2023

Report on Infrastructure

User Needs and Requirements

#EUSpace

EUSPA European Union Agency for the Space Programme

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1 INTRODUCTION AND CONTEXT OF THE REPORT

Infrastructure is one of the 17 market segments addressed in the latest EO and GNSS Market Report published by EUSPA at the beginning of 2022 ([RD1]). The segment addresses the basic systems and facilities that countries, states, regions, cities and organisations need to work effectively. This includes a wide range of man-made constructions such as buildings, civil engineering constructions, production and storage facilities, as well as telecommunication networks[1].

The EUSPA Market Report pinpoints that GNSS and Earth Observation are invaluable assets in the "toolbox" of private and public infrastructure owners and/or operators to manage their infrastructures during the entire lifecycle, to increase safety of operations and to improve resilience while safeguarding the environment.

In this context, it is therefore extremely important to have a very good understanding of the user needs and requirements relevant to GNSS and Earth Observation.

The User Consultation Platform (UCP) is a periodic forum organised by the European Union Agency for the Space Programme (EUSPA), where users from different market segments meet to discuss their needs and application-level requirements relevant for Position, Navigation and Timing (PNT), Earth Observation (EO) and secure telecommunications. The event is involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers and application developers. It also gathers organisations and institutions dealing, directly and indirectly, with the two European satellite navigation systems, Galileo and EGNOS and newly since 2020, also with the EU Earth Observation system, Copernicus, and with GOVSATCOM, the upcoming system for secure governmental satellite communications. The UCP event is a part of the process developed at EUSPA to collect user needs and requirements and take them as inputs for the provision of user driven space data-based services by the EU Space Programme.

In this context, the objective of this document is to provide a reference for the EU Space Programme and for the *Infrastructure* community, reporting periodically the most up-to-date user needs and requirements in the *Infrastructure* market segment. This report is a living and evolving document that will periodically be updated by EUSPA. It serves as a key input to the UCP, where it will be reviewed and subsequently updated and expanded in order to reflect the evolutions in the user needs, market and technology captured during the event.

The report aims to provide EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the development of the space downstream applications and services provided by the EU Space Programme components. In line with the extended mandate of EUSPA, the Report on User needs and Requirements (RURs) previously focused on GNSS, have been revamped in order to also encompass the needs of Earth Observation (EO) commercial users and is now organised according to the market segmentation of the EUSPA EO and GNSS Market Report.

[1] Networks related to energy distribution and finance (e.g. banking, stock exchange) are addressed in the related market segments (respectively "Energy and raw materials" and "Insurance and finance").

Finally, as the report is publicly available, it also serves as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of PNT and of Earth observation technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by space downstream applications which combine several signals and sensors. Therefore, the report does not represent any commitment of the EU Space Programme to address or satisfy the listed needs and requirements in the current or future versions of the services and/or data delivered by its different components.

1.1 Methodology

The following figure details the methodology adopted for the analysis of the Infrastructure user requirements at application level.

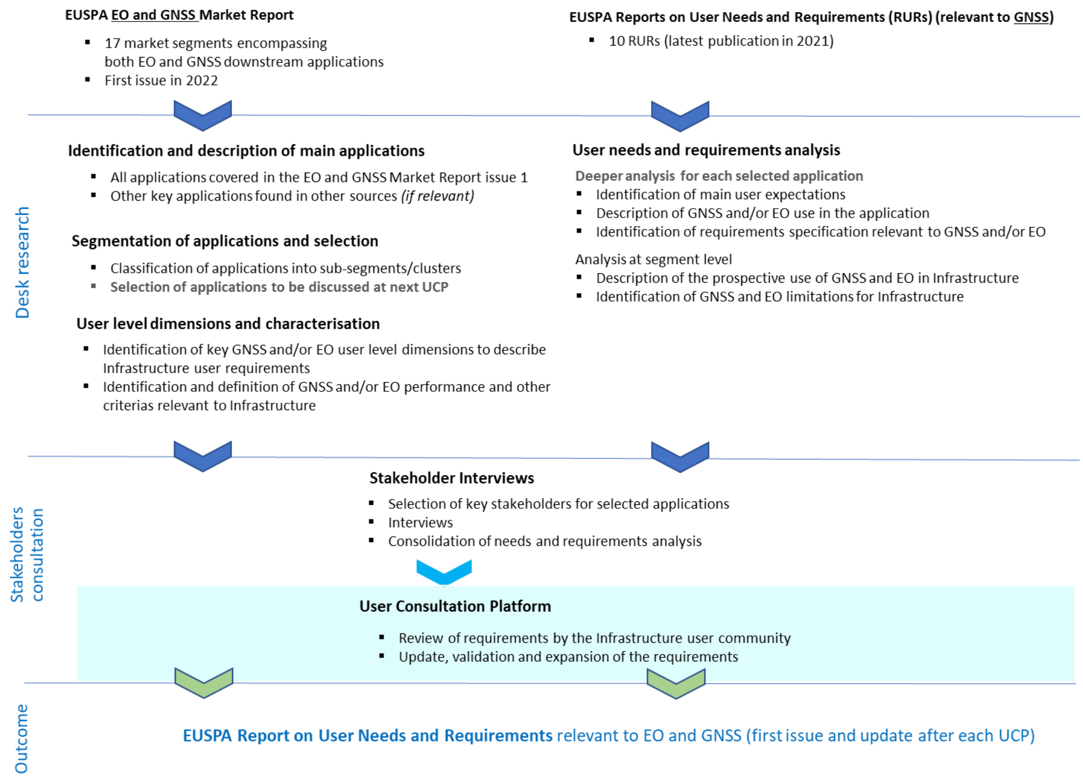

Figure 1. Infrastructure user requirements analysis methodology

As presented in the above figure, the work leverages on the latest EUSPA EO and GNSS Market Report, adopting as starting point the market segmentation for EO and GNSS downstream applications and takes on board the baseline of user needs and requirements relevant to GNSS compiled in the previous RURs published by the agency.

The analysis is split into two main steps, including a "desk research", aiming at refining and extending the heritage inputs and at gathering main insights, and a "stakeholders' consultation" to validate main outcomes.

More in details, the “desk research” was carried out to consolidate when required the list of applications and their classification, to identify the key parameters driving their performances or other relevant requirements together with the main requirements specification, etc. A deeper analysis was conducted for a set of applications prioritised for discussion at the last UCP event. The outcomes of this preliminary analysis were shared and consolidated prior to the UCP with a small group of key stakeholders, operating in the field of the selected applications.

These requirements analysis results were then presented and debated at the UCP with the Infrastructure user community. The outcomes of the Infrastructure forum discussions were finally examined in order to validate and fine-tune the study findings.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

1.2 Scope

This document is part of the User Requirements documents issued by the European Union Agency for the Space Programme for the Market Segments where Position Navigation and Time (PNT) and Earth Observation (EO) data play a key role. Its scope is to cover requirements on PNT and Earth Observation-based solutions from the strict user perspective and considering the market conditions, regulations, and standards that drive them.

The document starts with a market overview for Infrastructure (section 3), focusing on the market evolution and key trends applicable to the whole segment or more specific ones relevant to a group of applications or to the use of GNSS or EO. This section also presents the main market players and user communities. The report then provides a panorama of the applicable policies, regulations and standards (section 4). It then moves to the detailed analysis of user requirements (section 5). This section first presents an overview of the market segment downstream applications, and indicates for each application, the depth of information available in the current version of the report: i.e. broad specification of needs and requirements relevant to GNSS and EO, partial specification limited at this stage to needs and requirements relevant to GNSS, or limited to an introduction to the application and its main use cases at operational level. The content of this section will be expanded and completed in the next releases of the RUR.

Following its introduction, section 5 is organised as follows:

- Section 5.1 aims to present current GNSS and/or EO use and requirements per application, starting with a description of the application, presenting main user expectations and describing the current use of GNSS and/or EO space services and data for the application and providing a detailed overview of the related requirements at application level.
- Section 5.2 describes the main limitations of GNSS and EO to fulfil user needs in the market segment.
- Prospective use of GNSS and EO in Infrastructure is addressed in section 5.3.
- Section 5.4 concludes the section with a synthesis of the main drivers for the user requirements in Infrastructure.

Finally, section 6 summarises the main User Requirements for Infrastructure in the applications domains analysed in this report.

The current version of the report will be expanded and completed through its future releases.

The RUR is intended to serve as an input to more technical discussions on systems engineering and to shape the evolution of the European Union’s satellite navigation systems, Galileo and EGNOS and the Earth Observation system, Copernicus.

2 EXECUTIVE SUMMARY

This document reports on the user needs and requirements relevant to GNSS and Earth Observation (EO) in the Infrastructure market segment. It also aims at enhancing the understanding of market evolution and trends, strongpoints, limitations, key technological trends and main drivers related to the use of GNSS and EO solutions across the different applications of the infrastructure market segment.

Key trends and market evolution

GNSS and EO are invaluable assets to manage infrastructures during their entire lifecycle, notably to increase safety of operations and to improve resilience while safeguarding the environment.

In addition to the key trends already identified in previous reports issued by EUSPA (market reports, previous reports on user needs and requirements), the document identifies a number of EO-related trends likely to have an impact on the infrastructure market in the coming years. These include the multiplication of commercial constellations of small satellites offering optical and radar imagery with sub-meter resolution and several revisits per day, as well as the increasing use of Artificial Intelligence and Machine Learning for processing observation data.

In terms of market evolution, the document refers to the market forecasts for the period 2021 - 2031 presented in the latest Market Report published by EUSPA in January 2022. In particular, it highlights that the revenues from EO data and service sales are expected to keep on increasing during the next decade thanks to the penetration of EO-based applications in the various phases of the infrastructure life cycle.

The document also includes an overview of the policy, regulation and standards either directly related to infrastructure or likely to have an impact on this market segment.

Current and prospective use of GNSS and EO in infrastructure

In the latest EUSPA Market Report, fifteen applications related to Infrastructures have been identified and clustered into four different groups:

- “Environmental Impact Monitoring” applications;
- “Infrastructure Construction and Monitoring” applications;
- “Infrastructure Planning” applications;
- “Timing & Synchronisation of Telecommunication Networks” applications.

For each one of the identified applications, the present document describes the current contribution of GNSS (e.g. construction surveying, machine control, stability monitoring) and/or EO (e.g. ground deformation monitoring, land cover/land use classification, exposure to natural and climate risk, change detection) to the application.

It also describes the operational and technical limitations which affect GNSS (e.g. susceptibility to interference and multipath, sensibility to ambient humidity, availability in indoor conditions) and EO (cloud coverage in case of optical observation, vegetation cover, distribution of measurement points in case of synthetic aperture radar interferometry), and identifies prospective uses of GNSS and EO, both in terms of new capabilities being developed or of combined use with existing technologies

Drivers for user requirements

The document provides an overview of the user needs for each one of the fifteen infrastructure-related applications and a summary of the drivers for user requirements. For GNSS, high accuracy, time to first fix, time to convergence, redundancy and robustness are part of the identified drivers. For EO, drivers include spatial resolution, the availability of historical data and in some specific cases (line infrastructures), the ability to cover large-scale areas

For a subset of four selected applications (Infrastructure site selection and planning / Construction operations / Post-construction operations / Environmental impact assessment) the document goes a step further by defining different operational scenarios for the use of EO and identifying in more details the corresponding user requirements.

3 MARKET OVERVIEW & TRENDS

3.1 Market Evolution and Key Trends

3.1.1 Introduction to the Infrastructure Segment

As mentioned in the introduction chapter, the term "infrastructure" refers to the basic systems and facilities that a country (or a state, a region, a city) or organisation needs to work effectively. This Report on infrastructures User Requirements addresses the following types of infrastructures:

- Buildings (e.g. public buildings, private habitations);
- Transport infrastructures (e.g. roads, airports, ports);
- Civil engineering constructions (e.g. bridges, tunnels, dams, pipelines);
- Industrial infrastructures (e.g. production facilities, storage facilities);
- Telecommunication networks.

Note:

- For transport infrastructures, the document focusses on the GNSS and/or EO-based applications related to construction, structural health monitoring and environmental impact monitoring. It does not address the applications related to the operational use of these infrastructures, which are dealt with in the corresponding sector-specific Reports on User Requirements;
- Energy distribution networks[2] and space infrastructures are not covered in this report.

Within this wide variety of basic systems and facilities, those which are usually considered by Public Authorities as being essential to the proper functioning of the economy and the society constitute a subset of the above-mentioned infrastructures and are generally referred to as "critical infrastructures".

In the EO and GNSS EUSPA Market Report [RD1], GNSS and EO-based applications for infrastructure have been clustered in four main groups:

- **Infrastructure planning**, grouping applications related to the selection of sites for the construction of new infrastructures, including applications supporting the obtention of building permits and applications supporting vulnerability assessments;
- **Infrastructure construction and monitoring**, grouping applications related to the construction phase (e.g. construction progress monitoring, machine guidance and control) and to the post-construction phase (e.g. ground motion detection, vegetation encroachment detection);
- **Environmental impact monitoring**, grouping applications related to the assessment of the negative impacts that infrastructure may have on the surrounding environment, either during the construction phase (e.g. detection of ground movements induced by construction works) or after the construction (e.g. monitoring of air quality in the vicinity of the infrastructure in case of e.g. factories);

[2] This type of infrastructure is addressed in the report dealing with Renewable energy and raw materials

- **Timing and synchronisation of telecommunication networks**[3], grouping applications related to the timing and synchronisation of the various types of telecommunication networks (e.g. Digital Cellular Networks, Public Switched Telephone Network).

3.1.2 Key Market Trends

The European willingness to become the first continent to reach neutrality by 2050 drives the need for reducing the environmental footprint of infrastructures and strengthening their resilience to climate change. In this general context, the EO and GNSS EUSPA Market Report ([RD1]) and the previous Reports on User Needs and Requirements on surveying ([RD3]) and on Timing & Synchronisation ([RD4]) have identified several key trends in the infrastructure market.

These key trends are the uptake of services based on InSAR[4] for the identification of risks related to ground deformation, the increasing use of EO to better understand the impacts of climate change and support the design and construction of more resilient infrastructures, the growth of GNSS-based machine control solutions in construction, and the growing awareness of the role of GNSS-based solutions in supporting the resilience of European telecommunication infrastructures.

In addition to the above-mentioned trends, the multiplication of commercial constellations of EO satellites and the increasing use of Artificial Intelligence are expected to have a significant impact on satellite-based applications, including in the infrastructure market. An overview of these profound evolutions is provided hereafter:

- The emergence of low-cost satellite technology is leading to a multiplication of large constellations of small satellites (often referred to as “smallsats”) and has opened the door to a commercial offer, even in domains like Synthetic Aperture Radars (SARs) which were previously limited to institutional missions. In the domain of SAR, commercial constellations are now deployed by private operators[5]. Beyond the fact that the deployment of new constellations will lead to a decrease of the price of SAR imagery, it will also lead to significant improvements in terms of performance and more specifically in terms of revisit frequencies thanks to the large number of satellites in orbit (the revisit time being in the range of 1-3 hours in the best case). This will open the door to new applications, such as the monitoring and tracking of rapid ground deformation (during and after the construction of the infrastructure for instance).
- The trend is similar for optical imagery with operators[6] which are deploying constellations on the Low Earth Orbit (LEO) aiming to offer sub-meter resolution optical imagery with revisit times inferior to 1 hour. Some companies[7] are envisaging to deploy EO smallsats on the Very Low Earth Orbit (VLEO).
- The increasing use of Artificial Intelligence and Machine Learning is also part of the trends which are changing the physiognomy of the Earth Observation market and have direct impacts on

[3] Timing and synchronisation for other types of networks (e.g. those used for critical infrastructures such as smart grids or finance) are addressed in Reports on User Requirements (RURs) dealing specifically with these topics. They are therefore not addressed in the present report.
[4] Interferometric Synthetic-Aperture Radar
[5] E.g. ICEYE (www.iceye.com) in Europe or Capella Space (www.capellaspace.com) in the US
[6] E.g. Planet (www.planet.com) in the US or Satellogic (https://satellogic.com/) in Argentina
[7] E.g. Earth Observant Inc. (https://eoi.space/), a Californian start-up which aims to develop an optical imaging satellite constellation flying at 250 km above Earth

applications relevant to the infrastructure market. These technologies enable the automation of processes which are usually costly and time-consuming and bring Earth Observation applications a step forward by enabling the identification of patterns, trends or correlations which would have remained invisible and unexploited with more traditional processing techniques. They are also facilitating the fusion of data from multiple sources, which will become more and more available in the future notably due to the expected generalisation of the Internet-of-Things (IoT). At the end of the day, the use of Artificial Intelligence and Machine learning should increase service providers' ability to deliver solutions which meet the increasing needs of (non-technical) users for actionable insights (rather than for "data" or "maps") to support decision-making. Thus, the combined use of Artificial Intelligence/Machine learning and EO data supports[8]:

- Automated risk assessment of infrastructures;
- Automated change detection, for the monitoring of the progress of construction works for instance;
- Automated infrastructure monitoring.

The above-mentioned trends should support the penetration of EO-based applications in many market segments, including the infrastructure market. However, although the EO sector is rightly convinced of the value of its technology ([RD12]), the benefits it could bring to the infrastructure market are not fully exploited yet, notably because the EO-based products and services that are available on the market use technical terminology rather than the appropriate business jargon, do not match the infrastructure sector's use cases in terms of features and are not always offered in a smart commercial way.

3.1.3 GNSS Market Evolution

The infrastructure-related GNSS applications considered in the latest EO and GNSS Market Report published by EUSPA ([RD1]) include applications related to the construction market (e.g. surveying and machine guidance) and the telecommunication market (e.g. timing & synchronisation). The Market Report indicates that:

- For the construction market, during the past decade GNSS shipments have increased thanks to the strong growth of the construction industry. After a drop in 2020 due to the COVID-19 pandemic, construction activities are expected to renew with a significant growth.
- The telecommunication market witnessed solid growth over the last decade. The market growth should be sustained in the future, notably thanks to the wide-scale deployment of 5G networks.

3.1.4 EO Market Evolution

As underlined in the EO and GNSS Market Report published by EUSPA ([RD1]), the use of EO data is progressively penetrating the various phases of the infrastructure life cycle and is expected to keep on increasing over the next decade. However, the EUSPA Market Report also mentions that behind the global increase of revenues, strong regional disparities exist.

[8] Several providers already use Artificial Intelligence / Machine Learning as part as the solutions they offer (e.g. Overstory, Sobolt, Spacept, SpaceSense, SkyWatch, BlackSky, etc.)

3.2 Main User Communities

The main user communities to be considered for the infrastructure segment are:

- Infrastructure owners and/or operators, referred to as "infrastructure managers" in the rest of the document. They can be public or private entities and include the managers of infrastructures such as buildings, factories, power plants, airports, dams, etc., as well as managers of line infrastructure (e.g. railways, highways, pipelines), utility managers and telecommunication operators (see note below);
- Construction and public works companies (including civil engineering companies). They correspond to the (generally private) companies contracted by infrastructure owners and/or operators to design and construct the above-mentioned infrastructures;
- Public authorities, including regulatory authorities, at local (e.g. municipalities), regional, national or European level. This includes authorities responsible for spatial planning and authorities entrusted with the verification that infrastructures comply with applicable legislation and regulations;
- Financial institutions involved in the funding of infrastructures and therefore interested in the exposure to risk of the concerned infrastructures and in the progress of construction works;
- International development organisations (e.g. World Bank), when development projects involving the construction of large infrastructures such as dams or transport networks are at stake;
- Telecommunication operators, which are considered to be the end users when Timing & Synchronisation applications for telecommunication networks are at stake;
- Telecommunication network equipment providers, radio-spectrum regulators and standardisation organisations[9], also play a role in the definition of user requirements for applications related to telecommunication networks (see [RD4]).

3.3 Main Market Players

The value chains for GNSS-based applications and for EO-based applications are significantly different and are therefore addressed separately in this document. The main difference originates from the fact that the entire GNSS-related value chain is based on the manufacturing, integration and use of tangible GNSS devices (e.g. receivers) while the EO-related value chain is based on the delivery of processed data (e.g. maps, actionable information) and does not involve any "EO device".

3.3.1 GNSS Market Players

As presented in the EO and GNSS EUSPA Market Report (see [RD1]), the main market players in the GNSS value chain are:

- Augmentation service providers;
- Component manufacturers;
- Receiver manufacturers;
- System integrators, design consultancies, and testing & maintenance actors;
- (End) Users.

