Proceedings of the 10th World Congress on New Technologies (NewTech'24)
Barcelona, Spain - August 25-27, 2024
Paper No. ICCEIA 129
DOI: 10.11159/icceia24.129

Use of LandInfra Standard for GPR Data Digitization: Towards Sustainable Road Transport Infrastructure

Gemma Guillamón-Andreu[1], Mercedes Solla[1]
[1]CINTECX, GEOTECH research group/Universidade de Vigo
Campus As Lagoas - Marcosende, Vigo, Spain
gemma.guillamon@uvigo.gal; merchisolla@uvigo.gal

Abstract – To date, there is no focused standard for the storage, recording and metadata of data from non-destructive Ground-Penetrating Radar (GPR) auscultations. For road infrastructures inspection, the GPR allows for the detection of anomalies in the pavement layers at their earliest stage of formation, as well as other elements that could affect the bearing capacity and integrity of the pavement layers (e.g. deficiencies in layer thicknesses, debonding, cracking, etc). This work proposes the application of the Open Geospatial Consortium (OGC) Land and Infrastructure Conceptual Model Standard (LandInfra) to develop a standardized procedure for GPR data digitization into Geographic Information System (GIS) environments. The possibilities of the standard and its adaptation to a GPR survey are analysed, and a case study of monitoring a real track section is included. The proposed data model outlines to use the Facility and Survey classes of the standard, as well as the Property subclass to associate the observed properties to the monitored stretch of road (such as defects, speed bumps and pipes).

Keywords**:** GPR, Roads, OGC, LandInfra, GIS

1. Introduction

Having quantitative, qualitative and graphic information related to civil engineering infrastructure facilities is crucial in well-informed decision-making and effective planning, thus prioritizing resource allocation and proactive maintenance strategies in an objective and rational way. Within civil engineering infrastructure facilities, road infrastructure is one of the basic pillars in the socio-economic development of communities and nations. Roads facilitates the movement of citizens and goods and contributes to increasing business opportunities. Their correct design and maintenance are therefore essential to ensure the preservation of social and economic benefits for society. The digitisation of the information related to road infrastructure offers numerous benefits, including systematised processing and homogeneous structure, which guarantees its accessibility and interoperability between the different managing systems.

The Land and Infrastructure Conceptual Model Standard (LandInfra), published by the Open Geospatial Consortium (OGC) in 2016 (version 1.0), aims to bridge the gap between Building Information Modelling (BIM) and Geographic Information Systems (GIS) for civil engineering infrastructure projects [1]. LandInfra provides a standardized framework for modelling various elements of infrastructure, including roads, railways, facilities, alignments, land division, easements, condominiums, and also observational properties that characterise and locate them on the ground. LandInfra was developed as an OGC standard based on a subset of functionality from the XML-based open data model LandXML, originally developed for representing data from surveying and civil engineering measurements. Since LandXML has not been recognised as an official standard, has no conceptual model or requirements definition, the OGC proposed extracting a subset of functionality, and formalizing it into a standard format implemented with the Geography Markup Language (GML) and supported by a Unified Modelling Language (UML) conceptual model [2]. The adoption of the InfraGML schema for encoding LandInfra data plays a crucial role in achieving interoperability across different software systems and platforms for infrastructure management. In this context, buildingSMART has developed the Industry Foundation Classes (IFC) Alignment extension for modelling road infrastructure components, which is compatible with the LandInfra standard.

Despite its capabilities, the LandInfra standard still faces challenges and has not been widely adopted in BIM and GIS works. However, using LandInfra to create a conceptual model for developing a pipeline to digitise information from

Ground-Penetrating Radar (GPR) auscultations on road pavements is a promising approach. GPR is a highly effective non-destructive technique used in the assessment of infrastructure conditions. Its effectiveness has been widely demonstrated on concrete structures, rigid and flexible pavements and other types of structures, as well as in the location of buried installations [3]. In road infrastructures, the detection of defects in surface layers using GPR provides critical information on the appearance of subsidence, cracks, buried installations as well as the real thickness of the different pavement layers [4]. The knowledge of the real conditions of roads is invaluable for making informed decisions regarding repair and maintenance actions, as well as for generating risk maps and Key Performance Indicators (KPIs) to aid in integrated road network management. However, despite the importance of GPR data in road infrastructure management, there is currently no standardized procedure for digitizing GPR data into interoperable GIS / BIM formats.

