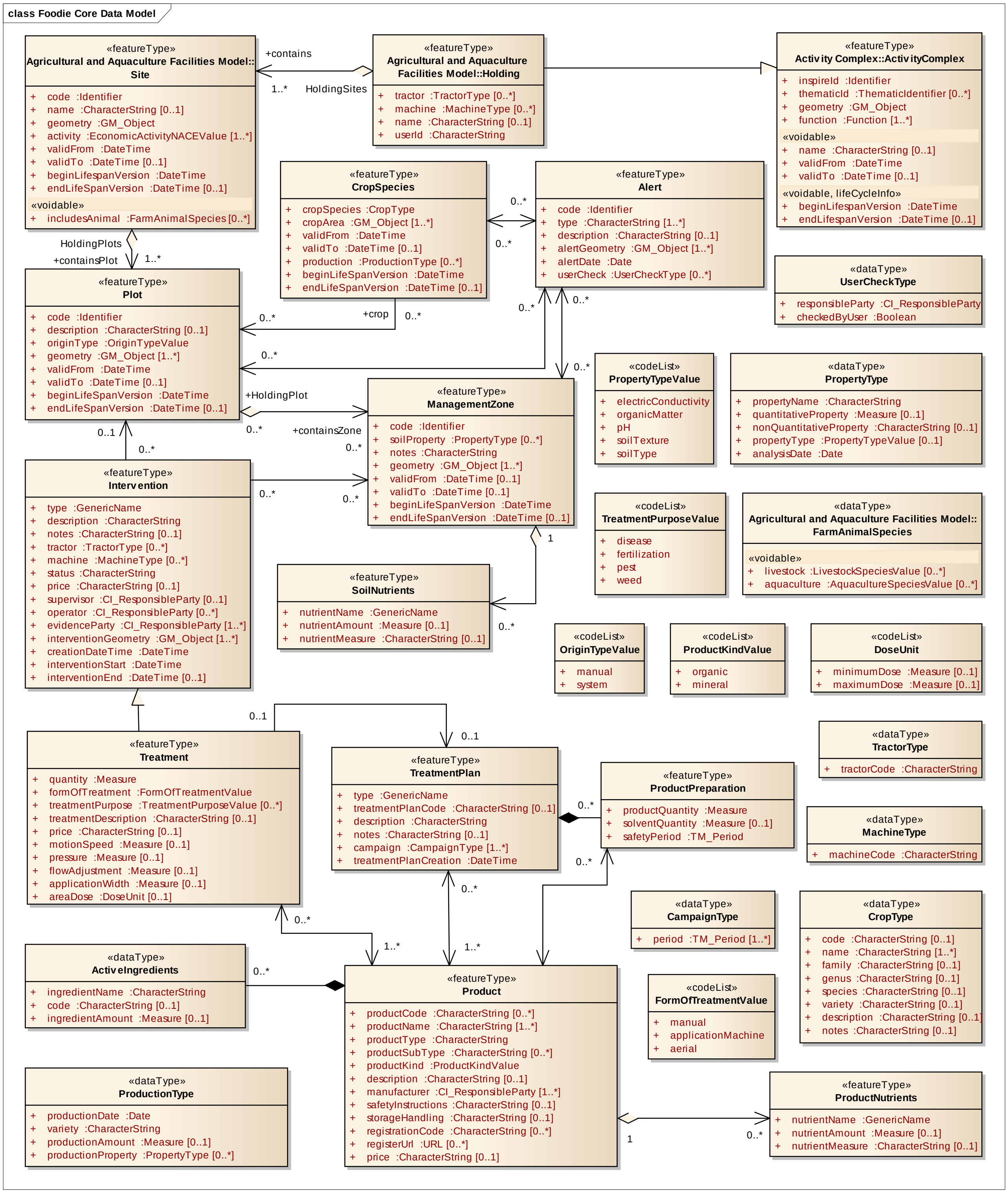

Fig 5. The FOODIE core application schema based on the Agricultural and Aquaculture Facilities Model application schema.