[9] e.g. the European Telecommunications Standards Institute (ETSI), the ITU Telecommunication Standardization Sector (ITU-T) and the ITU Radiocommunication Standardization Sector (ITU-R

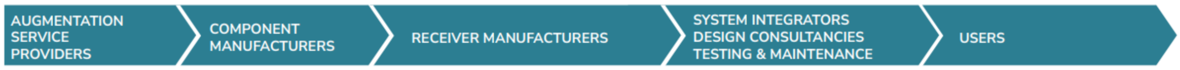

Figure 2: GNSS-related Value Chain for Infrastructure

(Note: A more detailed value-chain with a list of companies and organisations per type of actor is available in [RD1])

Augmentation service providers include the public organisations and private companies offering services aiming at improving the performance of GNSS (e.g. better accuracy, better reliability) through the provision of external information to be integrated into the PNT calculation process. This category includes providers of Satellite-Based Augmentation Systems (SBAS) and of Ground-Based Augmentation Systems (GBAS) (see [RD3]). In the Infrastructure market, this includes in particular the providers of precise positioning solutions, such as Fugro, Hemisphere, Hexagon, Topcon, Trimble.

Component manufacturers correspond to the companies producing the GNSS chipsets. They are not specific to a market and generally sell their chipsets to receiver/device manufacturers who serve different markets, including the infrastructure market. This category includes companies like Furuno, Novatel, U-Blox, ST-Microelectronics.

Receiver manufacturers integrate the chipsets produced by the "component manufacturers" in the receivers/devices to be integrated in end-users' equipment. Some of the above-mentioned "augmentation service providers" like Hexagon, Topcon or Trimble are also manufacturers of GNSS receivers. In the specific case of Timing & Synchronisation equipment (see [RD4]), it generally takes the form of rackmount equipment with specific interfaces supporting Time protocols such as PTP or NTP or synchronisation specific electrical or optical interfaces (e.g. IRIG B), which are often industry specific. However, there exist also Timing modules, particularly interesting for small cell synchronisation applications. Timing & Synchronisation equipment manufacturers include companies like Microsemi, Orolia/Spectracom (recently acquired by Safran) Meinberg, OscilloQuartz, Calnex, Rakon or TimeLink microsystems.

System integrators, Design Consultancy, Testing & Maintenance refers to the companies which perform the integration of the GNSS receivers/devices in the end-user equipment or platform or in telecommunication networks in the case of Timing & Synchronisation equipment. These companies therefore include construction machines manufacturers such as AB Volvo, Caterpillar, John Deere or Komatsu, measuring equipment manufacturers such as Faro Technologies, machine control equipment manufacturers such as CHCNAV, Timing & Synchronisation solution providers such as Chronos Technology, and telecommunication network equipment providers such as Ericsson, Huawei, Nokia or Siemens. With the emergence of the Open Radio Access Network (O-RAN) architecture for 5G networks, 5G is expected to run on "white box Hardware" such as powerful servers supporting virtualisation technologies and embedding Open-Source software. The O-RAN is leading to the introduction of server manufacturers such as Dell and HP into the T&S system integrators list for 5G telecommunication networks in addition to data centres.

End Users are the final users of the applications and services offered by the various providers. They belong to the various user communities described in section 3.2.

3.3.2 EO Market Players

As far as the EO-related value chain is concerned, the main market players identified in the EO and GNSS EUSPA Market Report ([RD1]) are:

- (Computing) Infrastructure providers;

- Data providers;
- Platform providers;
- EO Products and Service Providers;

Information providers;

- (End) Users.

Figure 3: EO-related Value Chain for Infrastructure

(Note: A more detailed value-chain with a list of companies and organisations per type of actor is available in [RD1])

The first block referred to as **Infrastructure providers** on the above figure corresponds to organisations offering cloud storage and computing capacities enabling their users to store and process EO data. This includes the US giants Amazon, Google and Microsoft.

Data providers include all the satellite operators which deliver Earth Observation data to their users/customers. These providers include large companies such as Airbus and Maxar Technologies for instance, as well as many constellation operators from the New Space, such as Planet and Iceye. This category also includes institutional providers through public programmes such as Copernicus and its fleet of Sentinel satellites in Europe or Landsat in the US.

Platform providers offer to their customers complete online solutions (data access, storage, processing tools, computing capacity, etc.) enabling them to obtain the product/data/information customised to their needs without having to invest in their own solution. The Copernicus Data and Information Access Services (DIAS) fall under this category.

EO Products and Service Providers correspond to companies or organisations which have an historical background in remote sensing and Earth Observation, such as GAF, Geoville or Planetek to mention a few. They generally address several market segments and are not sector-oriented. In Europe, the Entrusted Entities delivering the Copernicus core services are also part of "EO Products and Service Providers".

Information providers correspond to companies whose background is generally sector-specific rather than EO oriented. In most cases, they serve a more limited number of sectors. This includes companies like Dares or Sixsense. However, due to the evolutions of the companies' portfolios, the frontier between "EO Products and Service Providers" and "Information Providers" tends to be increasingly blurred. More generally, a trend towards vertical integration in the EO sector makes that an increasing number of companies cover the entire value chain, from the provision of satellite-based observation data to the delivery of value-added services to end-users.

End users are the final users of the applications and services offered by the various providers. They belong to the various user communities described in section 3.2.

4 POLICY, REGULATION AND STANDARDS

4.1 Policy and regulatory stakeholders

There is no regulatory authority dedicated to infrastructures in general but in the European Union, the European Commission plays an increasingly important transversal role with respect to Critical Infrastructure protection (see following section).

In the specific case of telecommunications, the Body of European Regulators of Electronic Communications (BEREC) is the regulating agency of the telecommunication market in the European Union. Besides, each Member State has set up its own National Regulatory Authorities (NRA) in charge of regulating telecommunications. However, neither BEREC nor the NRAs are directly involved in the definition of the Timing & Synchronisation architecture. Finally, spectrum regulation agencies (ITU-R world agreement, national agencies for enforcement) and telecom network regulation agencies (CCITT/ITU-T, national agencies for enforcement) are also involved in particular through their participation in Standardisation forums (see [RD4]).

4.2 Policy and Regulation

The Regulation (EU) 2021/696 of 28 April 2021 "*establishing the Union Space Programme and the European Union Agency for the Space Programme*" (EUSPA) ([RD5]) is the main Space policy document for the European Union.

Although the regulation highlights the role that Copernicus should play in supporting the Union's capacity to achieve independent decision-making and actions in a certain number of fields, among which infrastructure monitoring, it does no impose any regulatory obligations with regard to the use of space-based systems for infrastructure management.

Except for "critical infrastructures", there is in general no EU policy or regulatory document which directly addresses the infrastructure market. There are however a number of policy or regulatory documents which may have an indirect impact on the infrastructure market. An overview of these documents is provided in the Annex.

4.3 Standards

The standards relevant to infrastructure-related applications are addressed in the Annex.

5 USER REQUIREMENTS ANALYSIS

This chapter aims at providing a detailed analysis of user needs and requirements pertaining to Infrastructure-related applications introduced before, describing the different roles and needs covered by GNSS and EO and, ultimately, identifying the corresponding requirements from a user perspective.

Table 1 below depicts the main applications making use of GNSS and/or EO technologies for Infrastructure. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report being the first version of the infrastructure report on User Needs and Requirements relevant to EO in addition to GNSS, it is a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue of this report does not cover in detail the needs and requirements for all of these applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

● **Application Type A:** these applications correspond to those for which an in-depth investigation is presented and for which needs and requirements relevant to GNSS and EO have been identified and validated with the infrastructure user community at the UCP.

◐ **Application Type B:** these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

○ **Application Type C:** these applications correspond to EO-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

In the latest EO and GNSS Market Report published by EUSPA at the beginning of 2022, fifteen applications related to Infrastructures have been identified and clustered into four different groups (see page 117 of [RD1]):

- Infrastructure Planning;
- Infrastructure Construction and Monitoring;
- Environmental Impact Monitoring;
- Timing & Synchronisation of Telecommunication Networks.

The table below maps the fifteen infrastructure-related applications to the three above-mentioned types. **The following** list of **applications and their** categorisation are **expected to evolve in the next versions of the document**.

Legend

EO only application

GNSS only application

Hybrid/synergetic application (combined use of EO and GNSS)

Table 1: Applications, definitions and categorisation

Subsegment	Application	Types of Application / Level of Investigation	
Infrastructure Planning	Infrastructure Site Selection and Planning	A	●
	Permitting	C	○
	Vulnerability Analysis	C	○
Infrastructure Construction and Monitoring	Constructions Operations	A	●
	Monitoring of impact of human activities on infrastructure	C	○
	ODA Support Monitoring	C	○
	Pipeline Monitoring	B	◑
	Post-Construction Operations	A	●
Environmental Impact Monitoring	Environmental impact assessment of infrastructures	A	●
Timing & Synchronisation of Telecommunication Networks	Data Centre	B	◑
	Digital Cellular Network (DCN)	B	◑
	Professional Mobile Radio (PMR)	B	◑
	Public Switched Telephone Network (PSTN)	B	◑
	Satellite Communication (SATCOM)	B	◑
	Small Cells	B	◑

"Type A" applications (which correspond to those for which the user requirements are the most detailed in this document) are addressed in a first place in the following section. They are followed by "Type B" applications (for which only GNSS requirements are provided) and finally "Type C" applications (for which only definitions and general information on the EO contribution are provided).

For each EO-based "Type A" application, different operational scenarios are considered. For each operational scenario, the corresponding EO-related needs and requirements are summarised in a table which follows the template provided below.

Table 2: Description of needs and requirements relevant to EO Table[10]

ID	Identifier.
Application	Application covered.
Users	Common users of the product/service.
User Needs	
Operational scenario	**Describes the operational scenario faced by the user, which requires a solution.**
Size of area of interest	Describes the area of interest (e.g. typical size of the area in which construction works need to be monitored).
Scale	Describes the scale of interest (e.g. infrastructure operators are interested in monitoring ground deformation in the range of a few millimetres per year).
Frequency of information	How often the user requires the information.
Other (if applicable)	Other user needs such as contextual information (weather data) or file formatting requirements.
Service Provider Offer	
What the service does	Description of the service that satisfies the user's needs.
How the service works	(Technical) description of how the service works.
Service Provider Satellite EO Requirements	
Spatial resolution	Spatial resolution of the satellite imagery/data required by the service provider to realise the service.
Temporal resolution	Frequency of satellite data (revisit time) over the area of interest.
Data type / Spectral range	Type of data (e.g. RGB, SAR) and spectral range (if relevant).
Other (if applicable)	Other data requirements.
Service Inputs	
Satellite data sources	Type of required data and examples of operational satellites that can provide these data.
Other data sources	Other sources of data that the service provider uses to realise the service.

Disclaimer: The EO-related requirements presented in the next section should be considered as "work-in-progress". They must be seen as a first attempt to specify requirements relevant to EO and are likely to evolve throughout the UCP process in the coming years.

5.1 Current GNSS/EO use and requirements per application

Several terms used in this document refer to technologies, domain or activities which are relevant to several applications related to the monitoring/management of infrastructures. The corresponding definitions are provided in Annex A1.3.

[10] See key EO performance parameters (detailed) definition in Annex A1.2.

5.1.1 Infrastructure Site Selection and Planning

Description

Prior to the construction of any infrastructure, an important step is the selection of the most relevant site and the planning of construction operations before they start.

Site selection aims at comparing the merits of potential locations and how they fit to the needs of the infrastructure project. The selection criteria are depending on the infrastructure itself but a set of site characteristics to be assessed which is common to the various types of infrastructures can be defined, which include site topography, geology, land cover/land use on the site and its vicinity, terrain stability, exposure to risks and exposure to climate change impacts.

Overview of user needs

During this phase, the main needs from the user perspective with regard to the above-mentioned site characteristics are the following ones:

- Topography: determine the elevation and slope of the site to assess if it is well-adapted to the type of infrastructure to be built;
- Geology: analyse soil characteristics (e.g. density, depth of bedrock) to identify possible complications and design plans to remediate these complications ([RD30]);
- Land cover/land use: be informed about the natural and manmade characteristics of the site land cover and land use characteristics of the potential site and of its surroundings (e.g. presence of built areas, agricultural lands, natural areas, rivers, roads, railways, etc.);
- Terrain stability: be informed about the extent to which the potential site is subject to ground deformation and if so, be informed about the associated subsidence risk;
- Exposure to risks: be informed about the natural risks the potential site is exposed to (e.g. exposure to floods, to wildfires, etc.);
- Exposure to climate change impacts: be informed about the long-term impacts of climate change the potential site will be exposed to (e.g. higher risk of exposure to droughts).

The planning phase mainly consists in construction surveying activities, which as mentioned in the previous Reports on User Needs and Requirements on surveying ([RD3]) involve the staking out[11] of reference points and markers that will guide the execution of the construction project. These activities include establishing basic lines, grade control and principal points, positioning for corners, delineating the working areas, determining ground profiles and the placement of utilities, and preparing large-scale topographic maps for drainage and site design. The establishment of the coordinate framework for a construction site involves both high-order control surveys and low-order control surveys.

During this phase, users need to perform the construction surveying activities with a sufficient level of accuracy to guarantee that construction operations benefit from a high-quality reference framework.

In the specific case of telecommunication network deployment (e.g. establishment of new 5G telecommunication networks) several aspects have to be considered during the site selection and planning phase.

Firstly, as for any other type of infrastructure, parameters such as topography, terrain stability or exposure to risks have to be taken into account for the selection of the sites where the network components will be deployed. This assessment is done in order for the planned network to be designed in a robust and

[11] Staking also serves as a base for verification of location and quantities of completed work (see [RD3]).

reliable way, and deployed in a cost-effective manner. The projected build cost of individual network components can be assessed in part by analysing the parameters linked to the planned sites for these components, such as the nature of the selected ground and the accessibility of the site, which represent real cost drivers for the implantation of 5G antennas for instance. Moreover, the reliability of a site can depend on a variety of natural and human-related factors (floods and other natural disasters, subsidence induced by human activities, …) which are essential to be analysed in order to mitigate the risks these infrastructures can be exposed to.

As far as the planning / design of the telecommunication network is concerned, additional assessments need to be performed. Indeed, covering very large areas in the magnitude of countries or continents, these networks need to be optimised to offer the best performances at a reasonable cost. They thus need to be designed based on the constraints of their environment. While the architectures of these networks depend on intrinsic factors such as the technology under use (frequencies, antennas size, …), parameters relative to the sites itself have to be taken into account. In the case of the 5G network (for which the target is to have an uninterrupted 5G wireless broadband coverage for all urban areas and major roads and railways by 2025 and a full coverage by 2030, see [RD40]), data such as the nature of the propagation environment (e.g., rural, urban, dense urban, etc.), the topography of the site (e.g., open, forest, sea, etc.) and the atmospheric conditions on the site (e.g., rainfall, fog, and clouds, etc.) are key to design the propagation model of the network and thus define the positions of the different components of this network (cell tower, small cells, …).

GNSS contribution and related requirements

In this general context, GNSS contributes to both the selection and planning phases whereas Earth Observation mainly contributes to the site selection phase.

As far as the use of GNSS is concerned, GNSS-RTK (Real-Time Kinematic) solutions are the preferred solution for several construction activities including topographic measurements and construction surveying (see [RD3]) as they allow for significant cost savings thanks to faster survey times, reduced field expenses in setting out marks and reduced labour cost (often even only one field surveyor suffices for most operations), whilst enabling horizontal accuracy[12] of 1-2 cm and vertical accuracy of 2-5 cm. One can note that Post Processing Kinematic (PPK) solutions can be used to reach a sub-centimetre accuracy. However, long-static observations are required to reach such sub-centimetre accuracy. The PPP-RTK has been developed and combines both RTK and Precise Point Positioning (PPP) technologies. PPP-RTK aims at providing the PPP centimetre accuracy while reducing the PPP convergence time. Indeed, PPP-RTK enables the achievement of a centimetre accuracy within a few seconds (while several minutes are required with PPP only). As the technology is still relatively new, it has not yet been widely adopted by signal augmentation service providers, leading to a less competitively priced market. This market situation is exacerbated by the current lack of standardised data formats, highlighting the early development stage of the technology (see [RD34]).

The latest EO and GNSS EUSPA Market Report ([RD1]) also mentions that through geomatics applications like mapping and GIS, photogrammetry, laser scanning and remote sensing, GNSS can provide adequate methods for the development of detailed specialised maps or for the establishment of GIS database with accurate positions of all infrastructure site features.

[12] When less than 1cm horizontal accuracy is necessary, other complementary techniques are synergistically engaged (e.g. sensors, traditional methods, drones).

In addition to high-accuracy GNSS devices (smart antennas or integrated mapping/GIS devices), GNSS chipsets can feed high-accuracy positioning data into LiDAR and imaging devices (drone or land-based), and augmented reality technologies for an *a priori* in-situ visualisation of the future infrastructure.

The main GNSS-related user requirements are (see [RD15], [RD16], [RD17], [RD18], [RD19], [RD20], [RD21]):

- Accuracy
    - Horizontal: mm- to cm-level depending on construction application;
    - Vertical: mm- to cm-level depending on construction application;
- Availability
    - Availability in urban canyons, under canopy:
        - Better than 95%: mostly medium; high required by setting-out/staking, alignment;
        - Better than 99%: mostly medium; high required by setting-out/staking, alignment;
- Robustness
    - Mostly low; medium required by setting-out/staking, alignment;
- Integrity and reliability
    - Mostly low; high required by setting-out/staking, alignment;
- Fixing and convergence time
    - TTFaF: typically a few minutes; a few seconds required by setting-out/staking, alignment;
- Coverage service area
    - Mostly regional;
- GNSS contribution to the PNT solution
    - Typically high, with the exception of setting-out/staking, alignment and high-order control survey;

Table 3: Main GNSS requirements for site selection, planning and construction operations

Construction Surveying Specific Application	Accuracy		Availability			Robustness	Integrity andreliability	TTFaF	Coverage service Area	GNSS contribution to the PNT solution
	Horizontal	Vertical	Urban Canyon, Canopy	Better than 95%	Better than 99%					
	mm-level cm-level dm-level m-level	mm-level cm-level dm-level m-level	Yes/No	Low Medium High	Low Medium High	Low Medium High	Low Medium High	a few seconds a few min >20min	Global Regional Local	Low Medium High
Setting-out/ staking, alignment, trajectory, Machine control	cm-level	Cm/ mm-level	Yes	High	High	Medium	High	a few seconds	Regional/ Local	Low
Vehicle tracking and asset management	m-level	m-level or N/A	Yes	High	Medium	Low	Low	a few seconds	Regional/ Local	High
Asset positioning at 3m level	m-level	m-level or N/A	Yes	Medium	Medium	Low	Low	a few min	Regional/ Local	High
Low order control survey	cm-level	cm-level	Yes	Medium	Medium	Low	Low	a few min	Regional	High
High-order control survey	mm-level	cm-level	No	Medium	Medium	Low	Low	>20 min	Regional	High
Temporary DGNSS reference for monitor station positioning	cm-level	cm-level	Yes	Medium	Medium	Low	Low	a few min	Regional	High

(Note: the above table, which is extracted from [RD3], also addresses the requirements related to machine control, vehicle tracking and asset management, which are dealt with in the next section).

The most demanding requirements in terms of accuracy are those for high-order control surveys, which require mm-level accuracy. [RD3] indicates that this is achieved through several redundant observations deploying dual frequency static (for lines of less than 100 km) methods. High-order (and low-order) control surveys follow a number of best practices to achieve the required accuracy levels. These are related to the number of independent sessions performed, the number of control points established, the configuration of the antennas, the duration of the sessions, etc. A detailed account is provided in [RD15] (see p.51).

EO contribution and related requirements

As far as EO is concerned, it can provide relevant information in the various aspects users are interested in when site selection is at stake:

- Topography: Earth Observation supports the establishment of Digital Elevation Models (DEMs) representing the topography of the Earth surface;
- Geology: Satellite-based hyperspectral imagery provides a unique combination of both spatially and spectrally contiguous images that allow precise identification of minerals ([RD31][RD32][RD33]);
- Land cover/land use: the exploitation of optical and SAR imagery enables land cover / land use classification thus supporting the characterisation of any location in terms of ground surface cover (e.g. bare soil, vegetation, built assets, etc.) and of the purpose the land serves (e.g. agriculture, wildlife, transport, etc.);
- Terrain stability: satellite-based SAR interferometry can detect ground subsidence of a few millimetres per year. Thanks to the availability of historical data, trends over large periods can be identified;
- Exposure to risks: the availability of historical data on natural disasters such as floods or wildfires, gathered through Earth Observation supports the assessment of the natural risk level any location is exposed to;
- Exposure to climate change impacts: Earth Observation supports the establishment of long-term climate projections informing on the changes in average values and patterns of a number of parameters likely to affect the viability of infrastructures (e.g. temperature, precipitations, wind, etc.).