2. Methodology

The requirements Classes for LandInfra are structured as UML packages containing information about infrastructures, parcels, land boundaries, documents, and data collection works. The core of the standard is the only mandatory class in the model. Figure 1 shows the general class diagram of the standard, represented as UML packages. This diagram illustrates the dependencies of the LandInfra packages with external packages from OGC or ISO (International Organization for Standardization) standards on which it will be based, such as the reference coordinate systems or the types of geometry to be used.

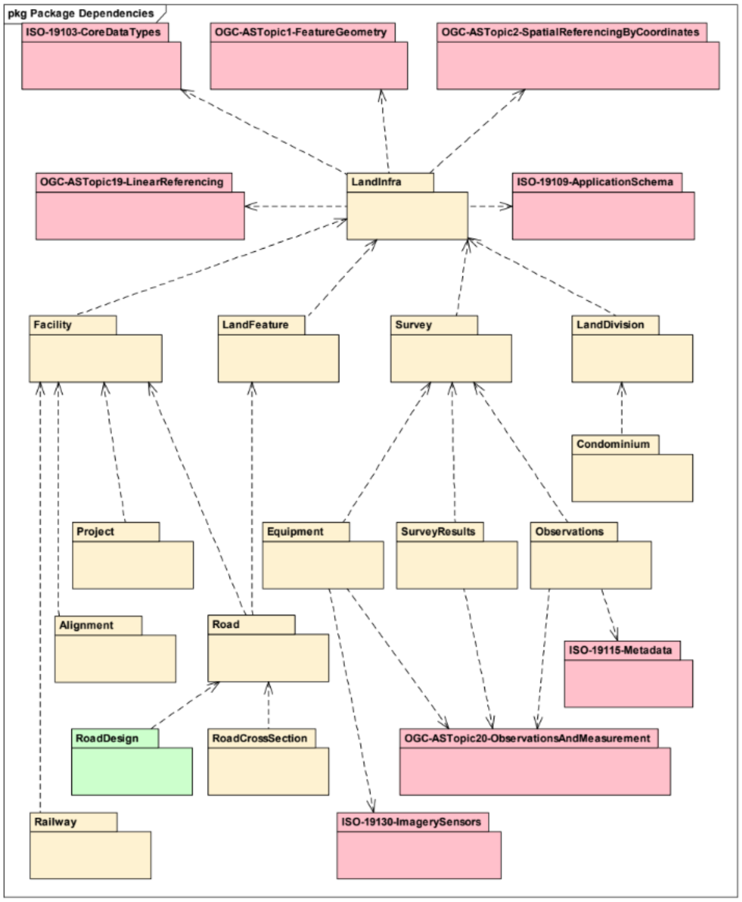

Fig. 1: Requirements Classes as UML Packages with their dependencies.

The Survey package is designed to collect information about the data collection process with different types of equipment: purpose of the work, operator, information about the equipment and sensors used and raw data. The general survey class serves to collect metadata related to data collection and organizes the associated information into three packages: Observations, SurveyResults and Equipment. Based on the OGC Abstract Specification Topic 20: Observations, measurements, and samples [5], which serves as the basis for LandInfra, a field data collection consists of a set of observations made from an InstrumentPoint. These observations are conducted according to a SurveyProcess by an Observer, with the goal of obtaining the value of a Property of the FeatureOfInterest. Additionally, metadata or contextual information is collected to help in the interpretation and subsequent use of the results. A schematic representation of this conceptualisation is shown in Figure 2.

