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D6.2 RECOMMENDATIONS AND OPTIONS FOR FUTURE STANDARDIZATION FOR DIGITAL BUILDING TWINS AT A EUROPEAN SCALE

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Number of the deliverable	D6.2
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Contributing partners	CERTH, MFL, EUR, PlanB, AUS, NCC, SBP
Reviewer(s)	CERTH, MFL, TUB

ABSTRACT

Contribution to Standardization is a key component of almost any H2020-funded project's success because standards and standardization enhance the market uptake of solutions developed by the projects. The following document provides a comprehensive set of ASHVIN's recommendations and options for standardization for digital building twins at a European Scale. In addition, the document outlines the methodology how these recommendations and options were elaborated and provides an outlook for their implementation.

KEYWORDS

Digital Twin, Building Information Modelling, Dissemination, Communication, Exploitation, Standardization, Technical Report, Technical Specification, construction industry, building, building modelling, building management, building monitoring, building maintenance, continuous monitoring, construction visualization, building simulation, worker protection,

worker safety, worker privacy, productivity, resource efficiency, health and safety, maintenance, risk predictive maintenance, monitoring, real-time monitoring, load test, use case, infrastructure, replication, crane, drone, road, bridge, lifetime, office building, data, unmanned aerial vehicles (UAV), airport, airport runway, inspection, deep machine learning

REVISIONS

Version	Submission date	Comments	Author
V0.1	2024-02-23	for internal review	Stefan Wagmeister
V0.2	2024-03-12	including internal review comments	Stefan Wagmeister
V0.3	2024-03-26	including PM review comments	Stefan Wagmeister
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DISCLAIMER

ACRONYMS & DEFINITIONS

AEC	Architecture, Engineering and Construction
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CEN/TR	A Technical Report gives information on the technical content of standardization work. A Technical Report is an informative document made available by CEN in at least one of the three official languages.
CEN/TS	A Technical Specification is a normative document made available by CEN in the three official languages.
CWA	CEN and/or CENELEC Workshop Agreement; standardization deliverable from a CEN and/or CENELEC workshop
DT	Digital Twin
EN	European Standard adopted by CEN or CENELEC
ESO	European Standardization organization (CEN, CENELEC and ETSI)
ETSI	European Telecommunications Standards Institute
IEC	International Electrotechnical Commission / International standard developed by IEC
IFC	Industry Foundation Classes
IoT	Internet of Things
ISO	International Standardization Organization / International standard developed by ISO
ITU	International Telecommunication Union
KPI	Key Performance Indicators
NSB	National Standardization Body
NWIP	New Work Item Proposal: a proposal for a new work item, submitted to a Technical Body (TC or SC) of a Standards Development Organization for approval
TC	Technical Committee established with a clearly specified scope to approve NWIP and to manage its work program.
SC	Subcommittee, under a TC; frequently in large ISO/TCs or IEC/TCs but

	being phased out in CEN and CENELEC. SCs operate more independently than WGs
SDO	Standards Development Organization
SME	Small and Medium Enterprise
TC	Technical committee
TR	Technical report developed by CEN, CENELEC, ISO or IEC
TS	Technical specification developed by CEN, CENELEC, ISO or IEC
WG	Working Group to which work is allocated by a TC or SC based on an approved new work items (NWI) and drafting standardization deliverables; decisions are not taken on WG-level but on TC- or SC-level.
WI	Work item; specifies among other the title, scope and necessary expertise for developing a standardization deliverable; the idea can also already be deposited at preliminary work item, which is further developed into a first full draft before it is activated
WTO TBT	World Trade Organization's Technical Barriers to Trade

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 Deliverable context

The current deliverable is the second out of six deliverables that were developed within WP6. The deliverable is the result of the Task 6.2 “Standardization for Digital Buildings Twins at EU scale”.

1.2 Structure of this deliverable

This deliverable is structured as follows:

- **Chapter 1** provides the introduction to the deliverable, including its context to ASHVIN project, the objectives of the WP and the task in which the deliverable was elaborated, the interdependencies with other ASHVIN deliverables and finally its purpose.
- **Chapter 2** presents the methodology which has been applied for identifying, prioritizing and elaborating recommendations and options for standardization for digital building twins at a European Scale.
- **Chapter 3** details and describes the potential standardization areas identified.
- **Chapter 4** includes the recommendations for standardization and outlines the degree of their implementation.
- **Chapter 5** provides the ASHVIN Use Cases (see D7.2); developed in WP7 (see D7.2) and based on Information Delivery Manual (IDM) standards (EN ISO 29481-series) to aid standardization practices and open accessibility within the industry.
- **Chapter 6** covers the conclusions**.**

1.3 Objectives of the WP6 – Social innovation, and standardization

The objectives of WP6 are to determine future trajectories of ASHVIN developed innovations, including standardization triggering standards to be applied by the market in connection with the deployment of new innovative privacy focused practices within the industry. These will enable the project results to be widely used afterwards, thus ensuring a sustainable impact of the project in the long run. The objectives of WP6 comprise:

- Elaborate and implement a standardization plan with project scope relevant standards – existing or under development – to be used in other WPs ensuring that project results are aligned with current regulations and on-going standardization activities.
- Provide concrete recommendations for future standardization for Digital Building Twins at a European scale.
- Determine innovative solutions that enhance and preserve worker data and privacy while increasing effective reductions in workplace risks.
- Emphasis will be paid to the use of measured data on public infrastructure and its potential availability for the public domain.

1.4 Objectives of the Task T6.2 – Standardization for Digital Building Twins at a European scale

The objective of Task T6.2 is to provide concrete recommendations for future standardization for Digital Building Twins at a European scale.