For the gathering of EO-related requirements, several operational scenarios have been considered. They are described in the table below.

Table 4: Operational scenarios for "Infrastructure Site Selection and Planning"

Operational Scenario	Description
Site characterisation (Land cover / land use, topography, geological evaluation…)	Determination of the various characteristics of the site and its surroundings (e.g. land cover / land use characteristics, topography, geology, obstacles) to assess whether the site is well-adapted to the construction and operation of the future infrastructure (or to the extension / improvement of an existing infrastructure).
Risk assessment wrt. ground deformation	Evaluate the ground stability of the site and the surrounding area in order to assess the subsidence risk the infrastructure will be exposed to during its lifecycle if the site is selected for construction.
Risk assessment wrt. natural hazards (e.g. floods, droughts)	Evaluate the level of risk related to natural hazards (e.g. floods, wildfires, earthquakes) the future infrastructure will be exposed to during its lifecycle if the site is selected for construction.
Risk assessment wrt. climate change	Evaluate the level of long-term risk related to climate change (e.g. droughts, sea level rise) the future infrastructure will be exposed to during its lifecycle if the site is selected for construction.

The requirements related to the size of the area of interest and to the update frequency of information are similar for the various aspects addressed under "Site selection and planning". As far as the size of the area of interest is concerned, it generally varies from a few km^2 for localised infrastructures up to a thousand of km^2 for line infrastructures. Information to characterise the site and perform risk assessment is needed once (no need for updates) but in the specific case of risk assessment, historical data are also needed in order to determine trends.

Note: For the purpose of specifying user requirements, a distinction has been made between “localised”, “line” and “extended” infrastructures in the tables below. “Localised” infrastructures correspond to infrastructures situated on a relatively small area. They correspond to buildings, bridges, factories, etc. “Extended” infrastructures correspond to infrastructures such as airports or ports which can spread over areas representing several km^2. “Line” infrastructures are characterised by a large length and a relatively small width (e.g. highways, railways).

Concerning the characteristics of the data needed by service providers to deliver services and products to end-users, they are depending on the “operational scenarios” to be addressed. These operational scenarios cover the various aspects mentioned above: determination of the site characteristics, terrain stability risk assessment, natural risk assessment and climate change risk assessment.

Table 5: EO Requirements for "Infrastructure Site Selection and Planning" (site characterisation)

ID	TBC
Application	Infrastructure Site Selection and Planning
Users	(Future) Infrastructure owners and/or operators, Construction and public works companies.
User Needs	
Operational scenario	**Site characterisation (Land cover / land use, topography, geological evaluation…)** - Determination of the various characteristics of the site and its surroundings (e.g. land cover / land use characteristics, topography, geology, obstacles) to assess whether the site is well-adapted to the construction and operation of the future infrastructure (or to the extension / improvement of an existing infrastructure).
Size of area of interest	From a few km² (localised infrastructure) up to ~1000 km² (line infrastructure).
Scale	Not applicable
Frequency of information	One-off
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Generate assessment reports and/or thematic and baseline maps for the site to be characterised and its surroundings. Note: Maps are usually generated with a large scale to capture all details of the current situation. When relevant, they can show outcomes of analysis (e.g. buffered area for certain types of infrastructures that need some specific distance, horizon angle with surrounding obstacle as in the case of communication infrastructures…).
How the service works	Automated extraction of e.g. land cover features from satellite imagery and production of various types of maps or reports (land cover / land use, topography…).
Service Provider Satellite EO Requirements	
Spatial resolution	From a few dozens of cm (e.g. to map transport / water networks, existing infrastructures) up to ~10 m for LC/LU mapping.
Temporal resolution	Typically a few months
Data type / Spectral range	Optical visible, Near Infrared (NIR), Short-Wave Infrared (SWIR), Hyperspectral imagery[13], SAR.
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Very High (VHR) and High (HR) resolution Optical satellites, Hyperspectral satellites, SAR satellites.
Other data sources	In-situ data, DEM/DSM/DTM (established through aerial means)

In the specific case of 5G telecommunication networks, spatial resolution requirements for the geospatial data used for network planning purposes have been gathered in the context of a EUSPA- founded project[14]. These requirements are depending on several parameters:

- The frequency band used by the network, from low band (700 MHz) to ultra-high band (26 GHz;

[13] Which is especially relevant for the geological evaluations of sites
[14] Project "Digital ecosystem deep dive - EU Space for 5G/6G infrastructure"

- The type of area in which the network is deployed (i.e. rural / urban / dense urban);
- The type of geospatial data (e.g. DTM/DSM, Clutter, 3D building models).

These requirements are summarised in the table below.

Table 6: Spatial resolution requirements for geospatial data used for 5G network planning purposes

Spectrum	**Low to C-Band**			**mm-wave**		
Minimal requirements	Rural	Urban	Dense urban	Rural	Urban	Dense urban
DTM/DSM	10 m	5 m	2 m	N/A	1-2 m	<1 m
Clutter	10 m	5 m	2 m	N/A	1-2 m	<1 m
Clutter with heights	10 m; average height per class	2 m; average height per class	N/A	N/A	0.5 m	N/A
3D Building models (vegetation)	N/A	N/A	Accuracy 0.2 – 0.5 m (no vegetation)	N/A	N/A	Accuracy 0.1 – 0.4 m

Table 7: EO Requirements for "Infrastructure Site Selection and Planning" (ground deformation risk)

ID	TBC
Application	Infrastructure Site Selection and Planning
Users	(Future) Infrastructure owners and/or operators, Construction and public works companies.
User Needs	
Operational scenario	**Risk assessment wrt. ground deformation** – Evaluate the ground stability of the site and the surrounding area in order to assess the subsidence risk the infrastructure will be exposed to during its lifecycle.
Size of area of interest	From a few km² (localised infrastructure) up to ~1000 km² (line-infrastructure).
Scale	Ability to detect ground movements of a few mm per year
Frequency of information	One-off
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on ground deformation gradients (displacement vectors, area impacted) for the site to be characterised and its surroundings. The risk assessment can take different forms depending on what users need (e.g. map, reports).
How the service works	Generation of displacement measurements using differential interferometry synthetic aperture radar (e.g. DinSAR, PS-inSAR) techniques.
Service Provider Satellite EO Requirements	
Spatial resolution	From a few meters up to ~10 m
Temporal resolution	From weekly to monthly
Data type / Spectral range	Synthetic-Aperture Radar (SAR)
Other (if applicable)	Availability of historical data over several years (min. 2 years) is required to assess trends relative to ground deformation.
Service Inputs	
Satellite data sources	SAR satellites (C, L, X frequency bands)
Other data sources	Pre-existing terrain models, geological maps.

Table 8: EO Requirements for “Infrastructure Site Selection and Planning” (natural hazards risk)

ID	TBC
Application	Infrastructure Site Selection and Planning
Users	(Future) Infrastructure owners and/or operators, Construction and public works companies.
User Needs	
Operational scenario	**Risk assessment wrt. natural hazards (e.g. floods, droughts)** – Evaluate the level of risk related to natural hazards (e.g. floods, wildfires, earthquakes) the future infrastructure will be exposed to if the site is selected for construction.
Size of area of interest	From a few km^2 (localised infrastructure) up to ~1000 km^2 (line-infrastructure).
Scale	Not applicable
Frequency of information	One-off
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide risk assessment maps (including probability, intensity and location) or reports for each type of risk for the site to be characterised and its surroundings.
How the service works	Calculation of a risk score / index based on information from the territory (rains, humidity, …), digital terrain models and historical data.
Service Provider Satellite EO Requirements	
Spatial resolution	From ~10 m up to ~100 m
Temporal resolution	Monthly in general
Data type / Spectral range	Optical/SAR, Thermal Infrared
Other (if applicable)	Historical data on similar events help to better understand potential risks (even over centuries for some risks like floods or earthquakes).
Service Inputs	
Satellite data sources	HR/LR optical/SAR satellites, Thermal IR satellites.
Other data sources	DTM (Digital Terrain Models), historical risk events over the last centuries, climate models.

Table 9: EO Requirements for “Infrastructure Site Selection and Planning” (climate risk)

ID	TBC
Application	Infrastructure Site Selection and Planning
Users	(Future) Infrastructure owners and/or operators, Construction and public works companies.
User Needs	
Operational scenario	**Risk assessment wrt. climate change** – Evaluate the level of long-term risk related to climate change (e.g. droughts, sea level rise) the future infrastructure will be exposed to if the site is selected for construction.
Size of area of interest	From 10 km^2 (localised infrastructure) up to ~1000 km^2 (line-infrastructure).
Scale	Not applicable
Frequency of information	One-off
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide a climate risk assessment report characterising the level of climate risk for the site to be characterised and its surrounding.
How the service works	Calculation of a climate change risk score / index using long-term modelling of climate evolution.
Service Provider Satellite EO Requirements	
Spatial resolution	From ~100 m up to ~1 km
Temporal resolution	Yearly in general
Data type / Spectral range	Optical, Thermal Infrared (TIR) and SAR
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Low resolution TIR satellites. Optical satellites (Medium/Low optical). SAR satellites.
Other data sources	Historical information (e.g. on average temperature) over 50-100 years. Meteorological and climate models

5.1.2 Constructions Operations

Description

Construction operations cover the activities carried out between the end of the "site selection and planning" phase and the time at which the infrastructure enters into its operational phase. They include activities such as earth-moving, excavation, concrete work, installation work, etc. Depending on the type of infrastructure, they may also include activities such as tunnelling and boring.

In this document, "Construction operations" involve two main types of applications: the monitoring of construction progress and machine control.

Overview of user needs

The monitoring of construction progress aims at verifying that construction operations are progressing in line with the foreseen schedule and with design plans. Users need to identify delays and deviations as soon as possible in the process while minimising inspection costs.

Machine control refers (see [RD3]) to the control and/or guidance of vehicles on construction sites, which mainly entails earth-moving machines (i.e. dozers, graders, excavators, diggers). Main user expectations are to increase productivity by optimising machine operations.

GNSS contribution and related requirements

Concerning the use of GNSS, in addition of being widely used in construction surveying (see [RD3]), GNSS-RTK is increasingly driving the rapid growth of machine control solutions in the construction sector. The EO and GNSS Market Report published by EUSPA (see [RD1]) underlines that GNSS is an ultimate supplier of positioning and orientation data for heavy machinery, which can be used for either semi-automatic operations (i.e. GNSS serves as a guide to the operator) or fully automatic operations (i.e. GNSS data is directly fused into the machine hydraulic control). Thanks to the use of RTK corrections (see [RD3]), machine operations can be undertaken at centimetre-level accuracy and optimised (e.g. optimisation of the number of passes needed to achieve grade specifications while reducing costs through a reduction of labour, wear and tear and fuel consumption).

As mentioned in [RD3], two different modes exist for GNSS-enabled machine control:

- An "indicate" mode, which provides visual signs to help the operator in cutting or filling according to the design for the earth-moving task;
- An "automatic" mode, which involves controlling the machine hydraulics to ensure for instance for graders that the blade is always "on grade".

In the latter case, accuracy requirements are more stringent and can typically be achieved with an on-site base station. The more advanced systems use two receivers mounted on the machine to allow for its control in a three-dimensional digital design. For example, for dozers or graders, the first GNSS antenna is installed on the blade interposing vibration damping systems while the second antenna (also on the blade) or slope sensor is used to compute cross slope and orientation of the blade. Other devices such as MEMS and inertial sensors are used to improve the productivity of the system and assist in case of poor satellite visibility.

Apart from boosting the efficiency of machine operators who can control in real-time the execution of the project on their on-board display, GNSS-enabled telematics solutions enable more efficient construction management. Thus, by accessing different sets of 3D machine control data coming from the various vehicles on the site, construction managers can better monitor, supervise and coordinate the construction works, identifying bottlenecks, optimising machine utilisation and, eventually, saving costs. Thus, with the increasing spread of GNSS-based machine control systems and the improved integration and visualisation of design and telemetry data the output of construction works is maximised.

In addition to the above-mentioned usages, the horizontal accuracy of 1-2 cm and vertical accuracy of 2-5 cm offered by RTK network solutions enable to other applications such as the determining the elevation during the installation of utilities (pipelines, cables, power lines, etc.) or comparing the "as-built" against the designs. GNSS can also feed with high-accuracy positioning data of all relevant construction assets in the models used in the context of Building Information Modelling (BIM).

The main GNSS user requirements are (see Table 3 for more details)(see [RD15], [RD16], [RD17], [RD18], [RD19], [RD20], [RD21]):

- Accuracy
    - Horizontal: cm- to m-level depending on construction application
    - Vertical: mm- to m-level depending on construction application
- Availability
    - Availability in urban canyons, under canopy:
        - Better than 95%: mostly high; medium required by asset positioning;
        - Better than 99%: mostly medium; high required by trajectory, machine control;
- Robustness
    - Mostly low; medium required by trajectory, machine control;
- Integrity and reliability
    - Mostly low; high required by trajectory, machine control;
- Fixing and convergence time
    - TTFaF: a few seconds; a few minutes for asset positioning;
- Coverage service area
    - Regional/Local;
- GNSS contribution to the PNT solution
    - High for vehicle tracking and asset management, low for trajectory, machine control.

On top of quantitative requirements, the Report on Surveying User Needs and Requirements (see [RD3]) identifies important requirements which also apply to construction surveying:

- Interoperability and software flexibility: In most land surveying operations, GNSS is used together with other technologies (e.g. total stations) and thus interoperability and integration-ability of the GNSS equipment with other technologies is considered critical. In that respect, most manufacturers of GNSS-enabled devices actually advertise these features. Integrated solutions are sought, so that surveyors can use the most appropriate tool (e.g. GNSS, total station) for certain operations (e.g. topographic surveys and stakeout especially in large construction sites), under the given operating environment conditions, without having to switch between field software applications.
- Real-time and post-processed capability: Given that different techniques are best suited for different surveying operations (i.e. static for control, dynamic for detail and asset data capturing), surveyors seek solutions that can support both real-time and post-processed surveying.

EO contribution and related requirements

For the gathering of EO-related requirements, several operational scenarios have been considered. They are described in the table below.

Table 10: Operational scenarios for "Construction Operations"

Operational Scenario	Description
Construction progress monitoring (alignment with schedule)	Monitor the progress of construction activities to verify that construction progresses according to the original planning and detect deviations from schedule if any.
Construction conformity monitoring (alignment with plans)	Monitor construction activities to verify that construction is consistent with design plans.
Construction stability monitoring	Monitor ground stability of the construction area during the construction phase in order to detect if some specific precautions (e.g. stabilisation works) must be taken.

Concerning the use of Earth Observation in construction operations, a main use is the monitoring of construction progress, for which satellite imagery is increasingly exploited. Monitoring a construction project generally requires either to rely on second-hand information (e.g. report from subcontractors) or to perform regular on-site inspections to have a true picture of the site. Such inspections generate significant costs, particularly when the construction site is located in a distant or remote area. They are also a source of accidents since construction sites are intrinsically dangerous places. The use of satellite imagery enables the remote monitoring of the progress achieved on a construction site, wherever this site is located on the globe, while reducing inspection costs and increasing workers' safety. Indeed, the comparison of successive images of a same location enables the detection of surface changes, and therefore the tracking of construction operations. Moreover, the high revisit frequency offered by current satellite constellations makes possible to perform progress monitoring in near-real-time, and the availability of historical imagery enables to keep records of the progress achieved between different dates.

When the spatial resolution is high enough, satellite imagery can also support the verification of the conformity of built assets to the plans (e.g. number, size and nature of built assets).

In addition to progress/conformity monitoring, thanks to its capacity to detect ground movement, Earth Observation enables the identification of areas where construction work needs to take specific precautions such as stabilisation interventions. In such cases, additional very precise measurements can be made using "corner reflectors"[15] installed on purpose to verify the effectiveness of stabilisation interventions ([RD12]).

The characteristics of the data needed by service providers to deliver services and products to end-users are described in the tables hereafter.

[15] Corner Reflectors are artificial reflectors which are installed at specific locations on site to reflect the radar signal back to the satellite. They are installed where there is a lack of natural reflectors (e.g. vegetated areas) or where very accurate measurements are required.

Table 11: EO Requirements for "Construction Operations" (construction progress monitoring)

ID	TBC.
Application	Construction operations
Users	Infrastructure owners and/or operators, Construction and public works companies, Financial institutions financing the construction (including international organisations in case of ODA projects).
User Needs	
Operational scenario	**Construction progress monitoring (alignment with schedule)** – Monitor the progress of construction activities to verify that construction progresses according to the original planning and detect deviations from schedule if any.
Size of area of interest	<1 km^2 for localised infrastructures <1 km-width corridor along line infrastructures Up to ~15 km^2 for extended infrastructures
Scale	Not applicable
Frequency of information	From weekly to quarterly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide reports on the construction progress achieved between two different moments in time and assess its compliance to the planning (when the planning is available to the provider).
How the service works	Automated or semi-automated detection of newly built assets based on algorithms comparing successive images of the construction area.
Service Provider Satellite EO Requirements	
Spatial resolution	From a few dozens of cm up to ~5 m
Temporal resolution	From daily to monthly
Data type / Spectral range	Optical Visible and NIR, SAR.
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	VHR/ HR Optical satellites and SAR satellites.
Other data sources	UAV

Table 12: EO Requirements for "Construction Operations" (construction conformity monitoring)

ID	TBC.
Application	Construction operations
Users	Infrastructure owners and/or operators, Construction and public works companies, financial institutions financing the construction (including international organisations in case of ODA projects).
User Needs	
Operational scenario	**Construction conformity monitoring (alignment with plans)** – Monitor construction activities to verify that construction is consistent with design plans.
Size of area of interest	<1 km² for localised infrastructures <1 km-width corridor along line infrastructures Up to ~15 km² for extended infrastructures
Scale	Not applicable
Frequency of information	From one-off (final control) to monthly (regular monitoring)
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide report on the conformity to the design plans.
How the service works	Automated or semi-automated comparison of built assets (e.g. footprint and elevation) to a reference plan of the construction project.
Service Provider Satellite EO Requirements	
Spatial resolution	From a few dozens of cm up to ~1 m
Temporal resolution	From weekly to monthly
Data type / Spectral range	Optical (visible)(Alternatively SAR when cloud coverage is an issue)
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	VHR / HR Optical satellites
Other data sources	UAV

Table 13: EO Requirements for “Construction Operations” (construction stability monitoring)

ID	TBC
Application	Construction operations
Users	Construction and public works companies.
User Needs	
Operational scenario	**Construction stability monitoring** – Monitor ground stability of the construction area during the construction phase in order to detect if some specific precautions (e.g. stabilisation works) must be taken.
Size of area of interest	Depends on each type of construction works
Scale	To be defined
Frequency of information	From weekly to monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide subsidence monitoring during the construction and alert on the existence of zones at risk in the construction area.
How the service works	Generation of displacement measurements using differential interferometry synthetic aperture radar (DinSAR) and Persistent scatterer interferometry SAR (PS-inSAR) techniques. Comparison with maximum expected displacements and identification of unexpected behaviours.
Service Provider Satellite EO Requirements	
Spatial resolution	From a few meters up to ~10 m in most cases
Temporal resolution	From daily to weekly
Data type / Spectral range	SAR
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	SAR satellites (C, X bands)
Other data sources	Not applicable

5.1.3 Post-Construction Operations

Description

Built infrastructures can suffer from natural phenomena (e.g. ground deformation, vegetation encroachment, extreme weather events, natural hazard) or anthropogenic activities (e.g. construction works in the vicinity of existing infrastructures). In this document, post-construction operations refer to the monitoring of the state (mainly the structural health) of existing infrastructures once their construction is completed.

Overview of user needs

Users need to ensure the protection of their infrastructures, to optimise maintenance operations and possibly to extend the infrastructure lifecycle within safety margin. To achieve this, they need to monitor aging damages, to improve maintenance effectiveness in terms of planning and cost reduction, reduce risks notably from more frequent extreme weather events and predict possible failures ([RD11][RD22][RD23]).

