D7.1 ASHVIN TECHNOLOGY DEMONSTRATION PLAN

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ABSTRACT

ASHVIN aims at the digitalization of the construction industry to increase productivity, resource efficiency, and safety. Towards this goal, digital twin technology is only one means to an end. Therefore, the core of all ASHVIN development aims at introducing two major process innovations enabled by the possibility to closely match as-build information with as-designed **information throughout the product development lifecycle** that is made possible by digital twin technology.

This report presents a plan for implementation of the ASHVIN platform and tools in the demonstration projects. For each of the demonstration project relevant challenges and needs are described, based on that appropriate tools and monitoring devices can be planned. It is significant to show that various type of structures (buildings, bridges, and industrial buildings) has different problems and boundary condition. Only after examination and understanding of the problems and challenges that each construction site faces it is possible to correctly apply new solution. The document that presents the implementation of digital twin technologies on demonstration projects: #1 Bridges for highspeed railways in Spain, #2 Building renovation in Poland, #3 Airport runway in Croatia, #4 Logistics hall construction in Germany, #5 Kineum office building in Sweden, #6 Office buildings in Spain, #7 Bridges in highway network in Spain, #8 Footbridge in Germany, #9 Sport stadium roof structure, #10 Quay wall in the Netherlands.

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DISCLAIMER

ACRONYMS & DEFINITIONS

API	Application programming interface
BIM	Building Information Modelling
CAD	Computer Aided Design
CoAP	Constrained Application Protocol
CSV	Comma-separated values
DDCV	Defect Detection using Computer Vision
DF	Data Fusion
EU	European Union
FEM	Finite Element Method
FOD	Foreign Object Damage
GIS	Geographic information system
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
IoT	Internet of Things
Jpg	Joint Photographic Expert Group
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LIDAR	Light Detection and Ranging
LoRa	Long Range
LPP	Lean project planning methodology
MEP	Mechanical, electrical and plumbing
MQTT	Message Queue Telemetry Transport
PI	Performance Indicator
R&I	Research and Innovation
SQL	Structured Query Language
WP	Work Package
VOC	Volatile organic compounds
3DRI	3D reconstruction from Images

ASHVIN PROJECT

ASHVIN aims at enabling the European construction industry to significantly improve its productivity, while reducing cost and ensuring absolutely safe work conditions, by providing a proposal for a European wide digital twin standard, an open-source digital twin platform integrating IoT and image technologies, and a set of tools and demonstrated procedures to apply the platform and the standard proven to guarantee specified productivity, cost, and safety improvements. The envisioned platform will provide a digital representation of the construction product at hand and allow to collect real-time digital data before, during, and after production of the product to continuously monitor changes in the environment and within the production process. Based on the platform, ASHVIN will develop and demonstrate applications that use the digital twin data. These applications will allow it to fully leverage the potential of the IoT based digital twin platform to reach the expected impacts (better scheduling forecast by 20%; better allocation of resources and optimization of equipment usage; reduced number of accidents; reduction of construction projects). The ASHVIN solutions will overcome worker protection and privacy issues that come with the tracking of construction activities, provide means to fuse video data and sensor data, integrate geo-monitoring data, provide multi-physics simulation methods for digital representing the behavior of a product (not only its shape), provide evidence based engineering methods to design for productivity and safety, provide 4D simulation and visualization methods of construction processes, and develop a lean planning process supported by real-time data. All innovations will be demonstrated on real-world construction projects across Europe. The ASHVIN consortium combines strong R&I players from 9 EU member states with strong expertise in construction and engineering management, digital twin technology, IoT, and data security / privacy.

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1 INTRODUCTION

1.1 Purpose of the document

This report presents a plan for implementation of the ASHVIN platform and toolkit in the demonstration projects. For each of the demonstration project relevant challenges and needs are identified and based on that appropriate tools and monitoring devices are planned. It is significant to show that various types of structures (buildings, bridges, and industrial buildings) have different problems and boundary condition. Only after examination and understanding of the problems and challenges that each construction site faces it is possible to correctly apply new solution. The document that presents the implementation of digital twin technologies on demonstration projects. The synthesis report containing of implementation of digital technologies on all demonstration sites, will be issued at Month 36.

The target groups for this document are consortium partners of the ASHVIN project (in particular tool developers and partners responsible for demonstration sites), construction management staff representing the main contractor (in particular site managers and engineers), subcontractors and investors (in particular technical supervisors).

1.2 Structure of the document

The document is divided into four main sections. First part of work is related to introduction of the ASHVIN platform and associated tools and presentation of the validation concept. Then ten demonstration projects are briefly introduced and presented. ASHVIN demonstrators are divided into three categories: buildings, bridges, and industrial structures. In addition, there are related to various phases of the construction process: design and engineering, construction, and maintenance. The goal is to show how digital twin technology can increase productivity, resource efficiency and safety on various projects in different phases of life cycle. For each of the demonstration projects following aspects are presented and discussed:

- Challenges and needs
- Main stakeholders participating in the process
- Plan for IoT measurements
- Selection of ASHVIN tools appropriate for implementation in the demonstration project

2 CONCEPT FOR VALIDATION OF THE ASHVIN PLATFORM AND TOOLS ON DEMO SITES

2.1 Introduction to the ASHVIN platform and tools

ASHVIN project aims at the digitalization of the construction industry to increase productivity, resource efficiency, and safety. Towards this goal, digital twin technology is only one means to an end. Therefore, the core of all ASHVIN development aims at introducing two major process innovations enabled by the possibility to closely match as-build information with as-designed **information throughout the product development lifecycle** that is made possible by digital twin technology.

ASHVIN develops digital processes that will allow for the seamless integration of all stakeholders within and across the **design / engineering, construction, and maintenance** of buildings and infrastructure. Vertical integration will be achieved by possibilities for back- and forward information and knowledge flow through all stages of the product development process. ASHVIN establishes design and engineering processes that can leverage experiences and lessons learned from past projects (evidence-based design). These processes can project the effects of design choices on the productivity, resource efficiency, and safety during early design stages (constructability analysis through generative design). By the core nature of the digital twin solutions a direct match between as-designed and as-build information will be achieved to ensure seamless knowledge and information integration from design /engineering phases to construction and further on to maintenance stages. ASHVIN develops corresponding process templates and recommendations as well as the required interoperability solutions and standards.

To achieve horizontal integration through all project phases, ASHVIN develops a set of clear impact indicators (Key Performance Indicators) that will allow steering the product development process in all phases jointly towards common goals as can be seen in Figure 1. In the project Key performance indicators (KPI) are performance aspects which are used for evaluation productivity, resource efficiency and safety of construction process. While the Performance indicators (PI) are a number of related and quantifiable and measurable parameters that constitute a KPI.

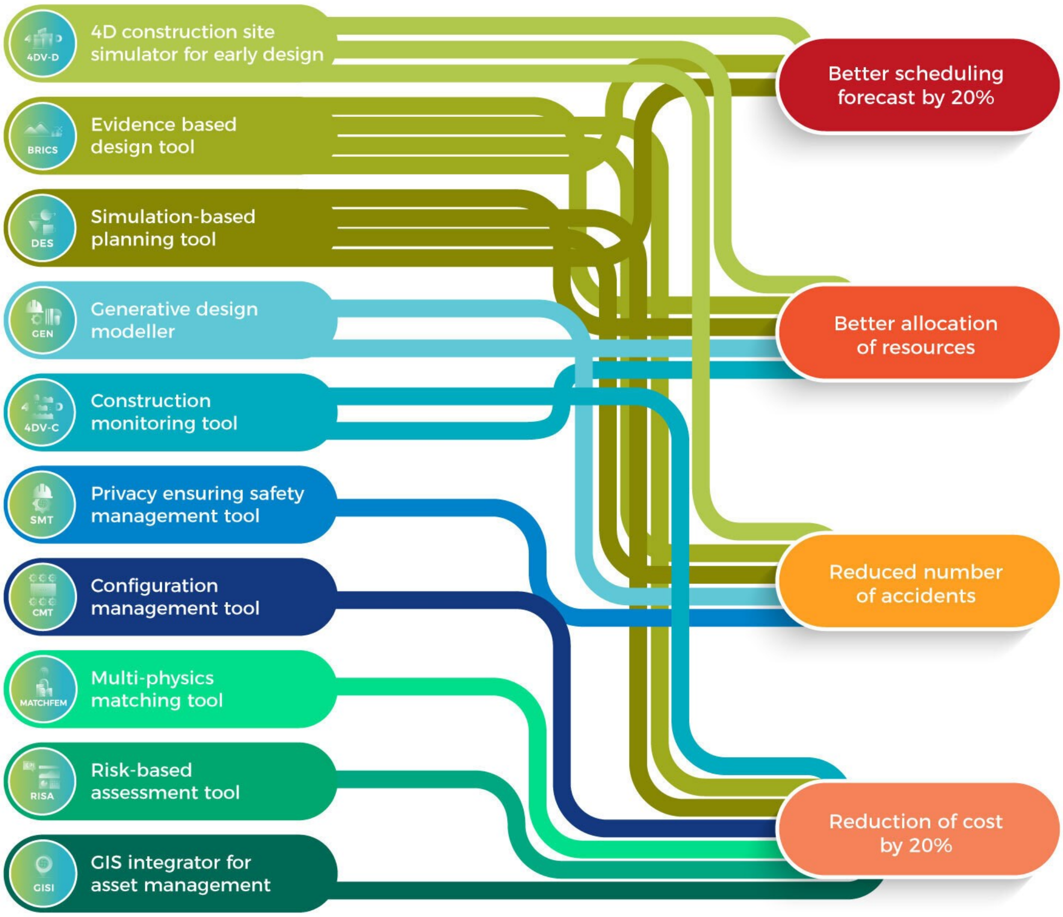


Figure 1: Illustration for the relation between ASHVIN tools and expected project outcomes monitored by using (K)PIs

Based on these KPIs (Productivity, Resource Efficiency, Safe construction work, Cost) advanced dashboarding and visualisation methods will be developed that will allow presenting digital twin information to all important stakeholders and decision makers at every stage in the design process. Together, KPIs, dashboards, and visualizations will allow for true collaborative decision making that is based upon facts established by an accurate representation of the real-world conditions by digital twins. A specific focus for horizontal integration is on the construction phase. For the construction phase, ASHVIN designs lean planning and control processes that will allow to integrate all parties that need to work together on a construction site to engage in collaborative decision-making processes. The lean processes will allow using digital twin data to clearly map value streams (in terms of productivity, resource efficiency, and safety), communicate these value streams among all parties involved during construction, and, in turn, allow for establishing information and material flows that truly rely on a pull system minimizing waste, idle resources, and circumventing unsafe construction conditions.

In the context of the ASHVIN project, we want to establish means to collect data generated during the process of building design, production, and maintenance. To do this, we need an all-encompassing IoT platform able to digitally represent real world devices, enable message exchange between devices and applications, persist messages in a database and, finally, filter and transform data gathered from the devices, preferably, on the very spot of data production.

However, the current situation in the world of IoT resembles the tower of Babel. There are a plethora of device types using different protocols to send and receive messages. Even when devices use the same protocol to communicate, they use different formats of messages. Likewise, applications speak different “languages” and form their “sentences” in different ways. As a result, device to device, application to application, and device to application communication lacks generality and is difficult and costly to implement and maintain.

The solution is not to establish one common “language” and one common “sentence” format. There is a reason why different protocols (LoRa[1], MQTT[2], OPC UA[3], HTTP[4],etc.) exist: though some of them are still there for legacy reasons, a good number of different protocols correspond to different real-world needs. The solution is, rather, to find a way to translate between different communication protocols (IoT “languages”).

Architecture for the ASHVIN platform is presented in Figure 2.

[1] https://en.wikipedia.org/wiki/LoRa

[2] https://en.wikipedia.org/wiki/MQTT

[3] https://en.wikipedia.org/wiki/OPC_Unified_Architecture

[4] https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol

Figure 2: ASHVIN platform software architecture

ASHVIN toolkit developing during the project is defined in the below Table 1.

Table 1 Tools developed during ASHVIN project

ASHVIN Tool	Description
BRICS	<u>Evidence based design support tool for productivity, resource efficiency and safety</u> - ASHVIN develops a knowledge base for identifying design patterns from digital twin data and historical project data and past project data. These design patterns will be formulated in practical rules that can be queried by designers to improve the productivity, resource efficiency, and safety of their designs.
GEN	<u>Generative design modeller to support design for productivity, resource efficiency and safety</u> - Generative design methods will be developed that allow designers to automatically generate many alternatives based on a specific set of input parameters. The application will also allow to score each alternative based on developed KPIs for productivity, resource efficiency, and safety.

4DV-D	Construction site simulator for early design phases with 4D visualizer - This application will allow to clearly visualize the effects of specific design options on productivity, resource efficiency, and safety. Different options can be compared with each other by visualizing projected construction sequences.
4DV-C	Construction monitoring tool with productivity and safety KPI decision making dashboard - A 4D tool visualizing past construction activities based on activities tracked by the digital twin platform. The tool allows to plan future construction sequences and site layout options based on accurately mapped past activities.
DES	Simulation-based real-time construction site and logistics planning tool - A tool to set-up discrete event based stochastic simulations of planned construction activities and site layouts. The tool will use stochastic productivity data tracked with the ASHVIN digital twin platform.
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings - Implemented methods that allow to stochastically adjust input parameters for different multi-physics simulations using sensor-based measurements. These methods will allow for the accurate representation of behavioural digital twins.
RISA	Risk-based status assessment tool with KPI dashboard - Visualization tool allowing for the detailed understanding of an asset's status for designing optimized maintenance plans.
GISI	GIS integrator for digital twin-based asset management - A GIS tool allowing asset managers to keep track of the digital twin predicted status of multiple assets based on a specific set of asset management KPIs.
SMT	Privacy ensuring safety management, simulation, and training tool - An application that will allow safety managers to understand possible safety hazards on site and to analyse past construction activities without being able to target specific workers personally.
CMT	A configuration management tool to track as-designed and as-built, as well as, to allow for seamless commissioning - Software that will allow for establishing and maintaining consistency among requirements, design, configured items, and associated construction, operations and maintenance data, equipment, and other enablers throughout the project lifecycle based on digital twin data.

2.2 Verification and validation concept

The ASHVIN platform and tools allow for real-time monitoring of a variety of indicators related to processes in design, construction, and asset management. The indicators are developed in three work packages: WP2, WP4 and WP5.

These indicators provide input regarding key processes such as resource efficiency, health and safety and productivity. Some indicators provide a direct input, whereas others combined with other indicators, and data analyses provide this input.