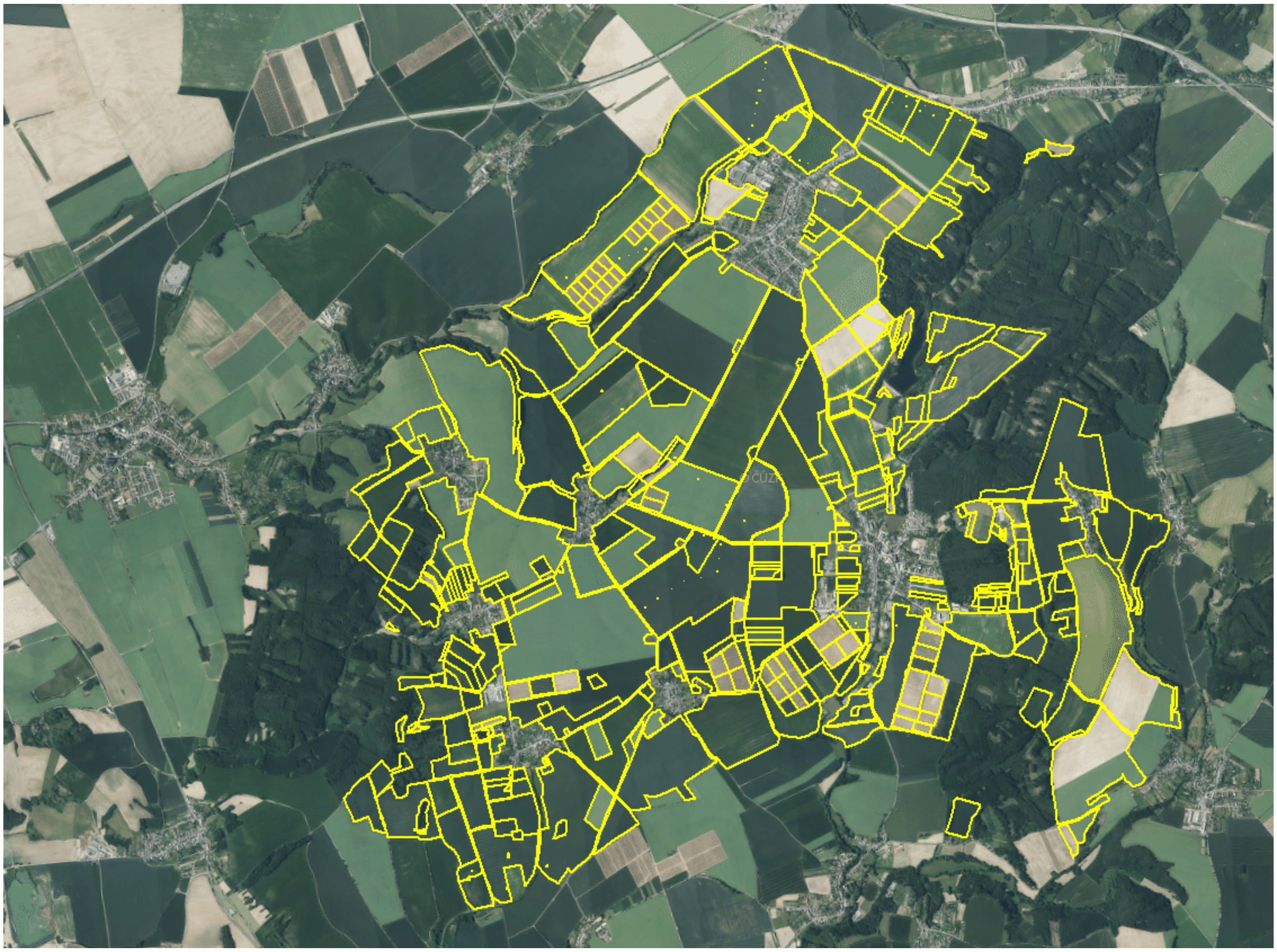

Fig 6. Example of a Plot according to the FOODIE data model specification.

The *Plot* is the key feature type in the FOODIE Core Data Model since it:

- is the level to which majority of agro-related data is related;
- acts as a mediator between different developed application schemas.