GNSS contribution and related requirements

Concerning GNSS, the stability of built infrastructure can be monitored via high-precision GNSS methods, e.g. by post-processing of static relative GNSS observations at field control points (established directly into or in the vicinity of the object) with station data from local or global CORS networks. In addition, GNSS data may be utilised to feed various smart sensors, mounted into the infrastructure body for real-time stability monitoring (see [RD1]).

EO contribution and related requirements

As far as Earth Observation is concerned, it is considered very cost-effective for monitoring infrastructure on a large scale and with high frequency ([RD12]).

For the gathering of EO-related requirements, several operational scenarios have been considered. They are described in the table below.

Table 14: Operational scenarios for "Post-Construction Operations"

Operational Scenario	Description
Ground deformation monitoring (to assess risk on structural health)	Monitor ground stability of the infrastructure location and of its surrounding to detect slow ground subsidence (<30mm per year) likely to cause structural damages to the infrastructure.
Vegetation encroachment monitoring	Detect areas with vegetation encroachment on the infrastructure, or with a risk for vegetation encroachment (e.g. due to vegetation growth), for maintenance scheduling purposes.
Land cover / land use change monitoring (in the surroundings)	Monitor changes of Land cover / Land use in the vicinity of the infrastructure likely to put at risk the safety / efficiency of operations or requiring specific inspection or maintenance operations.

The satellite-based SAR interferometry solutions mentioned in section 0 which enable the detection of mm-level ground movements can also be used for the monitoring of infrastructure stability. These solutions support the identification of recent ground movements as well as the identification of trends over long periods thanks to the analysis of existing satellite data archives[16]. The analysis of optical imagery also enables to identify areas where a risk of vegetation encroachment exists[17]. The use of optical and SAR imagery supports the detection of land cover / land use changes (e.g. new constructions) in the vicinity of existing infrastructures.

The characteristics of the data needed by service providers to deliver services and products to end-users are described in the tables hereafter.

[16] According to [RD12] detailed and historical ground motion information is difficult (or even impossible) to obtain without satellite data archives.
[17] This mainly concerns line infrastructures

Table 15: EO Requirements for "Post-Construction Operations" (ground deformation monitoring)

ID	TBC
Application	Post-Construction operations
Users	Infrastructure owners and/or operators
User Needs	
Operational scenario	**Ground deformation monitoring (to assess risk on structural health)** – Monitor ground stability of the infrastructure location and of its surrounding to detect slow ground subsidence (<30 mm per year) likely to cause structural damages to the infrastructure.
Size of area of interest	Local scale (1-2 km^2) for localised infrastructures From local to national scale (Extent of line infrastructure, from 10 to 1000+ km) Extent in the range of 5-10 km^2 for extended infrastructures
Scale	Ability to detect ground movements of a few mm per year
Frequency of information	6-monthly to yearly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide continuous monitoring after construction to inform on potential ground deformation larger than expected.
How the service works	Automatic data processing of ground motion data and ancillary data to assess the level of risk over each infrastructure.
Service Provider Satellite EO Requirements	
Spatial resolution	From ~1 m up to ~20 m for localised or line infrastructures From ~5 m up to ~20 m for extended infrastructures
Temporal resolution	Monthly in general
Data type / Spectral range	SAR
Other (if applicable)	Availability of historical data since the end of the construction is required to assess ground deformation.
Service Inputs	
Satellite data sources	SAR satellites (C, L, X bands)
Other data sources	Not applicable

Table 16: EO Requirements for "Post-Construction Operations" (vegetation encroachment monitoring)

ID	TBC
Application	Post-Construction operations
Users	Infrastructure owners and/or operators
User Needs	
Operational scenario	**Vegetation encroachment monitoring** – Detect areas with vegetation encroachment on the infrastructure, or with a risk for vegetation encroachment (e.g. due to vegetation growth), for maintenance scheduling purposes.
Size of area of interest	Buffer area of up to ~50 m width each side of the line infrastructure.
Scale	Not applicable
Frequency of information	Every 3-6 months
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Identify zones in the buffer area where changes in vegetation constitute a threat to the safety and/or efficiency of the infrastructure.
How the service works	Automatic processing of optical satellite imagery to derive vegetation geo-analytics.
Service Provider Satellite EO Requirements	
Spatial resolution	From a few dozens of cm up to ~20 m
Temporal resolution	From quarterly to 6-monthly
Data type / Spectral range	Optical Visible, NIR
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	VHR/ HR Optical satellites
Other data sources	Not applicable

Table 17: EO Requirements for "Post-Construction Operations" (land cover/use change monitoring)

ID	TBC
Application	Post-Construction operations
Users	Infrastructure owners and/or operators
User Needs	
Operational scenario	**Land cover / land use change monitoring (in the surroundings)** – Monitor changes of Land cover / Land use in the vicinity of the infrastructure likely to put at risk the safety / efficiency of operations or requiring specific inspection or maintenance operations.
Size of area of interest	Local scale (1-2km²) for localised infrastructures Buffer area of up to a few hundreds m width each side of the line-infrastructure 5-10 km² for extended infrastructures
Scale	Not applicable
Frequency of information	6-monthly to yearly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Highlight where natural or human induced changes can be a threat to the safety and/or efficiency of the infrastructure.
How the service works	Automatic processing of radar and optical satellite imagery to derive the land cover /land use classes.
Service Provider Satellite EO Requirements	
Spatial resolution	From ~1 m up to ~20 m
Temporal resolution	Monthly in general
Data type / Spectral range	Optical/NIR/SAR
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	VHR/HR optical satellites, SAR satellites
Other data sources	Not applicable

5.1.4 Environmental impact assessment of infrastructures

Description

Environmental impact assessment (EIA) of infrastructures consists in assessing and characterising the impacts caused by infrastructures on their environments, either during or after the construction phase of these infrastructures. Most projects even require that an environmental impact assessment is performed before the construction starts (see [RD29]).

Overview of user needs

Environmental impacts can be very diverse, ranging from ground deformation, air and water pollution and impact on the environmental dynamics and ecosystems. EIA are often performed to follow legal obligations. Indeed, depending on local/regional/national, infrastructures owners and operators or construction companies may have to justify that their infrastructures do not have any impact on the environment, or that these ones are understood and mitigated. In addition, public administration may have to assess the impact of infrastructures on the environment for controlling purposes.

EO contribution and related requirements

Earth Observation can support the analysis of the impact of existing infrastructures on the environment and ecosystem in their surroundings, including during the construction phase. Indeed, thanks to its ability to provide an assessment not only of the site but also of its surroundings, it enables to better understand the interactions between complex ecosystems. Relevant EO-based products and services include pollution monitoring (air, water, soil), vegetation and biodiversity monitoring, etc. For instance, multispectral and hyperspectral data support the detection of subtle stress invisible to the human eye in vegetation and water bodies. Moreover, the existence of satellite data archives (up to a few decades sometimes) enables to understand if changes are caused by the presence of infrastructure of if they had already started before the infrastructure exists ([RD1][RD29]). Another example of use is satellite-based SAR interferometry which can detect ground subsidence of a few millimetres per year and can therefore be used to assess if construction operations cause ground movements in their surroundings[18].

For the gathering of EO-related requirements, several operational scenarios have been considered. They are described in the table hereafter.

Table 18: Operational scenarios for “Environmental impact assessment of infrastructures”

Operational Scenario	Description
Ground motion monitoring (caused by works during the construction phase, e.g. in case of tunnel digging)	Monitor the area surrounding the infrastructure to detect if construction works induce ground instability likely to cause structural damages to neighbouring infrastructures.
Air and water pollution assessment	Monitor the presence of pollution (air pollution / water pollution) in the vicinity of the infrastructure and assess whether pollution is caused by the infrastructure.
Biodiversity loss assessment	Monitor whether the presence of the infrastructure induces biodiversity loss in the vicinity of the infrastructure.

The characteristics of the data needed by service providers to deliver services and products to end-users are described in the tables hereafter.

[18] For example, monitoring of stability of urban infrastructure in the context of tunnelling projects has been successfully demonstrated ([RD11]).

Table 19: EO Requirements for "Environmental impact assessment of infrastructures" (ground motion monitoring)

ID	TBC
Application	Environmental impact assessment of infrastructures
Users	Infrastructure owners and/or operators, Construction and public works companies, Public authorities.
User Needs	
Operational scenario	**Ground motion monitoring (caused by works during the construction phase, e.g. in case of tunnel digging)** – Monitor the area surrounding the infrastructure to detect if construction works induce ground instability likely to cause structural damages to neighbouring infrastructures.
Size of area of interest	Up to ~100 km²
Scale	To be defined
Frequency of information	From weekly to monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on ground displacement in the surroundings of the infrastructure. The risk assessment can take different forms depending on what users need (e.g. map, reports).
How the service works	Generation of displacement measurements using differential interferometry synthetic aperture radar (DinSAR) techniques.
Service Provider Satellite EO Requirements	
Spatial resolution	From ~1 m up to ~10 m
Temporal resolution	Weekly in general
Data type / Spectral range	SAR
Other (if applicable)	Availability of historical data is required to establish the "reference" ground instability assessment.
Service Inputs	
Satellite data sources	SAR satellites (C, X bands)
Other data sources	Not applicable

Table 20: EO Requirements for "Environmental impact assessment of infrastructures" (Air and water pollution assessment)

ID	TBC
Application	Environmental impact assessment of infrastructures
Users	Infrastructure owners and/or operators, Construction and public works companies, Public authorities.
User Needs	
Operational scenario	**Air and water pollution assessment** – Monitor the presence of pollution (air pollution / water pollution) in the vicinity of the infrastructure and assess whether pollution is caused by the infrastructure.
Size of area of interest	Up to ~100 km^2
Scale	Not applicable
Frequency of information	From daily to weekly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide reports / alerts on air/water quality in the surroundings of the infrastructure.
How the service works	Estimation of pollutant concentrations based on modelling and satellite-based measurements
Service Provider Satellite EO Requirements	
Spatial resolution	From ~10 m up to ~100 m
Temporal resolution	From daily to sub-daily
Data type / Spectral range	Optical (Spectrometer)
Other (if applicable)	Historical data is required to understand the initial conditions on the site
Service Inputs	
Satellite data sources	Multispectral and Hyperspectral satellites. Spectrometer sensor.
Other data sources	Not applicable

Table 21: EO Requirements for "Environmental impact assessment of infrastructures" (biodiversity loss assessment)

ID	TBC
Application	Environmental impact assessment of infrastructures
Users	Infrastructure owners and/or operators, Public authorities.
User Needs	
Operational scenario	**Biodiversity loss assessment** – Monitor whether the presence of the infrastructure induces biodiversity loss in the vicinity of the infrastructure.
Size of area of interest	Up to ~100 km²
Scale	Not applicable
Frequency of information	Yearly in general
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide report / alerts on biodiversity losses.
How the service works	Estimation of biodiversity indexes based on the analysis of different types of information (land use/land cover, vegetation type, etc.)
Service Provider Satellite EO Requirements	
Spatial resolution	From ~1 m up to ~10 m
Temporal resolution	Monthly in general
Data type / Spectral range	Optical and SAR
Other (if applicable)	Historical data is required to understand the initial conditions on the site
Service Inputs	
Satellite data sources	Multispectral and SAR satellites
Other data sources	Not applicable

5.1.5 Pipeline Monitoring

Description

“Pipeline monitoring” refers to the monitoring of the evolution of the state of pipelines and their surroundings with the objective to detect problems related to the natural aging of the infrastructure (e.g. structural deformation, leakages) and to assess the risks likely to threaten the infrastructure, whatever they are natural (e.g. vegetation encroachment) or anthropogenic (e.g. new construction in the vicinity of a pipeline).

Overview of user needs

Users need to detect anomalies (e.g. leakages) when they occur in the pipeline corridor, and to optimise maintenance operations by identifying zones at risks along the pipeline and concentrating monitoring activities (e.g. on-site inspections) where more appropriate.

GNSS contribution and related requirements

For above-ground pipelines, GNSS provides methods for stability monitoring similar to post-construction operations, while for underground assets it may feed high-accuracy positioning data into ground-penetration radars (GPRs) to map and detect leakages and other faults. (see [RD1]). RTK (Real-Time Kinematic) network, which uses GNSS for real time and cm-level positioning, is of key value for pipeline monitoring thanks to its horizontal accuracy of 1-2 cm and vertical accuracy of 2-5 cm. (see [RD3]).

EO contribution and related requirements

As far as Earth Observation is concerned, InSAR ground deformation monitoring supports the identification of zones where ground subsidence puts the infrastructure at risk. The processing of satellite images with change detection algorithms enables the identification of vegetation encroachments and third-party interferences.

5.1.6 Data Centre ◐

Description

A Data Centre is a dedicated space within a building, or a group of buildings which houses computer systems and associated components offering remote processing and storage capacity to their end-users through telecommunication networks.

Overview of user needs

For their daily operations, data centres need to be provided with an accurate and reliable timing and synchronisation source. The need relates to the following use cases[19]:

- **Enterprise applications:** professional tools such as distributed transactional applications, databases, artificial intelligence, big data, and machine learning require precise T&S to work efficiently. In addition, enterprise security tools (e.g. SIEM, IDS/IPS, PKI) also require precise time for ordering logs, checking certificate validity as well as identifying and preventing online attacks (sequence of event);
- **Manufacturing**: robotics and automated operations require precise T&S across different digital systems to provide a converged network with audio/video streaming and real-time control flow. As a matter of example, the Time Sensitive Network (TSN) standard has been developed to enable a more reliable and efficient automation as well as a standardisation of the processing of global packets of information within the same industry;
- **Media & Entertainment**: the broadcasting industry requires synchronicity between audio and video feeds to prevent "lip-sync" errors. Also, the e-sport and gaming require time synchronisation to ensure chronological order of play in multi-player games.

GNSS contribution and related requirements

GNSS contributes to the provision of T&S to data centres for both aspects (see [RD4]):

- Timing: GNSS provides a direct and accurate access to a prediction of Coordinated Universal Time (UTC);
- Synchronisation: As mentioned in [RD4], synchronisation can be achieved in two different ways, i.e. either synchronisation between receivers at different locations can be established and maintained using GNSS reference time, or a master clock synchronised itself using the time provided by GNSS can redistribute this time to the slave clocks disseminated within the systems.

On-premise GNSS receiver use is assessed as the most accurate T&S solution (sub-micro second precision) but it can be costly to setup and challenging to manage for IT support teams. "Time as a Service" (TaaS) concept has emerged to answer such a drawback and provides an acceptable level of precision for most of the data centre services (microsecond level). However, TaaS is for the time being only available in some specific locations and could generate multiple dependencies to the TaaS service provider.

[19] Source: ITSF webinars (https://itsf2022.executiveindustryevents.com/Event/Webinars/webinars.php)

5.1.7 Digital Cellular Network (DCN)

Description

A digital cellular network (DCN) also referred to as “mobile network” is a communication network where the link to and from end nodes is wireless. The network is distributed over land areas called “cells”, each cell being served by at least one fixed-location transceiver. The fixed -location transceiver generally consists of three “base stations” which provide the cell with the network coverage for the transmission of voice, data, and other types of content. As mentioned in [RD4], Digital cellular technology is constantly evolving as the demand for broadband data speeds continually increases.

Europe’s digital cellular infrastructure comprises of a blend of GSM, UMTS, LTE and more recently 5G deployments. LTE technology, the latest commercially available standard fully deployed, is the prominent technology and is increasingly reliant on precise timing information as it evolves into LTE- Advanced. Due to the number of LTE based base stations deployed in Europe and its dependency on accurate synchronisation, the digital cellular segment is the Time & Synchronisation market’s major economic driver (see [RD4]).

Overview of user needs

Telecommunication operators require accurate and consistent time and frequency at distant points of their networks to meet increasingly demanding broadband requirements (see [RD1]).

GNSS contribution and related requirements

GNSS is used to provide consistent frequency and time alignment between all base stations within the network (as a primary source of timing information or as a redundancy solution).

There are two mobile wireless synchronisation approaches, depending on whether networks employ time or frequency division duplexing. Frequency division (such as WCMDA) uses the same equipment and approaches employed in fixed line circuits. Time division (such as CDMA, WiMax and LTE) requires frequency accuracy, phase alignment and (in some case) time alignment between all base stations within the network. It is unable to rely on traditional circuit-based approaches as there is no time or phase relationship between the terminating points on the clock circuit. The Timing & Sync system shall provide a Timing accuracy of 30 ns to UTC, a Phase Sync accuracy of less than 65 ns and a Freq Sync accuracy of 1.10-11 ([RD24][RD25][RD55]). 3G is using synchronisation from the derivate of timing acquisition from GNSS external source and sometimes combined with a frequency distribution along the backhaul network to supply the Radio Access Network (RAN) from eNB. Requested frequency accuracy is ±5ppb. Timing need is for LTE-TDD (Time-Division Duplex). For extension of LTE-A service extending throughput to 100 Mb with Coordinated Multi-Point (CoMP) transmission and reception requirement reaches 0.5 µs accuracy requirement for cells extend < 800 m ([RD26]).

The push for innovation on 5G applications have led, among other, on the creation of the O-RAN (Open Radio Access Network) alliance in 2018 to answer one key issue in the area: the lack of standard communication and interfaces between systems. The O-RAN alliance work has led to the provision of specifications for the management, user, and control planes but also for the synchronisation plane of 5G architectures. In particular, the ORAN-WG4-CUS.0 document [RD35] includes specifications of the O-RAN fronthaul Synchronization Plane and the basic synchronization requirements. This synchronisation plane specification includes four different clock model and synchronisation topologies. Each topology (called Lower Layer Split – LLS) uses GNSS equipment for T&S purpose, but implements them at various location of the 5G network (use of local, central, or remote Primary Reference Time Clock – PRTC). The synchronisation flow is then provided using ethernet technologies such as the Precision Time Protocol (PTP) and the Synchronous Ethernet (SyncE). Depending on the operators’ decisions related to the 5G architecture, getting the GNSS equipment closer to the 5G base station could lead to further investments in the deployment of more GNSS receivers.

Stringent T&S specification for 5G architecture has also induced the need for an accurate testing and calibration of the synchronisation plane and validating the timing performance from the Radio Access Network (RAN) is expected to be an essential part of network proof-of-concept and troubleshooting. Therefore, the manufacturers are offering handheld T&S testing equipment synchronised by GNSS and embedding highly stable and accurate clocks (such as Rubidium clocks). Such trend could lead to the adoption of further GNSS receivers for the DCN market.

Other user requirements for DCN applications consist in (see [RD4][RD27]):

- A Timing accuracy of 30 ns to UTC;
- A Phase Sync accuracy of less than 65 ns;
- A Frequency Synchronization accuracy of 1.10^{-11}.

5.1.8 Professional Mobile Radio (PMR)

Description

“Professional mobile radio” (PMR) refers to person-to-person two-way radio voice communications systems. These systems are used by governmental users such as police, fire, ambulance, and emergency services, and by commercial firms such as taxis and delivery services. Most systems are half-duplex, in which multiple radios share a common radio channel, and only one can transmit at a time. Repeaters installed on tall buildings, hills or mountain peaks are used to increase the range of systems.

In Europe, PMR services are based on Terrestrial Trunked Radio (TETRA) and Terrestrial Trunked Radio POLice (TETRAPOL) standards (see [RD4]). TETRA, the predominant technology, was specifically designed for use by government agencies, emergency services, (police forces, fire departments, ambulance) for public safety networks, rail transportation staff for train radios, transport services and the military. TETRA’s ability to set up one-to-many and many-to-many calls makes it the chosen tactical communications method for the emergency services.

Overview of user needs

To work properly, PMR systems need a timing reference.

GNSS contribution and related requirements

GNSS provides a timing reference which is used to provide air interface synchronisation for roaming and assigning communication channels (as a primary source of timing information or as a redundancy solution). This allows users to hand over from one base station service coverage area to another without dropping a call. TETRA and PMR in general require a precision of 10 µs to allow for successful handover. Where feasible, GNSS receivers are located at every base station to allow signal handover from base station to base station. Loss of GNSS timing will cause graceful degradation as local oscillators act as failover (see Table 1 in [RD4] for typical performance of local oscillators). Due to limitations on volume of data that can be transmitted over existing PMR technologies and increasing functionality of LTE (4G) followed by the 5G, PMR networks may be complemented by LTE technology to allow for high quality video streaming and broadband data services (this may still be under the management of specialist PMR providers). The development of PMR solution based on LTE (4G) and 5G technologies leads to more strict frequency and time synchronisation requirements for a PMR network. It is unclear whether this will provide a further opportunity for GNSS timing as the industry may opt for non-GNSS time solutions or reduce the instances of GNSS receivers due to developments in synchronisation flow protocols such as PTP ([RD24][RD25]).