The verification and validation concepts aim to establish several procedures that are applied to the various demo sites. The purpose of the verification and validation concept is to ensure that the different identified indicators collectively contribute to the key processes according to the above.

For each indicator and each related key process, a standard procedure is formalised to verify and validate the relation. The procedures include processes such as set up of demo site, plan for data collection, input device calibration, etc.

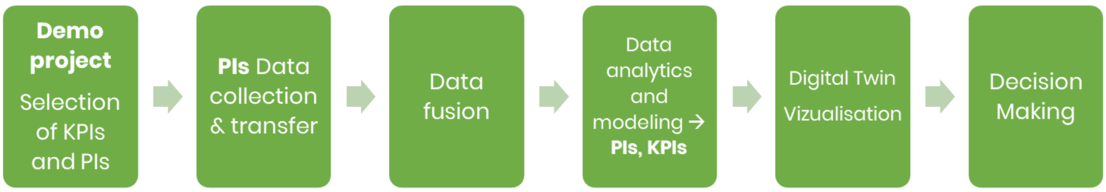


Figure 3: Illustration of verification concept for ASHVIN platform

2.3 ASHVIN Demonstration projects

ASHVIN platform and technologies will be implemented on ten real-word projects covering buildings, bridges, viaducts, and industrial structures. Demonstration projects are introduced in tables below.

Table 2 Demonstration project #1: Bridges for highspeed railways in Spain

#1 Bridges for highspeed railways in Spain	  
Location Function Owner Year of construction	Plasencia-Cáceres Bridges, viaducts, underpass Renfe, ADIF Under construction (MEP stages)
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☐ Construction ☒ Maintenance
Data/information available for the demonstration site	Design projects as well as executive projects are only available in pdf formats, no BIM

Table 3 Demonstration project #2: Building renovation in Poland

#2 Building renovation in Poland	
Location Function Owner Status	Zbożowa 30 street, Gdynia, Poland Residential building (social housing) City of Gdynia (Public) Constructed in 1931
Phase of the construction process the ASHVIN solution can be applied	☒ Design and Engineering ☐ Construction ☒ Maintenance
Data/information available for the demonstration site	Old paper building design, no digital design is available

Table 4 Demonstration project #3: Airport runway in Croatia

#3 Airport runway in Croatia	
Location Function Owner Status	Airport Zadar, Zemunik Donji, 8km form Zadar city centre, Croatia International Airport 55% state, 20% Zadar county, 20% City of Zadar, 5% Municipality Zemunik Donji Constructed in 1968
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☐ Construction ☒ Maintenance
Data/information available for the demonstration site	Schedule about runway regular inspections of runway and other operational areas, No BIM models are available, CAD drawings are available, Weather station.

Table 5 Demonstration project #4: Logistics hall construction in Germany

#4 Logistics hall construction in Germany	
Location Function Owner Status	Röntgenstraße, 31737 Rinteln, Germany Goldbeck Under construction
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☒ Construction ☐ Maintenance
Data/information available for the demonstration site	Schedule, Execution plans, No BIM models are available and only limited CAD drawings are available; Access to the data need to be made by signature of NDA

Table 6 Demonstration project #5: Kineum office building in Sweden

#5 Kineum office building in Sweden	
Location Function Owner Status	Drakegatan, Göteborg, Sweden Office building Platzer & NCC Under construction
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☒ Construction ☐ Maintenance
Data/information available for the demonstration site	BIM, Virtual Design and Construction data

Table 7 Demonstration project #6: Office buildings in Spain

#6 Office buildings in Spain	
Location Function Owner Status	Barcelona, Spain Office Building. Reinforced Concrete Structure FUSTOR and Bellersil property Under construction
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☒ Construction ☐ Maintenance
Data/information available for the demonstration site	BIM Construction data (limited)

Table 8 Demonstration project #7: Bridges in highway network in Spain

#7 Bridges in highway network in Spain	
Location Function Owner Status	Barcelona área, Spain Bridge Ministerio de Transporte, Movilidad y Agenda Urbana Constructed in 2020
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☐ Construction ☒ Maintenance
Data/information available for the demonstration site	Design projects as well as executive projects are available in pdf formats, no BIM

Table 9 Demonstration project #8: Footbridge in Germany

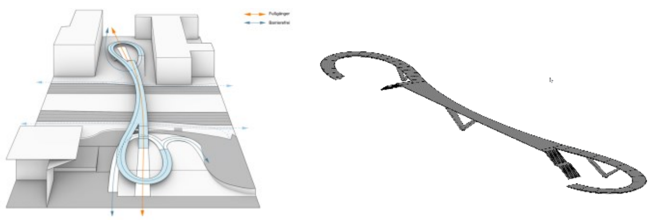
#8 Footbridge in Germany	
Location Function Owner Status	Dortmund, Lindemannstraße – Rheinlanddamm (51.498068, 7.452253) Pedestrian Bridge (Girder steel bridge); Stadt Dortmund (Tiefbauamt) Design (Aug. 2020 – Jun. 2022); Under construction (Jul. 2022 – Dec.2022)
Phase of the construction process the ASHVIN solution can be applied	☒ Design and Engineering ☒ Construction ☐ Maintenance
Data/information available for the demonstration site	Structural mechanical model, BIM Model, Time schedule, drawings

Table 10 Demonstration project #9: Sport stadium roof structure

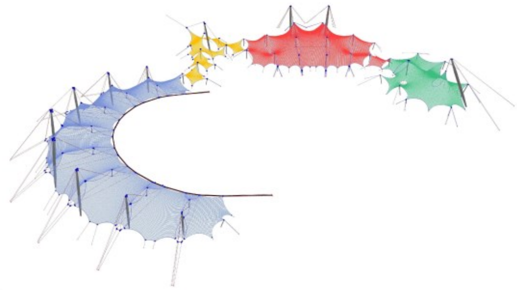
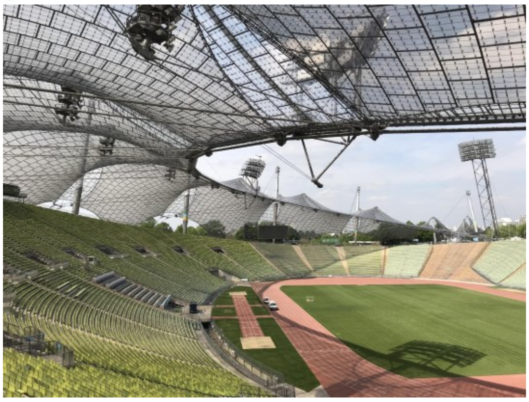
#9 Sport stadium roof structure	 
Location Function Owner Status	Spiridon-Louis-Ring 27, 80809 Munich, Germany Pre-stressed cable net roof structure (74 000 m^2) City of Munich Stadtwerke München (SWM) Olympiapark München GmbH (OMG) Constructed in 1972
Phase of the construction process the ASHVIN solution can be applied	☐ Design and Engineering ☐ Construction ☒ Maintenance
Data/information available for the demonstration site	Rhino topology model Structural mechanical model

Table 11 Demonstration site: #10 Quay wall in the Netherlands

#10 Quay wall in the Netherlands	
Location Function Owner Status	Euromax, Yangstehaven, Maasvlakte II, Port of Rotterdam, the Netherlands Quay wall Port of Rotterdam Constructed in 2007
Phase of the construction process the ASHVIN solution can be applied	☒ Design and Engineering ☐ Construction ☐ Maintenance
Data/information available for the demonstration site	Monitoring data, site investigation, construction records, tidal charts

3 IMPLEMENTATION OF DIGITAL TWIN TECHNOLOGIES ON DEMO SITES

3.1 #1 Bridges for high-speed railways in Spain

3.1.1 Introduction

Alta Velocidad Española (AVE) is a service of high-speed rail in Spain operated by Renfe, the Spanish national railway company, at speeds of up to 310 km/h (193 mph). AVE trains run on a network of high-speed rail tracks owned and managed by ADIF (Administrador de Infraestructuras Ferroviarias). The first line was opened in 1992, connecting the cities of Madrid, Córdoba and Seville. Unlike the rest of the Iberian broad gauge network, the AVE uses standard gauge. This permits direct connections to outside Spain through the link to the French network at the Perthus Tunnel. AVE trains are operated by RENFE, but private companies may be able to operate trains in the future using other brands, in accordance with European Union legislation. Alta Velocidad Española translates to "Spanish High Speed", but the acronym also stands for the word ave, meaning "bird". Figure 3 displays the network at February 2021 in which “in service”, “under construction”, “projected” and “in partial service” branches are highlighted.

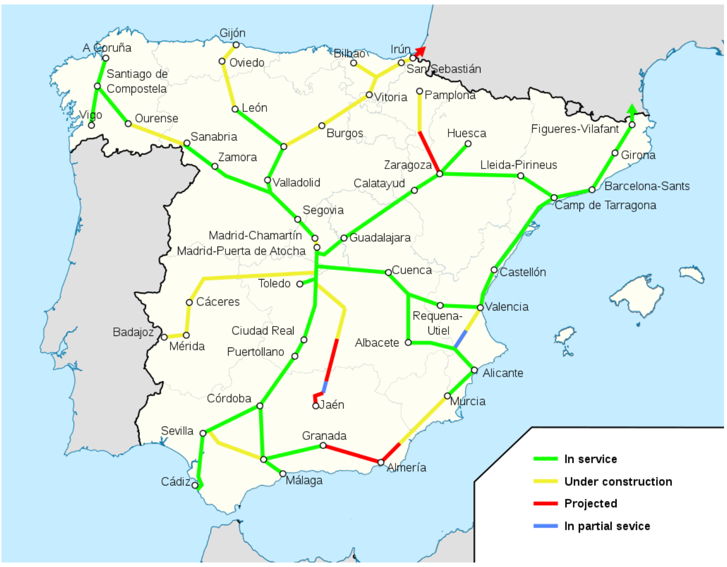


Figure 4: High Speed Railway Network. Spain. February 2021. Source Wikipedia

The branch of the Highspeed Railway; Madrid-Bajadoz has been under construction in recent years. It is supposed to connect in the years to come two major European cities in nearly 3 hours by train: Lisbon and Madrid. The map provided in Figure 4 shows its specific location. Its origin is some 50 kilometres South of Madrid and then the line goes South-West direction towards Badajoz. Presently, it has been built only on the Spanish side. The length of the double line from Madrid to Badajoz is 437 kilometres and it includes several viaducts, bridges and tunnels. European funds (FEDER) under the challenge of sustainable transportation helped develop this strategic infrastructure. Figure 5 displays a schematic overview of the major stations connected by the line.

Figure 5: High Speed Railway Network. Spain. February 2021. Source ADIF

The branch of the Highspeed Railway; Plasencia-Bajadoz is expected to open in the years to come. Presently, works on the mechanics, electrics, services and other necessary infrastructure are being finished. The railways as well as major infrastructure are being tested and monitored. The Spanish design and engineering firm GEOCISA, which is a collaborator in ASHVIN, is currently performing systematic load tests on the bridges belonging to this branch. The company has access to load tests of more than 15 bridges of different sizes. The bridges vary in type from simple underpasses to complex arch bridges, including a top-5 world record defined by a concrete arch (Almonte Viaduct). Geocisa has provided access to the documentation of those assets.

These routine load tests are meant to verify standards on the design and construction of the bridges. Load tests consist of the development of a structural model representing a realistic load that is put on the bridge. Measurements related to the response of the structure when subjected to those loads are taken and compared. If results are within tolerances, the bridge is considered as acceptable for operational stage.

The load tests represent an ideal milestone for twinning bridges. On the one hand, specific, bespoke structural models are performed. On the other hand, measurements quantifying the structural response are taken. If both results are matched using not only basic comparisons but comprehensive digital twinning, the asset enters the service phase not only physically, but also virtually. The demonstrator #1 is aimed at establishing requirements, procedures and for the generation of the most realistic virtual replica of the physical bridges that can be used during operation. Presently, current numerical methods focus primarily on the virtual reproduction of the assets. Models are generally calibrated with existing laboratory or real tests. The twinning of these bridges also includes the integration of data from sensors for model updating or hybrid simulations within the realm of such simulations.

A close inspection of the pool of bridges has already been given. Together with ***Geocisa***, documentation of all assets has been studied. Among all bridges, three assets have been selected for implementation of the ASHVIN set of measurements and developments while others are used for the analysis of the whole line, Figure 6, Figure 7, Figure 8.

Figure 6: A viaduct formed of 8 simply supported beams. Its name is "Valdelinares".

Figure 7: Viaduct formed of a continuous beam. Its name is "Viaducto de la Plata".

Figure 8: Underpass located at the 3 + 93 PK.

The selection of these assets is based on the criteria of repetitiveness according to the needs of the stakeholders. These structural typologies represent a considerable proportion of the pool of assets of this particular line but also, of the whole network. As a result, developing digital twins of the load tests of these structural types is a very representative sample. The impact on the maintenance plan of systematically twinned assets is maximized. Since ASHVIN is aimed at demonstrating how to support the entire product delivery lifecycle for bridges with different ASHVIN interoperability solutions, choosing a representative sample is of the utmost importance.

In addition, specific measurements will be taken in two specific assets: El Tajo Viaduct and Almonte Viaduct. These assets will provide information about remote sensing techniques, such as radar interferometry, which are discussed in detail in Deliverable 5.1 of the project.

Figure 9: El Tajo Viaduct

Figure 10: Almonte Viaduct

3.1.2 Challenges and needs

This demonstration site is particularly interesting for maintenance activities, as these assets are part of a network. Administration usually deploys inspection and maintenance plans based on non-digital methods for condition ratings. Under request, in case of visual deterioration, more refined projects and numerical simulations are deployed. The challenge is to develop a Digital-twin enabled reproduction of the assets that generate an impact on cost reduction and safety at operational stages. This reproduction should integrate the following steps and needs within the platform, Figure 11. It is aimed at integrating sensors, images and other file inputs to the load tests.