The UML class diagram presented in Figure 5 depicts the FOODIE core application schema. As such it may also be re-used for an LPIS in any (Member) State (of the European Union). The following paragraphs describe the main aspects of the FOODIE data model.

The FOODIE core application schema is as tighten to the standardization frameworks as possible. For that reason, it re-uses the data types already defined in ISO standards (especially ISO 19101, ISO/TS 19103, ISO 8601 and ISO 19115) as well standardization efforts published under the INSPIRE Directive (like structure of unique identifiers). Where feasible, the allowed units of the *Measure* data type should be limited to SI units or non-SI units accepted for use with the International System of Units.

The full description of the FOODIE Core Data Model may be found in the Conference Proceedings (Řezník, et al.) .

Transport data model

There are many sources of road network data for the navigation purposes in FOODIE, however open transport data in a global scale is very rare. Perhaps the well-known is the OpenStreetMap (https://www.openstreetmap.org) that is also the basis for derived routing products. Developing an application or using data from more than one pilot city or a region requires having the data in a unified (harmonized) structure. Therefore, a data model described in this section aims at harmonization of geo data related to transportation. Understanding the theory of spatial data harmonization – a joint initiative of harmonization experts from three running European projects (FOODIE, OTN, SDI4Apps), with experiences from INSPIRE thematic working groups, and earlier project such as Plan4bussines, Plan4all and Humboldt were involved. Understanding source data - data owners in the OTN project filled in a detailed questionnaire related to the data they have, and next, the existing metadata catalogues of pilot cities were harvested. No formal description of the data model (in UML) existed. Interviews were also held with the pilot cities to understand the data structure. Understanding target data - the INSPIRE Transport Network specification was studied. Due to the complexity of the INSPIRE Transport Network application scheme, only a core subset of its elements (*RoadLink* and *RoadNode*) were selected for the target data model creation. The target data model (later named Open Transport Map, hereinafter OTM) contains mentioned INSPIRE features and additional elements. The target data model, see Figure 8, is therefore decomposable to INSPIRE. The logical overview of the target data model is depicted in Figure 7.

Fig 7. Open Transport Map data model geometrical elements created as a consensus of the FOODIE, OTN and SDI4Apps.