1.5 Deliverable interdependencies

The involvement of all WPs was a crucial factor for the development of this Deliverable. Based on the results available so far from D6.1 of the accompanying gap analysis and feedback on developments in the individual tasks (e.g. identification of relevant standards, standards already used in the project), all WPs contributors were invited to participate in the development of potential standardization ideas. At the same time, an attempt was made to involve partners from the "sister projects" (BIM2TWIN, COGITO, BIMprove) in the process to use synergies on the one hand and to avoid duplication on the other.

There were interdependencies with all WPs. As potential standardization ideas have condensed, intensive networking with those tasks that have a strong connection to the demonstration projects has emerged as important. Use cases in real environments are particularly suitable for evaluation, e.g. broad applicability in practice and thus for standardization.

Task 6.2 "Standardization for Digital Buildings Twins at EU scale" is developed taking into consideration the findings from the following Work Packages:

1. WP1 IoT driven digital twin platform: development of common semantic data models.
2. WP2 Design for productivity and safety: establishment of evidence-based design practices based on historical digital twin data.
3. WP3 Data fusion for real-time construction monitoring: development of novel algorithms for transferring the necessary features from the real world to the simulated reality.
4. WP4 Control and real-time simulation of construction: development of visualizations, simulation management dashboard and applications, as well as progress controlling solutions.
5. WP5 Digital twin based structural monitoring and asset management: development of measurements, calculations, prediction and decision-making KPIs; integration of spatially distributed assets into the ASHVIN platform.

Consequently, this deliverable will provide inputs into the WP8 Communication, Dissemination and Exploitation.

This ensures that the recommendations and options for standardization for digital building twins at a European Scale are in line with other project activities, represents the interests of the consortium members, and addresses the relevant stakeholders outside of the consortium. In addition, this Deliverable provides a structured framework for the sustainable exploitation of ASHVIN solutions after the end of the project through its contribution to standardization.

In addition, the Task 6.2 "Standardization for Digital Buildings Twins at EU scale" enables a quick market adoption of project results. Trust into and acceptance of any proposed solution to facilitate the construction processes at the building site, as well as ensure privacy and protection of workers' data is directly related to its compliance to standards, which guarantees the reliability and interoperability of such solution.

1.6 Purpose of the Deliverable D6.2

Based on the D6.1, Standardization plan, and input provided by other WPs, especially WP1, but also WP 2-5, the feasibility of future standardization for Digital Building Twins at a European scale must be evaluated in this task. Based on the evaluation, recommendation and options for such standardization must be elaborated considering its applicability against real demonstration projects. The recommendations are provided as a basis for a proposal for elaborating a standard to the appropriate standardization community (CEN and/or ISO).

2 METHODOLOGY

2.1 Overview

The methodology applied follows the following steps:

1. Inviting stakeholders (ASHVIN partners and representatives from other related Horizon projects) to the idea generation to make them familiar with the goal of the exercise and ensure a common understanding (see Chapter 2.2).
2. Performing standardization workshops to gather ideas for potential standardization in an open but structured brainstorming, evaluating, ranking and jointly detailing those ideas (see Chapter 2.3) to be followed by deep dives (see Chapter 2.4).
3. Reflecting the preliminary results and ideas from chapter 2.4 with external representatives (ASHVIN Advisory Board) to obtain their feedback and confirmation that the needs of the related research sector and industry are met (see Chapter 2.5).

The output of this process is then used as input for formulating in more detail the potential standardization areas (see Chapter 3) and finally the recommendations for future standardization (see Chapter 4).

2.2 Common understanding

Based on the gap analysis made within D6.1 "Standardization plan" and feedback loop on ideas on standardization and standardized procedures and an updated list of standards in February 2022 all partners of ASHVIN have been invited as well as partners from the following “sister projects”:

- BIM2TWIN (Grant agreement ID: 958398),
- COGITO (Grant agreement ID: 958310),
- BIMprove (Grant agreement ID: 958450),

to work actively on inputs for recommendation for future standardization. As this should be an iterative and interactive process, Workshops (standardization workshops) were chosen as the method for the further procedure. Miro (https://miro.com/) was used as an online visual workspace for the digital collaboration between the workshop participants.

In preparation for the following workshop series, all partners were asked to address the following questions and, in the best case, to bring ideas for the further workshop process.

The following goals for the workshop series were communicated to the invitees:

Close gaps by using standards or standardized processes to become scalable and marketable (market application);

Use/develop standards to bridge the gap from demonstrators/demonstration sites to the brought use of digital twins in EU:

- Identify existing standards (or standards under development) which could/should be considered within the tasks.
- Identify standardization or standardized process needs which are critical to success of the project.