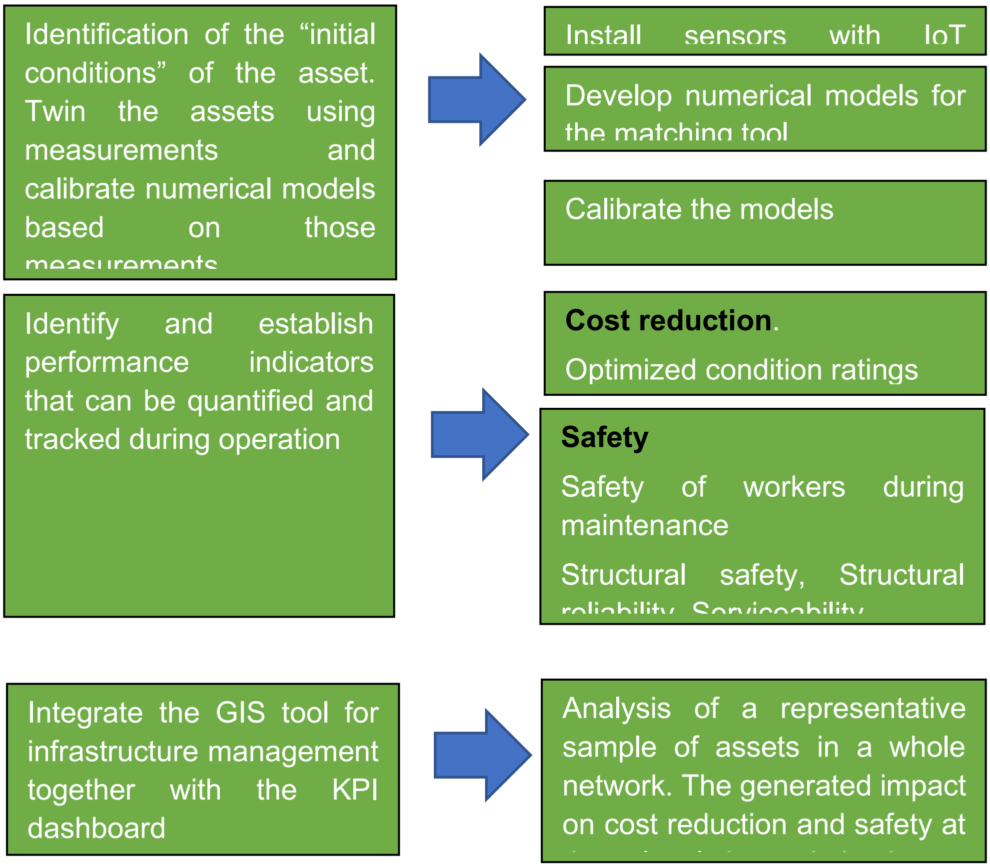


Figure 11: Main steps for implementation of the ASHVIN platform.

The ASHVIN consortium combines expertise in collecting and handling all types of data and generating a wide variety of simulations that will be infused within the platform for a real time updating of the assessment of assets. Data from sensors will seamlessly flow bidirectionally from sensors to the platform to simulation. Very importantly, a set of KPIs for the assessment of assets during their lifetime based on digital-twin technologies will be integrated within a GIS environment.

3.1.3 Main stakeholders

- **Renfe:** Public company that represents the Spanish operator of the railway networks. Its origins date back 80 years, when a process of reconstructing and nationalising the railway industry took place in Spain and gave rise to the "Red Nacional de Ferrocarriles Españoles" (RENFE: National Network of Spanish Railways) in 1941. In 2005, it was split into "operator" and "infrastructure management", from which ADIF was created. The project for liberalising rail transport has marked the history of both companies.

- **Adif:** Administrator of Railway Infrastructures, it is a state-owned company that answers to the Ministerio de de Transportes, Movilidad y Agenda Urbana. Adif plays a leading role in promoting the railway sector, working towards converting it into the ideal mode of transport and facilitating access to the infrastructure under fair conditions. Its aim is to promote the Spanish railway system by means of the development and management of a safe, efficient and sustainable infrastructure to the highest quality standards in environmental terms. Adif is in charge of:

- Administrating rail infrastructures (tracks, stations, freight terminals, etc).
- Managing rail traffic
- Distributing capacity to rail operators.
- The collection of fees for infrastructure, station and freight terminal use.

- **Geocisa**: It is a private company highly specialized in diverse activities. Geocisa is a sister Company of Dragados, an international contractor established in 1941 that specializes in major infrastructure projects worldwide. Dragados is the construction arm of ACS Group, which is one of the leading infrastructure developers in the world with a presence in more than 40 countries. GEOCISA is a company with expertise across a range of technical projects such as: Geology and Geotechnics, Instrumentation and Monitoring, Soil Investigation and Ground Treatments, Deep Foundations, Laboratories, Infrastructure Management and Highway Maintenance, Restoration and Rehabilitation of Monuments, Bridges and Singular Buildings, Environmental Protection. Geocisa has a contract with ADIF for the development of systematic load tests on a series of bridges of the branch Plasencia-Badajoz depicted in previous sections. These routine tests follow standard procedures and the documentation provided by Geocisa to ADIF after testing is a technical report (pdf document) with the measurements performed during testing.

3.1.4 Plan for IoT measurement and sensing devices

Table 12 List of measurements for demonstration site #1.

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[5]	Storing of data
Deflection at midspan and displacement of supports	During the load test	LVDT +- 5 mm	100-to-200 samples per second	2-3 Hours of continuous measurement	Txt	Data from sensors is sent using a HBM MGCPlus data logger owned by Geocisa. Data is stored locally and subsequently prepared for proper insertion in Mainflux	Locally and then sent to the Mainflux platform.
Inclination	During the load test	WitMotion WT901B TTL	100-to-200 samples per second	2-3 Hours of continuous measurement	JSON	Data is directly sent to Mainflux using a MQQT	Directly to Mainflux Format

[5] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA…). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

Acceleration	During the load test	BeanAir (MQQT Protocol) ADX345 + ESP32 Netplus	100-to-200 samples per second	2-3 Hours of continuous measurement	.txt	Data is directly sent to Mainflux using a MQQT	Directly to Mainflux Format
Environmental conditions (Temperature and Humidity)	During the load test	DHT22	1 samples per minute	2-3 Days of continuous measurement	JSON	Data is directly sent to Mainflux using a MQQT	Directly to Mainflux Format
Deflections (remote sensing)	During the load test	Interferometer	200 samples per second	Episodic	Point Cloud	A radar interferometer is owned by the company GEOZONE which collaborates with Geocisa. Data is collected and stored locally. Treated data is given to Geocisa and subsequently, to Ashvin for further adaptation to Mainflux and subsequent twinning.	Locally, treated and subsequently sent to Mainflux

3.1.5 Plan for implementation of ASHVIN tools and methods

Table 13 Plan for application of ASHVIN tools on demonstration site #1

ASHVIN tool/method	Name	How the tools will be used on the project
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	In particular, numerical models for these assets will be programmed in the form of MatchFEM tool. Nonlinear realistic beam models will be based on longitudinal discretization with finite elements and cross-sectional discretization using fibres. These models will be directly plugged to sensors for adequate representation of the digital twins. The models will be capable of reproducing the behaviour of the assets throughout long term operation since they will include rheology of the materials. In real time, these models will feed ASHVIN with sensor-infused data. On the other hand, advanced solid models will be included using other existing platforms such as PICD. This connection will establish the requirements that are necessary to enable the use of other existing Multi-Physics platforms already available in the market.
RISA	Risk-based status assessment tool with KPI dashboard	Selected performance indicators will be displayed. In particular, Valdelinares, de la Plata and 3 + 93 PK will be established as “initial conditions” of the KPI dashboard. During operation, sensors can be installed feeding the IoT platform identically to the load test.
GISI	GIS integrator for digital twin-based asset management	All assets are spatially located and embedded within Ashvin as part of the highspeed railway network
3DRI (method)	3D reconstruction from Images	3DRI will be used for estimating 3D structures from 2D drones’ imagery in real or near real time according to the user requirements. The development of the tool will base on two complementary axes: the method part and the means of execution. Drone footage of the assets, including telemetry. All footage must include .srt files with flight coordinates.

3.2 #2 Building renovation in Poland

3.2.1 Introduction

This demonstration building is a typical example of the residential building that needs intermediate renovation activities. This two-storey building was constructed in 1921, it has 7 flats and 16 building occupants, it is located in Gdynia in Poland (). It is a public building that has a function of social housing.

Figure 12: Pictures of the demonstration case.

The building is owned by the City of Gdynia, the unit that is responsible for the building management is the **Municipal Buildings and Housing Administration of Gdynia.** The build up area is 260m2 and the heat is generated by the tiled stoves (for coal and wood). The building envelope is not insulated. The building has very low energy performance estimated as 689 kWh/m^2 year, see Figure 12.

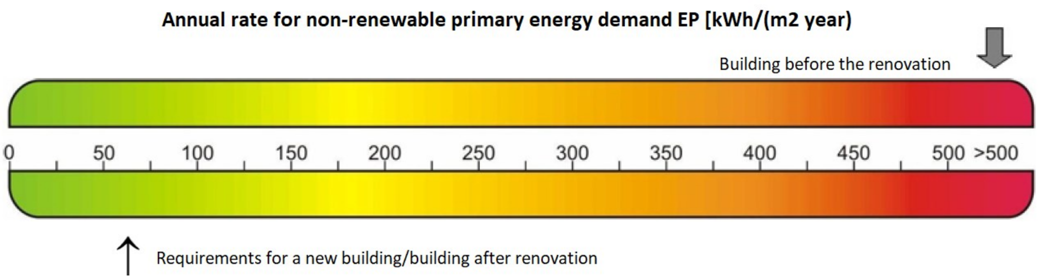


Figure 13: Energy Performance certificate for demonstration building.

3.2.2 Challenges and needs

Building refurbishment aims to protect the building from heat loss and to drastically reduce the energy consumption needed to heat the building and to heat the water. In the vast majority of cases, excessive heat loss is one of the reasons for the high operating costs of buildings. These are the result of poor insulation of external walls, leaky windows and insufficiently efficient heating systems. That is why many buildings need to be renovated (in some cases need to undergo the deep renovation). Renovation activities contribute to reduction of the energy demand of a building. Building refurbishment concerns already existing buildings, which due to their age and technical condition do not meet modern requirements. This is caused by the fact that before, the regulations were not as strict as they are now, and the construction process was focused on savings rather than heat loss aspects.

Municipal Buildings and Housing Administration of Gdynia has only old paper documentation and this slow down the decision about the renovation. There is no information about the existing building technical and energetic condition. In addition, the housing administration has neither a license for commercial computer-aided design (CAD) nor building information modelling software.

ASHVIN should provide accurate digital twin information of existing building as a baseline for better planning of the renovation process. The goal is to support the building owner and develop a digital twin that accurately describe the energetic behavior of the building. This allows the Investor to select the most suitable and adjusted to the building condition renovation scenario**.**

3.2.3 Main stakeholders

Main stakeholders participating involved in the #2 Building renovation in Poland are:

- **Municipal Buildings and Housing Administration of Gdynia** (ZBLIK) – It is a public body established in 2017 in the City of Gdynia, and owner of the demonstration building. The main task of the unit is to manage communal housing stock, communal utility and administrative buildings that are owned by the City of Gdynia. In 2018, the stock comprises 6,281 units. The largest part of these are residential units, of which there are 5,280. Housing administration is responsible for planning, commissioning, and financing activities the renovation activities. Also, for the buildings that they own they are responsible for the maintenance activities.
- **Occupants** – People living in the social flats
- **Designer** – Person or the company hired by the Housing Administration to perform the design.
- **FASADA** – partner of the ASHVIN consortium, responsible for contacts with the Housing administration

3.2.4 Plan for IoT measurement and sensing devices

Table 14 List of measurements for demonstration site #2.

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is/will be gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[6]	Storing of data
Temperature, humidity, CO2, CO, VOC, PM 2.5 and PM 10, pressure	From autumn/winter 2021	Nanoenvi IAQ device	10 min measurement	0.05GBper year	json	MQTT	Mainflux platform
Wall Temperature	From autumn/winter 2021	Thermocouples.	1 measurement / hour	10 Mb /year	JSON	MQTT	Mainflux platform

[6] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA…). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

3.2.5 Plan for implementation of ASHVIN tools and methods

Table 15 Plan for application of ASHVIN tools on demonstration site #2

ASHVIN tool Acronim	Name	How the tools will be used on the project
4DV-D	Construction site simulator for early design phases with 4D visualizer	This tool can help to plan the construction phase, the renovation design will be verified with 4DV-D to prepare for the renovation activities.
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	Information for the building owner and designers about indoor air quality inside the building and development of the thermal model of the existing external wall. The Tool will support the development of an accurate digital twin of the existing building.

3.3 #3 Airport runway in Croatia

3.3.1 Introduction

Zadar airport is one of nine airports in Republic Croatia situated in the middle of the Adriatic coast, 7 km east of the City of Zadar and is. Zadar Airport was opened in 1969 as an addition to the existing military runway, and with the construction of a civilian runway, it became the only airport in Croatia with two runways. The airport had a steady growth of traffic during the 1970s and 1980s, when tourism in Croatia, and especially in Dalmatia, reached its peak at the time. However, this was abruptly interrupted by the war in Croatia in the first half of the 1990s, when the Zadar airport was occupied and destroyed, with severely damaged terms. After the war the airport was repaired and it is since then 55 percent owned by the Republic of Croatia, Zadar County with 20 percent, the city of Zadar also with 20 percent, and the municipality of Zemunik Donji with five percent.

After the post-war renovation traffic grew steadily from 1996 to 2006, from 20.000 to 65.000 passengers. Zadar Airport experienced its new rise in 2007 after which it has not only reached pre-war numbers but has increased traffic tenfold since its renovation reaching more than 800.000 passengers. In 2019, just prior to the COVID-19 decline of airline traffic worldwide Zadar airport was among the top 5 in terms of traffic growth (+37,6% increase in passenger traffic, ACI EUROPE Airport Traffic Report, www.aci-europe.org). The Zadar Airport is responsible for transport operating services and maintenance and developments regarding airport infrastructure.

Traffic infrastructure, which includes all operational areas for receiving and dispatching passengers and aircraft, was built, as already stated above, almost 50 years ago. In that period there were several partial renovations of asphalt surfaces, but no major reconstructions. This means that the essential infrastructure of the airport including runways is not in a very good condition degrading further rapidly, starting to influence the safety of traffic. In addition to its existing runway 04-22 (length 2000m), the airport is also using all operational areas in the military part of the airport (runway 13-31 (length 2500m, width 45m) , tracks A, H, F, G and K) Zemunik Air Base (which is an air center for the Croatian Air Force).