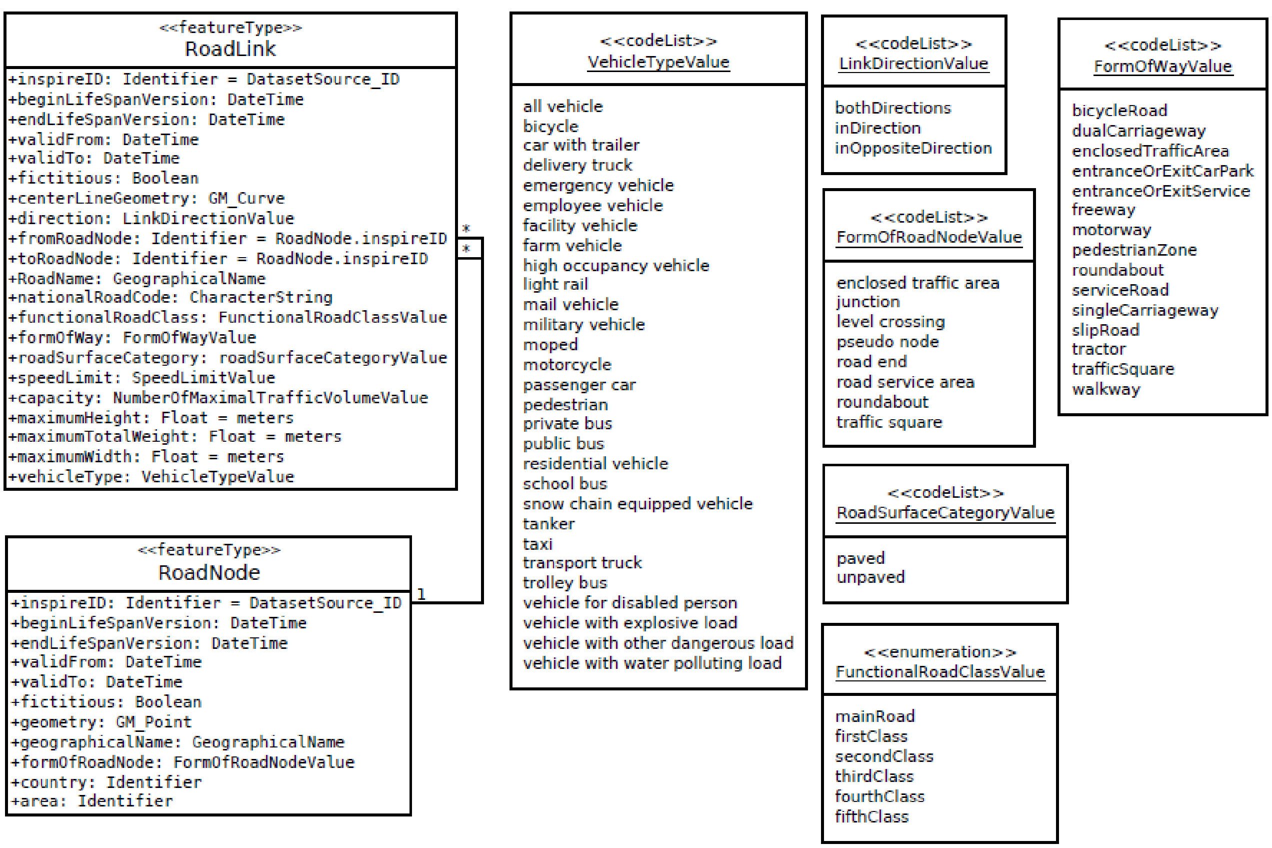

Fig 8. The full view on the Open Transport Map data model as a consensus of the FOODIE, OTN and SDI4Apps.

The model was populated by OpenStreetMap data from the whole Europe and the dataset was named Open Transport Map (OTM). OTM can be therefore shortly described as an "INSPIRE compatible and routable OpenStreetMap (OSM) available for the EU territory". This statement shortly outlines the crucial difference between OSM and OTM. Basically the OSM data model has not a clear road network concept which would follow the basic topological concept – a line has to begin and end in a node. This causes that the OSM is not routable and is not ready to use for analytical tasks. Contrariwise to OSM, OTM provides a data model which is topologically correct and compatible with the INSPIRE Transport Network Schema. Currently, the OTM faces a challenge of periodical update of OTM – to keep the OTM sustainable. There is an on-going work on developing an automated way to keep the OTM up to date.