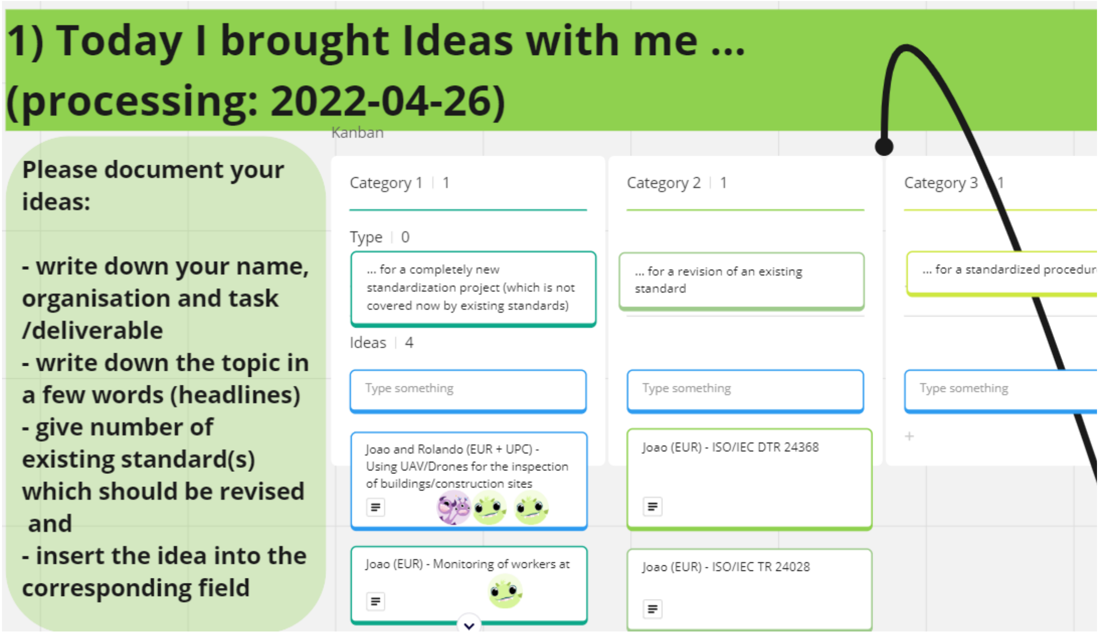
Before starting workshop work, it was necessary and useful to explain again and deepen the standardization process (CEN- and ISO-level) to all participants to be aware not only of requirements, advantages, and opportunities using standardization as a propriate tool to transfer research results into widely applicable and accepted technical deliverables but also of differences between CEN- and ISO deliverables (e. g. EN-European standard, CEN/TS-Technical Specification, CEN/TR-Technical Report, CWA-CEN workshop agreement).

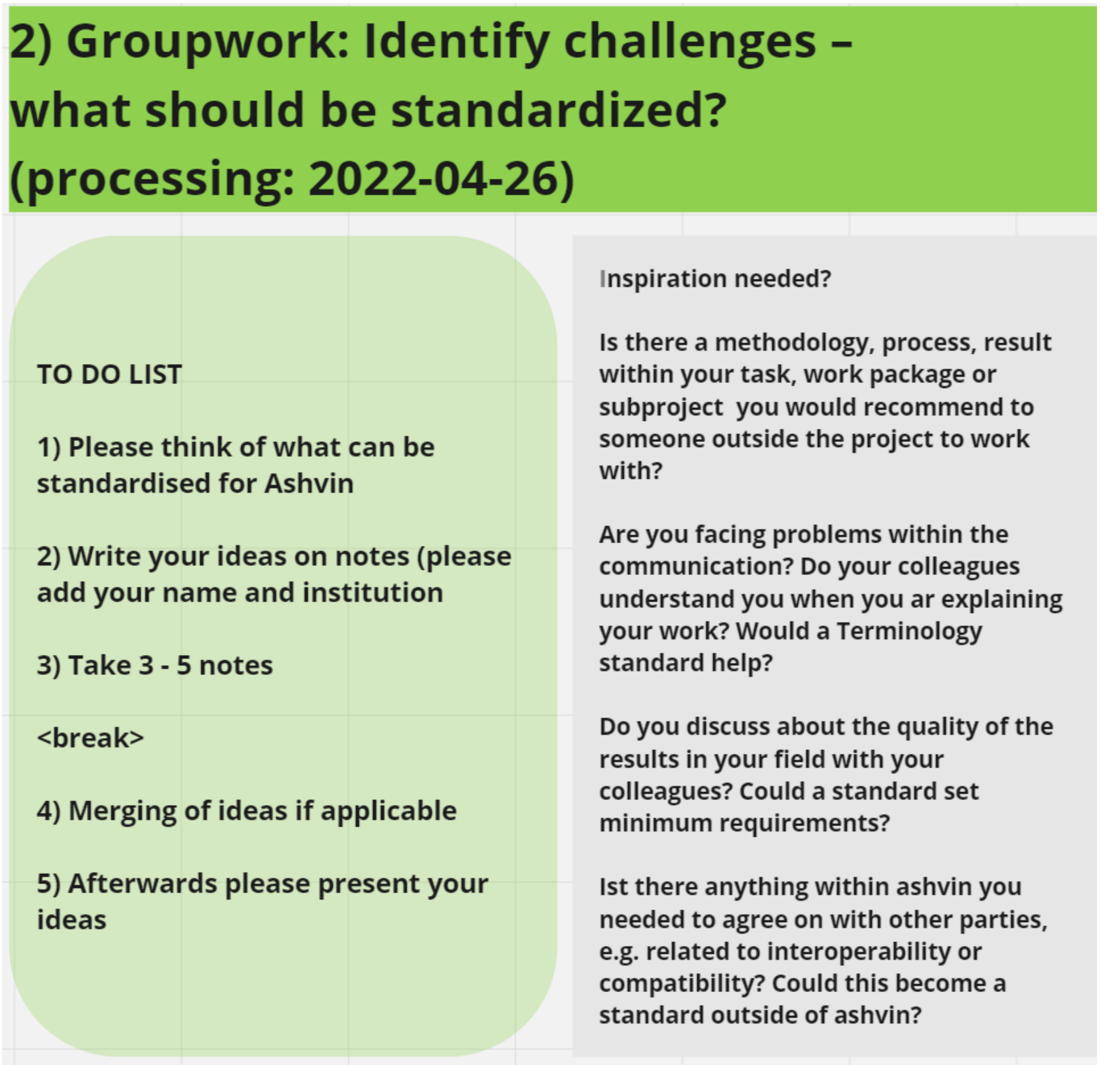
Not only the partners of the ASHVIN consortium, but also those of the BIM2TWIN, COGITO, BIMprove projects were invited to actively participate in the workshops; Experts from all three projects actively participated in the workshops.