5.1.9 Public Switched Telephone Network (PSTN)

Description

The Public Switched Telephone Network (PSTN), also referred to as the Plain Old Telephone Service (POTS), provides infrastructure and services for public telecommunications. The PSTN is the aggregate of the world's circuit-switched telephone networks that are operated by national, regional, or local telephone operators. These consist of telephone lines, fiber optic cables, microwave transmission links, cellular networks, communications satellites, and undersea telephone cables, all interconnected by switching centres which allow most telephones to communicate with each other. Today, it is almost entirely digital in technology except for the final link from the central (local) telephone office to the user (see [RD4]).

Overview of user needs

Telecom operators require accurate and consistent time and frequency at distant points of their networks to meet increasingly demanding broadband requirements.

GNSS contribution and related requirements

For the PSTN application, GNSS is usually a back-up to atomic clocks to provide time slot management.

Use of GNSS-derived synchronisation within European PSTN operators is dependent on whether atomic clocks are already incorporated into their networks. Large operators typically have access to their own atomic clocks installed within their networks in the 1970s and 80s prior to the availability of GPS.

The current accuracy performance of the GPS technology is matching the current and expected performance that would be required in the future.

The use of synchronisation references within telecom networks is used for the synchronisation of the network and has undergone (and continues to undergo) considerable changes. Traditionally telecom networks relied upon a central primary reference clock with timing distributed to the various network layers via SDH. The distributed clock signal was then re-filtered by various Synchronisation Supply Units (SSU) distributed within the network. Around 10 years ago this would in all cases have been based on Caesium primary reference clocks.

Developments over the last 10 years have resulted in flatter hierarchies with more primary reference clocks (often GPS based) and less distribution. This is typically implemented with a hybrid architecture where GPS Primary reference clocks are used at a mid-layer but the traceability to a caesium reference is maintained to ensure continued operation in the event of loss of GPS.

Another key change which has been occurring over the last decade is the move to packet-based services which do not support traditional mechanisms for the distribution of synchronisation. This might lead some telecom operators to make use of GNSS based synchronisation. A contrario, developing standards such as NTP and PTP are providing mechanisms to enable timing information to be distributed and hence an alternative source of synchronisation to be made available. GNSS usage within PSTN would decline as distribution over fixed infrastructure and new network architecture are adopted ([RD24][RD25]).

As of today, user requirements for PSTN applications consist in a timing & synchronization accuracy of 1 µs.

5.1.10 Satellite Communication (SATCOM)

Description

Satellite communication (Satcom) covers the use of satellites to provide communication links between various points on Earth and deliver different types of services among which radio, television, data and telephone transmissions ([RD4]). Satellite communication systems have two main components: the ground segment, which consists of fixed or mobile transmission, reception, and ancillary equipment, and the space segment, which consists of a single satellite or of a constellation of satellites. A typical satellite link involves the transmission or uplinking of a signal from an Earth station to a satellite. The satellite then receives and amplifies the signal and retransmits it back to Earth, where it is received and reamplified by Earth stations and terminals. Satellite receivers on the ground include direct-to-home (DTH) satellite equipment, mobile reception equipment in aircraft, satellite telephones, and handheld devices.

Overview of user needs

Telecom operators require accurate and consistent time and frequency at distant points of their networks to meet increasingly demanding broadband requirements.

GNSS contribution and related requirements

GNSS is typically used in Telecommunications Gateways, mostly for frequency control, and also in Satellite Control Stations for timing applications (as a primary or as a redundancy source).

Applications can include ([RD4]) synchronisation and user mobility management (as per 3GPP standard). The synchronisation requirement is divided into:

- TDMA timing on the satellite links and terrestrial links.
- TTCM timing
- NTP type services for IT/network/satellite monitoring/control/billing

It is estimated that each Satellite Control Station would have a minimum of four local GNSS receivers, but this can range up to ten depending on a number of factors and criteria. GNSS receivers are typically backed up with local (atomic) oscillators, although the SATCOM industry has increased its confidence in GNSS derived timing as they have experienced little if no negative performance of the received GNSS signal.

The synchronisation requirements are typically based upon the recommendations set out in ITU G.811 (Stratum 1) (G.812 provides recommendations for slave clocks in telecoms networks) or proprietary technology. Accuracy requirements are mainly driven by proprietary technology requirements of the telemetry tracking loops but are likely to be around 100 ns accuracy.

Regarding the user requirements, the Timing & Sync system shall provide an accuracy of 100 ns for Satcom applications.

5.1.11 Small Cells

Description

A small cell[20] is a low-cost radio access point with low radio frequency (RF) power output, footprint and range. It can be deployed indoors or outdoors, and in licensed, shared or unlicensed spectrum. Small cells deliver high-quality, secure cellular coverage indoors and out, complementing the macro network to improve coverage, add targeted capacity, and support new services and user experiences. There are various types of small cell, with varying ranges, power levels and form factors, according to use case. The smallest units are for indoor residential use. The largest are urban or rural outdoor picocells.

Overview of user needs

Telecom operators require accurate and consistent time and frequency at distant points of their networks to meet increasingly demanding broadband requirements.

GNSS contribution and related requirements

For the above-mentioned use, GNSS is used to provide frequency and phase alignment in small cells networks.

5.1.12 Monitoring of impact of human activities on infrastructure

Description

Various human activities can have impacts on the structural health of infrastructures because they induce ground deformations which can in turn damage infrastructures located in the areas where the deformation takes place.

The two main types of activities likely to induce such impacts are aquifer overexploitation in urban areas or construction works (in particular those involving significant excavation works like tunnelling activities).

Overview of user needs

Users need to identify ground subsidence in the concerned areas and to establish correlations between subsidence and human activities, notably thanks to the exploitation of historical data.

EO contribution

Thanks to its capacity to detect millimetric ground deformation, Earth Observation supports the monitoring of the impact of human activities on infrastructures.

[20] See https://www.smallcellforum.org/small-cells/

5.1.13 ODA Support Monitoring

Description

Official development assistance (ODA) is defined by the OECD Development Assistance Committee[21] (DAC) as government aid that promotes and specifically targets the economic development and welfare of developing countries. The application described as "ODA Support Monitoring" consists in verifying that infrastructures financed through ODA are built in line with plans. This supports the assessment of the good use of the grant or loan received by a country for the specific objective it was initially planned for. This is often directly informing the further release of funds from a donor country to a receiving one.

Overview of user needs

In most cases, infrastructures financed through ODA are located very far from the financing institutions and on-site inspections are therefore costly. The main needs of these institutions with regard to infrastructure monitoring are to assess the real progress of construction activities while minimising inspection costs.

EO contribution

Thanks to the change detection capacity it offers, EO can support the monitoring of the construction progress anywhere in the world, even in remote locations.

5.1.14 Permitting

Description

Permitting covers all the actions required towards authorities to obtain the necessary authorisations before construction can start. The permitting procedure generally consists in six steps (see [RD28]): the scoping of the project, the preparation of the application documents, the verification of the application, the public consultation, the decision phase and the appeal and litigation (after the permit has been granted).

Overview of user needs

During the permitting phase, users need to be provided with the environmental information required to obtain the necessary authorisations.

EO contribution

Earth Observation can support the evaluations to be carried out before a permit is delivered for the construction of a new infrastructure. In particular, EO can deliver information related to land cover/land use, geological evaluation, exposure to natural disasters (e.g. floods), ground deformation, etc. (see [RD1]).

[21] https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/What-is-ODA.pdf

5.1.15 Vulnerability Analysis

Description

A vulnerability analysis is a risk management process used to identify, quantify and rank possible vulnerabilities that threats a given system. In the Infrastructures context, these vulnerabilities are mainly linked to natural phenomena (e.g. ground subsidence) and hazards (e.g. floods, drought, fires, …), natural aging of infrastructures and climate change. Vulnerability assessment is generally carried out during the site selection phase but it can be performed at any moment of the infrastructure lifecycle.

Overview of user needs

Depending on the moment at which the vulnerability assessment is performed in the infrastructure life cycle, users need to be provided either with an assessment of the current risks or with an assessment of the future risks threatening their infrastructure.

EO contribution

Earth Observation can contribute to the vulnerability assessment through the provision of historical data on various types of natural phenomena, including ground subsidence, floods, wildfires and droughts. It also supports the establishment of climate change projections on the long-term (e.g. decadal projections) which help better characterising the evolution of natural risks.

5.2 Limitations of GNSS and EO

5.2.1 GNSS limitations

The Reports on User Needs and Requirements on surveying (see [RD3]) identifies several limitations which apply to the surveying domain in general but are also relevant for construction surveying. The document indicates however that these limitations can be typically overcome by employing complementary technologies described in [RD3] or by following best practices regarding the type of GNSS equipment used. These limitations are repeated hereafter.

Operating environment limitations

These are mostly related to constraints related to the environment in which survey operations are carried out. Thus, in dense urban environments, in sites where there are natural (e.g. tree canopy) or artificial (e.g. buildings or highly-reflective surfaces in construction sites) obstructions, and in areas with complex topographies, interference and multipath effects as well as limited GNSS signal availability, should be overcome by deploying complementary technologies.

Vertical position determination

When there is a need for highly accurate vertical position determination (e.g. in control surveys) considerations related to antenna phase centre variations should be taken into account. These are a function of the elevation and azimuth angle between the antenna and a given satellite. For short baselines, and where the same antenna is used (between rover and base), the variations cancel out. But as the baseline length increases, and even more if different antennas are used, the variations pertain and there is a significant deterioration in height determination accuracy. Advanced software methodologies are deployed to model these variations and improve the final outcome. However, it is typically recommended that traditional spirit levelling is deployed to accurately determine the orthometric height of a given site.

Demanding data point collection

When there is a need of collecting a vast number of data points per second, typically in order to construct 3D models or digital terrain models, laser scanner and LIDAR technologies need to be deployed. In addition, when the access to certain areas is difficult or safety considerations apply, surveying from a distance is ensured with RPAS or aircrafts.

Susceptibility to interference

Radio interference can be defined as the reception of a mix of multiple signals with one signal being the desired signal to be received and processed and the other signals being undesired. If the undesired signals degrade, obstructs, or repeatedly interrupts the reception of the desired signal it is referred to harmful interference. The origin of the radio interference can be intentional (e.g., GNSS jammers) or unintentional (e.g., malfunctioning equipment in wireless telecom networks creating in-band spurious emissions).

GNSS interference is critical for ground CORS infrastructure receivers. Innovative dedicated mitigation techniques within the receiver chipsets are capable to overall limit its negative effects.

Sensibility to ambient humidity

Additional errors are detected when surveyors perform measurements in extreme conditions and/or with big fluctuations in ambient humidity, such as in Antarctica, or at high altitudes in mountainous areas (e.g., when installing telecom antennas, repeaters) when measurements are taken at points with height difference between the reference station and the rover of orders of 600 m. If such meteorological conditions exist, one practical approach for high-precision surveying is to choose the days for GNSS observations with minimal moisture content (no higher than 12 g/m^3)[22].

The reports on User Needs and Requirements on surveying (see [RD3]) also identifies limitations which are more specific to construction surveying and relate to the performance of GNSS-RTK in construction sites. These limitations relate to satellite availability due to site obstructions (trees, nearby buildings), multipath errors due to nearby surfaces and positioning latency, i.e. the time needed to transmit the reference data to the rover station. The advent of RTK networks ([RD18]), including regional or nationwide CORS operated commercially or maintained by institutions, has allowed to mitigate these effects, whilst also alleviating the reference-to-range distance limitations and providing consistent coordinates. In addition, where such networks exist, the costs related to setting up of base stations on the specific construction site are eliminated.

As far as Timing & Synchronisation is concerned, the report on time & synchronisation user needs and requirements ([RD4]) identifies the following limitations:

- Spoofing threats (including residual spoofing threats for GNSS that provide authentication function), and the possible remaining after strategies currently developed by the receiver manufacturers to improve the resilience to spoofing);
- Low resistance against interference;
- Availability issue for Indoor/Urban use;
- Receiver power consumption.

[22] http://science.lpnu.ua/sites/default/files/journal-paper/2018/jul/13632/180934geodez-30-35.pdf

5.2.2 Earth Observation limitations

Earth observation also has limitations it is important to be aware of. EO-based solution should not be oversold in order to avoid to create disappointment[23].

Beyond the fact that the use of EO is limited to the surface and is therefore not suitable for the monitoring of all types of infrastructure (e.g. those deep below the surface like tunnels), it faces some intrinsic limitations, which are mentioned hereafter.

Optical imagery limitations

The use of optical imagery is limited in case of presence of clouds above the area of interest. This can be a problem for applications related to infrastructure in areas prone to bad weather, particularly if these applications require frequent revisits[24].

In some specific cases, for instance in case of roads located under a tree canopy, optical imagery cannot be used either.

SAR imagery limitations

Contrary to optical imagery, SAR imagery can be obtained night and day and is not affected by the cloud coverage. Nevertheless, it also suffers limitations ([RD13]) among which:

- Depending on the frequency used, vegetation can limit data acquisition. For instance, the C-band SAR used in Sentinel-1 cannot capture image of the ground in vegetated areas while L-band SAR (e.g. ALOS mission) can penetrate vegetation;
- SAR interferometry is based on measurements of the phase difference between the signal emitted by the sensor and the signal backscattered by "objects" on the surface (see Annex A1.3). The distribution of measurement points is therefore depending on land cover and on the presence of natural or man-made "objects", generally referred to as "reflectors", able to reflect the radar signal (such as rocks, buildings, road, etc.). In case of unsuitable land cover (e.g. dense vegetation, insufficient number of natural or man-made reflectors) the use of SAR interferometry requires that dedicated artificial reflectors[25] are installed on site to enable measurements;
- SAR interferometry measures movements in the line-of-sight of the satellite and cannot measure displacement parallel to the orbit of the satellite (i.e. in the North-South direction in the case of near-polar, sun-synchronous orbits like for Sentinel-1)). The discrimination between vertical and horizontal (West-East) movements is only possible if several geometries (ascending and descending orbits) are used (see [RD39]);
- The detection of abrupt and very localised movements is limited by the radar wavelength.

[23] [RD12] underlines that for instance InSAR has been oversold in the past in the infrastructure sector, which has been counterproductive in the end

[24] For applications requiring weekly updates, it may be necessary to have daily revisits of the satellites in areas prone to cloudy weather to be sure that an image without cloud coverage can be captured during the period. In Europe for instance, the average cloud coverage is around 70% according to Planet.

[25] Due to their shape, these dedicated reflectors are generally referred to as "corner reflectors". See [RD37] et [RD38] for more details on the use of corner reflectors

Performance/Cost balance

The performance of EO satellite missions and constellations may vary significantly from a mission/constellation to another. The data relevant to infrastructure applications (mainly optical and SAR data) and made available by public missions generally have lower performances than commercial missions in terms of spatial resolution and revisit frequency. The best commercially available imagery has a spatial resolution in the range of 30cm and an update frequency in the range of 12-24 hours[26] but few commercial constellations have been announced which once completed should offer similar or slightly lower spatial resolutions (~50cm) but with higher revisit frequency (1-4 hours). Main limitations are therefore related to finding the balance between cost and performance. For applications requiring the acquisition of a high number of images (e.g. in case of line infrastructure spreading over several hundreds of kilometres) or in case of applications requiring frequent updates, the price of satellite imagery can become relatively significant.

Absence of certification process

According to the FIRE[27] Focus Group on Infrastructure, the absence of certification process or quality "label" enabling to assert the quality of satellite-derived monitoring products and services limits the penetration of EO-based applications in the infrastructure sector ([RD12]). The Focus Group has underlined that infrastructure managers are convinced of the business case of using EO (e.g. for replacing manual surveys and inspections with satellite-based monitoring) but need some kind of certification of both the data source and the processing algorithms. In other words, a proof is needed that EO-based methods are equally accurate or better as current alternatives. The Focus Group suggests that infrastructure managers, contractors, governments, and other stakeholders agree together to accept the measurement results derived from satellite data as an objective representation of the reality, but underlines that this would require "contracts, regulations, and laws" to accept certain EO-based methods as valid alternatives to the currently prescribed methods.

5.3 Prospective use of GNSS and EO

5.3.1 Prospective use of GNSS

The Reports on User Needs and Requirements on surveying (see [RD3]) identifies prospective uses of GNSS in surveying (including construction surveying), some of them being relevant to the infrastructure sector. These latter are repeated hereafter.

Emerging multi-frequency and multi-constellation solutions

The advent of the multi-constellation era has brought surveyors across practically all sub-disciplines, several important benefits including increased availability (especially in attenuated environments), faster ambiguity resolution and better coverage (relevant especially for northern latitudes). Indeed, the vast majority of receivers used in the surveying sector are equipped with software that can track – at minima – two constellations[28]. [RD3] mentioned that as of 2020, around 80% of the surveying GNSS receivers already supported Galileo and around 98% were EGNOS-capable. In Europe, the majority of RTK providers have already upgraded or have started to upgrade to Galileo. At the same time, and recalling that several surveying applications require double-frequency receivers, the introduction of Galileo High

[26] Several operators have announced the launch of constellations with similar spatial resolutions but targeting revisit every 2 hours (e.g. Planet Pelican constellation)
[27] https://fire-forum.eu/
[28] 85% according to [RD3] (and 40% able to track all four global constellations)

Accuracy Service on E6 and GPS L5, will allow surveyors to benefit from triple frequency solutions. These are expected to significantly reduce convergence time for PPP and differential techniques.

High accuracy service novelties

Various analyses have shown that the Galileo High Accuracy Service E6-B signal is well suited for transmitting PPP information, allowing an adequate update rate for the achievement of centimetre level accuracy. In addition, as the HAS allows for the transmission of different bits from different satellites, the total bandwidth can be highly increased leading to a better performance that, when combined with other factors may reduce the PPP receiver convergence time. Moreover, HAS will offer triple frequency, enabling faster convergence time for surveying applications and accuracy comparable to RTK. Another intriguing future high-accuracy prospect for mapping and surveying are brought through the use of GNSS raw phase measurements of Galileo signals via Android-based devices[29]. Finally, the signal authentication service (SAS) of Galileo would be particularly interesting in sectors where volumetric surveys take place, i.e. where one measures the work performed by contractors against their contractual arrangements.

RTK VS PPP uptake

The landscape of RTK is changing with:

- The proliferation of RTK GNSS receiver “boards” such as the Trimble BD series, Novatel OEM series, Hemisphere GNSS P series, and Septentrio AsteRx series.
- Massive uptake of RTK solutions in fast-growing markets such as China – which lies in the so-called GNSS hotspot of satellite visibility.
- The development of active and passive reference stations and network RTK reference station networks by several national mapping agencies and commercial vendors
- Significant decrease of the price of RTK GNSS receivers, due to a congested market and the competitive pressure from emerging PPP solutions (described next).

These elements are driving, according to some experts, the trends towards the commodisation of high-precision GNSS receivers, in particular low-cost dual frequency (L1/L5) receivers capable of centimetre-level horizontal/vertical precision which should become widely available and thus enable the proliferation of RTK for a given range of surveying applications. In 2022, GNSS RTK receiver prices range from 4.000-20.000 EUR for surveying and can reach more than 40 000 EUR in case of automatic navigation. At the same time, and despite the challenges in delivering PPP solutions – especially in a real-time environment, they are currently seen as a viable alternative to DGNSS solutions and are trending amongst users who want good accuracy but at a lesser investment than that required for RTK (or in environments where RTK is not an option, e.g. further from the coast or in countries where such networks are not available). A prime example of well-performing PPP solution

Integrated solutions with complementary technologies

Driven by rigorous demands, surveying has been traditionally a forward-looking sector, with regards to adopting innovative technologies. In the past few years, several “tools” have been added in arsenal of surveyors, including:

- 3D laser scanners: By scanning a horizontal and vertical field from a static location they allow the collection of dense clouds of points used to create digital 3D models of buildings or land;

[29] In 2017 a dedicated Task Force was established by GSA (predecessor to EUSPA) to share knowledge and expertise on Android raw measurements and its use, including its potential for high accuracy positioning techniques. The Task Force included GNSS experts, scientists and GNSS market players, and promotes a wider use of these raw measurements.