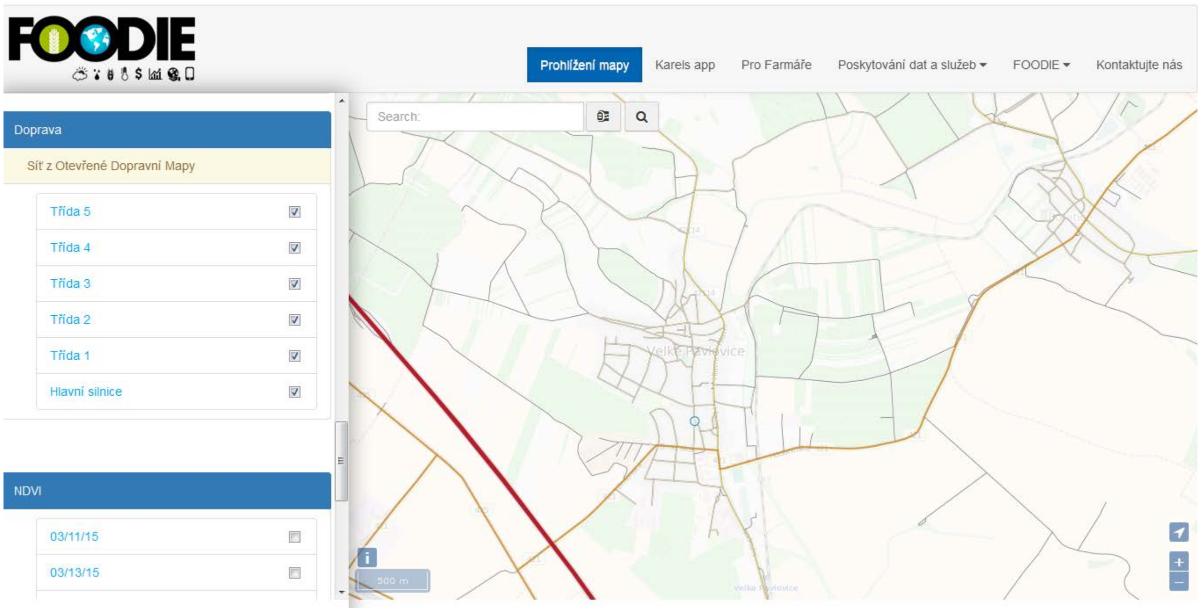

Fig 9. A sample visualization of the OTN at the Czech version of the FOODIE portal.

Volunteered Geographical Information (VGI)

Volunteered geographic information (VGI) is the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals (Goodchild, 2007). We may find several examples on these activities nowadays, like Wikimapia, OpenStreetMap, Flickr and Google Map Mapper. All these initiatives use the same principle, they provide general base map information and allow users to create their own content by marking locations where various events occurred or certain features exist, but aren't already shown on the base map.

In FOODIE, we consider the farmers as the main source for collecting volunteered geographical information in FOODIE platform repositories. In this regard, FOODIE Architecture contemplates two main types of volunteered geographical information:

- Sensor observations measured by different sensor types that the farmers may have deployed on their fields and machinery. These observations may comprehend weather information (e.g., air temperature, wind speed, amount of rain, etc.), soil status (e.g., humidity), etc.;
- Information gathered from farmers' typical procedures and practices (such as farm parcels, land use, crop production, irrigation, etc.)

All this information, once processed and aggregated with other pieces of information available in FOODIE platform repositories, can be used by FOODIE to provide specialized advisory services for farmers, enabling them for instance to improve their soil analysis and reduce their fertilization and irrigation costs by proposing alternative/enhanced practices based on their individual characteristics.

To that end, FOODIE aims at defining a specific and simplified VGI profile for gathering that sort of information. Such profile will be developed during the following iteration of the FOODIE data model specification.

FOODIE sensor observations profile

ISO 19156 Geographic information – Observations and Measurements (O&M) (ISO 19156, 2011) *“defines a conceptual schema for observations, and for features involved in sampling when making observations. These provide models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities”*. The O&M standard defines a basic observation model which is not limited to geographic information. The O&M also defines unique terminology across all domains that are using sensor information. An observation is defined as the following:

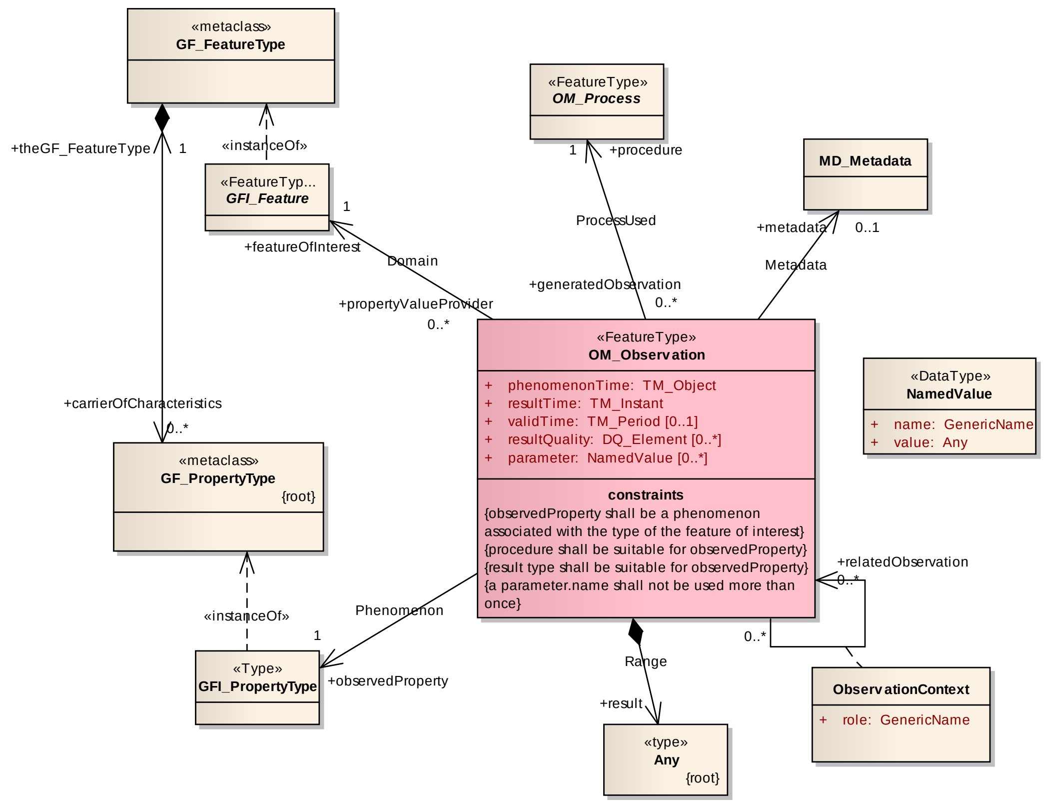

Fig 10. The basic Observation type (OM_Observation) from the Observations and Measurements concept - adopted from (ISO, 2015).

FOODIE VGI profile

Within FOODIE data modelling activities, a VGI profile will be developed enabling farmers and other volunteers to add agro-based content on the top of the base map provided by FOODIE platform.

An example of such approach is currently used in the United States of America for the drought monitoring (CLIMAS). The primary assumption is that a farmer or volunteer is not a laic, he/she has skills for the monitoring. For that reason, we see as useful registration of the volunteers to the FOODIE platform. Reporting options will be then limited by the VGI profile that suits the skills of a volunteer. In that regard, the VGI profile for meteorological monitoring is foreseen as the initial one.

To sum up, volunteer geographic information is mainly used for reporting of negative features. Examples in the agriculture domain may be found in the reporting of drought, mildew, wrong application of a pesticide beyond the field etc. As a result, the FOODIE VGI profile has been developed in mid-2016 as a consensus of the FOODIE consortium. The developed FOODIE VGI profile was incorporated into the sensor observation profile as additional extension (see also Figure 11). The FOODIE VGI profile is available in the version 1.0.0 that is considered as the first stable version for the implementation within the FOODIE platform. The VGI profile as extension for Sensor Observation profile takes advantages of tested structure and respects conception of universal observation with result value of any data type.