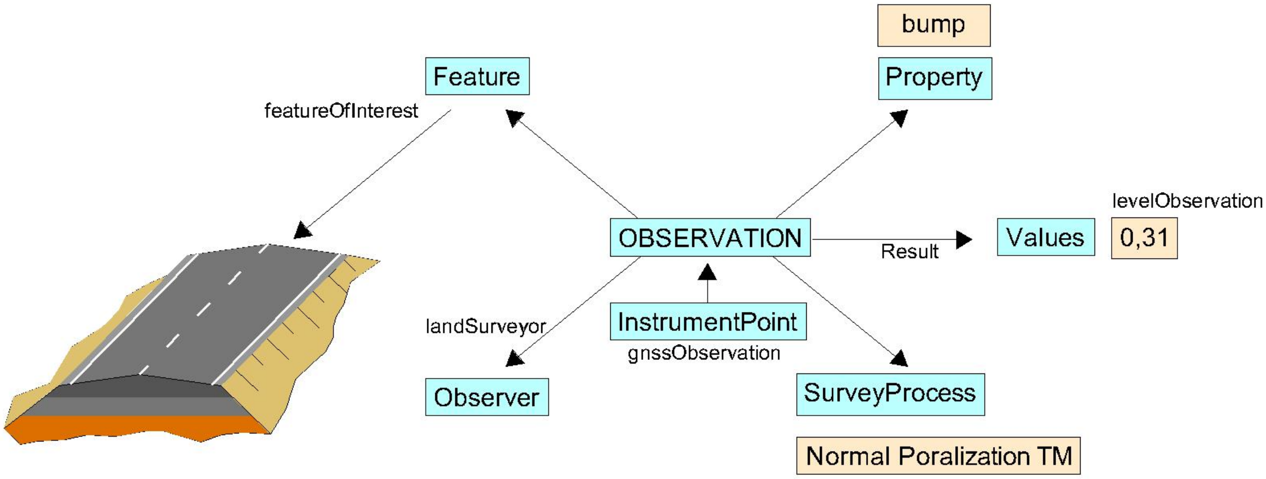

Fig. 2: Observation properties.

Figure 3 summarises the adopted scheme based on LandInfra. It has been chosen to use the Facility class that can be decomposed into different FacilityPart entities (equivalent to IfcSpatialElement), with the capability to represent various components of infrastructure, including roads, railways, tunnels, etc. By using a MultiString geometry, it is possible to model the object of interest on which GPR auscultation is performed in a general way. While the standard allows for a more detailed definition of troad elements and considerations for different alignments, the objectives of this study require only the representation of the road axis to materialise the relationship with the GPR auscultation data.

This study has taken advantage of the high level of detail provided by the LandInfra standard in the description of the Survey package and its components. It was necessary to extend the CodeList to incorporate the types of sensors used in GPR equipment, and parameters specific to GPR data collection process (SurveyProcess), such asinline, timewindow and antenna frequency.

In the conceptualisation carried out for incorporating data from a GPR survey, each point from which a trace is generated by the transmitting antenna must be considered as an InstrumentPoint. These points represent the location where the sensor (GPR antenna) is located during the survey. The coordinates of these InstrumentPoints are determined by a Global Positioning System (GPS) coupled to the GPR equipment. At each of these InstrumentPoints, a SurveyResult can be generated as a result of the measurement at a specific location (e.g., depth of an anomaly, installation or constructive difference in the track).