Physical characteristics of operational surfaces:

Runways

- 13 – 31 - CONC, ASPH PCN 44 F/R/A/X/U RWY 2500 m x 45 m, SWY no, CWY no, strip 2620 m x 300 m
- 04 – 22 - ASPH PCN 33 F/A/X/U RWY 2000 m x 45 m, SWY nema, CWY nema, strip 2120 m x 125 m

Taxiways:

- A - width 22 m, CONC, PCN 42/R/B/W/T
- B - width 18 m, CONC, PCN 44/R/B/W/T
- C - width 10 m, ASPH, PCN 22/F/B/Y/T
- D - width 10 m, ASPH, PCN 22/F/B/Y/T
- E - width 18 m, CONC, PCN 20/R/B/W/T
- F - width 45 m, CONC, PCN 36/R/B/W/T

- G - width 27 m, CONC+ASPH, CONC PCN 31/R/B/W/T ASPH PCN 39/F/B/X/T
- H - width 15 m, CONC, PCN 26/R/B/W/T
- K - width 18 m, ASPH, PCN 36/F/B/W/T
- L – width 10.5 m, ASPH, PCN 15/F/B/Y/T

Aprons:

- Main apron – ASPH, PCN 40/F/B/X/T
- Apron for general aviation – ASPH, PCN 15/F/B/Y/T

Figure 14: Zadar airport terminal building (left), connection of Zadar with European airports (right) from croatiotravel.com

The Zadar airport is planned to be extended and reconstructed. The project is to be executed in several phases. The original plans before the COVID crisis included the extension of the runway, and expansion of the terminal building and apron in the first phase and construction of the new passenger terminal in the second phase. Due to 2020 steep decrease in airline traffic the plans are currently postponed, therefore the focus of the demo project has been changed and agreed with the owner to the existing management decision making and maintenance of the operational areas.

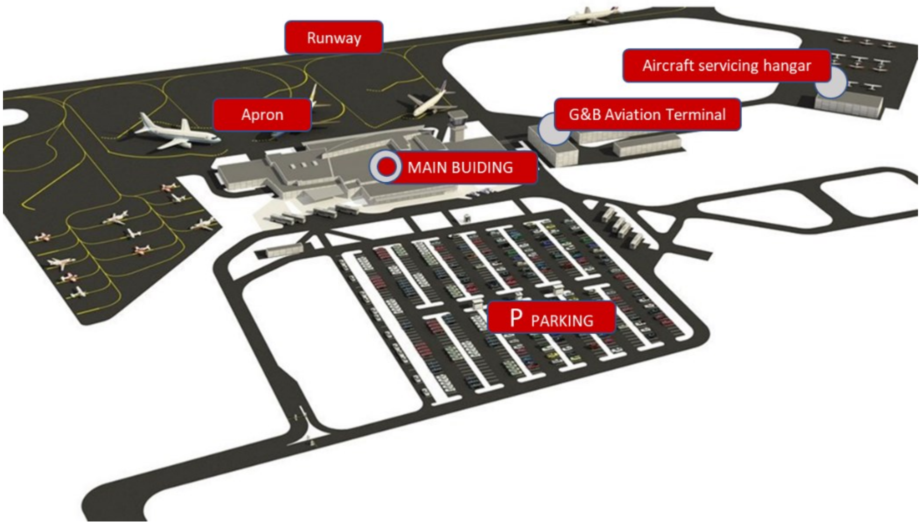


Figure 15: Zadar airport map from https://www.zadar-airport.hr/

3.3.2 Challenges and needs

Digitalization of airport infrastructure is developed with the purpose to optimize maintenance and operational planning. Within ASHVIN the implementation of a digital twin on Zadar airport demo site focuses on the maintenance and condition monitoring of the existing runway. Runways are exposed to considerable loading and because of high safety standards require daily inspections and monitoring. All processes related to inspection and consequently maintenance, are currently performed by non-digital methods. One of many important daily tasks at the airport is the inspection of Runways, Taxiways, Aprons, Security Fences, Obstacle limitation surfaces, and all other infrastructure, which are monitored manually by teams going physically to the spot in a vehicle, inspecting and taking photographs. Frequency of these inspections depend on the purpose and the activity and can vary from several times a day to once a year.

Table 16 Estimation of daily distances driven by diesel vehicles in order to perform regular inspection activities

Topic	Period	Tool	Km per day
Inspection of the pavement structure and condition	Daily – Min. 2 times a day	Diesel Vehicles	30 km
Inspections of the runway horizontal signage	Daily - Min. 2 times per day	Diesel Vehicles	30 km
Inspection of markings on taxiways	Daily - Min. 2 times per day	Diesel Vehicles	30 km
Inspection of markings on aprons	Daily - Min. 2 times per day	Diesel Vehicles	30 km
Inspection of signage	Daily - Min. 2 times per day	Diesel Vehicles	30 km
Inspection of the lighting system of the operating area	Daily - Min. 2 times per day - periodically	Diesel Vehicles	30 km
Inspection of obstacles limitation surfaces	Daily - Min. 4 times per day	Diesel Vehicles	60 km

In Figure 16 the main steps within the process for integration of new solutions into the current practice of airport operators are shown.

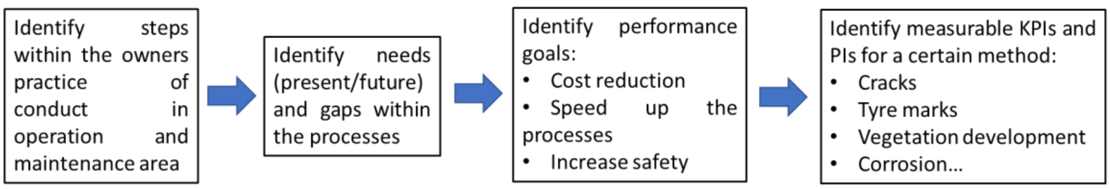


Figure 16: Integration of owners current practice into proposed new monitoring solution

3.3.3 Main stakeholders

- **Owner - Zadar airport** is publicly owned with different percentages between the state, city and municipality and is used for military purposes as well as civil. Goal: developed air traffic especially regarding tourism, provide area for military operations and training.
- **Zadar airport Ltd**. – managing daily operations and maintenance of all airport areas: fast and reliable inspection of the runway and green areas. Goal: Quality of services for receiving and dispatching aircraft and passengers, good scheduling, safety of traffic.
- **Personnel performing the inspection and maintenance** – the ones hand on performing visual inspection, damage detection, storing data about inspection, making decisions about maintenance. Goal: fast and reliable inspections, efficient and usable data storage, data processing that leads to maintenance decisions.
- **Maintenance contractor** – the one performing actual repair and maintenance works. Goal: reliable information about damage, location and extent, efficient use of all resources

3.3.4 Plan for IoT measurement and sensing devices

An unmanned aerial vehicles (UAVs) can significantly improve and automate those processes, enabling detection of any foreign objects or defects at the very early stage (which often can be missed by a human eye), and continuous monitoring of any on-going deterioration process or damages. The time needed for an inspection is going to be decreased while increasing the inspections' quality. The collected data will be used for a development of BIM or digital twin models, which will enable continuous and accurate monitoring of the whole infrastructure, finally being used for the GIS-based asset management models and optimization of maintenance planning.

Table 17 List of measurements for demonstration site #3.

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[7]	Storing of data
Images	ongoing periodically	Camera and drone	every 3 months	~100 GB per year	e.g. jpg, point cloud, etc.	Not defined yet	not defined yet
Environmental data (temperature, humidity, wind	Continuous, hourly data	Weather station	Every hour		open source link to xml file[8]	Open source data	Meteo.hr

[7] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

[8] https://meteo.hr/proizvodi.php?section=podaci&param=xml_korisnici

3.3.5 Plan for implementation of ASHVIN tools and methods

Table 18 Plan for application of ASHVIN tools on demonstration site #3

ASHVIN tool/method	Name	How the tools will be used on the project
	Risk-based status assessment tool with KPI dashboard	Various life cycle scenarios will be developed, by estimating the consequences and risks of determined condition of airport operational areas, using inspection and monitoring data. 3DRI and DDCV methods will be integrated into RISA tool with the aim to digitalize and automatize the condition assessment and development of maintenance planning.
	GIS integrator for digital twin-based asset management	Integration of all data related to monitoring and maintenance of airport operational areas into GIS based asset management tool on all levels, from short to long term decision making.
3DRI (method)	3D reconstruction from Images	Estimation of 3D structures from 2D imagery coming from drones, hand-held cameras or smartphones to detect potential defects (crack detection) on the runway surface and green areas around the runway.
DDCV (method)	Defect Detection using Computer Vision	The AI-powered solution is used to detect damages, anomalies and objects on the runway surface and green areas around the runway. The aim is to integrate the automated damage detection into inspection and maintenance planning process, as part of RISA tool.

3.4 #4 Logistics hall construction in Germany

3.4.1 Introduction

The demo site is an industrial building located in Rinteln, Germany. The building is currently under construction. The building shall host state-of-the-art production facilities to ensure a Smart Factory. It consists of four different halls with a height of 12 meters. Hall 1 and hall 2 forming one building part, which will be used for production of food packaging. Hall 3 and hall 4 forming the other part for storage and logistics. Overall, the building has a size of nearly 30.000 m², while halls 1 and 2 take one third of it. The structure of the building consists mainly of prefabricated components such as precast concrete pillars, steel walls, and steel roof panels.

3.4.2 Challenges and needs

ASHVIN should support planning and control of construction processes. As the building consists of prefabricated components, the whole construction process has a high degree of automation. A more automated construction process can increase productivity on construction site. However, this requires detailed information about the sequence of the construction process.

Currently, planning is performed by conventional critical path method, which entails several shortcomings such as neglect of risks or uncertainties. Sensors will be installed on construction site on equipment to record construction progress data, which can be used to build a digital twin. The collected data can be used for enhanced predictions of activity durations by probability distributions and risk factors. Thus, by applying discrete event simulation it is aimed to achieve more reliable planning of the whole construction process. Additionally, this information can be used to enable a more productive construction process by allocation of resources and material deliveries. Furthermore, as there are movements of heavy equipment and different trades working simultaneously on construction site, it is aimed to avoid hazardous situations for workers by analysing movement data.

Due to the digital twin, progress on construction site can be controlled continuously and it can be reacted near real-time, if deviations of planned schedule occur, such as stop of work due to weather conditions or breakdown of equipment. Thus, the data from construction site about equipment operations can be used to support planning and control in this and future construction projects for improved resource allocation, material flow, safer working conditions, lower costs, and overall a higher degree of productivity.

3.4.3 Main stakeholders

- **GPD Packaging** (owner & users of the final product): GPD Packaging is a manufacturing company. It is aimed to manufacture packaging, especially for frozen food, automatically on a large scale. *Goals: delivery of the product in time and within the budget.*
- **Goldbeck** – main contractor – managing the construction – the ones benefiting from the demonstration of Ashvin tools during the construction

phase. *Goals: delivery in time, within the agreed budget, and without any safety incidents. Ensure the continuity of the supply chain.*

- **Construction workers** – the ones hand on the construction - improved safety and wellbeing. *Goals: working in a safe environment.*
- **Subcontractors** – Main contractor (Goldbeck) will subcontract the construction work to several subcontractors. *Goals: deliver the agreed sub-parts in time, without additional delays and costs.*

3.4.4 Plan for IoT measurement and sensing devices

Table 19 List of measurements for demonstration site #4

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[9]	Storing of data
Equipment (such as cranes, cherry pickers, …) movement		WinMotion: WT901WIFI, WTGAHRS2 (3-axis accelerometer, GPS,,…)	-	-	CSV	Sensor data are saved on laptop on construction site as CSV files and can be used	-
Time lapse photos	Whole construction process	Camera	-	-	images	-	-
Environmental data (temperature, humidity, CO2)	During the time the data is collected for the equipment operation	Sensors (TBD)	-	-	CSV	-	-

[9] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

3.4.5 Plan for implementation of ASHVIN tools and methods

Table 20 Plan for application of ASHVIN tools on demonstration site #4

ASHVIN tool Acronim	Name	How the tools will be used on the project
GEN	Generative design modeller to support designing for productivity, resource efficiency and safety	The tool will allow the generation of various alternatives with a focus on improving productivity, resources efficiency, and safety during the construction.
4DV-D	Construction site simulator for early design phases with 4D visualizer	Visualize the alternatives generated by the tool GEN to support informed decision making and highlight the advantages and the pitfalls of various alternatives
DES	Simulation-based real-time construction site and logistics planning tool	Sensor data and /or pictures videos can be used to calculate productivity rates of construction activities. These data can be used for improved planning and the continuous data collection helps to create a digital twin for control of the construction process. Hence, safe, resource efficient, and productive conditions can be enabled. Planning of material flow and allocation of resources (Equipment and worker) can be improved.
4DV-C	Construction monitoring tool with productivity and safety KPI decision making dashboard	A 4D tool visualizing past construction activities based on activities tracked by the digital twin platform. The tool allows to plan future construction sequences and site layout options based on accurately mapped past activities.

CMT	A configuration management tool to track as-designed and as-built, as well as, to allow for seamless commissioning	Software that will allow for establishing and maintaining consistency among requirements, design, configured items, and associated construction, operations and maintenance data, equipment, and other enablers throughout the project lifecycle based on digital twin data.
SMT	Privacy ensuring safety management, simulation, and training tool	An application that will allow safety managers to understand possible safety hazards on site and to analyse past construction activities without being able to target specific workers personally.
LPP (method)	Lean project planning methodology	Application of pull process for just in time delivery and allocation of resources (Equipment and worker)

3.5 #5 Kineum office building in Sweden

3.5.1 Introduction

The Kineum case is a high-rise building located in the city of Gothenburg, Sweden, Figure 17. The project started in 2019 and ends in summer of 2022. It consists of 30 000 m2, 960-1400 m2/floor and has 27 floors. Once completed it will have a height of 110 meters.

Figure 17: Kineum building demonstration project.

The main idea of the project is to establish a 4D model that allows for planning and monitoring of resource use, productivity and safety. The 4D model will be analysed in conjunction with data from the site collected by cameras and sensors. One of the data collection methods is based on the application of the Spot robot collecting video spatial data, temperature etc. In addition, Kineum has prior to the Ashvin project several sensors installed on site that can be utilised to produce performance indicators. Existing sensors measure dust, noise and moisture in construction components and indoor spaces on site and the data they collect can be used to calculate the performance the project has in these areas.

To scan some parts of the demonstration building and to capture images and video streams for later image recognition analysis (by other ASHVIN partners), NCC is using their SPOT robot (purchase not funded by the EC), Figure 18. SPOT is a quadruped robot that can climb stairs and traverse rough terrain, making it suitable for construction sites. How data can be collected autonomously, the quality of the data, and the volume will be further examined within the Ashvin project. We will also study how this type of data can contribute to the development of a dynamic digital twin of the Kineum demonstrator. Finally, it will be examined if the captured data can be used to effectively track the progress of the project and the quality of the work.