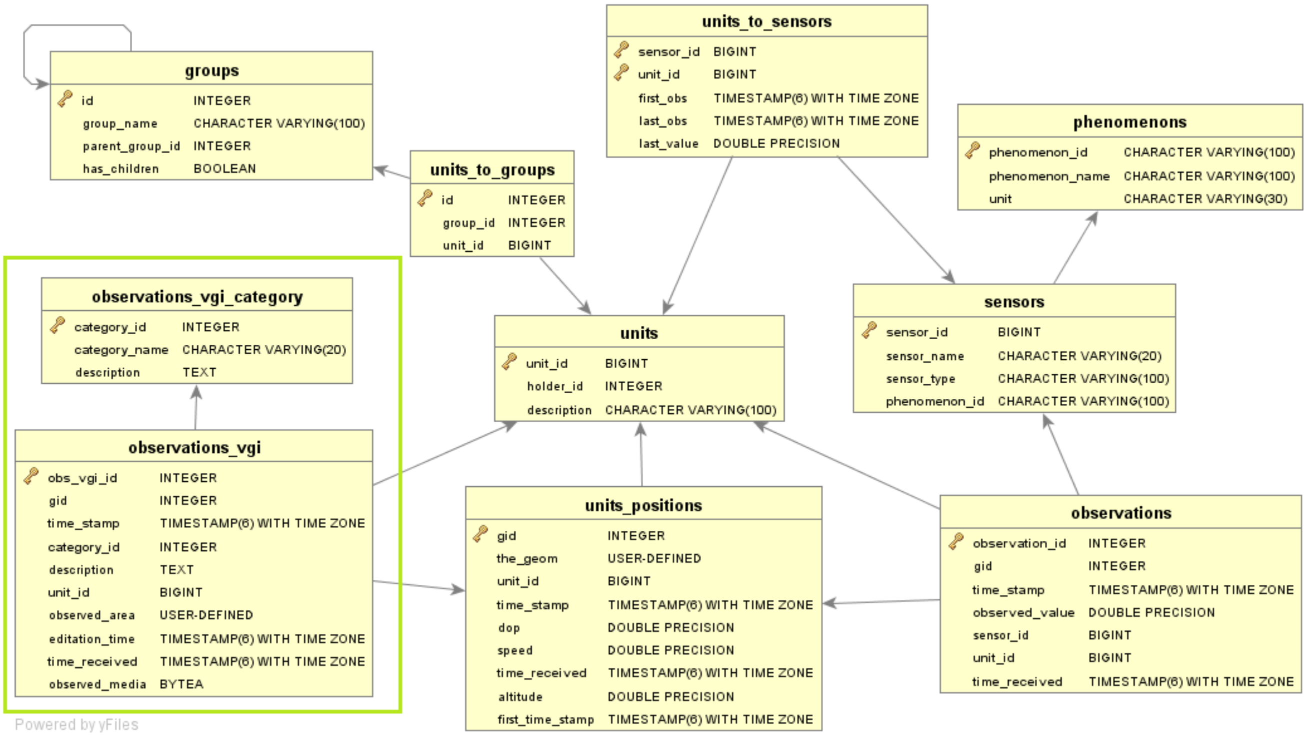

Fig 11: The core of Sensor Observation profile with additional extension of VGI profile (in green).

Conclusions

Precision agriculture is a domain which requires to integrate dozens of (geospatial) data sources in order to make economically and ecologically sound decisions. Standardized data models may therefore be understood as the “backbone” for any information system managing and/or exchanging agricultural (geospatial) information.

The FOODIE data models presented in this paper are standardization frontiers to achieve exchangeable information between heterogeneous information systems. More specifically:

- The Core Data Model, in its version 4.5.1, is a stable standardization framework for management of economically and ecologically related agricultural information. It comprises unified definitions for collecting data on yield, reference materials for subsidies, evidence of environmental burden (e.g. phosphates, nitrates, pesticides) etc.
- The Transport Data Model aims narrowly on issues related to routing of different kinds of agricultural vehicles to save fuel and time. For instance, it is the basis for a farmer/farm manager to decide which tractor and application machine is the most efficient as well as to optimise its trajectory, e.g. with regard to the steepness and/or soil graininess.
- The Sensor Observations Profile is an agriculture-specific customization of the ISO/OGC concept of Observations and Measurements, i.e. standardized handling with geospatially located measurements provided by sensor networks.
- The VGI profile supports the Core Data Model with typically negative ad hoc findings such as drought, mildew, wrong application of a pesticide beyond the field etc. Information provided through the VGI profile is primarily intended for internal purposes of a farmer to collect

valuable field geospatially located information in a form of a text, photography or video.

All the above mentioned data models are being verified within the FOODIE project on several farms within seven countries around the world. Databases established according to the FOODIE data models are being populated. Data quality and metadata management are indivisible parts of the development. At the same time, business/application logic of the FOODIE platform is being developed as well. As the result, the FOODIE platform is going to offer its functionality through services that are re-using information stored in the FOODIE data models.

Another open issue lies in the area that affects Big Data in all its forms. Farmers in particular commonly distrust the companies aggregating data. Farmers are afraid that their sensitive data may be misused. Future efforts should, therefore, focus on the technological as well as the personal level in order to ensure that the FOODIE platform remains useful in daily life. In other words, the geospatial technology is ready to help minimise the environmental burden while maximising the economic benefits; the main obstacles now consist in insufficient policies and people.

Acknowledgements

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