2.3 Standardization workshops

The standardization workshops were held in April, May and June 2022. The workshops were structured in such a way that the following process chain was worked step by step as part of an iterative process (see Figure 1):

1. Idea generation and description (based on GAP analysis or new as part of the workshop) and description of the added value or problem solving.
    - for a completely new standardization project (which is not covered now by existing standards),
    - for a revision of an existing standard and
    - for a standardized procedure.
2. Clustering the topics while simultaneously assigning them in a matrix "WP and task topics at a technical level" and "type of possible standardization topic (e.g. common language, uniform tests, uniform interfaces, products, services)".
3. Evaluation of the ideas.
4. Ranking of the ideas.
5. Deepening of ideas
6. In-depth work on the three best-rated topics (requirements for NWIP – e.g. challenges, benefits, WPs and Tasks effected, legal and market environment, scope, relevant stakeholders).


1) Today I brought Ideas with me …
(processing: 2022-04-26)
Kanban
Please document your ideas:
- write down your name, organisation and task /deliverable
- write down the topic in a few words (headlines)
- give number of existing standard(s) which should be revised and
- insert the idea into the corresponding field
Category 1 | 1
Type | 0
… for a completely new standardization project (which is not covered now by existing standards)
Ideas | 4
Type something
Joao and Rolando (EUR + UPC) - Using UAV/Drones for the inspection of buildings/construction sites
Joao (EUR) - Monitoring of workers at
Category 2 | 1
… for a revision of an existing standard
Type something
Joao (EUR) - ISO/IEC DTR 24368
Joao (EUR) - ISO/IEC TR 24028
Category 3 | 1
… for a standardized procedur
Type something


2) Groupwork: Identify challenges – what should be standardized?
(processing: 2022-04-26)
TO DO LIST
1) Please think of what can be standardised for Ashvin
2) Write your ideas on notes (please add your name and institution
3) Take 3 - 5 notes
<break>
4) Merging of ideas if applicable
5) Afterwards please present your ideas
Inspiration needed?
Is there a methodology, process, result within your task, work package or subproject you would recommend to someone outside the project to work with?
Are you facing problems within the communication? Do your colleagues understand you when you ar explaining your work? Would a Terminology standard help?
Do you discuss about the quality of the results in your field with your colleagues? Could a standard set minimum requirements?
Ist there anything within ashvin you needed to agree on with other parties, e.g. related to interoperability or compatibility? Could this become a standard outside of ashvin?

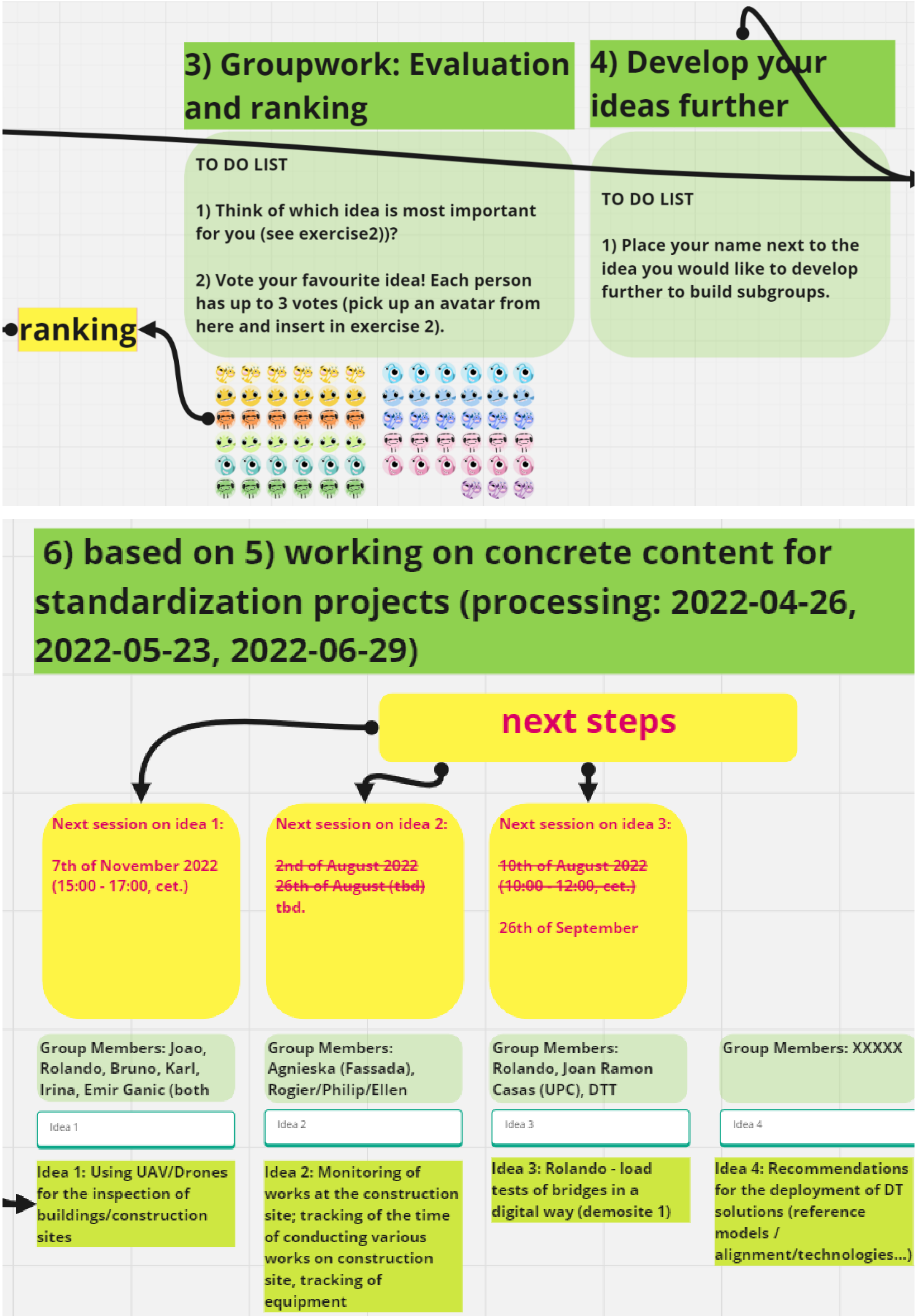


Figure 1 Methodology gaining possible standardization ideas coming up from ASHVIN using "miro" (standardization workshops)