Figure 18: Mobile robot bought by NCC

3.5.2 Challenges and needs

- NCC wants to further expand our use of VDC (virtual design and construction) in the production (construction) phase to add value (from the design phase) and increase Health and Safety on site.
- The construction site is limited in size which puts logistic constraints.
- We want to explore new ways of collecting data and translating this data into information and knowledge. A lot of data is currently collected manually and stored on paper or in pdf-format. There is a huge productivity potential if the data could be collected automatically. Furthermore, continuous (or at least frequent) collection of data can make the identification of possible errors sooner which will decrease cost of re-work.
- A digital twin will connect our physical asset to our digital one with real-time data as the interlinks.

3.5.3 Main stakeholders

– **Platzer:** Co-owner of the building. Local commercial property investor, developer and owner, that currently holds about 70 premises in the area with a total area of 800 000 m2. Goal: investing in a property that will support the tenants' operations with a small carbon footprint
– **NCC:** Property developer and main contractor. NCC is also planned to occupy two floors in the completed office part as their new Göteborg office
– Goals: delivery in time, within the agreed budget, and provide a safe and healthy work site. Ensure the continuity of the supply chain.
– **Construction workers** – improved safety and wellbeing. Goals: working in a safe environment.
– **Subcontractors (several)** – Main contractor will subcontract the construction work to several subcontractors. Goals: deliver the agreed sub-parts in time, without additional delays and costs.

3.5.4 Plan for IoT measurement and sensing devices

Table 21 List of measurements for demonstration site #5.

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[10]	Storing of data
Scanning by robot and human	Autumn 2021	LEICA 360	Periodically	-	.lgs .pts .e57	The results of the scanning is currently manually uploaded	NextCloud
Monitoring data such as temperature, RH, noise, dust	Autumn 2021 until hand-over mid 2022	BRINJA	Regularly	-	.xls	Data is collected and connected through an app.	Locally
Use of machines	In discussions, envisioned 1-2 weeks but COVID-19 situation does not allow visitors at the moment	WT901WIFI WTGAHRS2	-	-		Sensors will be mounted on machines and then connected through Mainflux	Mainflux

[10] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

3.5.5 Plan for implementation of ASHVIN tools and methods

Table 22 Plan for application of ASHVIN tools on demonstration site #5

ASHVIN tool Acronim	Name	How the tools will be used on the project
4DV-D	Construction site simulator for early design phases with 4D visualizer	Visualize the alternatives generated by the tool GEN to support informed decision making and highlight the advantages and the pitfalls of various alternatives
DES	Simulation-based real-time construction site and logistics planning tool	Sensor data and /or pictures videos can be used to calculate productivity rates of construction activities. These data can be used for improved planning and the continuous data collection helps to create a digital twin for control of the construction process. Hence, safe, resource efficient, and productive conditions can be enabled. Planning of material flow and allocation of resources (Equipment and worker) can be improved.
4DV-C	Construction monitoring tool with productivity and safety KPI decision making dashboard	A 4D tool visualizing past construction activities based on activities tracked by the digital twin platform. The tool allows to plan future construction sequences and site layout options based on accurately mapped past activities.
CMT	A configuration management tool to track as-designed and as-built, as well as, to allow for seamless commissioning	Software that will allow for establishing and maintaining consistency among requirements, design, configured items, and associated construction, operations and maintenance data, equipment, and other enablers throughout the project lifecycle based on digital twin data.
	Privacy ensuring safety management, simulation, and training tool	An application that will allow safety managers to understand possible safety hazards on site and to analyse past construction activities without being able to target specific workers personally.

LPP (method)	Lean project planning methodology	Application of pull process for just in time delivery and allocation of resources (Equipment and worker)
DDCV (method)	Defect Detection using Computer Vision	The AI-powered solution is used to detect deviations from BIM model, safety issues and progress

3.6 #6 Office buildings in Spain

3.6.1 Introduction

Demonstration buildings #6 are located in Barcelona (Spain) and they are part of project 22@, also known as 22@Barcelona and “Innovation district” (“Districte de la innovació”), Figure 19. The 22@Barcelona project changes the urban, social and functional structure of the central areas as well as contributes to the transformation of Barcelona from the City of Industrial Civilization into the City of Knowledge Civilization. Its aim is to convert the industrial area of Poblenou into the city's technological and innovation district, as well as to increase leisure and residential spaces. Centered on Plaça de les Glòries Catalanes (Figure 20), it is part of one of Europe's biggest urban regeneration schemes, begun during the 2000s and still ongoing, spanning 115 blocks or 198,26 ha. The plan was approved in 2000 by the city council when the new 22@ land designation was introduced, replacing the 22a designation, used in industrial soil contexts.

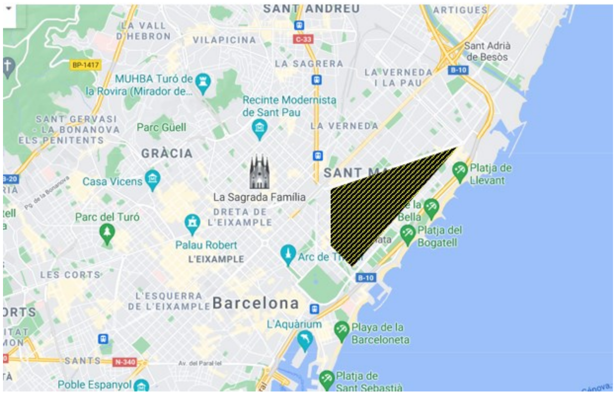


Figure 19: 22@district within the city of Barcelona

Figure 20: The Glòries square, milestone of the urban design.

Several of the construction sites that are presently under development at 22@ are under the management of BIS, a Barcelona-based structural engineering office. BIS designs and supervises the construction of highly technical structures in the building sector in the Spain and other countries. The company agreed upon collaborating with ASHVIN by providing access to construction projects and sites for demonstration of procedures.

3.6.2 Challenges and needs

Among these buildings, “Mile” is an office building located at 22@, Figure 21. It is a reinforced concrete building with long-spanned slabs. The construction of this building is heavily controlled and dependent of the slab deformation and serviceability limit states. This demonstrator may provide an ideal testbed at several levels:

- The construction site is within an urban area in which stringent conditions related to time and space apply. Space is limited and traffic cuts are strictly limited. The concrete casting is continuous, and it represents a critical aspect on the use of space around the site. Concrete trucks, pumps,
- Site analysis of machinery and space allocation during sequential construction can a be studied using a digital twin approach. Sensors installed within

Figure 21: On the left: MILE. Construction site in February 2021 - Excavation levels; on the right construction site in May 2021

The project aims at demonstrating how digital twin implementations through the life cycle can increase the productivity, resource efficiency, and safety on real projects in the buildings, bridges, and industrial market segments. The goal is to pull the digital threads and methodologies from other work packages and knit them into coherent solutions to be implemented on this demonstration project.

3.6.3 Main stakeholders

- **Bellersil Property** and **Fustor** are the owners of the office building under construction “MILE”.
- **Dragados** is the construction company in charge. DRAGADOS is one construction brand of the ACS Group. ACS Group is an international construction and engineering group, according to the list compiled by specialist journal "Engineering News-Record" (ENR); it operates in 68 countries and has been classified by the Public Works Financing (PWF) as the world-leading infrastructure concession group. DRAGADOS has international experience in infrastructure projects, bridges, highways, tunnels, dams and marine works, and is a leader in the execution of concession projects. Dragados has built more than 7,000 km of highways, 3,500 kilometres of roads, 1,500 bridges, 1,380 kilometres of tunnels, 545 maritime works, 250 dams and hydroelectric power plants, 1,700 kilometres of railroads, rail transportation and numerous railway facilities and 70 million square metres of different types of buildings such as airports, hospitals, museums, high-rise buildings, and residential building constructions.

- **BIS Structures** is a structural engineering consultancy company. BIS structures works with architects, promoters and construction companies to get technical solutions for projects of any nature, size and complexity. In MILE, BIS is monitoring the corresponding coherence between the conceptual development of the project and its implementation by the constructor. a structural engineering consultancy company. BIS structures works with architects, promoters and construction companies to get technical solutions for projects of different nature, size and complexity.

3.6.4 Plan for IoT measurement and sensing devices

Table 23 List of measurements for demonstration site #6

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[11]	Storing of data
Monitoring of the fleet	As soon as possible. Access already granted	Tower Cranes: WitMotion WTGAHRS2 10 Axis. Phone Cameras. Concrete trucks: Arrival time, cubic meters, type of elements to pour, productivity rate. Steel and formwork delivery manoeuvres.	-	-	JSON, Imagery and video	-	-
Inertial measurements + GPS	As soon as possible. Access already granted	WitMotion WTGAHRS2 10 Axis + ESP32	10-200 Hz	-	Json	Continuous measurements at specific time intervals. Remote activation via AIP.	Data stored in AIP.

[11] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

						Sensor-Network interface using ESP32. ESP32 supports Wi-Fi and Bluetooth. MQTT CoAP and HTTP protocols can be used	
Images and Video + metadata	As soon as possible. Access already granted	Personal mobile phones.	-	-	.mp4	Short videos of specific activities in the construction site. Metadata is added manually using .csv or .xlsx files.	nextCloud
Monitoring of the construction process	As soon as possible. Access already granted	Cameras. Storage sites, crane lifting operations, formwork, concrete and reinforcement productivity, numbers of workers.	-	-	Imagery and video	-	-
Measurement of deflections of the slabs	Episodic, September 2021 onwards	Terrestrial Laser Scanner	-	-	Point Cloud	-	Data stored in AIP.

Monitoring of the sequential concrete casting	-	-	-	-	-	-	nextCloud

3.6.5 Plan for implementation of ASHVIN tools and methods

Table 23 Plan for application of ASHVIN tools on demonstration site #6

ASHVIN tool/method	Name	How the tools will be used on the project
DES	Simulation-based real-time construction site and logistics planning tool	Sensor data and /or pictures videos can be used to calculate productivity rates of construction activities. These data can be used for improved planning and the continuous data collection helps to create a digital twin for control of the construction process. Hence, safe, resource efficient, and productive conditions can be enabled. Planning of material flow and allocation of resources (Equipment and worker) can be improved.
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	A beam-based FEM model is under development at UPC. It is able to track the sequential construction of RC structures. A more realistic picture of the structural behaviour of the asset during construction can be matched to the measurements twinned.
3DRI (method)	3D reconstruction from Images	The central element for creating 3D digital models of the physical world is the 3D point cloud reconstruction. Conventionally, the techniques used to reconstruct point clouds of complex scenes are based on multi-view computer vision methods or special hardware such as depth or LIDAR sensors. This tool will introduce a pipeline for estimating 3D structures from 2D imagery. The depth information is calculated from 2D data using common information that is present in overlapping parts between different images or videos
DF (method)	Data Fusion	Data coming from different sensors during monitoring of the fleet needs fusion. Data coming from imagery together with data coming from sensors needs also fusion.

3.7 #7 Bridges in highway network in Spain

3.7.1 Introduction

This demonstration site is the PR-04-B015 bridge, that is located within the Metropolitan Area of Barcelona (Spain). Its main objective is to connect two main road axes: the AP-7 Highway (heading North) and the A-2 Road (Heading West),Figure 22. This connection belongs to a strategic link for users of those axes whose aim is to avoid urban areas while crossing the Metropolitan Area of Barcelona. The link helps reducing approximately in 12 Kilometres the distance with the present connection between roads. It is a strategic asset for transporting goods from Barcelona port to northern Europe.

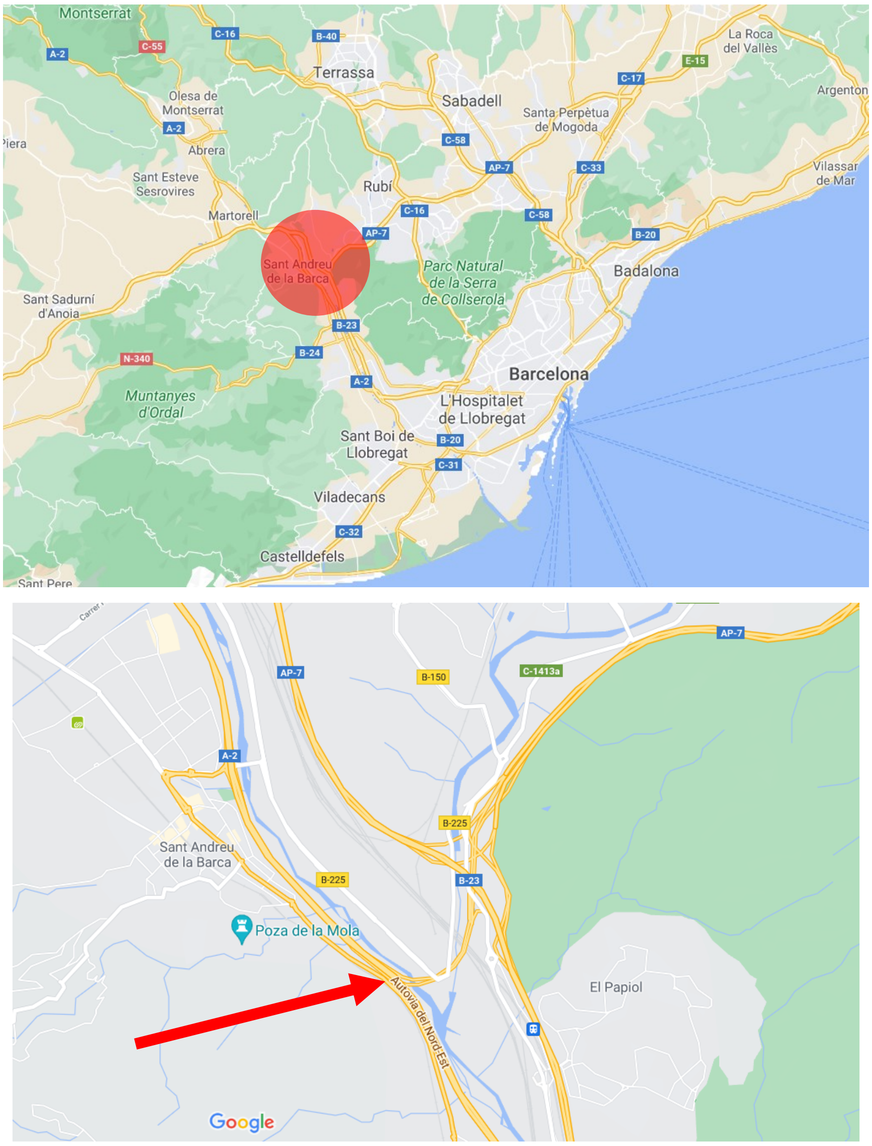


Figure 22: Location of the demonstration site #7.

The PR-04-B015 bridge is a continuous beam drawn on a horizontally curved alignment, Figure 23. Two separated viaducts are defined by the driving direction (heading North or West). The structures allow bridging a river (Llobregat), a creek (Rubi), several roads and a line of railways.