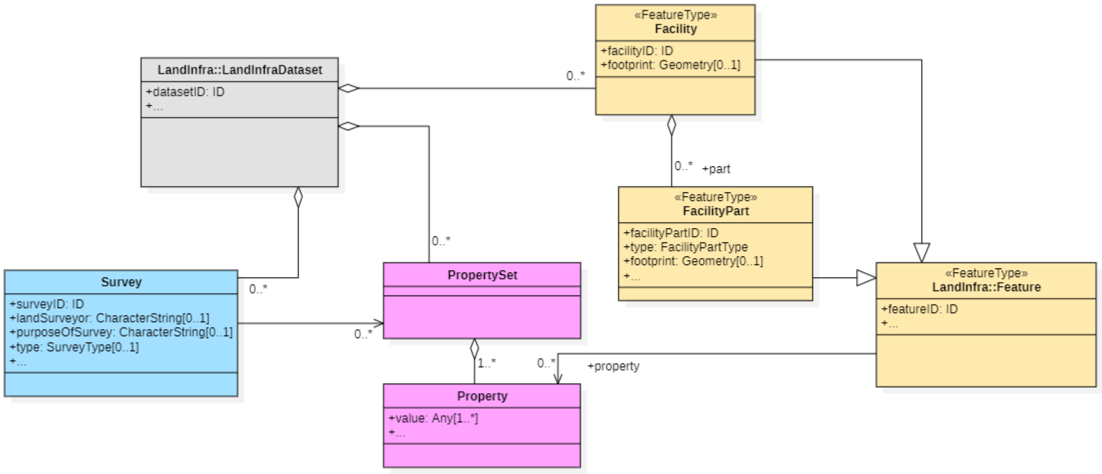

Fig. 3: UML diagram of the adopted solution.

Each GPR survey trace (response received by the receiving antenna after emitting a pulse) is a set of observations made from the same InstrumentPoint. Within a single trace, there can be observations of different types, serving various purposes: location of the InstrumentPoint or property observations.

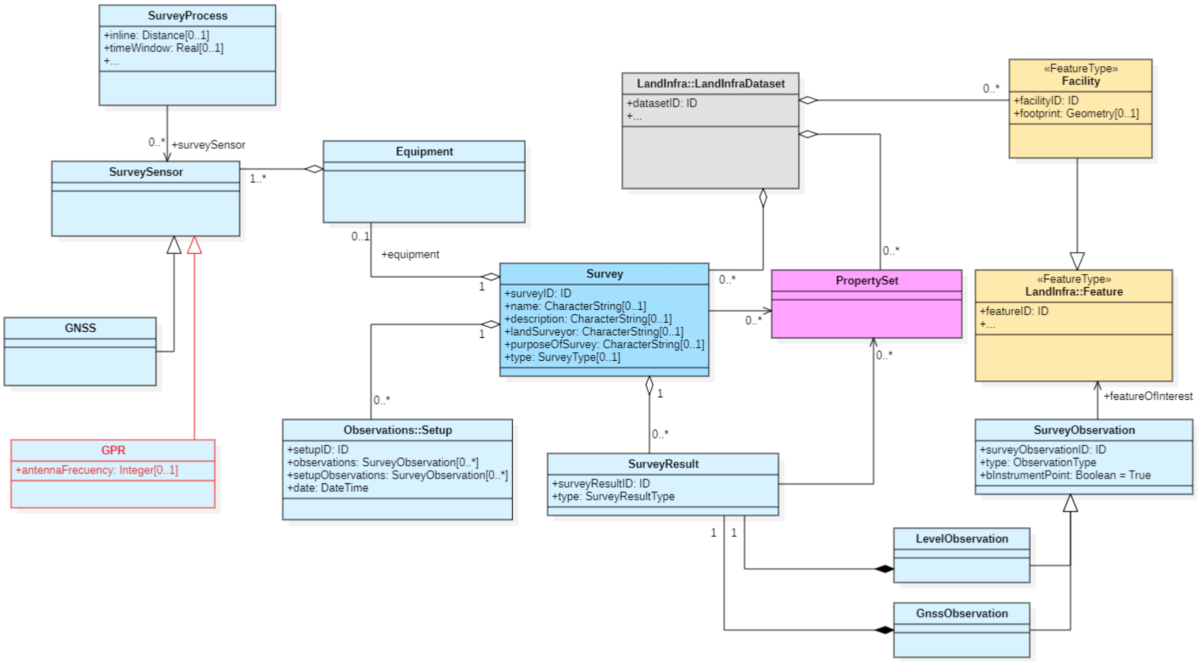

Fig. 4: Detail UML Diagram about package Survey.