- Total Stations: Theodolites used to electronically calculate distances to centimetre accuracy, using a laser or infrared beam along with electronic data logging systems. Robotic versions of total stations are available, allowing surveyors to remotely operate them;
- LIDAR and photogrammetric cameras: Usually mounted on-board aircrafts, they are used to measure distances by illuminating different targets and calculating the backscattering of light. Using different wavelengths LIDARs can create elaborate 3D point cloud models of the landscape, with detailed representation of different elevations;
- RPAS: Airborne RPAS equipped with different optical or LIDAR sensors are bringing a host of benefits for surveyors, including significant reduction of surveying time, access to areas of complex topography, and increased stream of data at a roughly equivalent accuracy but lesser cost compared to other techniques. [RD1] underlines the continuous uptake of drone applications across infrastructure life cycles and mentions that drones have become the fastest growing tool for site selection and mapping, with techniques like hybrid aerial mapping on the rise;
- Augmented Reality (AR): AR provides a live view of a physical, real-world environment whose elements are "augmented" by computer-generated input such as geo-related projects and cable information or extracted real-world sensory input such as GNSS data – typically performed in real time and in semantic context with environmental elements.

GNSS-enabled devices are integrated together with these technologies to provide the coordinates of the sensor performing the measurement – both for the needed initial known point and any further coordinate measurements. This is applicable, for example, to infrastructure visualisation of oil and gas pipelines (LIDAR+GNSS+IMU) and geo-referenced laser scanning data collection (terrestrial, airborne, and mobile).

As far as the prospective use of GNSS in telecommunications is concerned, the report on Time & Synchronisation User Needs and Requirements published by EUSPA ([RD4]) indicates that in the future, the accuracy requirements should not go below 100 ns even if 10ns timing accuracy could help future complex emission profiles or even create new markets not existing today. 5G networks are expected to support hyper connected society: very high data rates, very low latency and massive type communications on the same mobile infrastructure. Stringent time and phase accuracy are now requested but also robustness against spoofing, jamming and natural disturbances. Moreover, to respond to the increased GNSS spoofing threat, authentication and trustability are the main drivers to foster GNSS adoption in Telecom.

5.3.2 Prospective use of Earth Observation

Although the benefits of using Earth observation for infrastructure-related applications are recognised, the operational use of EO products and services in the infrastructure market remains relatively low. It is therefore a bit premature to talk about "prospective" use while the main target remains to achieve full adoption in the market.

Yet, a few elements can be mentioned:

- The clear trend towards very high spatial resolutions (~30cm) and very high revisit frequencies (~1 hour or less) might be well adapted to the monitoring of construction progress in Near-Real-Time.
- A few constellations are already offering "video from space" services (e.g. Vivid-I constellation from Earth-I, Skysat constellation from Planet or Satellogic constellation) with 1m spatial

resolution. Even though the sequence duration remains relatively short (from 60s to 120s in general), it potentially opens the door to new opportunities[30]:

    - Coupled with artificial intelligence techniques, it can allow a faster and more accurate recognition of objects, sites and infrastructures, which can be of key value for construction and post construction operations;
    - Giving various angle of view of infrastructures, it can allow 3D models to be created to much higher precision than from a single stereo pair;
    - Providing more contextual information to analysts and researchers by capturing movement, it can allow a better assessment of the surroundings of key infrastructures and thus a more accurate change detection including detection of 3D changes over time;
    - Providing the ability to mitigate patchy cloud and haze in a scene, it can allow to derive clearer images and thus improve the revisit time of the system.

- Data offered by earth observation can be coupled with observation data provided by other means such as drones or High-Altitude Pseudo Satellites (HAPS). Being closer to the ground, they can offer way more defined images than what satellites can do, and in the case of drones, they can also move around or under infrastructure to observe areas not visible from above. This enables complementary use of earth observation and ground data by allowing to use EO data as a first mean to identify areas of interest, and then reduce the perimeter to be assessed and subsequently the amount a ground data required by the end user ("tip and cue" paradigm).
- Digital twins are going to be increasingly used in infrastructure-related applications, in particular to simulate how infrastructures evolve when time passes and when their surroundings change (e.g. due to climate change). Earth observation will provide environmental data that will feed digital twin models.

5.4 Summary of drivers for user requirements

5.4.1 Drivers for GNSS-related user requirements

The Reports on User Needs and Requirements on surveying (see [RD3]) identifies the main drivers for the use of GNSS in surveying (including construction surveying), some of them being relevant to the infrastructure sector. These latter are repeated hereafter.

The report indicates that surveying applications have the most stringent accuracy requirements, ranging from sub-centimetre level to metre level, and also rely heavily on good signal availability, integrity and reliability. The high accuracy required in several surveying applications (e.g. geodetic control surveys) as well as the high cost for the execution of certain surveying operations, call for GNSS-based solutions that provide good redundancy and optimal Time to First Fix (TTFF) and Time-to-Convergence (TTC).

The report also underlines that price-dependent technological trends are driving the evolution of GNSS performance requirements in different surveying disciplines. On one side, lie geographical regions (i.e. quickly developing countries such as India and China) and specific sectors (e.g. mapping) that can strongly benefit from the availability of efficient, low-cost GNSS solutions even if these do not meet the most demanding accuracy requirements. On the other side, capital intensive sectors, are heavily investing in the development of highly-sophisticated solutions that can increase productivity and profitability.

[30] See for instance https://earthi.space/vantage/

Apart from the purely quantitative requirements, some qualitative aspects are central to the greater uptake of GNSS solutions in the surveying sector. This concerns first and foremost interoperability and compatibility between different GNSS-solutions but also with regards to solutions combining GNSS with other technologies and sensors.

Further sought features are robustness and high-quality of GNSS products including their main sub-components, for instance the antenna phase centre stability and the RMS of code and carrier measurements; as well as the flexibility of receivers for upgrades and re-configuration.

As far as the main drivers for the use of GNSS in telecommunications are concerned, the report on Time & Synchronisation User Needs and Requirements published by EUSPA ([RD4]) mentions the following:

- Resilience and reliability;
- GNSS Authentication;
- Improved robustness to interference;
- High availability;
- Accuracy Low(1ms) /medium (1 μs) for Timing, Low (1 ms) /High (100 ns) for synchronisation;
- Increasing demand for calibration of hardware equipment delays.

5.4.2 Drivers for EO-related user requirements

Except in a few specific cases where other types of satellite imagery (e.g. thermal infrared) may be required, most infrastructure-related EO-based applications require optical (visible) and/or SAR imagery. The main drivers are:

- Spatial resolution (several applications require Very High Resolution imagery, with meter-level or submeter-level resolution);
- The availability of historical data (to enable change detection or to identify trends);
- For line infrastructure, the ability to cover large-scale areas (e.g. several hundreds of square kilometres).

Except for construction progress monitoring, the frequency at which the information provided to users must be updated is not that critical (monthly or above in most cases) and can therefore not be considered as a main driver.

In addition to the above-mentioned performance-related drivers, other aspects can be considered as drivers for the uptake of EO in the infrastructure market:

- Legislation/regulation, which is a main driver for the uptake of EO-based applications related to the monitoring of the impact that infrastructures have on their environment (i.e. in general, infrastructure managers monitor environmental impacts if there is a legal/regulatory obligation to do so). For some specific infrastructures, this can also apply to structural health monitoring (e.g. obligation to verify the structural health of bridges every X months or years);
- Willingness to optimise maintenance costs, notably by reducing the number of on-site inspection (which by the same occasion contributes to increase worker safety by reducing the risk of accidents related to on-site inspections). In this perspective, the availability of cost/benefits analyses demonstrating the gains that EO can bring to the sector would be helpful.

Without really being a "driver", the definition/availability of best practices for the use of Earth Observation in the sector would support the uptake of EO-based services for infrastructure management.

6 USER REQUIREMENTS SPECIFICATION

The chapter provides a synthesis of the requirements described in section 5.1 respectively on GNSS in section 6.1 and on EO in section 6.2.

6.1 Synthesis of Requirements Relevant to GNSS

The GNSS-related requirements presented in this chapter are the same as those related to "construction" in the *Report on surveying user needs and requirements (and its annexes)* ([RD3]) and as those related to telecommunications (and cross sectors) in the *Report on time & synchronisation user needs and requirements (and its annexes)* ([RD4]). The "Specific Applications" mentioned in the two tables below correspond to those identified in the two previously mentioned reports.

Table 22: PNT Requirements for Construction

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-SURV-0040	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be high (>95%), including in harsh environments	All	Performance (Availability)	[RD15] [RD16]
EUSPA-GN-UR-SURV-0080	The PNT information shall be transmitted in two or more bands (E1, E5, E6) thus enabling dual or triple frequency RTK and PPP solutions.	All	Function (Multiple Frequencies)	[RD42]
EUSPA-GN-UR-SURV-0130	Galileo precise orbit and clock corrections shall be available in a similar way as GPS/GLONASS are provided in the IGS Real Time Service	All	Coverage	[RD48]
EUSPA-GN-UR-SURV-0150	Documentation related to reference systems, needed data for the compliance to the INSPIRE directive (transformation from GTRF to ETRF2000) shall be available at the GSC portal.	All	Functional	[RD48]
EUSPA-GN-UR-SURV--2101	The PNT solution shall provide 10 to 80 mm horizontal accuracy	Construction Surv. Machine based Set out, trajectory, machine control	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2102	The PNT solution shall provide 3 mm vertical accuracy	Construction Surv. Machine based	Performance	[RD56]

ID	Description	Specific Application	Type	Source
		Set out, trajectory, machine control		
EUSPA-GN-UR-SURV-2107	The PNT solution shall be available regionally or locally	Construction Surv. Machine based Set out, trajectory, machine control	Functional	[RD56]
EUSPA-GN-UR-SURV-2108	The PNT solution shall be available in urban canyon with a 95% probability	Construction Surv. Machine based Set out, trajectory, machine control	Functional	[RD56]
EUSPA-GN-UR-SURV-2109	The PNT solution shall be available under canopy with a 95% probability	Construction Surv. Machine based Set out, trajectory, machine control	Functional	[RD56]
EUSPA-GN-UR-SURV-2110	The PNT solution shall be available with a TTFF of 10 s or less	Construction Surv. Machine based Set out, trajectory, machine control	Performance	[RD56]
EUSPA-GN-UR-SURV-2111	The PNT solution shall be available with an update rate of 10 Hz min	Construction Surv. Machine based Set out, trajectory, machine control	Performance	[RD56]
EUSPA-GN-UR-SURV-2112	The PNT solution shall be provided with high integrity requirements	Construction Surv. Machine based Set out, trajectory, machine control	Functional	[RD56]
EUSPA-GN-UR-SURV-2115	The solution shall provide PNT information that is trustable Medium level (to be understood as robustness to spoofing)	Construction Surv. Machine based Set out, trajectory, machine control	Functional	[RD42]
EUSPA-GN-UR-SURV-2201	The PNT solution shall provide 1 to 5 m horizontal accuracy	Construction Surv. Machine based Vehicle tracking, Asset management	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2202	The PNT solution shall provide m level vertical accuracy when applicable	Construction Surv. Machine based Vehicle tracking, Asset management	Performance	[RD56]
EUSPA-GN-UR-SURV-2207	The PNT solution shall be available regionally or locally	Construction Surv. Machine based Vehicle tracking, Asset management	Functional	[RD56]
EUSPA-GN-UR-SURV-2208	The PNT solution shall be available in urban canyon with a 95% probability	Construction Surv. Machine based Vehicle tracking, Asset management	Functional	[RD56]

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-SURV-2209	The PNT solution shall be available under canopy with a 95% probability	Construction Surv. Machine based Vehicle tracking, Asset management	Functional	[RD56]
EUSPA-GN-UR-SURV-2210	The PNT solution shall be available with a TTFF of 10 s or less	Construction Surv. Machine based Vehicle tracking, Asset management	Performance	[RD56]
EUSPA-GN-UR-SURV-2211	The PNT solution shall be available with an update rate of 5 Hz min	Construction Surv. Machine based Vehicle tracking, Asset management	Performance	[RD56]
EUSPA-GN-UR-SURV-2212	The PNT solution shall be provided with low integrity requirements	Construction Surv. Machine based Vehicle tracking, Asset management	Functional	[RD56]
EUSPA-GN-UR-SURV-2301	The PNT solution shall provide 3 m horizontal accuracy	Construction Surv. Machine based Asset positioning 3m	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2302	The PNT solution shall provide m level vertical accuracy when applicable	Construction Surv. Machine based Asset positioning 3m	Performance	[RD56]
EUSPA-GN-UR-SURV-2307	The PNT solution shall be available regionally or locally	Construction Surv. Machine based Asset positioning 3m	Functional	[RD56]
EUSPA-GN-UR-SURV-2308	The PNT solution shall be available in urban canyon with a 95% probability	Construction Surv. Machine based Asset positioning 3m	Functional	[RD56]
EUSPA-GN-UR-SURV-2309	The PNT solution shall be available under canopy with a 95% probability	Construction Surv. Machine based Asset positioning 3m	Functional	[RD56]
EUSPA-GN-UR-SURV-2310	The PNT solution shall be available with a TTFF of 5 min or less	Construction Surv. Machine based Asset positioning 3m	Performance	[RD56]
EUSPA-GN-UR-SURV-2311	The PNT solution shall be available with an update rate of 1 Hz min	Construction Surv. Machine based Asset positioning 3m	Performance	[RD56]
EUSPA-GN-UR-SURV-2312	The PNT solution shall be provided with low integrity requirements	Construction Surv. Machine based Asset positioning 3m	Functional	[RD56]
EUSPA-GN-UR-SURV-2401	The PNT solution shall provide 10 to 60 mm horizontal accuracy	Construction Surv. Human based Low Order Control	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2402	The PNT solution shall provide cm level vertical accuracy	Construction Surv. Human based Low Order Control	Performance	[RD56]

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-SURV-2407	The PNT solution shall be available regionally	Construction Surv. Human based Low Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2408	The PNT solution shall be available in urban canyon with a 95% probability	Construction Surv. Human based Low Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2409	The PNT solution shall be available under canopy with a 95% probability	Construction Surv. Human based Low Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2410	The PNT solution shall be available with a TTFF of 5 min or less	Construction Surv. Human based Low Order Control	Performance	[RD56]
EUSPA-GN-UR-SURV-2412	The PNT solution shall be provided with low integrity requirements	Construction Surv. Human based Low Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2501	The PNT solution shall provide 5 to 10 mm horizontal accuracy	Construction Surv. Human based High Order Control	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2502	The PNT solution shall provide cm level vertical accuracy	Construction Surv. Human based High Order Control	Performance	[RD56]
EUSPA-GN-UR-SURV-2507	The PNT solution shall be available regionally	Construction Surv. Human based High Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2508	The PNT solution shall be available in urban canyon with a 95% probability when applicable	Construction Surv. Human based High Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2509	The PNT solution shall be available under canopy with a 95% probability when applicable	Construction Surv. Human based High Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2510	The PNT solution shall be available with a TTFF of 20 min or more	Construction Surv. Human based High Order Control	Performance	[RD56]
EUSPA-GN-UR-SURV-2512	The PNT solution shall be provided with low integrity requirements	Construction Surv. Human based High Order Control	Functional	[RD56]
EUSPA-GN-UR-SURV-2601	The PNT solution shall provide 15 cm horizontal accuracy	Construction Surv. Human based Temporary DGNSS Reference station	Performance	[RD15] [RD56]
EUSPA-GN-UR-SURV-2602	The PNT solution shall provide cm level vertical accuracy	Construction Surv. Human based Temporary DGNSS Reference station	Performance	[RD56]
EUSPA-GN-UR-SURV-2607	The PNT solution shall be available regionally	Construction Surv. Human based	Functional	[RD56]

ID	Description	Specific Application	Type	Source
		Temporary DGNSS Reference station		
EUSPA-GN-UR-SURV-2608	The PNT solution shall be available in urban canyon with a 95% probability	Construction Surv. Human based Temporary DGNSS Reference station	Functional	[RD56]
EUSPA-GN-UR-SURV-2609	The PNT solution shall be available under canopy with a 95% probability	Construction Surv. Human based Temporary DGNSS Reference station	Functional	[RD56]
EUSPA-GN-UR-SURV-2610	The PNT solution shall be available with a TTFF of 5 min or less	Construction Surv. Human based Temporary DGNSS Reference station	Performance	[RD56]
EUSPA-GN-UR-SURV-2612	The PNT solution shall be provided with low integrity requirements	Construction Surv. Human based Temporary DGNSS Reference station	Functional	[RD56]

Table 23: Requirements for Telecom

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-TSC-0070	The Timing & Sync system shall provide continuity of service	All	Functional	[RD24] [RD25] [RD53]
EUSPA-GN-UR-TSC-0110	The Timing & Sync system shall be trustable	All	Functional	[RD24] [RD25] [RD50] [RD51] [RD52] [RD26]
EUSPA-GN-UR-TSC-0130	The Timing & Sync system shall be resilient	All	Functional	[RD24] [RD25] [RD50] [RD51] [RD52] [RD53]
EUSPA-GN-UR-TSC-0140	The Timing & Sync system shall be able to detect and characterization GNSS interference	All	Functional	[RD24] [RD25]
EUSPA-GN-UR-TSC-0150	The Timing & Sync system shall provide service commitment	All	Functional	[RD24] [RD25]

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-TSC-0160	The Timing & Sync system shall get access to integrity information with a certain level of confidence	All	Functional	[RD24] [RD25] [RD54]
EUSPA-GN-UR-TSC-0268	The Timing & Sync system shall provide an update rate of 1Hz to 10 Hz	All	Performance	[RD55]
EUSPA-GN-UR-TSC-0190	The Timing & Sync system shall be preferably provided worldwide and regionally as a minimum	All	Performance	[RD55]
EUSPA-GN-UR-TSC-0200	The Timing & Sync system shall be able to demonstrate traceability to UTC	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0210	The Timing & Sync system shall be able to provide an authentication capability at User Equipment level	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0220	The Timing & Sync system shall be able to provide an authentication capability on a continuous basis	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0230	The Timing & Sync system shall be able to provide an authentication capability with a duration between successive authentications of 5 to 10 seconds	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0240	The Timing & Sync system shall be able to provide an authentication capability with no degradation of the time accuracy	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0250	The Timing & Sync system shall be able to provide an authentication capability with a key management procedure as transparent as possible	All	Functional	[RD55]
EUSPA-GN-UR-TSC-0020	The Timing & Sync system shall provide a Timing accuracy of 30 ns to UTC for DCN applications.	DCN applications	Performance	[RD24] [RD25] [RD26] [RD49] [RD55]
EUSPA-GN-UR-TSC-0021	The Timing & Sync system shall provide a Phase Sync accuracy	DCN applications	Performance	[RD55]

ID	Description	Specific Application	Type	Source
	of less than 65 ns for DCN applications			
EUSPA-GN-UR-TSC-0022	The Timing & Sync system shall provide a Freq Sync accuracy of 1.10-11 for DCN applications	DCN applications	Performance	[RD55]
EUSPA-GN-UR-TSC-0102	The Timing & Sync system shall provide a high level of availability (99.9%)	DCN applications	Performance	[RD56]
EUSPA-GN-UR-TSC-0172	The Timing & Sync system shall provide robustness against “non-synchronised” GNSS spoofing attacks for DCN	DCN applications	Functional	[RD24] [RD25] [RD50] [RD51] [RD54]
EUSPA-GN-UR-TSC-0232	The Timing & Sync system shall have an availability "desirable" in urban canyons	DCN applications	Functional	[RD56]
EUSPA-GN-UR-TSC-0242	The Timing & Sync system shall have an availability "desirable" indoors	DCN applications	Performance	[RD56]
EUSPA-GN-UR-TSC-0040	The Timing & Sync system shall provide an accuracy of 10 µs for PMR	PMR applications	Performance	[RD24] [RD25] [RD26]
EUSPA-GN-UR-TSC-0104	The Timing & Sync system shall provide a high level of availability (99.9%)	PMR applications	Performance	[RD56]
EUSPA-GN-UR-TSC-0173	The Timing & Sync system shall provide robustness against “synchronised” GNSS spoofing attacks for PMR	PMR applications	Functional	[RD24] [RD25] [RD50] [RD51] [RD54]
EUSPA-GN-UR-TSC-0234	The Timing & Sync system shall have an availability "desirable" in urban canyons	PMR applications	Functional	[RD56]
EUSPA-GN-UR-TSC-0244	The Timing & Sync system shall have an availability "desirable" indoors	PMR applications	Performance	[RD56]
EUSPA-GN-UR-TSC-0030	The Timing & Sync system shall provide an accuracy of 1 µs for PSTN	PSTN applications	Performance	[RD24] [RD25] [RD26]
EUSPA-GN-UR-TSC-0103	The Timing & Sync system shall provide a high level of availability (99.9%)	PSTN applications	Performance	[RD56]

ID	Description	Specific Application	Type	Source
EUSPA-GN-UR-TSC-0171	The Timing & Sync system shall provide robustness against "Record and replay" GNSS spoofing attacks for PSTN	PSTN applications	Functional	[RD24] [RD25] [RD50] [RD51] [RD54]
EUSPA-GN-UR-TSC-0233	The Timing & Sync system shall have an availability "desirable" in urban canyons	PSTN applications	Functional	[RD56]
EUSPA-GN-UR-TSC-0243	The Timing & Sync system shall have an availability "desirable" indoors	PSTN applications	Performance	[RD56]
EUSPA-GN-UR-TSC-0010	Accuracy (95%) up to 100ns for Satcom	Satcom applications	Performance	[RD24] [RD25] [RD26]
EUSPA-GN-UR-TSC-0101	The Timing & Sync system shall provide a high level of availability (99.9%)	Satcom	Performance	[RD56]
EUSPA-GN-UR-TSC-0174	The Timing & Sync system shall provide robustness against "Record and replay" GNSS spoofing attacks for Satcom	Satcom applications	Functional	[RD24] [RD25] [RD50] [RD51] [RD54]
EUSPA-GN-UR-TSC-0106	The Timing & Sync system shall provide a high level of availability (99.9%)	5G - small cells	Performance	[RD56]
EUSPA-GN-UR-TSC-0237	The Timing & Sync system shall have an availability "desirable" in urban canyons	5G - small cells	Functional	[RD56]
EUSPA-GN-UR-TSC-0247	The Timing & Sync system shall have an availability "desirable" indoors	5G - small cells	Performance	[RD56]

6.2 Synthesis of Requirements Relevant to EO

The tables on the next pages summarise the EO-related requirements presented in Chapter 5.1.