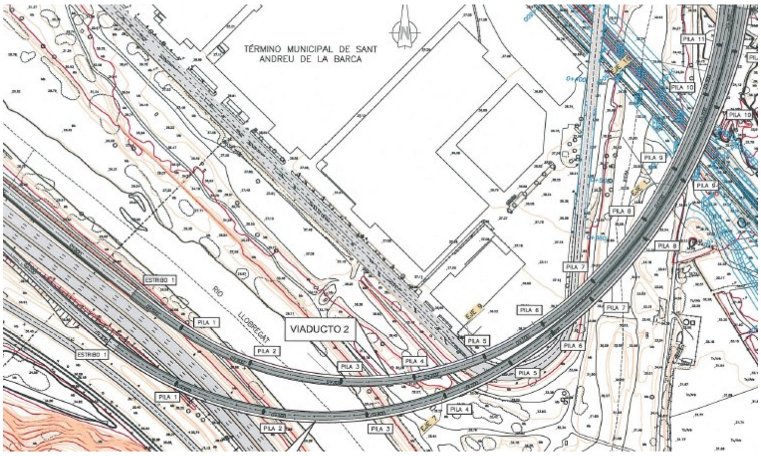


Figure 23: Demonstration site #7: PR-04-B015 bridge.

Both viaducts are supported by 12 piers with varying span. The cross-section is a composite bridge (Figure 24). Box section with variable web height (3,5 m-5,0 m) and a concrete slab with varying width (11,50 m-17,00 m). Longitudinally, the cross-section is provided with stiffeners and transversally, with stiffeners and diaphragms. The total length of the structure is approximately 840 meters.

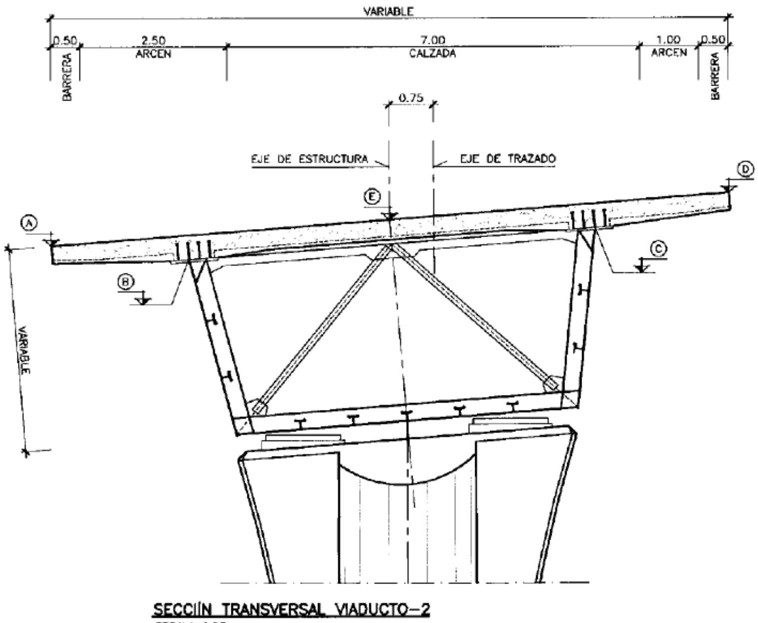


Figure 24: Cross-section of the bridge.

The bridge has been recently finished and it is about to be open to circulation, Figure 25.

Figure 25: Bridge after construction.

3.7.2 Challenges and needs

The PR-04-B015 bridge represents a strategic asset for the Spanish road administration. The main challenge is to generate a Digital Twin whose main aim is to provide meaningful information to road managers for the deployment of efficient and productive maintenance plans. This Digital Twin must be conceived for a cost-effective long-term monitoring that feeds several of the tools provided by Ashvin.

For the sake of developing this Digital Twin one should bear in mind the following needs:

- To characterize the traffic of both roads.
- To characterize the structural behavior of the asset.
- To characterize the present maintenance plans deployed by the administration.
- To deploy a set of sensors and cameras for digital twinning and short-term monitoring.
- To design a suitable efficient, cost-effective set of sensors and cameras for long-term monitoring.

For adequate installation of sensors in the asset, one of the key needs is to access its structure underneath. Auxiliary supports and platforms will be needed for this task.

3.7.3 Main stakeholders

- **The Ministry of Transport, Mobility and Urban Agenda** (Spanish: Ministerio de Transportes, Movilidad y Agenda Urbana): The department of the Government of Spain responsible for preparing and implementing the government policy on land, air and maritime transport infrastructure and the control, planning and regulation of the transport services on these areas. It is also responsible for guaranteeing access to housing; urban, soil and architecture policies; planning and controlling the postal and telegraph services, directing the services related to astronomy, geodesy, geophysics and mapping, and planning and programming the government investments on infrastructure and services related to this scope[12]. The branch of Roads and Public works manages the asset.

- **BAGH Técnica**: Private company specialized in diverse activities. Bagh has contract for maintenance of several bridges in Spain owned by the aforementioned Ministry

.

[12] "Royal Decree 953/2018, of July 27, which develops the basic organic structure of the Ministry of Development". *boe.es. Retrieved 15 December 2018*

3.7.4 Plan for IoT measurement and sensing devices

Table 24 List of measurements for demonstration site #7

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[13]	Storing of data
Inclination at key supports and/or bearings	3 to 6 months. Beginning by the 2022.	-	High rate (200Hz episodic) and Low rate (0,01 continuous)	-	JSON	-	Mainflux Platform
Acceleration along several spans of the bridge	3 to 6 months. Beginning by the end of 2021	-	High rate (200Hz)	-	.txt	Data will be transmitted via Microcontrollers using MQQT protocols	Mainflux Platform

[13] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

Environmental conditions (Temperature and Humidity)	3 to 6 months. Beginning by the end of 2021	-	Every hour.	-	JSON	Data will be transmitted via Microcontrollers using MQQT protocols	Mainflux Platform
Cameras for traffic measurement (anonymized)	Based on episodic gathering (hourly, daily)	DJI Mavic Air 2.	Continuous, Slow motion (180 FPS)	-	.JPG	-	Local drive. Post-processed and sent to Mainflux Platform
Cameras for telemetry	Based on episodic gathering (hourly, daily)	DJI Mavic Air 2.	Continuous, 4K (30 FPS)	-	.MP4	-	Local drive. Post-processed and sent to Mainflux Platform
Thermocouples	3 to 6 months. Beginning by the end of 2021		Low rate (0,01 continuous)	-	JSON	-	Mainflux Platform

3.7.5 Plan for implementation of ASHVIN tools and methods

Table 25 Plan for application of ASHVIN tools on demonstration site #7

ASHVIN tool/method	Name	How the tools will be used on the project
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	In particular, numerical models for these assets will be programmed. Advanced nonlinear beam models will be based on longitudinal discretization with finite elements and cross-sectional discretization using fibres. These models will be directly plugged to sensors for adequate representation of the digital twins. The models will be capable of reproducing the behaviour of the assets throughout long term operation since they will include rheology of the materials. In real time, these models will feed ASHVIN with sensor-infused data.
RISA	Risk-based status assessment tool with KPI dashboard	Selected PI's will be displayed. In particular, Valdelinares, de la Plata and 3 + 93 PK will be established as "initial conditions" of the KPI dashboard. During operation, sensors can be installed feeding the IoT platform identically to the load test. The activation of numerical analysis related to potential damage detection (image- or sensor-based) can enable optimal data-based decision-making processes related to maintenance plans.
GISI	GIS integrator for digital twin-based asset management	All assets are spatially located and embedded within Ashvin as part of the highway network

3.8 #8 Footbridge in Germany

3.8.1 Introduction

The City of Dortmund is planning to replace the existing Lindemannstrasse foot and cycle path bridge, which connects Max-Ophüls-Platz with the forecourt of the Dortmund Trade Fair Centre. The bridge crosses the Rheinlanddamm, a highly frequented inner-city main road with six lanes. In a central location in the Dortmund city area, it provides a pedestrian link from the city center to the most important event centers of the town, the Messe Dortmund area, the Westfalenhalle and the adjoining football stadium.

The existing structure from the 1950s has gradients of far more than over 6% and, according to the recognised rules of technology, is not barrier-free. Therefore, the city of Dortmund is planning a barrier-free replacement of the Lindemannstraße bridge over the Rheinlanddamm.

The new bridge (Figure 26) allows users to directly connect the two squares in the same way as the existing structure, replacing the previous steep ramps with stairs. The stairs are supplemented by wide cantilevered ramps ("loops") that overcome the height level, whereby the freely cantilevered loops create a new, widely exposed view, especially on the side of the trade fair forecourt.

The bridge design envisages the superstructure, the stairs and the supports as a monolithic, jointless steel construction. The continuous superstructure has a total length of approx. 210m and is regularly supported at intervals of approx. 50-60m by splayed V-shaped supports. The span of the superstructure is approx. 35-48m in free length and approx. 14-17m in the support area. The cantilever of the loops from the column axis to the abutment is approx. 17.5m from the support axis to the abutment (Figure 27, Figure 28 and Figure 26).

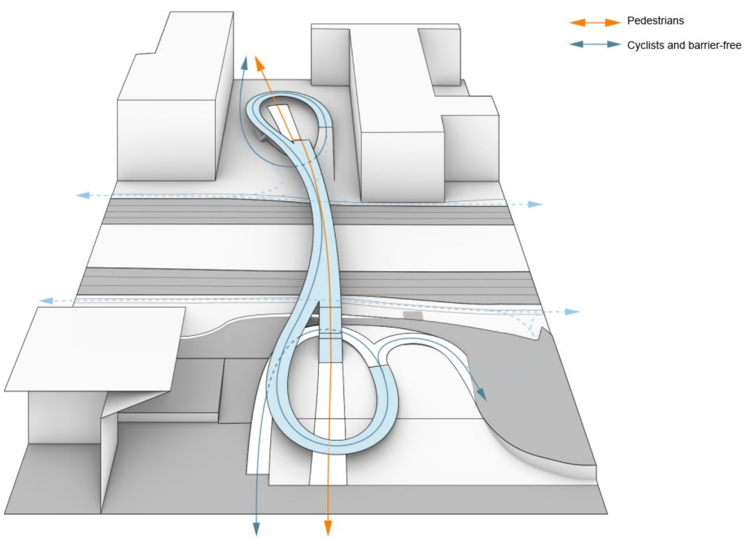


Figure 26: Footbridge over the Rheinlanddamm in Dortmund – demonstration site #8.

The timetable of the project is as follows:

- Start of planning (August 2020)
- Tendering and award of contract (October 2021)

- Deconstruction of the existing bridge (August 2022)
- Construction of the new bridge (June 2022)
- Completion (November 2023)

Figure 27: Plan view of demonstration site #7

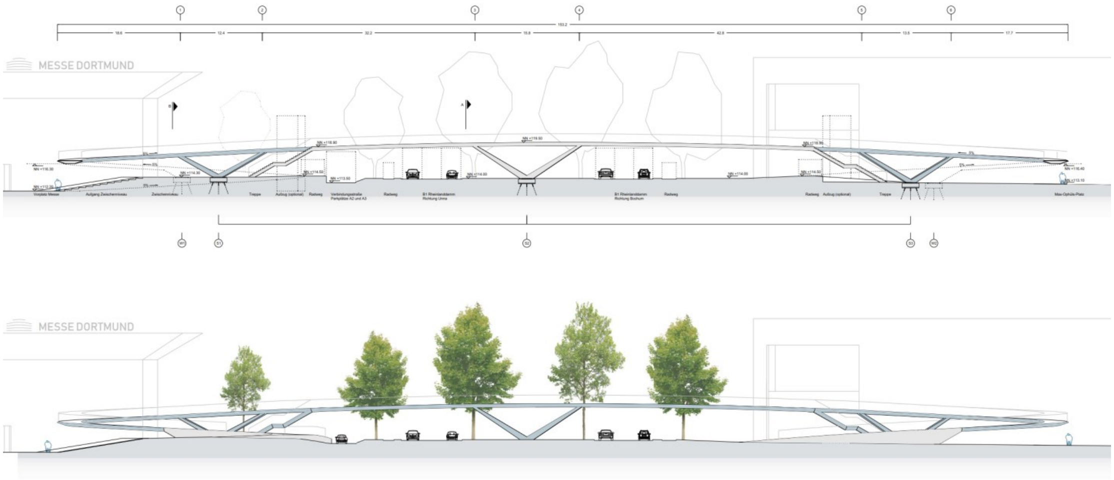


Figure 28: Side view of demonstration site #7

3.8.2 Challenges and needs

The main goals and challenges for the demonstration project are:

- The bridge is heavily frequented during trade fair events and especially on match days of Borussia Dortmund and is also popular with stadium visitors as a meeting point. This makes it necessary to transport large flows of people safely.

- The city of Dortmund has committed itself to barrier-free construction and underpinned this with a corresponding council resolution in 2006.
- The location of the bridge in a prominent position on an axis with the Dortmund Trade Fair Centre, the Westfalenhalle and the football stadium calls for a representative and aesthetically pleasing structure.
- Execution on schedule and within the estimated costs; Dortmund is one of the venues planned for the UEFA European Football Championship 2024. The completion of the construction project must therefore be completed before the start of the UEFA European Football Championship 2024.
- Low maintenance costs.
- Safe construction works (especially the heavy lifting operations).
- Project partner SBP has an additional planning focus on sustainability. In addition to engineering aspects, the bridge is also designed with special regard to social-cultural added value, aesthetically pleasing design, and environmentally changing influences (e.g. Carbon footprint).

Boundary conditions that need to be considered design and construction process:

- Avoidance or minimisation of possible closure times of the six-lane Rheinlanddamm road during construction of the bridge.
- In the area of the central strip of the Rheinlanddamm there is a protected avenue of trees, which should be preserved as far as possible both during the construction phase and in its final state.
- In the course of the basic evaluation and preliminary planning, it was already determined that there are existing pipelines in the ground in areas of future foundations. These lines include gas, water and electricity lines, telephone lines and fibre optic lines. In the event of collisions of the building foundations with the existing lines, appropriate coordination must be established in advance and possible measures determined.

The main objective is a safe and cost-efficient construction, based on a design that already takes these aspects into account in an early planning phase. A further and essential goal is sustainable and resource efficient construction. From the design team's point of view, an additional aim is to increase the productivity of the design process.

Within the framework of the ASHIVIN project, an already existing project database will be expanded. It contains data, experience and knowledge from previously implemented footbridges. The data will be filtered according to project-relevant performance and key performance indicators, i.e. safety, productivity, costs and resource efficiency, and thus serve as an orientation aid, as a benchmark, in the ongoing design process. This database serves to assess design variants on an ongoing basis in the design phase.