The following potential new standardization areas (ideas) were developed in these workshops:

- Idea 1: Using UAV/Drones for the inspection of buildings/construction sites;
- Idea 2: Monitoring of works at the construction site; tracking of the time of conducting various works on construction site, tracking of equipment;
- Idea 3: Load tests of bridges in a digital way (demo site 1).

Further processing of possible standardization ideas took place as part of many "deep dives" (in-depth examination and analysis of the ideas) in smaller groups (see Chapter 2.3).

2.4 Standardization deep dives

Based on the standardization workshop outputs, it was useful to deepen the ideas in smaller groups arranging "deep dive" sessions. The relevant partners joined the different topics for the ongoing work on the questions which must be answered coming up from the New Work Item Proposal (NWIP) template to prove if the project idea could be feasible for a future standardization project on CEN- or ISO-level:

- Explanation of the purpose and justification for a NWIP
- Scope of the proposed work item
- Possible title
- Stakeholders immediately affected by the proposal
- How will these Stakeholders benefit from or be impacted by the proposed deliverable?
- Identification of a responsible drafting body
- Environmental aspects and how to address them
- Indication whether the proposed project is linked to a specific European Research and Innovation Project etc.

After a few "deep dive" sessions it was decided to focus on the following potential standardization areas to make them feasible for NWIP.

- Idea 1: Using UAV/Drones for the inspection of buildings/construction sites;
- Idea 2: Monitoring of works at the construction site; tracking of the time of conducting various works on construction site, tracking of equipment;
- Idea 3: Load tests of bridges in a digital way.

2.5 Standardization workshop with Advisory Board of ASHVIN

On February 6th, 2023, the ASHVIN Advisory Board with external industry representatives present was engaged to seek their feedback on the preliminary results and ideas and, if necessary, to consider recommendation for further work. Participants: Salla Eckhardt (company: OACSVCS), Mona Marill (Australo), Karl Grün (ASI), Stefan Wagmeister (ASI).

The goal of the workshop was to obtain feedback and recommendations from our top-notch experts making sure that the engaged standardization process meets the needs of the related research sector and industry.

The feedback received from the Advisory Board was positive and confirmed the usefulness of the intended standardization. It was emphasized, that in the best case, when enforcing standards of future digital solutions, standardized data will be used harmoniously in the design, construction and maintenance of buildings and infrastructure. This can mitigate or prevent risks, errors, and accidents, which enables field of engineering prevent potential future disasters, and even to save lives.

3 POTENTIAL STANDARDIZATION AREAS

3.1 STANDARDIZATION AREA 1: Using UAV/Drones for the inspection of buildings/construction sites

3.1.1 Description of the idea

The possible standardization area should allow integrating drone images into the Digital Twin done by defining requirements about the acquisition performances i.e.: on replicability, quality, coordinates, place, date, identification, resolution of images, baseline for camera position, frame rate of videos, data storage and archiving.

It should also describe procedures for data minimization so that video and images that are irrelevant for the specified purpose are not stored and are deleted when to be stored. When deletion of data with personal information is not possible, the possible standard should define recommended deidentification procedures (e.g. face/body blurring) of images to comply with GDPR and other relevant legal requirements.

3.1.2 Further procedure

In mid-2022, a working group WG 9 "Digital Twins in the built environment" was established in CEN/TC 442 "Building Information Modelling". A development that took place at the same time as possible standardizations were being processed within the ASHVIN project. Fortunately, this opened new opportunities in terms of standardization in digital twins. ASI (Stefan Wagmeister) has been delegated to this working group as an observer via the National Standardization Body ASI (NSB) to act as a link between CEN and ASHVIN.

A NWI (standards project) “Building information modelling - Digital twins applied to the built environment - Use cases” was started in March 2023 in CEN/TC 442/WG 9, Digital twins in built environment. CEN-members were asked to participate actively and bring in use cases/case studies. Starting discussion on use cases/case studies coming up from ASHVIN project, it was decided to bring in this idea as a use case to become part of this Technical Report (CEN/TR) (see Chapter 4.1). With this decision and taking advantage of the work in CEN/TC 442/WG 9 the idea was operationalized and ASHVIN achieved a successful contribution to ongoing standardization.

3.2 STANDARDIZATION AREA 2: Monitoring of works at the construction site; tracking of the time of conducting various works on construction site, tracking of equipment

3.2.1 Description of the idea

The possible standardization area should define recommendations for the creation of a data flow for collecting, handling and storage of data of DT. Furthermore, it could offer a summary of examples of compatible files/formats/processes for data flow managements in DT.

It should also describe processes and requirements of data gathering to improve productivity, safety and efficiency on construction sites and give recommendations to define what is a current or outdated data.

It should be noted data protection, privacy from the individuals to be tracked/monitored; such a standard can be process oriented based on principles like "privacy and data protection by design", integrity of data, data minimization, transparency. Furthermore, checklists with data protection issues and methods/recommendations on how to address them could be included in the document.