The SurveyResult class aggregates the result of each observation made during a survey. In the context of GPR data, a SurveyResult corresponds to the point where an anomaly or other feature is detected, after transforming the travel-time distance (ns) of the signal into depth (m),and subtracting it from the Z coordinate obtained for its corresponding InstrumentPoint. The structured framework of the Survey class for this study is represented in Figure 4.

Although the initial aim of this study is to provide a standardised format for the storage of GPR data, the structure of the standard allows for the incorporation of complementary or other sets of properties of the GPR survey. From this model, the relational database Entity-Relationship Diagram (ERD) has been configured. To design an open-source procedure, the database was implemented with PostGIS version 3.4.1, and then populated from QGIS 3.28.15 desktop software.

The classes of the conceptual model, in their transposition to the ERD diagram, correspond to a table (or feature class in a GIS context), and the attributes of the class become fields (or columns) in those tables. The relationships between classes are represented as relationships between the corresponding tables in the ERD diagram (Figure 5). This includes specifying the cardinality and the type of associations between tables, thus preserving the relational integrity of the standard.

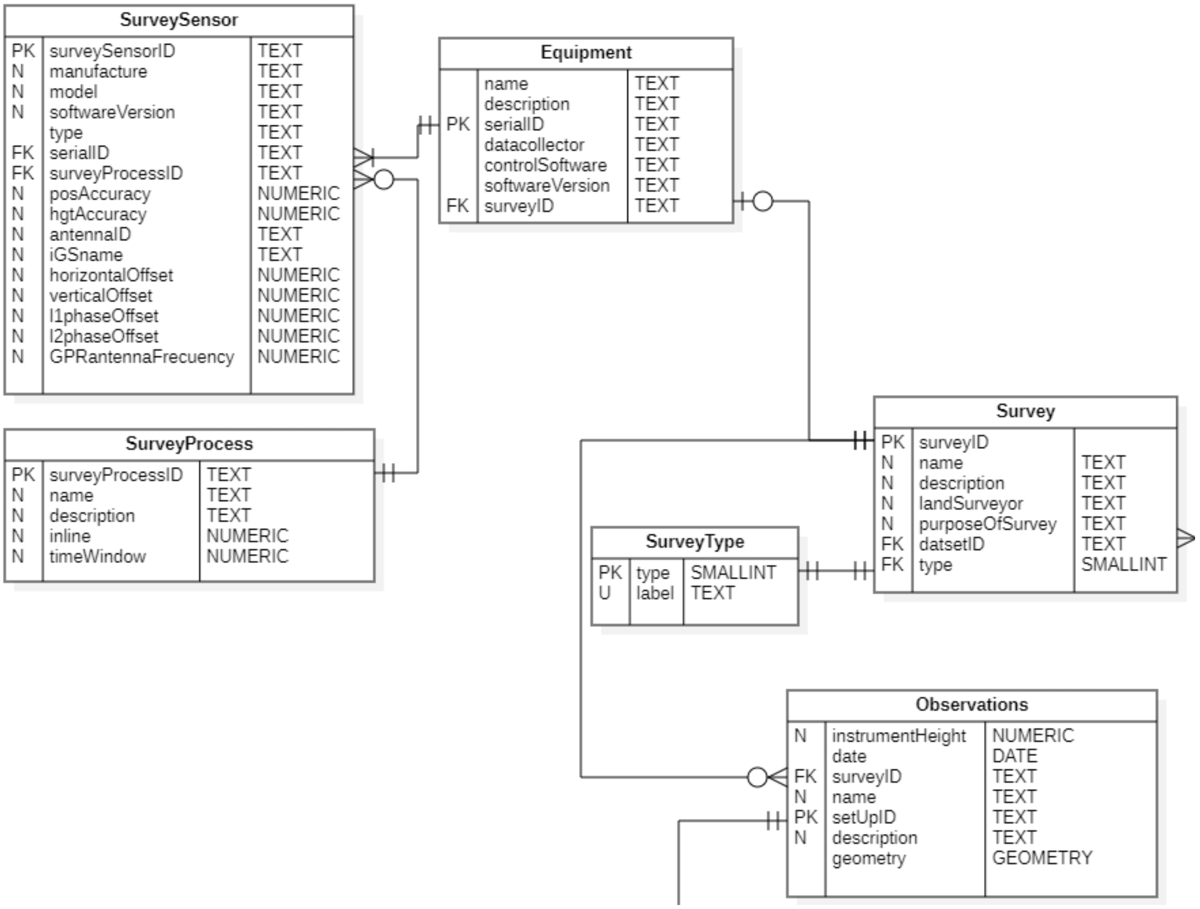

Fig. 5: ERD database diagram excerpt.

3. Results

The GPR data used to test the suitability of the model was collected in an urban road in Pontevedra (Spain) in June 2022. The GPR survey was conducted using a ProEx system with a 500 MHz ground-coupled antenna from the manufacturer MALÅ GEOSCIENCE. As seen in Figure 6, several longitudinal profile lines were acquired. Additionally, a GPS system (Trimble RTK R8) was connected to the GPR system to obtain the absolute coordinates for each of the traces registered.

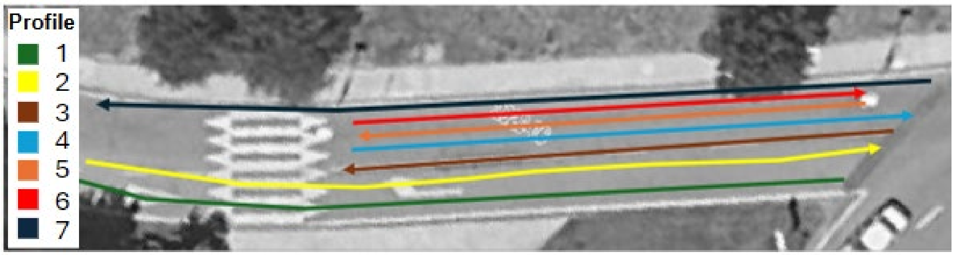

Fig. 6: GPR data collection planning.

Once the GPR data is processed, the reflections of interest (such as pipes, defects and pavement changes) were identified and drawn on the B-scans (or radargrams) (see Fig. 7). For each reflection, the corresponding traces and respective depths (horizontal and vertical positioning, respectively) are extracted, and then converted into an ASCII file (one file for each profile line). Finally, the exported traces were associated with their GPS coordinates, and compile into a CSV (Comma-Separated Values) file.