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ID	Application	Users	User Needs						Service Provider Offer		Service Provider Satellite EO Requirements				Service Inputs	
			Operational scenario	**Infrastructure typology**	**Size Area of Interest**	**Scale**	**Frequency of Information**	**Other (if applicable)** *(e.g. non-functional, data format, contextual info…)*	**What the service does**	**How the service work**	**Spatial Resolution**	**Temporal Resolution**	**Data Type / Spectral Range**	**Other (if applicable)** (e.g. non-functional, latency, historical availability, reanalysis, pre-processing…)	**Satellite data sources**	**Other Data Sources**
EUSPA-EO-UR-INF-0001	Infrastructure Site Selection and Planning	(Future) Infrastructure owners and/or operators, Construction and public works companies.	**Site characterisation (Land cover / land use, topography, geological evaluation...)** - Determination of the various characteristics of the site and its surroundings (e.g. land cover / land use characteristics, topography, geology, obstacles) to assess whether the site is well-adapted to the construction and operation of the future infrastructure (or to the extension / improvement of an existing infrastructure) .	All	From a few km2 (localised infrastructure) up to ~1000 km2 (line-infrastructure)	-	One-off	-	Generate assessment reports and/or thematic and baseline maps for the site to be characterised and its surroundings. Note: Maps are usually generated with a large scale to capture all details of the current situation. When relevant, they can show outcomes of analysis (e.g. buffered area for certain types of infrastructures that need some specific distance, horizon angle with surrounding obstacle as in the case of communication infrastructures…).	Automated extraction of e.g. land cover features from satellite imagery and production of various types of maps or reports (land cover / land use, topography…)	From a few dozens of cm (e.g. to map transport / water networks, existing infrastructures) to ~10m for LC/LU mapping	Typically a few months	Optical visible, Near Infrared (NIR), Short-Wave Infrared (SWIR), Hyperspectral imagery, SAR.	-	Very High (VHR) and High (HR) resolution Optical satellites, Hyperspectral satellites, SAR satellites	In-situ data, DEM/DSM/DTM established by aerial means
EUSPA-EO-UR-INF-0002		(Future) Infrastructure owners and/or operators, Construction and public works companies.	**Risk assessment wrt. ground deformation** - Evaluate the ground stability of the site and the surrounding area in order to assess the subsidence risk the infrastructure will be exposed to during its lifecycle.	All	From a few km2 (localised infrastructure) up to ~1000 km2 (line-infrastructure)	Ability to detect ground movements of a few mm per year	One-off	-	Provide information on ground deformation gradients (displacement vectors, area impacted) for the site to be characterised and its surroundings. The risk assessment can take different forms depending on what users need (e.g. map, reports).	Generation of displacement measurements using differential interferometry synthetic aperture radar (e.g. DinSAR, PS-inSAR) techniques.	From a few meters up to ~10 m	From weekly to monthly	SAR	Availability of historical data over several years (Min. 2 years) is required to assess trends relative to ground deformation.	SAR satellites (C, L, X frequency bands).	Pre-existing terrain models, geological maps.
EUSPA-EO-UR-INF-0003		(Future) Infrastructure owners and/or operators, Construction and public works companies.	**Risk assessment wrt. natural hazards (e.g. floods, droughts)** - Evaluate the level of risk related to natural hazards (e.g. floods, wildfires, earthquakes) the future infrastructure will be exposed to if the site is selected for construction.	All	From a few km2 (localised infrastructure) up to ~1000 km2 (line-infrastructure)	-	One-off	-	Provide risk assessment maps (including probability, intensity and location) or reports for each type of risk for the site to be characterised and its surroundings.	Calculation of a risk score / index based on information from the territory (rains, humidity, …), digital terrain models and historical data.	From ~10 m up to ~100 m	Monthly in general	Optical/SAR, Thermal Infrared	Historical data on similar events help to better understand potential risks (even over centuries for some risks like floods or earthquakes).	HR/LR optical/SAR satellites, Thermal IR satellites	DTM (Digital Terrain Models), historical risk events over the last centuries, climate models.
EUSPA-EO-UR-INF-0004		(Future) Infrastructure owners and/or operators, Construction and public works companies.	**Risk assessment wrt. climate change** - Evaluate the level of long-term risk related to climate change (e.g. droughts, sea level rise) the future infrastructure will be exposed to if the site is selected for construction.	All	From 10 km2 (localised infrastructure) up to ~1000 km2 (line-infrastructure)	-	One-off	-	Provide a climate risk assessment report characterising the level of climate risk for the site to be characterised and its surrounding.	Calculation of a climate change risk score / index using long-term modelling of climate evolution.	From ~100 m up to ~1 km	Yearly in general	Optical, Thermal Infrared (TIR) and SAR	-	Low resolution TIR satellites. Optical satellites (Medium resolution optical). SAR satellites.	Historical information (e.g. on average temperature) over 50-100 years. Meteorological and climate models

ID	Application	Users	User Needs						Service Provider Offer		Service Provider Satellite EO Requirements				Service Inputs	
			Operational scenario	Infrastructure typology	Size Area of Interest	Scale	Frequency of Information	Other (if applicable) *(e.g. non-functional, data format, contextual info…)*	What the service does	How the service work	Spatial Resolution	Temporal Resolution	Data Type / Spectral Range	Other (if applicable) (e.g. non-functional, latency, historical availability, reanalysis, pre-processing…)	Satellite data sources	Other Data Sources
EUSPA-EO-UR-INF-0005	Construction Operations	Infrastructure owners and/or operators, Construction and public works companies, Financial institutions financing the construction (including international organisations in case of ODA projects).	**Construction progress monitoring (alignment with schedule)** - Monitor the progress of construction activities to verify that construction progresses according to the original planning and detect deviations from schedule if any.	Localised	1 km2	-	From weekly to quarterly	-	Provide reports on the construction progress achieved between two different moments in time and assess its compliance to the planning (when the planning is available to the provider).	Automated or semi-automated detection of newly built assets based on algorithms comparing successive images of the construction area.	From a few dozens of cm up to ~5 m	From daily to monthly	Optical Visible and NIR, SAR	-	VHR/ HR Optical satellites and SAR satellites	UAV
EUSPA-EO-UR-INF-0006				Linear	<1km-width corridor along line infrastructures	-	From weekly to quarterly				From a few dozens of cm up to ~5 m	From daily to monthly	Optical Visible and NIR, SAR	-	VHR/ HR Optical satellites and SAR satellites	UAV
EUSPA-EO-UR-INF-0007				Extended	Up to ~15 km2	-	From weekly to quarterly				From a few dozens of cm up to ~5 m	From daily to monthly	Optical Visible and NIR, SAR	-	VHR/ HR Optical satellites and SAR satellites	UAV
EUSPA-EO-UR-INF-0008		Infrastructure owners and/or operators, Construction and public works companies, Financial institutions financing the construction (including international organisations in case of ODA projects).	**Construction conformity monitoring (alignment with plans)** - Monitor construction activities to verify that construction is consistent with design plans.	Localised	1 km2	-	From one-off (final control) to monthly (regular monitoring)		Provide report on the conformity to the design plans.	Automated or semi-automated comparison of built assets (e.g. footprint and elevation) to a reference plan of the construction project.	From a few dozens of cm up to ~1 m	From weekly to monthly	Optical Visible, Alternatively SAR if cloud coverage is an issue	-	VHR/ HR Optical satellites	UAV
EUSPA-EO-UR-INF-0009				Linear	<1km-width corridor along line infrastructures	-	From one-off (final control) to monthly (regular monitoring)				From a few dozens of cm up to ~1 m	From weekly to monthly	Optical Visible, Alternatively SAR if cloud coverage is an issue	-	VHR/ HR Optical satellites	UAV
EUSPA-EO-UR-INF-0010				Extended	Up to ~15 km2	-	From one-off (final control) to monthly (regular monitoring)				From a few dozens of cm up to ~1 m	From weekly to monthly	Optical Visible, Alternatively SAR if cloud coverage is an issue	-	VHR/ HR Optical satellites	UAV
EUSPA-EO-UR-INF-0011		Infrastructure owners and/or operators, Construction and public works companies, Financial institutions financing the construction (including international organisations in case of ODA projects).	**Construction stability monitoring** - Monitor ground stability of the construction area during the construction phase in order to detect if some specific precautions (e.g. stabilisation works) must be taken.	All	Depends on each type of construction works	To be defined	From weekly to monthly		Provide subsidence monitoring during the construction and alert on the existence of zones at risk in the construction area.	Generation of displacement measurements using differential interferometry synthetic aperture radar (DinSAR) and Persistent scatterer interferometry SAR (PS-inSAR) techniques. Comparison with maximum expected displacements and identification of unexpected behaviours.	From a few meters up to ~10 m in most cases	From daily to weekly	SAR	-	SAR satellites (C, X bands)	-

ID	Application	Users	User Needs						Service Provider Offer		Service Provider Satellite EO Requirements				Service Inputs	
			Operational scenario	Infrastructure typology	Size Area of Interest	Scale	Frequency of Information	Other (if applicable) *(e.g. non-functional, data format, contextual info…)*	What the service does	How the service work	Spatial Resolution	Temporal Resolution	Data Type / Spectral Range	Other (if applicable) (e.g. non-functional, latency, historical availability, reanalysis, pre-processing…)	Satellite data sources	Other Data Sources
EUSPA-EO-UR-INF-0012	Post-Construction Operations	Infrastructure owners and/or operators	**Ground deformation monitoring (to assess risk on structural health)** - Monitor ground stability of the infrastructure location and of its surrounding to detect slow ground subsidence (<30mm per year) likely to cause structural damages to the infrastructure.	Localised	Local scale (1-2km²)	Ability to detect ground movements of a few mm per year	6-monthly to yearly		Provide continuous monitoring after construction to inform on potential ground deformation larger than expected.	Automatic data processing of ground motion data and ancillary data to assess the level of risk over each infrastructure.	From ~1 m up to ~20 m	Monthly in general	SAR	Availability of historical data since the end of the construction is required to assess ground deformation.	SAR satellites (C,L, X bands)	-
EUSPA-EO-UR-INF-0013				Linear	From local to national scale (Extent of line infrastructure, from 10 to 1000+ km)	Ability to detect ground movements of a few mm per year	6-monthly to yearly				From ~1 m up to ~20 m	Monthly in general				-
EUSPA-EO-UR-INF-0014				Extended	Extent in the range of 5-10 km2	Ability to detect ground movements of a few mm per year	6-monthly to yearly				From ~5 m up to ~20 m	Monthly in general				-
EUSPA-EO-UR-INF-0015		Infrastructure owners and/or operators	**Vegetation encroachment monitoring** - Detect areas with vegetation encroachment on the infrastructure, or with a risk for vegetation encroachment (e.g. due to vegetation growth), for maintenance scheduling purposes.	Linear	Buffer area of up to 50m width each side of the line infrastructure.	-	3 - 6 months		Identify zones in the buffer area where changes in vegetation constitute a threat to the safety and/or efficiency of the infrastructure.	Automatic processing of optical satellite imagery to derive vegetation geo-analytics.	From a few dozens of cm up to ~20 m	From quarterly to 6-monthly	Optical Visible, NIR		VHR/ HR Optical satellites	-
EUSPA-EO-UR-INF-0016		Infrastructure owners and/or operators	**Land cover / land use change monitoring (in the surroundings)** - Monitor changes of Land cover / Land use in the vicinity of the infrastructure likely to put at risk the safety / efficiency of operations or requiring specific inspection or maintenance operations.	Localised	Local scale (1-2km²)	-	6-monthly to yearly		Highlight where natural or human induced changes can be a threat to the safety and/or efficiency of the infrastructure	Automatic processing of radar and optical satellite imagery to derive the land cover /land use classes	From ~1 m up to ~20 m	Monthly in general	Optical/NIR/SAR	-	VHR/HR optical satellites, SAR satellites	-
EUSPA-EO-UR-INF-0017				Linear	Few hundreds m width each side	-	6-monthly to yearly				From ~1 m up to ~20 m	Monthly in general		-		-
EUSPA-EO-UR-INF-0018				Extended	Extent in the range of 5-10 km2	-	6-monthly to yearly				From ~1 m up to ~20 m	Monthly in general		-		-

ID	Application	Users	User Needs						Service Provider Offer		Service Provider Satellite EO Requirements				Service Inputs	
			Operational scenario	Infrastructure typology	Size Area of Interest	Scale	Frequency of Information	Other (if applicable) *(e.g. non-functional, data format, contextual info…)*	What the service does	How the service work	Spatial Resolution	Temporal Resolution	Data Type / Spectral Range	Other (if applicable) (e.g. non-functional, latency, historical availability, reanalysis, pre-processing…)	Satellite data sources	Other Data Sources
EUSPA-EO-UR-INF-0019	Environmental impact assessment of infrastructures	Infrastructure owners and/or operators, Construction and public works companies, Public authorities.	**Ground motion monitoring (caused by works during the construction phase, e.g. in case of tunnel digging)** - Monitor the area surrounding the infrastructure to detect if construction works induce ground instability likely to cause structural damages to neighbouring infrastructures.	All	Up to ~100 km2	To be defined	From weekly to monthly	-	Provide information on ground displacement in the surroundings of the infrastructure. The risk assessment can take different forms depending on what users need (e.g. map, reports).	Generation of displacement measurements using differential interferometry synthetic aperture radar (DinSAR) techniques.	From ~1 m up to ~10 m	Weekly in general	SAR	Availability of historical data is required to establish the "reference" ground instability assessment.	SAR satellites (C, X bands)	-
EUSPA-EO-UR-INF-0020		Infrastructure owners and/or operators, Construction and public works companies, Public authorities.	**Air and water pollution assessment** - Monitor the presence of pollution (air pollution / water pollution) in the vicinity of the infrastructure and assess whether pollution is caused by the infrastructure.	All	Up to ~100 km2	-	From daily to weekly		Provide reports / alerts on air/water quality in the surroundings of the infrastructure.	Estimation of pollutant concentrations based on modelling and satellite-based measurements	From ~10 m up to ~100 m	From daily to sub-daily	Optical (Spectrometer)	Historical data is required to understand the initial conditions on the site	Multispectral and Hyperspectral satellites. Spectrometer sensor.	
EUSPA-EO-UR-INF-0021		Infrastructure owners and/or operators, Construction and public works companies, Public authorities.	**Biodiversity loss assessment** - Monitor whether the presence of the infrastructure induces biodiversity loss in the vicinity of the infrastructure.	All	Up to ~100 km2	-	Yearly in general		Provide report / alerts on biodiversity losses.	Estimation of biodiversity indexes based on the analysis of different types of information (land use/land cover, vegetation type, etc.)	From ~1 m up to ~10 m	Monthly in general	Optical and SAR	Historical data is required to understand the initial conditions on the site	Multispectral and SAR satellites.	

7 ANNEXES

A1.1 Definition of key GNSS performance parameters

This annex provides a definition of the most commonly used GNSS performance parameters, taken from [RD1] and [RD3] and includes additional details which are relevant for the Infrastructure community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- System availability: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to.
- Overall availability: takes into account the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

Accuracy is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion – usually 95% – of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10 cm; decimetre level: 10-100 cm; metre-level: 1-10 metres.

Continuity is the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1*10-4 over the course of the procedure where the system is in use.

Indoor penetration is the ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of WiFi base stations for WiFi-based positioning).

Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the "integrity concept" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

Latency is the difference between the reference time of the solution and the time this solution is made available to the end user or application (i.e. including all delays). Latency is typically accounted for in a receiver, but presents a potential problem for integration (fusion) of multiple positioning solutions, or for high dynamics mobile devices.

Robustness relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter and depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.

Authentication gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system, resulting in false data as output of the system itself.

Power consumption is the amount of power a device uses to provide a position. It will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of milliwatts (for smartphone chipsets).

Time To First Fix (TTFF) is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes.); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).

A1.2 Definition of key EO performance parameters

This annex provides a definition of the most commonly used EO performance parameters and includes additional details which are relevant for the Infrastructure community.

Spatial resolution relates to the level of detail that can be retrieved from a scene. In the case of a satellite image, which consists of an array of pixels, it corresponds to the smallest feature that can be detected on the image. A common way of characterising the spatial resolution is to use the Ground Sample Distance (GSD) which corresponds to the distance measured on the ground between the centres of two adjacent pixels. Thus, a spatial resolution of 1 meter means that each pixel represents a 1 by 1 meter area on the ground.

Temporal resolution relates to the time elapsed between two consecutive observations of the same area on the ground. The higher the temporal resolution, the shorter the time between the acquisitions of two consecutive observations of the same area. In absolute terms, the temporal resolution of a remote sensing system corresponds to the time elapsed between two consecutive passes of the satellite over the exact same point on the ground (generally referred to as “revisit time” or “orbit cycle”). However, several parameters like the overlap between the swaths of adjacent passes, the agility of the satellites and in case of a constellation, the number of satellites mean that some areas of the Earth can be reimaged more frequently. For a given system, the temporal resolution can therefore be better than the revisit time of the satellite(s).

Spectral range refers to the wavelength range of a particular channel or band over in which remote sensing data must be collected.

Latency is the difference between the reference time of the satellite measurement and the time the final product is made available to the user (here the service provider).

A1.3 Additional definitions

Ground deformation monitoring is the process which consists in tracking the vertical and horizontal movements of the land surface and their dynamics, whatever these movements are caused by natural phenomena (e.g. volcanic activity) or by human activities (e.g. aquifer exploitation).

Change detection is the process which aims at identifying difference in the state of "objects" (e.g. bridges, constructions, urban areas) or of a phenomenon (e.g. deforestation, soil sealing) by comparing snapshots of the situation at different times. In Earth Observation, change detection is extensively based on satellite imagery obtained through a wide variety of sensors (e.g. optical, radar, infrared, microwave, etc.

Geodesy (see [RD3]) is the earth science of accurately measuring and understanding three of Earth's fundamental properties: its geometric shape, orientation in space, and gravitational field. The field also studies of how these properties change over time. Today, geodesy goes beyond that, being the geoscience that deals among other with the monitoring the solid Earth (which includes the monitoring of displacement, subsidence or deformation of the ground and structures due to tectonic, volcanic and other natural phenomena as well as human activity.