3.2.2 Further procedure

A NWI (standards project) “Building information modelling - Digital twins applied to the built environment - Use cases” was started in March 2023 in CEN/TC 442/WG 9, Digital twins in built environment. CEN-members were asked to participate actively and bring in use cases/case studies. Starting discussion on use cases/case studies coming up from ASHVIN project, it was decided to bring in this idea as a use case to become part of this Technical Report (CEN/TR) (see Chapter 4.1). Unfortunately, the use case/case study description was not mature enough to meet the content requirements for the Technical Report process in time. Therefore, work on this idea was not continued.

3.3 STANDARDIZATION AREA 3: Load tests of bridges in a digital way (demo site 1)

3.3.1 Description of the idea

This possible field of standardization is to find an open, scalable structure of verification and validation of the virtual models of railway bridges. The load test represents a compulsory episode of those bridges that occurs at the end of construction and on the verge of being open to service. Using such episode for the verification and validation of models that will feed the digital twin of the asset may have substantial beneficial effects during the maintenance phase. It is about integrating of data from the following perspectives:

- Measurements obtained under controlled loading conditions.
- Prediction of the expected behaviour of models developed before the load tests.
- Update of models with more realistic behaviour that feed more adequately the digital twin of the asset.
- Integration of existing standardised comparisons between models and reality established in the relevant guidelines.

The standardized method should bridge the gap between the created data coming from real load test and models (existing precise documentation) by developing a method to collect and document these data, so that they are usable for everyone who needs data (data exchange) for further test in future or to maintain bridges during their lifetime in a more efficient way.

Figure 2 illustrates the “under development” possible and digital way to offer, store, exchange data (demo site 1) using different functionalities included in the current version of the tool “MATCHFEM” (https://ashvin-integration.digitaltwin.technology/Dev/).

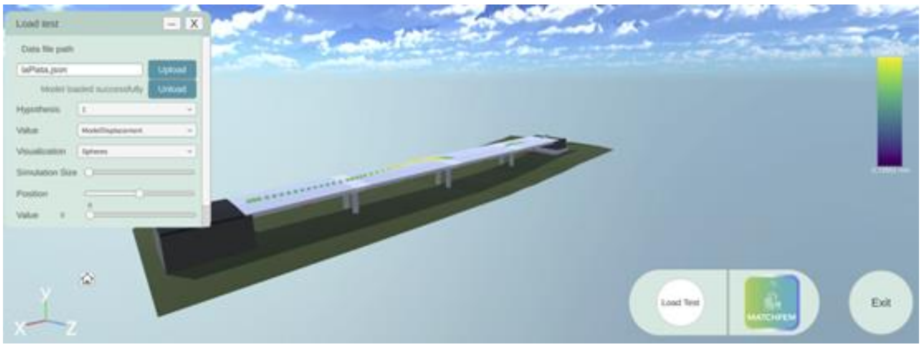


Figure 2 possible and digital way to offer, store, exchange data (demo site 1) using different functionalities included in the current version of the tool "MATCHFEM"

The example shows the way of establishing meaningful data exchange of utmost importance for:

- verification and validation of road bridges,
- comparison of test results with requirements coming from standards (e. g. Eurocodes, national standards),
- planning and increasing optimization of the maintenance of railway bridges.

The possible benefits of this field of standardization are:

- increasing efficiency by enabling future users to gather verified models;
- optimizing data storage and data exchange;
- optimizing maintenance of bridges.

The additional benefit of this idea is the applicability not only for railway bridges but also for other use cases (e. g. road bridges).

3.3.2 Further procedure

A NWI (standards project) "Building information modelling - Digital twins applied to the built environment - Use cases" was started in March 2023 in CEN/TC 442/WG 9. CEN-members were asked to participate actively and bring in use cases/case studies. Starting discussion on use cases/case studies coming up from ASHVIN project, it was decided to bring in this idea as a use case to become part of this Technical Report (CEN/TR) and in parallel to proceed work on a NWIP "Digital twinning of bridges during diagnostic load testing" (see Chapter 4.2).

4 RECOMMENDATIONS FOR FUTURE STANDARDIZATION

4.1 CEN-Technical Report CEN/TR 18077„Building information modelling — Digital twins applied to the built environment — Use cases“ (WI 00442049)

4.1.1 Procedure of participating on development of this Technical Report

In mid-2022, a working group WG 9 "Digital Twins in the built environment" was established in CEN/TC 442 "Building Information Modelling". A development that took place at the same time as possible standardizations were being processed within the ASHVIN project. Fortunately, this opened new opportunities in terms of standardization in digital twins. ASI (Stefan Wagmeister) has been delegated to this working group as an observer via the National Standards Organization ASI (NSO) to act as a link between CEN and ASHVIN.

A NWI (standards project) CEN/TR 18077 (Technical Report[1]) “Building information modelling - Digital twins applied to the built environment - Use cases” was started in March 2023 in CEN/TC 442/WG 9. CEN-members were asked to participate actively in this project and bring in use cases[2]/case studies[3] for digital twin (DT) applications.

> Description of the need of this CEN/TR: *Complementary to a building information model, which contains as built and historical data, a digital twin (DT) can be used to assess the current state of the asset and to potentially forecast the future state.*
>
> *Given the wide range of buildings and infrastructure in the built environment, both in application and in scale, there is currently insufficient information available to make informed decisions about good practice in the development of digital twins. There is a need for clear use cases to inform any such provisions. This document will collect and collate use cases from throughout Europe to show how digital twins are currently being applied, and then to analyse these use case to identify common characteristics and methods. This analysis could then be used to support future projects of CEN/TC 442/WG 9 “Digital Twins in built environment”.*
>
> Scope of this CEN/TR[4]: *This document collates case studies of digital twins applied to the built environment, including infrastructures, in Europe. These case studies have been obtained from CEN experts and related EU research projects. This document identifies common characteristics to support further standardization work.*

<u>What was needed?</u>

The drafting body (CEN/TC 442/WG 9) asked for the following essential information about use cases:

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[1] In the context of this document (FprCEN/TR 18077:2024, 2.2), a use case is a document set of actions performed by one or more actors and by the system itself.
[2] Record of research relating to a sequence of actions. In the context of this document, a case study is an instance of a use case or, more generally, a record of specific set of actions (FprCEN/TR 18077:2024, 2.1).
[3] Definition of CEN/TR (Technical Report) see https://boss.cen.eu/reference-material/guidancedoc/pages/del/
[4] Project data see official CEN/TC 442-website/technical work

- general information (typology, location, Building Digital Twin (BDT) manager,
- main use of the DT.
- description of the DT.
- main improvements beyond the state of the art,
- replication potential.