Following action plan is proposed for demonstration site #8:

- Establish a database of past footbridge projects (“Knowledge database”)

  - Define the relevant performance indicators, which serve as a basis to quantify the relevant key performance indicators, i.e. safety, productivity, costs and resource efficiency.
- Based on past footbridge projects calculate the defined PIs and KPIs and establish a reference frame, which will later be used for a new bridge design
- Assess the design of the bridge in Dortmund in the ongoing design phase with respect to the performance indicators, comparing values to the ones calculated from the past projects
- Automation of the aforementioned steps using a software tool (“app”), which is part of the ASHVIN tool kit (BRICS tool). Workflow for the tool BRICS is shown in Figure 29.

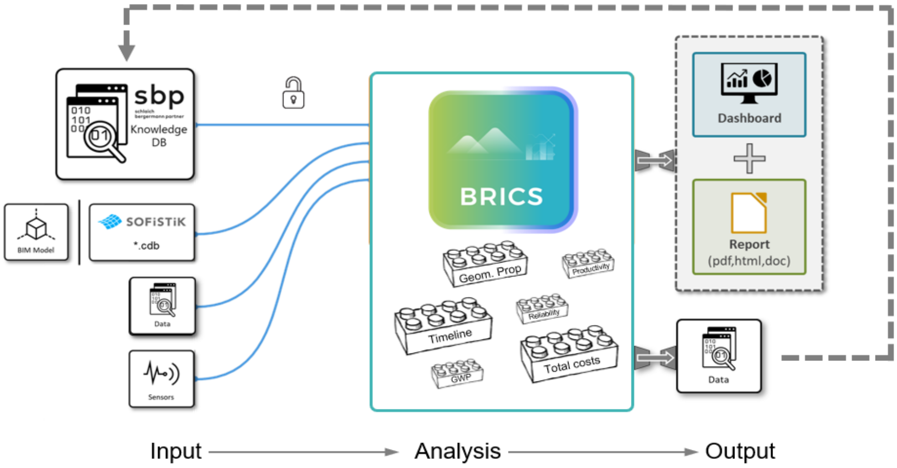


Figure 29: ASHVIN tool “BRICS” – envisaged workflow

3.8.3 Main stakeholders

The main stakeholders are:

- **City of Dortmund** (www.dortmund.de): Owner of the bridge
- Tiefbauamt (www.dortmund.de): The Civil Engineering Office (“Tiefbauamt”) with around 430 employees is responsible for the planning, construction and operation and maintenance of the infrastructure in Dortmund.
- **Schlaich bergermann und partner/sbp** (www.sbp.de) and Terrabiota (www.terrabiota.de): sbp (structural engineers and designers, consortium partners) and terrabiota (landscape designers) form the design team of the new pedestrian bridge and are responsible for the structural design, the static calculation of the superstructure and substructure, the lighting and the forecourt design concept.

3.8.4 Plan for IoT measurement and sensing devices

Table 26 List of measurements for demonstration site #8

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[14]	Storing of data
Data from project database (geometry, costs, carbon footprint,etc)	Within 30 yrs	-	-	-	csv, txt	Existing database, from archive, exiting drawings, 3D models, or structural analysis databases	Knowledge database (linked to IoT platform)
Data from current design project	Design phase, Construction phase	-	-	-	csv,txt	Data is extracted from 3D CAD models, BIM models, and structural analysis models	Project database (linked to IoT platform)

[14] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

3.8.5 Plan for implementation of ASHVIN tools and methods

Table 27 Plan for application of ASHVIN tools on demonstration site #8

ASHVIN tool/method	Name	How the tools will be used on the project
BRICS	BRidge AnalytICS: Evidence based design support tool for productivity resource efficiency and safety	- Automated extraction of data from various data sources, such as BIM models, 3D CAD models and structural analysis models (e.g. Software Sofistik) - Calculation of various performance indicators based on the previously extracted data - Comparison of the performance indicators with those from the docked knowledge database - Visualisation of the calculated PIs and KPIs and automated documentation - Enrichment of the knowledge database with the newly evaluated data
GEN	GEN tool: Generative design modeller to support optimization of productivity, resource-efficiency, safety, and cost-effectiveness	– Different construction options will be explored and analysed to give best alternatives, for productivity, resource-efficiency, and safety; at the pareto front – Evaluation of the best alternatives will be done to select the optimal construction sequence and methods to ensure productivity, resource-efficiency, safety, and cost-effectiveness – Real-time visual analyses and assessment as adjustments are made to the model will be useful to understand the ramifications of different design choices
4DV-D	Construction site simulator for early design phases with 4D visualizer	– Evidence-based design will be ensured by using historical data from past projects to define the virtual space requirements within the 4DV-D tool – Actual site-specific details of the democase #8 site will be input to define the physical space – Using DTT's bi-directional mapping of both the physical and virtual spaces, 4D visualizations of the construction site alternatives (obtained from the D2.3 GEN tool's pareto front) will then be done in ASHVIN's digital twin platform – Different construction alternatives based on KPIs to ensure productivity, resource-efficiency, safety and cost effectiveness will be explored by toggling views within a multi-viewport 3D environment

4DV-C	Construction monitoring tool with productivity and safety KPI decision making dashboard	– Real-time tracking of the dashboard will enhance efficient monitoring of the construction progress – Continuous tracking of the project as it progresses will enable modifications of the construction sequence to ensure productivity and safety – Toggling between the different views of the project within a multi-viewport 3D environment will enhance reallocation of resources to optimize the construction process – Through optimization of the construction process and appropriation of the resources, the carbon dioxide emissions will be reduced to a minimum thereby lowering the Carbon-footprint
DES	Simulation-based real-time construction site and logistics planning tool	– Real-time data acquisition, management and provision of as-built condition will be done – Modifications of the project construction schedules will be affected real-time with efficient filing of work package change orders – Logistics planning will be synchronised to align with schedule modifications thereby ensuring seamless transitions in workflows
SMT	Privacy ensuring safety management, simulation, and training tool	– The natural user interfaces developed will be standardised, software independent workflows to further delineate the human being from the construction process – To ensure that human privacy is safeguarded, activity-based data will be collected in distinct ways

3.9 #9 Sport stadium roof structure

3.9.1 Introduction

The Olympic Roof in Munich was built for the 1972 Olympic Games and will soon celebrate its 50th anniversary. This impressive cable net structure is, both from an aesthetic - architectural point of view and as a technical venture, an icon of the construction and engineering art of the second half of the 20th century.

The Olympiapark ensemble is one of the most important event venues and sports centres in the south of Germany.

The Olympic tent roof structure consists of four almost independent and highly prestressed cable net constructions (Figure 30**Error! Reference source not found.**). In total, the cable net forms a roof area of 74,000m^2. Prior to the upcoming anniversary, a comprehensive structural survey was carried out by sbp (Stuttgart) and Prof. Feix ingenieure (Munich). As part of this investigation, a complete static model of the cable net construction was done by sbp for the first time since the roof's existence. The core task was to determine the existing internal force or pre-stressing state in the cable net structure using novel calculation techniques in combination with cable force measurements.

The investigation will focus on the intermediate roof structure due to its size and easy accessibility (Figure 31 and Figure 32).

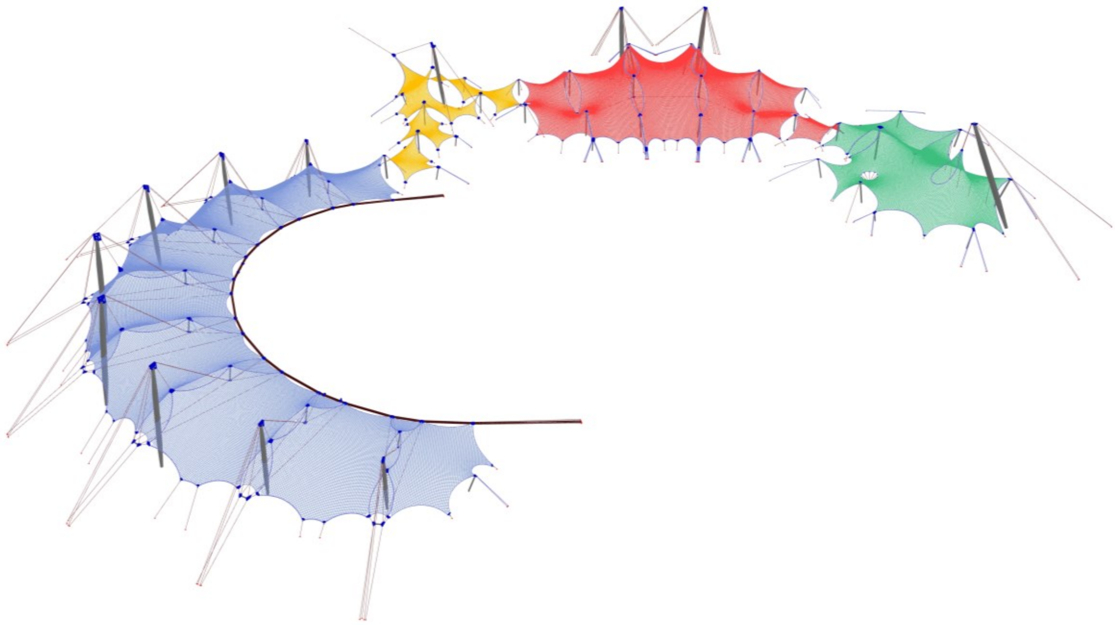


Figure 30: Overview over all four cable net structures forming the Olympic roof; Stadium (blue), Intermediate roof (yellow), Sports arena (red), and Swimming arena (green)

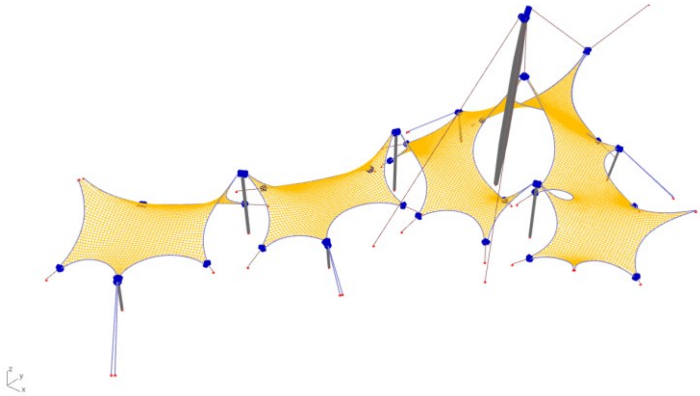


Figure 31: Cable net structure of the intermediate roof

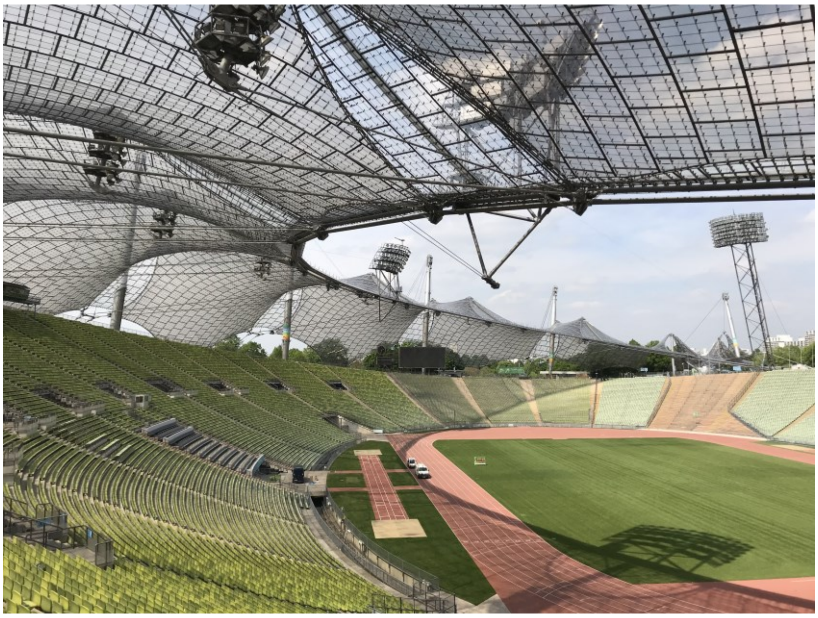


Figure 32: Cable net structure of the Munich Olympic Stadium

3.9.2 Challenges and needs

The main cables are either strand bundles or fully locked steel cables. Due to large cable forces and the diameter of the cables (82 mm to 182 mm), a direct measurement, of the cable forces, un-pinning the cables and applying hydraulic jacks or using cable tension meters, is not feasible.

In order to determine the cable forces, indirect measurement methods such as local strain or vibration measurements have to be considered.

Strains on the surface of the cables can be determined by glass fibre methods or strain gauge sensors. The former is somewhat more costly but can also be applied over a certain length of the cable to obtain continuous measurement results in this area.

Strain measurements are not applicable to strand bundles because these cables are coated, removal of the coating is not possible, and measurement of surface strains cannot provide any indication of the force within the cable itself.

Strain measurements are also critical due to their local application, as they only measure the locally limited strain, i.e. in the case of fully locked cable they can only provide information about the distortion of a single wire strand.

A possible and also cost-effective method are vibration measurements. These have already been used in the survey of the structure. The results were satisfactory. The disadvantage is the back-calculation of the cable forces from the measured frequencies; depending on the assumed oscillation length, the material stiffness, and the cable end node support stiffness, the calculated cable forces change significantly.

In order to obtain measurement results in fixed and relatively short time intervals, the rope must always be made to vibrate by an automatically applied impulse at these time intervals.

A hybrid method to determine the internal forces in the structure could be a combination of deformation measurements and the use of the existing calculation model, supported by an machine learning algorithm. With the structural analysis model, a load and internal force state would have to be back-calculated based on deformations. However, the necessary methods and the theoretical approach still have to be worked out.