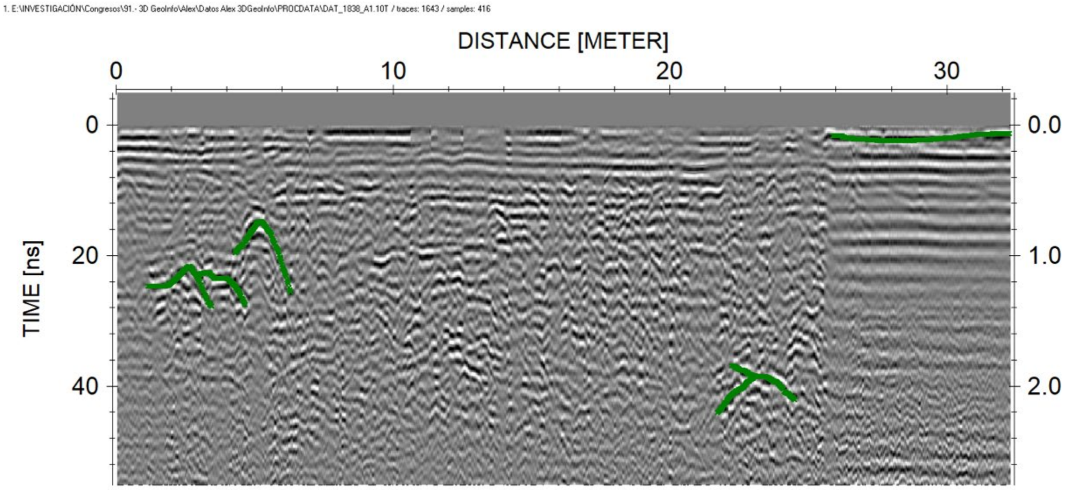

Fig. 7: Radargram resulting from profile line 7.

The point collections stored in the CSV files were incorporated into the database schema implemented on PostGIS from the QGIS desktop software. Specifically, they are part of two feature layers: Observation and SurveyResult with geometry type of 3DPoint.

The geometry of the monitored infrastructures was obtained from the CNIG (National Center for Geographic Information) download centre. This geometry data matches the transport network of the Geographical Reference Information of the Spanish National Cartographic System, defined and published in accordance with the INSPIRE Directive (Figures 8 and 9).

Fig. 8: Example view of model-integrated data on QGIS desktop software.

Fig. 9: Integrated data view categorised according to Property (flaw).

4. Conclusion

In the last decades, important efforts have been made by user associations and administrations to create an ecosystem for sharing information between them and different applications. In this sense, LandInfra provides a common environment on which specialised data models required for various disciplines can be formulated. It is drafted to act as a link between BIM models and GIS systems, when both environments need to be interconnected, as it provides extensive semantic data for both terrain features and the infrastructure built on it.

The application of this standard to the field of data collected with GPR sensors fills a crucial gap in the standardization of data recording and storage practices in this sector. There has been no specific standard for them until now. However, this application has not been direct since the standard, although it has a very complete package dedicated to field surveys, does not consider GPR as a type of sensor to be used. Therefore, different parameters associated with this technique (timewindow, inline or antenna frequency) have been implemented as attributes in different data tables of the relational model.

Further research will be oriented towards the codification of the conceptual model based on LandInfra using the GML-dependent InfraGML schema, which will allow the modelling, transport and storage of the modelled information based on LandInfra. It is also important to advance in the automation of incorporating field-collected information stored in text files into the relational database designed. Automation will allow a more efficient and fluid workflow of the methodology presented in this work.

Acknowledgements

Authors acknowledge the funding received from the STRADAR project (TED2021-130183B-I00), funded by MCIN/AEI/10.13039/501100011033 and by the “European Union NextGenerarionEU/PRTR”. This work has also been supported by the Xunta de Galicia through the project ENDITi (Ref. ED431F 2021/08). M. Solla acknowledges the grant RYC2019-026604-I, funded by MCIN/AEI/10,13039/501100011033 and by “ESF Investing in your future”.

References

[1] OGC, OGC®Land and Infrastructure conceptual model standard, 2016.
[2] K. Kumar, A. Labetski, K. Ohori, H. Ledoux and J. Stoter, “The LandInfra standard and its role in solving the BIM-GIS quagmire,” 2019. https://doi.org/10.1186/s40965-019-0065-z
[3] B. Riveiro and M. Solla, “Ground Penetrating Radar: Fundamentals, Methodologies and Applications in Structures and Infrastructures,”. Springer, 2016.
[4] A. Elseicy, A. Alonso-Díaz, M. Solla, M. Rasol and S. Santos-Assunçao, “Combined Use of GPR and Other NDTs for Road Pavement Assessment: An Overview,” *Remote Sens.*, vol. 14, 4336, 2022.
[5] OGC, OGC Abstract Specification Topic 20:Observations, measurements and samples, 2023.