In March 2023, Austrian Standards drew the attention of all members of ASHVIN to participate actively in the development of use cases for digital twins within the scope of the Technical Report.

This was a great opportunity to incorporate use cases based on the previous results of the demo sites directly into the standardization process that has started, thereby making the broad applicability of ASHVIN results known and accessible at an early stage.

What was delivered?

ASHVIN has provided 5 different use cases related to its research on digital twin technologies on several ASHVIN demonstration sites related to maintaining infrastructure assets with the support of digital twin technologies within the submission deadline (June 2023) to CEN/TC 442/WG 9 via ASI.

ASI (Stefan Wagmeister) and UPS (Rolando Chacón) were active participants in WG 9 starting in March 2023 and are currently active participants in WG 9, working together to ensure that any questions that may arise regarding ASHVIN-input were clarified and necessary refinements were made in time.

What was the result?

It was succeeded to manifest the use cases described in Chapter 4.1.3 in this final draft of the CEN Technical Report. These 5 (five) ASHVIN use cases will become integral part of a new European standardization deliverable (CEN/TR 18077), the publication is expected in October 2024.

4.1.2 Result of ASHVIN´s contribution to the CEN standardization deliverable - recommendations for uses case descriptions bases on domo sites

4.1.2.1 Real-time discrete event simulation of crane operations ("case study 8") – Office building, Spain, Barcelona[5]

a. General information

   Typology: Office building, but applicable for many kinds of buildings

   Location: Barcelona, Spain

   Building Digital Twin (BDT) manager: ASHVIN

b. Main use of the DT

   The DT will be used for improved construction planning, especially in the short term. Due to real time data, information can be gained, which enable real-time

[5] Relevant documents and links:
M. Jungmann, L. Ungureanu, T. Hartmann, H. Posada and R. Chacon, "Real-Time Activity Duration Extraction of Crane Works for Data-Driven Discrete Event Simulation," 2022 Winter Simulation Conference (WSC), Singapore, 2022, pp. 2365-2376, doi: 10.1109/WSC57314.2022.10015250.
M. Jungmann and T. Hartmann, "D4.2 Discrete Event Simulation Formalism for Productive, Resource Efficient, and Safe Construction Planning" Deliverable 4.2 ASHVIN. 2022, https://doi.org/10.5281/zenodo.7220125

discrete event simulation. Thus, more reliable forecasts of crane operations are possible.

c. Description of the DT

Kinematic data are collected by sensors mounted on a crane hook. By analysing the data with artificial intelligence, valuable information about movements and construction processes are provided.

In particular, activity durations are extracted. These durations are used for stochastic discrete event simulations of construction works. (Video: https://nextcloud.ashvin.eu/s/wM88CdDLxJq27rb)

Figure 3 Crane on construction site

Figure 4 sensors mounted on a crane hook

d. Main improvements beyond the state of the art

Conventional simulation relies on static and generic assumptions for input parameters, resulting in unreliable forecasts. By continuously tracking the construction process and updating the activity durations, more reliable input parameters are available. Thus, more accurate forecasts are enabled, especially for short-term planning. These meaningful forecasts support the inclusion of lean construction principles, such as just-in-time delivery or improved allocation of resources.

Thus, KPIs such as productivity or resource-efficiency can be improved. Additionally, costs can be reduced due to a suitable allocation of resources and by considering weather forecasts, safety can be improved due to improved planning of crane operations.

e. Replication potential

Cranes are used on every construction site. The construction industry tends to use increasingly prefabricated components, which require cranes for attachment. Therefore, there is a high replication potential.

4.1.2.2 Maintenance of a road bridge - Demo 7 ("case study 17") – Road infrastructure, Spain, Barcelona Metropolitan Area[6]

a. General information

Typology: Road infrastructure

Location: Barcelona Metropolitan Area, Spain

Asset owner: MITMA (Ministerio de Transportes, Movilidad y Agenda Urbana, SPAIN).

b. Main use of the DT

The DT under development is primarily intended to generate a human-bridge interface designed for end-users in which different conditions of the bridge can be tracked throughout its lifetime.

Using manifold sources of information, users can assess individual behaviours of the bridge. With an overview of all phenomena in an aggregated form, the user can make more informed decisions.