The main goals for demo site #9 are:

- Seeking to become a UNESCO world heritage site
- Cost efficient and lean Asset Management using a DT model
- Guarantee structural safety
- further engineering support by sbp in the coming decades
- Test on an existing stadium structure possibilities to install and plan for a Digital Twin representation, as a support for future maintenance tasks

The action plan is presented below:

- Measurements of cable forces, strain, displacements, weather data (wind data locally and weather stations around Munich; temperature (surrounding, cable surface), snow pattern on roof (satellite photographs), over a certain time period (2-3 months)
- Correlate data of measurements with structural model (automatic creation of load cases, etc.); or using the existing structural model to back-calculate internal forces from displacement measurements

3.9.3 Main stakeholders

The main stakeholders are

- **City of Munich** (https://www.muenchen.de/): Owner of the stadium
- **Stadtwerke München** - SWM (https://www.swm.de/): one of Germany's largest municipal utility and service companies. It is owned by the City of Munich. SWM is active in the areas of electricity, natural gas, district heating, district cooling and drinking water supply, local public transport, operation of the Munich public baths and telecommunications. The SWM is responsible for the maintenance and operation of the Olympic swimming hall.
- **Olympiapark München GmbH** – OMG (https://www.olympiapark.de/): wholly owned subsidiary of the City of Munich. One of its tasks is to operate the facilities of the Olympic Park Munich including buildings and outdoor facilities.
- **Behnisch Architekten** (https://behnisch.com/): Architects schlaich bergermann und partner/sbp (www.sbp.de): Jörg Schlaich (then with Leonhard & Andrä) was the chief engineer responsible for the roof. Structural inspections and renewals were mainly carried out with the involvement of sbp over the past decades.

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3.9.4 Plan for IoT measurement and sensing devices

Table 28 List of measurements for demonstration site #9

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting[15]	Storing of data
Measurement of deflections of the cable net	Episodic, Spring 2022 onwards	Terrestrial Laser Scanner	-	-	Point Cloud	-	Data stored in AIP.
Images of the roof cladding (Plexiglas)	Episodic, Spring 2022 onwards	Camera and drone	every 3 months	~100 GB per year	e.g. jpg, point cloud, etc.	Not defined yet	not defined yet

[15] How is data being collected from sensors? What kind of connection do they support? What kind of protocols do sensors support (MQTT, CoAP, HTTP, LoRA). Is there a service that aggregates sensors data and makes them available at one central point, or expose them via REST API

3.9.5 Plan for implementation of ASHVIN tools and methods

Table 29 Plan for application of ASHVIN tools on demonstration site #9

ASHVIN tool/method	Name	How the tools will be used on the project
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	- Real-time measurement of displacements, temperature, wind, etc - Back calculation of internal and external forces in the cable net using a structural mechanical model supported by a machine learning procedure - Calibration of the force, displacement and load conditions correspondence and the theoretical model using a small laboratory mockup – Improvement of the correspondence using machine learning techniques
RISA	Risk-based status assessment tool with KPI dashboard	Selected PI's will be displayed, in particular the utilization (Rd/Sd) of specific highly stressed cables. Visual imaged based cladding assessment (done by drones) will be displayed. The activation of numerical analysis related to potential damage detection (image- or sensor-based) can enable optimal data-based decision-making processes related to maintenance plans.
GISI	GIS integrator for digital twin-based asset management	The asset will be spatially located and embedded within Ashvin

3.10 Quay wall in the Netherlands

3.10.1 Introduction

The Port of Rotterdam is the largest port in Europe and one of the biggest in the world. They are striving to develop intelligent infrastructure and one of the key assets they have identified is Smart Quay Walls. The Euromax Quay Wall (Figure 33) was constructed between 2005 and 2008. The structure has extensive instrumentation including displacement of the retaining wall, strains in the anchor piles, strains in the axially loaded piles and loads on the fenders. These measurements have been made since the completion of the quay wall, up until 2015. The ground conditions of the site consist of a very dense sand in which many of the foundation structures are located, overlain by reclaimed sands from the North Sea approximately 40 years ago. Numerical models are capable of predicting the current safety level of the quay wall and allow the Port to make decisions such as (i) can the load be increased or (ii) can the water-side be dredged to allow larger ships. However, there are a number of uncertainties regarding soil properties and modelling that are currently too risky to apply these methods.

The research aims at reducing these uncertainties using a combination of field work, laboratory tests, numerical analyses and life-cycle assessment. By taking this holistic approach, the work will significantly advance the scientific state of the art by developing and validating advanced numerical and probabilistic approaches for calculating the safety of quay walls.

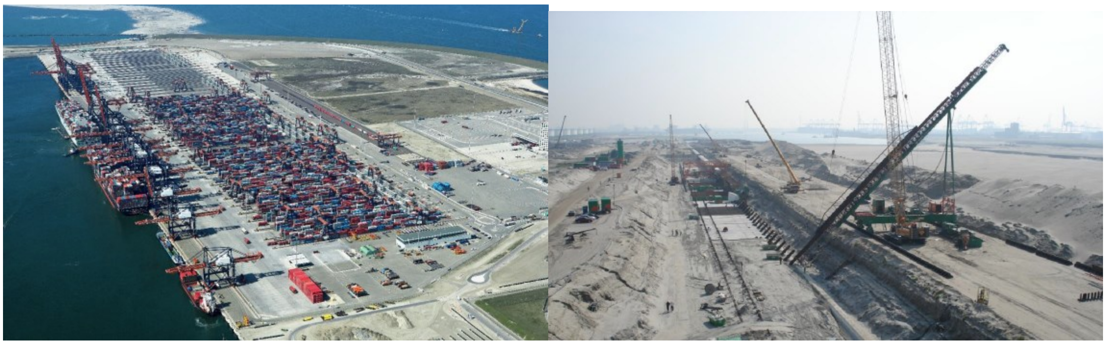

Figure 33: Demonstration site #10: Euromax Quay Wall at the Port of Rotterdam

3.10.2 Challenges and needs

The Port of Rotterdam is a critical part of the supply chain in Europe and is operating in a highly competitive market. The throughput of goods at the Port was 469 million tonnes in 2019. The ability to increase the utilisation of the infrastructure is key to keeping the Port competitive and they are undertaking significant research to develop the world's smartest port.

The focus of this work will be on the development of a finite element model as a predictive twin of the quay wall. The combination of monitoring data and finite element analyses will provide insight into physical mechanisms that will allow new understanding to be formulated that reflect actual quay wall response in a fundamental manner. Using the calibrated model, stress-tests can be performed, and field tests can be undertaken, for example loading the back of the wall or dredging in front of the wall to confirm the model matches the actual performance in real-time. Together with the capacity models, probabilistic life-cycle models will allow the complete financial and environmental costs of such systems to be compared.

3.10.3 Main stakeholders

- **Port of Rotterdam**: Asset Owner, Responsible for safety assurance of quay walls. The Port strive to implement innovations to maintain their competitive position as one of the world's leading ports.
- **Voestalpine Signaling:** Subcontractor to the Port responsible for the development of monitoring system & database

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3.10.4 Plan for IoT measurement and sensing devices

Table 30 List of measurements for demonstration site #9

List of IoT measurement and sensing devices							
Type of data	Period of time for which data is gathered	Device/sensor producer name and specification number	Velocity	Volume	Data format	Data collecting	Where the data are stored?
BOTDR installed at 6 locations in diaphragm wall	From 2008-2015	FO Cable: DiTeSt SMARTprofile Interrogator: Yokogawa AQ8603 (min. spatial resolution of 5cm)	n/a	n/a	Binary in SQL database and .csv	Measurement programme currently suspended. Possibility of reconnecting with the existing measurement system using alternative fibre optic interrogators	Local drive at TU Delft
8 MV anchor piles instrumented with extensometers at top and 1 with FO's along entire length	From 2008-2015	Extensometer: Smartec SOFO (fibre optic based)	n/a	n/a	Binary in SQL database and .csv	Measurement programme currently suspended. Possibility of reconnecting with the existing measurement system using alternative fibre optic interrogators	Local drive at TU Delft

8 vibro axial piles with extensometers at top and 2 with FO's along entire length	From 2008-2015	FO Cable: DiTeSt SMARTprofile Interrogator: Yokogawa AQ8603 Extensometer: Smartec SOFO	n/a	n/a	Binary in SQL database and .csv	Measurement programme currently suspended. Possibility of reconnecting with the existing measurement system using alternative fibre optic interrogators	Local drive at TU Delft
25 Fenders & Bolders instrumented with FO's (FBG)	From 2008-2015	Interrogator: Micron Optics sm130	n/a	n/a	Binary in SQL database and .csv	Measurement programme currently suspended. Possibility of reconnecting with the existing measurement system using alternative fibre optic interrogators	Local drive at TU Delft

3.10.5 Plan for implementation of ASHVIN tools and methods

Table 31 Plan for application of ASHVIN tools on demonstration site #10

ASHVIN tool/method	Name	How the tools will be used on the project
MATCHFEM	Multi-physics model matching tool for status assessment of bridges and buildings	The tool shall be used to incorporate the sensor data across the quay wall into a physics-based model and provide insights into the structural behaviour over a long time-span.
GEN	Generative design modeller to support optimization of productivity, resource-efficiency, safety, and cost-effectiveness.	Current existing data will be used to calibrate the numerical model and to develop a parametric model of the smart quay wall. Both the numerical and parametric models will then be used as inputs to the GEN tool. The Generative design modeller of the smart quay wall will be used to efficiently optimize Operation and Maintenance (O&M) of the existing port based on real-time analytical interpretations of the data. Furthermore, it will be most useful to inform the design of similar structures through interpolation and extrapolation techniques, thereby presenting potential cost-reductions that would otherwise be associated with the would-be uncertainties and risks. Capabilities of the GEN tool to iteratively incorporate, query changes as they occur real-time, and compare multiple scenarios presents benefits to significantly reduce ground uncertainties, structural loading or unloading of the port by giving best-alternatives at the pareto front. By using this approach, the port can predictively plan and identify optimal methods, schedules, routines, processes, and activities to ensure productivity during construction and/or operations, resource-efficiency, safety and cost-effectiveness. Using the GEN tool to design projects prior to actual implementation, by pre-emptively predicting best alternatives for productivity, resource-efficiency, and safety, will ensure cost-effectiveness when only desirable scenarios with higher probabilities of certainty are implemented.

3.11 Overview of demonstration projects and related ASHVIN tools

Table 32 provides an overview for all demonstration projects and related tools developed within the framework of ASHVIN.

Table 32 Mapping of demonstration sites and ASHVIN tools

ASHVIN tool/method	Demo #1	Demo #2	Demo #3	Demo #4	Demo #5	Demo #6	Demo #7	Demo #8	Demo #9	Demo #10
BRICS								✓		
GEN				✓				✓		✓
4DV-D		✓		✓	✓			✓		
4DV-C				✓	✓			✓		

DES				✓	✓	✓		✓		
SMT				✓				✓		
CMT				✓	✓					
MATCHFEM	✓	✓				✓	✓		✓	✓
RISA	✓		✓				✓		✓	
GISI	✓		✓				✓		✓	

4 DATA SAFETY AND PRIVACY CONTEXT

Taking into consideration the privacy implications of the project of those whom the data is collected, and the safety of these data is vital. Adequate procedures for data management and security not only protect the multiple stakeholders involved in the demonstration sites (e.g., workers, owners, subcontractors, the consortium), but also ensures that work can be carried our efficiently and unhindered by legal, ethical and social concerns. This section presents the different privacy implications of the technologies employed by the demo sites as well as how the data collected is going to remain safe from unwanted access, tampering and dissemination.

The data collected and processed by the Demo Sites' have several privacy implications to have in consideration. First, the employment of CCTV (Closed-Circuit TeleVision) cameras and drones in several demo sites may be used to identify workers and their performance. Under the GDPR (General Data Protection Regulation) the use of CCTV footage is allowed without asking the data subjects' consent if they are informed and there is a legitimate interest. Considering that the ASHVIN project aims at safety and efficiency, these can be considered legitimate interests for collection of video and imaging. However, to ensure proper transparency and accountability procedures were followed, a privacy notice was prepared and distributed throughout the Demonstriation Sites in which this sort of data occurred. Furthermore, in the scope of other tasks, data processing measures such as (e.g. Task 1.4 and Task4.6) body blurring, data aggregation, and data access log control are being developed to mitigate the misuse of personal information.

Similarly, Light Detection and Ranging (LIDAR) scans may capture data subjects' bodily features such as face maps, and other 3D representations of a person's body. Even though the purpose behind the employment of LIDAR technologies is not to collect these data, its collection and processing can happen as a secondary activity. This is potentially problematic since detailed LIDAR and point cloud data can be used to map a 3D representation of an individual's face. To mitigate this, LIDAR data collection should only take place once no individual is present in the area where data collection is happening.

The accelerometers and Global Positioning System (GPS) data embedded in the trucks, cranes and other human-operated machinery may inform all that have access to the data of the worker's performance during the task. For instance, how fast are certain tasks executed, and how often the worker takes breaks, thus being able to calculate their efficiency and efficacy. As these types of data may be used to decide the future of the workers in the company, extra care is advisable when handling and disseminating this information, with data aggregation methods being used whenever possible in order to meet safety and efficiency requirements without using data that can be traceable to individuals.

The data collection methods mentioned above require the use of sensors, specified in the previous sections of this document. While some of these sensors were already used at demonstration sites without ASHVIN's involvement, some have to be installed by the consortium in order to collect the required data. While the additional data collected enables gains in terms of efficiency and safety, it may also introduce additional vulnerabilities that could be exploited by attackers. In order to ensure secure communications, direct raw data collection is privileged whenever possible (i.e. avoiding third party providers) and strict cybersecurity and privacy measures are put in place (as a part of Task 1.4).

For more general information on privacy and data safety, please consult ASHVIN's Data Management Plan, Privacy Impact Assessment, and Privacy Notice. In addition to these documents, it is important to mention that, whenever required, specific agreements have been signed with demonstration case owners with additional provisions for data ownership, management and use.

Finally, Table 33 summarising privacy concerns directly related to demonstration sites is presented below.

Table 33 Table summarising privacy concerns

Issue	Type of Data	General Recommendations	Technical Recommendations
CCTV footage collected from demo sites can be used to identify workers and assess their performance.	Video / Time-lapse	1. Workers should be informed about the collection of data and how it is going to be used. 2. Allow data subjects to review the footage and delete on request. 3. Involve workers and their representatives in the decision-making process	1. Blur faces/bodies 2. Generate access logs to raw video / images. 3. Implement automated processing and deletion processes.
Machine sensor data can be used to track workers	Location / Activity Data	Aggregate and anonymise data.	Implementation of data aggregation and anonymisation procedures, either in the platform or, whenever possible, as an edge computing component.

LIDAR scans may capture bodily features	Point cloud data	Collect LIDAR data whenever humans are not on site	Implement automated measures to remove bodily features from the scanned data.
Accelerometers / GPS data may collect the movements of workers throughout the construction site as well as how fast they work, thus being able to extrapolate their efficiency.	Location data, speed data	1. Accelerometers may be only present in non-human operated machinery. 2. Allow workers to review their personal data. 3. Anonymise the collected data	Implement automated measures to anonymise the data collected where subjects are present (e.g., where a human is operating a construction equipment).