Interferometric Synthetic Aperture Radar (InSAR) is a technique enabling to generate surface deformation maps based on the processing of SAR images captured at different moments in time. The processing uses the fact that if the ground has moved between the times of two SAR images of the same area, a slightly different portion of the wavelength is reflected back to the satellite resulting in a measurable phase shift that is proportional to displacement. The processing therefore consists in obtaining information about the vertical movements of the ground surface by calculating the phase difference between the emitted radar signal and the signal backscattered by the surface for successive images. InSAR can potentially measure deformations of millimetre-scale during periods ranging from days to years.

Near-Real-Time (NRT) refers, when used in the context of EO applications, to applications/services/products for which the time delay between the occurrence of a given event and the availability of the outcomes of the processing of the Earth observation data corresponding to that event is considered as being not significant from a user perspective. The notion of "near real-time" is therefore depending on user requirements. For Earth observation, the corresponding time delays may range from a few hours to a few days depending on the application/service/product.

Timing (see [RD4]) is the marking of an event with respect to a reference origin, usually UTC (Coordinated Universal Time), or more precisely a realization of UTC maintained by a time laboratory, named UTC(k), as UTC does not exist in real time. The precise time user requires the time tagging of events (also called Time stamping). Time stamping refers to the use of an electronic timestamp to provide a temporal order among a set of events.

Synchronisation (see [RD4]) deals with understanding the temporal ordering of events produced by concurrent processes. Two clocks can be synchronised between them and/or with respect to an absolute time. Synchronisation is particularly important to ensure successful communication between nodes of a network. It is also required in applications in which two events have to be initiated within a specific time frame. In this document, the term "synchronisation" refers to both phase and frequency synchronisation (frequency synchronisation is actually called syntonisation).

A1.4 List of Acronyms

Acronym	Definition
BEREC	Body of European Regulators of Electronic Communications
BIM	Building information modelling
CCITT	Comité consultatif international téléphonique et télégraphique
CDMA	Code Division Multiple Access
CORS	Continuously Operating Reference Stations
DEM	Digital Elevation Model
DEMETRA	Demonstrator of EGNSS services based on Time Reference Architecture
DGNSS	Differential GNSS
DIAS	(Copernicus) Data and Information Access Services
DSM/DTM	Digital Surface Model / Digital Terrain Model
ECI	European Critical Infrastructures
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS
EMS	Energy Management System
EO	Earth Observation
ETSI	European Telecommunications Standards Institute
EUSPA	EU Agency for the Space Programme
GBAS	Ground-Based Augmentation Systems
3GPP	3rd Generation Partnership Project
GHG	Greenhouse Gases
GIS	Geographic Information System
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European GNSS Agency
GSM	Global System for Mobile Communications
ICT	Information & Communications Technology
IGS	International GNSS Service
IMU	Inertial Measurement Unit
IoT	Internet of Things
IRIG	Inter-range instrumentation group
ITSF	International Timing & Sync Forum
ITU	International Telecommunications Union

Acronym	Definition
ITU-R	ITU Radiocommunication Standardization Sector
ITU-T	ITU Telecommunication Standardization Sector
LIDAR	Light Detection And Ranging
LTE	Long-Term Evolution
LEO	Low Earth Orbit
MEMS	Microelectromechanical systems
NRA	National Regulatory Authority
NTP	Network Time Protocol
ODA	Official Development Assistance
OEM	Original Equipment Manufacturer
O-RAN	Open Radio Access Network
PKI	Public Key Infrastructure
PMR	Professional Mobile Radio PMU
PMU	Phase Measurements Unit
POTS	Plain Old Telephone Service
PPK	Post Processing Kinematic
PPP	Precise Point Positioning
PRTC	Primary Reference Time Clock
PSTN	Public Switched Telephone Network
PTP	Precision Time Protocol
RAN	Radio Access Network
RICS	Royal Institution of Chartered Surveyors
RMS	Root Mean Square
RPAS	Remotely Piloted Aircraft System
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SBAS	Satellite-based augmentation system
SDH	Synchronous Digital Hierarchy
SDR	Software Defined Radio
SSR	State Space Representation
TDD	Time-Division Duplex
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
TETRAPOL	Terrestrial Trunked Radio POLice

Acronym	Definition
TTCM	Turbo Trellis Coded Modulation
T&S	Timing and Synchronisation
T&S	Timing and Synchronisation
TTFF	Time to First Fix
UCP	User Consultation Platform
UMTS/HSPA	Universal Mobile Telecommunications System / High Speed Packet Access
UTC	Coordinated Universal Time
VLEO	Very Low Earth Orbit

A1.5 Reference Documents

Id.	Reference	Title	Date
[RD1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (*Issue 7*). Downloadable at https://www.euspa.europa.eu/sites/default/files/uploads/euspa_market_report_2022.pdf	Jan. 2022
[RD2]	GNSS Technology Report	GSA GNSS Technology Report (*Issue 3*)	Sep. 2020
[RD3]	GSA-MKD-SM-UREQ-229766	Report on surveying user needs and requirements (and its annexes)	Sep. 2021
[RD4]	GSA-MKD-TS-UREQ-250285	Report on time & synchronisation user needs and requirements (and its annexes)	Sep. 2021
[RD5]	Regulation (EU) 2021/696	Regulation (EU) 2021/696 "establishing the Union Space Programme and the European Union Agency for the Space Programme" of 28 April 2021	Apr. 2021
[RD6]	COM(2019) 640 final	Communication from the Commission to the European Parliament, the European Council, the Council, The European Economic and Social Committee and the Committee of the Regions – "The European Green Deal" of 11/12/2019	Dec. 2019
[RD7]	COM(2020) 380 final	Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions – "EU Biodiversity Strategy for 2030 – Bringing nature back into our lives" of 20/05/2020	May 2020
[RD8]	COM(2021) 400 final	Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions – "Pathway to a Healthy Planet for All – EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil" of 20/05/2020	May 2021
[RD9]	COM(2020) 98 final	Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions – "A new Circular Economy Action Plan – For a cleaner and more competitive Europe" of 11/03/2020	Mar 2020
[RD10]	COM(2020) 829 final	Proposal for a Directive of the European Parliament and of the Council on the resilience of critical entities of 12/12/2020	Dec. 2020
[RD11]	FIRE Project D3.1	Focus Group Activity Summary 1 – Infrastructure	Mar. 2021
[RD12]	FIRE Project D3.2	Focus Group Activity Summary 2 – Infrastructure	Jun. 2022
[RD13]	ITAtech Report n°3-v2	ITAtech Guidelines for Remote Measurements Monitoring Systems	May 2015
[RD14]	2008/114/EC Directive	2008/114/EC Directive on the "identification and designation of European critical infrastructures and the assessment of the need to improve their protection"	Dec. 2008

Id.	Reference	Title	Date
[RD15]	RICS Guidelines	RICS Guidelines for the use of GNSS in land surveying and mapping	Nov. 2010
[RD16]	Surveyor's General Guidelines	New South Wales Government – GNSS for Cadastral Surveys	May 2014
[RD17]	Surveying with GPS for Construction Works	Ahmed El-Mowafy – Surveying with GPS for Construction Works Using the National RTK Reference Network and Precise Geoid Models	Jul. 2014
[RD18]	RTK Networks for Machine Control	Keenan et al – RTK Networks for competitive advantage in Machine Control and Site Positioning	Jan. 2010
[RD19]	GNSS Machine Control	Fastellini et al – GNSS machine control with RTCM corrections from permanent networks	May 2009
[RD20]	User Requirements Interview	UCP follow-up validation interview with industry	Jan 2018
[RD21]	UCP 2017	Surveying Session at the UCP MoM (Ref. doc. GSA-MKDMS-MOM-236055-Professional-Mapping-and-Surveying)	Dec. 2017
[RD22]	InSAR4Insurance project	Project description on ESA website https://business.esa.int/projects/insar4insurance	Apr. 2022
[RD23]	AIDA project	Project description on ESA website https://business.esa.int/projects/aida-shm	Dec. 2021
[RD24]	GSA Lot4 SC1, D1 V2.0	Market research and quantification of the timing and synchronisation	Jan. 2014
[RD25]	GSA Lot4 SC1, D2.2 V2.0	Existing and Potential GNSS TS applications and products	Oct. 2014
[RD26]	Consultation with Mr Gilles Boime	Consultation report with Mr Gilles Boime (Spectracom)	Feb. 2012
[RD27]	GSA-MKD-CI-MOM-A09266	User Consultation Platform 2020 Minutes of Meeting of the Infrastructure Panel	Dec. 2020
[RD28]	Permitting procedures – Final Report	Permitting procedures for energy infrastructure projects in the EU: evaluation and legal recommendations	Jul. 2011
[RD29]	Picterra Blog	Construction Site Monitoring: Drone or Satellite Imagery?	Nov. 2020
[RD30]	Shield Engineering Blog	What geology has to do with construction project	Jan. 2021
[RD31]	International Journal of Applied EO and Geoinformation, Volume 47, Pages 69-90	A review on spectral processing methods for geological remote sensing (https://www.sciencedirect.com/science/article/abs/pii/S0303243415300696)	May 2016
[RD32]	10.13140/RG.2.2.26594.15040	A Primer for the use of Satellite Imagery in Geologic Investigations	May 2020
[RD33]	Researchgate.net Publication 274079602	Hyperspectral remote sensing and geological applications	Mar. 2015
[RD34]	-	PPP-RTK Market and Technology Report published by GSA	2019
[RD35]	ORAN-WG4.CUS.0-v01.00	O-RAN Fronthaul Working Group Control, User and Synchronization Plane Specification	2019
[RD36]	EGMS White Paper v1.0	European Ground Motion Service (EU-GMS) - A proposed Copernicus service element - White Paper (downloadable at https://land.copernicus.eu/user-corner/technical-library/egms-white-paper)	2017

Id.	Reference	Title	Date
[RD37]	Researchgate.net Publication 224723863	Differential SAR interferometry using corner reflectors	Jul. 2002
[RD38]	Researchgate.net Publication 261339291	Using corner reflectors and X-band SAR interferometry for slope instability monitoring	Sep. 2012
[RD39]	United Nations UN-SPIDER portal	Data Application of the Month: Land Deformation Mapping Using DInSAR https://www.un-spider.org/links-and-resources/data-sources/daotm-land-deformation	-
[RD40]	Project "Digital ecosystem deep dive - EU Space for 5G/6G infrastructure"	Final workshop of the Proof of Concept: Copernicus for 5G cross-border corridors	Oct. 2022
[RD41]	PPP versus DGNSS	Rizos, C., Janssen, V., Roberts, C. and Grinter, T. - PPP versus DGNSS	Oct. 2012
[RD42]	Galileo CS GNSS High Accuracy and Authentication	InsideGNSS - Galileo's Commercial Service: Testing GNSS High Accuracy and Authentication	Feb. 2015
[RD43]	Satellite Clock estimation for PPP	Chen et al, Efficient High-Rate Satellite Clock Estimation for PPP Ambiguity Resolution Using Carrier-Ranges	Nov. 2014
[RD44]	Galileo's surveying potential	GPS World – Galileo's Surveying Potential	Mar. 2012
[RD45]	Exploiting Galileo E5	Diessongo et al - Exploiting the Galileo E5 Wideband Signal	Sep. 2012
[RD46]	Comparative analysis of measurement noise and multipath	Cai et al - A comparative analysis of measurement noise and multipath for four constellations: GPS, BeiDou, GLONASS and Galileo	Dec. 2014
[RD47]	User Requirements Interview	UCP follow-up validation interview with industry	Jan. 2018
[RD48]	UCP 2017	Surveying Session at the UCP MoM (Ref. doc. GSA-MKDMS-MOM-236055-Professional-Mapping-and-Surveying)	Dec. 2017
[RD49]	GSA-MKD-TS-UREQ-233690	Report on Time & Synchronisation User Needs and Requirements	Nov. 2017
[RD50]	Homeland Security Researching GPS Disruptions, Solutions	Inside GNSS News, Homeland Security Researching GPS Disruptions, Solutions, Latest News, Dee Ann Divis http://insidegnss.com/homeland-security-researchinggps-disruptions-solutions/	Jun. 2014
[RD51]	Critical Infrastructure Vulnerabilities to GPS Disruptions	Critical Infrastructure Vulnerabilities to GPS Disruptions Sarah Mahmood, Program Manager, Resilient Systems Division Homeland Security Advanced Research Projects Agency Science & Technology Directorate	Jun. 2014
[RD52]	GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced	"GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced", GAO-14-15	Nov. 2013
[RD53]	Consultation with Mr Jiri Luhan	Consultation report with Mr Jiri Luhan	Feb. 2012
[RD54]	GSA-MKD-T-SMOM- 246199	User Consultation Platform 2018 – Minutes of Meeting of the Timing and Synchronisation Panel	Dec. 2018

Id.	Reference	Title	Date
[RD55]	GSA-MKD-CI-MOM-A09266	User Consultation Platform 2020 – Minutes of the Infrastructure Panel	Dec. 2020
[RD56]	NA	GSA Market Development internal analysis	2020

A1.6 Policy and regulation relevant to infrastructure

As mentioned in section 4.1, there are a number of policy or regulatory documents which may have an indirect impact on the infrastructure market.

The first of them is the Communication from the Commission on the European Green Deal ([RD6]) which ambitions to achieve climate neutrality by 2050 and indicates that efforts will have to be strengthened in several domains among which climate-proofing, resilience building, prevention and preparedness. All of them apply to the infrastructure sector and the Communication from the Commission recommends that all the actors across the EU develop instruments to integrate climate change into their risk management practices. Applied to infrastructures, this would mean in particular to take climate change into account when selecting new sites for construction, when designing new infrastructures and when operating/maintaining infrastructures. Interestingly, the Communication from the Commission mentions a number of digital technologies considered to be a critical enabler for attaining the sustainability goals of the Green deal (e.g. artificial intelligence, 5G, cloud and edge computing and the internet of things) but does not mention GNSS or Earth Observation.

The European Green Deal refers in turn to two other potentially relevant documents: the Communication from the Commission on the EU Biodiversity Strategy for 2030 ([RD7]) and the EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', formalised later in 2021 through another Communication from the Commission ([RD8]).

The EU's Biodiversity Strategy for 2030 is a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030, and contains specific actions and commitments. In particular, it aims at stopping loss of green urban ecosystems and recommends to systematically integrate the promotion of healthy ecosystems, green infrastructure and nature-based solutions into urban planning, including in public spaces, infrastructure, and the design of buildings and their surroundings.

The EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' aims to improve public health protection. It indicates among others that the Commission will introduce stricter requirements to tackle air pollution at source in several sectors including agriculture, industry, transport, energy and also buildings, this latter aspect being directly related to the construction sector and therefore to infrastructure. The EU Action Plan mentions Copernicus as major building block for the EU's Destination Earth Initiative. The EU action plan identifies a number of "Flagships", one of them being dedicated to "showcasing zero pollution solutions for buildings" (Flagship 6). Through this flagship, the Commission aims to showcase from the renovation wave strategy and New European Bauhaus initiative how building projects and the use of Local Digital Twins can also contribute to zero pollution objectives.

Another potentially relevant document is the "new Circular Economy Action Plan For a cleaner and more competitive Europe" ([RD9]). This Communication from the Commission indicates that the Commission will launch a new comprehensive Strategy for a Sustainable Built Environment, which will ensure coherence across the relevant policy areas such as climate, energy and resource efficiency, management of construction and demolition waste, accessibility, digitalisation and skills. The document mentions Copernicus as a source of data to improve circularity metrics.

As mentioned previously, the case of "critical infrastructures" is subject to a specific policy/regulatory framework.

In December 2008, the European Commission issued a Directive on the "identification and designation of European Critical Infrastructures and the assessment of the need to improve their protection" ([RD14]). The Directive, also known as "ECI Directive" distinguishes the "critical infrastructure" from "European critical infrastructure" and mentions that "*There are a certain number of critical infrastructures in the Community, the disruption or destruction of which would have significant cross-border impacts […]. The* *evaluation of security requirements for such infrastructures should be done under a common minimum approach.*" Although the Directive applies only to the energy and transport sectors ("*The sectors to be used for the purposes of implementing this Directive shall be the energy and transport sectors.*"), it mentions that "*if deemed appropriate, subsequent sectors to be used for the purpose of implementing the Directive may be identified. Priority shall be given to the ICT sector*". The ECI Directive also sets out specific protection requirements on ECI operators and competent Member State authorities.

In December 2020, the European Commission issued a proposal for a Directive on the resilience of critical entities ([RD10]) to replace the ECI Directive. In this document, the European Commission proposes to switch from the approach consisting in protecting specific assets toward an approach aiming at reinforcing the resilience of the critical entities that operate these assets. The proposed directive has a much wider sectoral scope, covering ten sectors, namely energy, transport, banking, financial market infrastructure, health, drinking water, waste water, digital infrastructure, public administration, and space. It defines obligations for Member States (e.g. obligation to identify critical entities and to define a strategy for reinforcing the resilience of these critical entities) and for critical entities (e.g. obligation to assess at least every four years the risks that may disrupt their operations). The proposed directive also requires that measures to prevent incidents from occurring are defined and explicitly mentions the need for "*disaster risk reduction and climate adaptation measures*". However, the proposed directive does not impose any obligation on the means or type of information to be used by Member States and critical entities to implement the Directive and does not refer either to Earth Observation or to GNSS. It therefore does not impose any obligation on the use of EO and GNSS in the Infrastructure sector.

A1.7 Standards relevant to infrastructure

The Report on Surveying User Needs and Requirements (see [RD3]) refers to a number of standards, frameworks and reference systems on which rely the surveying, cartographic and geodetic professions. These systems establish a “reference framework” useful to other sectors, including the infrastructure sector for the activities related to site selection and construction (e.g. the European Terrestrial Reference System – ETRS89). Yet, although they are used in the infrastructure sector, these systems have no direct impact on the user requirements of the Infrastructure sector itself. The corresponding standards are therefore not addressed in the present document.

There are however some international standards which are relevant to the Infrastructure sector. The EO and GNSS EUSPA Market Report (see [RD1]) mentions in particular two GNSS-related standards important for construction surveys and infrastructure monitoring.

The first one is IGS-SSR format v1.0, the first version of the State Space Representation (SSR) standard released by the International GNSS Service (IGS) in October 2020, after a long push from the user community. This is the first open standard for dissemination of real-time Precise Point Positioning (PPP) products to support the IGS Real-Time Service to the wider community. The messages support multi-GNSS and include corrections for orbits, clocks, differential code biases (DCBs), phase-biases and ionospheric delays. This standard may be well utilised by construction GNSS receiver manufacturers and facilitate high-accuracy GNSS workflows in the lack of network Real Time Kinematics (RTK) coverage, especially in remote construction areas.

The second one is the new version of the Receiver Independent Exchange format (RINEX version 3.05), released by IGS in December 2020 and which provides better integration of Russian and Chinese GNSS (GLONASS and BeiDou respectively) for maximum high-accuracy applications, such as infrastructure monitoring, where precise post-processing of static GNSS data is increasingly demanded.

EUSPA Mission Statement

The mission of the European Union Agency for the Space Programme (EUSPA) is defined by the EU Space Programme Regulation. EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the European Union.

Its goal is to:

- Provide long-term, state-of-the-art safe and secure Galileo and EGNOS positioning, navigation and timing services and cost-effective satellite communications services for GOVSATCOM, whilst ensuring service continuity and robustness;
- Communicate, promote, and develop the market for data, information and services offered by Galileo, EGNOS, Copernicus and GOVSATCOM;
- Provide space-based tools and services to enhance the safety of the Union and its Member States. In particular, to support PRS usage across the EU;
- Implement and monitor the security of the EU Space Programme and to assist in and be the reference for the use of the secured services, enhancing the security of the Union and its Member States;
- Contribute to fostering a competitive European industry for Galileo, EGNOS, and GOVSATCOM, reinforcing the autonomy, including technological autonomy, of the Union and its Member States;
- Contribute to maximising the socio-economic benefits of the EU Space Programme by fostering the development of a competitive and innovative downstream industry for Galileo, EGNOS, and Copernicus, leveraging also Horizon Europe, other EU funding mechanisms and innovative procurement mechanisms;
- Contribute to fostering the development of a wider European space ecosystem, with a particular focus on innovation, entrepreneurship and start-ups, and reinforcing know-how in Member States and Union regions.
- As of July 2023, EUSPA will take the responsibility for the Programme's Space Surveillance Tracking Front Desk operations service.

The European Union Agency for the Space Programme: linking space to user needs.

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