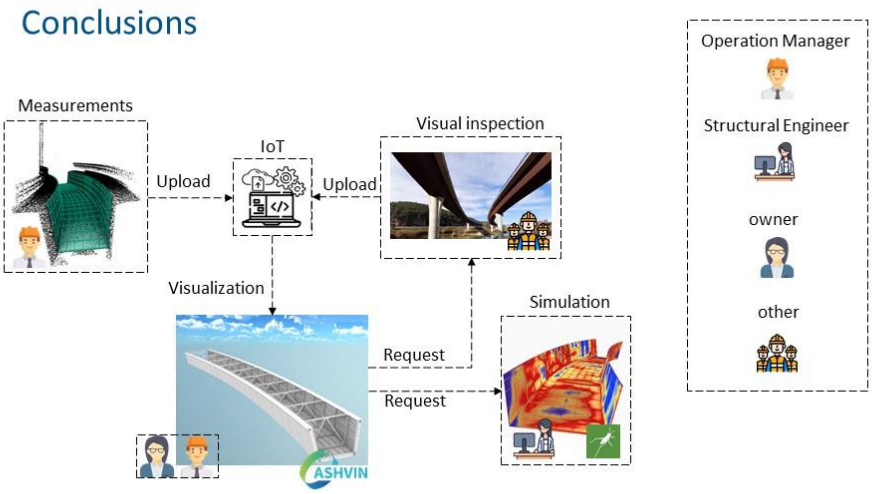

Figure 5 Intended end-user interface within the ASHVIN digital twin platform

c. Description of the DT

The bridge belongs to a main highway in Barcelona area. Its length is 846 meters with a steel composite structure (horizontally curved, tapered and stiffened). A detailed IFC model has been developed, seasonal analysis with varied measured magnitudes has already been performed. The use case is still under development and the measuring period will finish by the beginning of 2024.

[6] Relevant documents and links:
Ramonell C., Chacón R. (2023). Seasonal analysis of a 846 long steel box girder bridge using Terrestrial Laser Scanners (TLS) and FE-models. Proceedings of the Annual Stability Conference Structural Stability Research Council. AISC-SSRC. North Carolina, USA.
Chacon, R.; Ramonell, C.; Puig-Polo, C.; Mirambell, E. (2022). Geometrical digital twinning of a tapered, horizontally curved composite box girder bridge. International Colloquium on Stability and Ductility of Steel Structures. Aveiro, Portugal. p. 52-58. DOI: 10.1002/cepa.1727

Figure 6 Location and general view of PR-04-B015 bridge

d. <u>Main improvements beyond the state of the art</u>

The objective of the ongoing study is to understand how to develop automated procedures for introducing BIM geometries, real measurements, and simulations within a common digital twin. Many different automated pipelines are under development. For instance, the structural analysis of the composite structure with a seasonal perspective. Terrestrial laser scanners help collecting point clouds with the actual shape of the bridge at a given season. This automated pipeline will help to perform systematic, structurally concerned assessments of plates, stiffeners, diaphragms or other subsets of the asset in an orderly fashion. Accessing open BIM standards such as the Industry Foundation Class (IFC) (EN ISO 16739-1[7]) is vital when integrating bridge information in vaster information constructs. For the latter, measurements require establishing semi-automated processes of identification of initial imperfections of the steel plates for subsequently, integrating such geometries in potential advanced inelastic FE simulations for structural analysis at different levels. The structural remaining life of the asset can be continuously assessed.

[7] EN ISO 16739-1:2020 "Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries - Part 1: Data schema (ISO 16739-1:2018)"

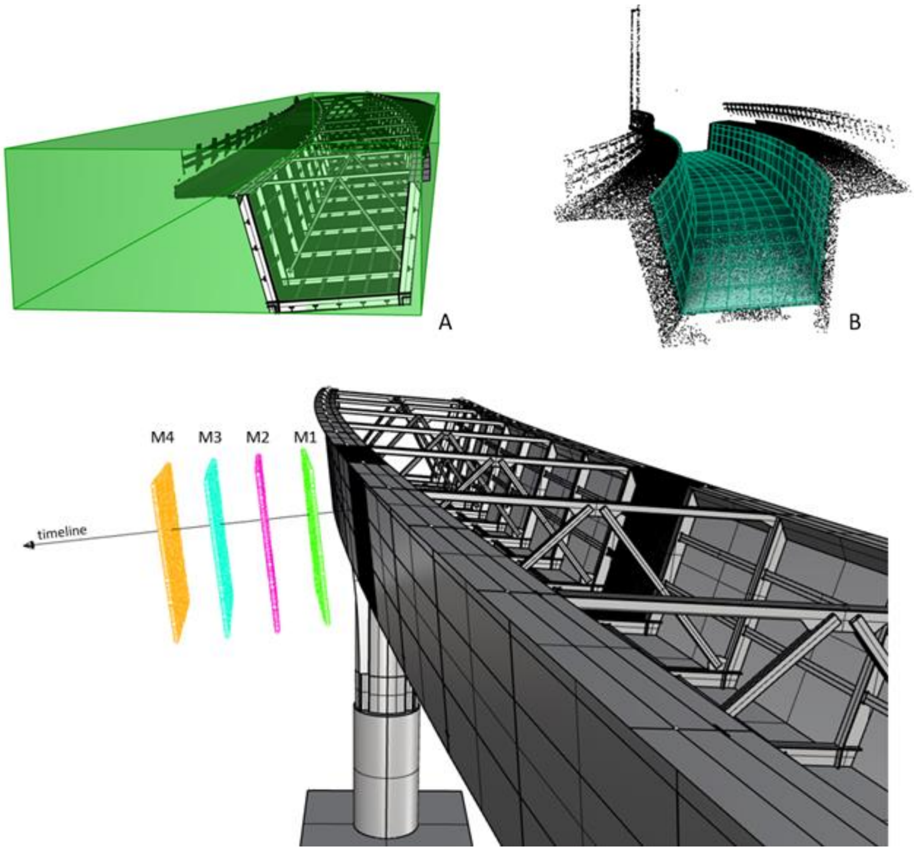

Figure 7 Multiple scans (M1 to M4) result in overlayed point clouds that are associated with the elements of the bridge and are used for simulation

In addition, measurements on accelerations are gathered for the sake of inferring structural information related to the vibrational condition of the asset. Accelerations are also measured as an indirect assessment of the road joints. Visual Inspection forms are also part of the digitization of the asset.

e. <u>Replication potential</u>

The potential of digital twinning of bridges is considerable. Assets are counted in Europe by the thousands. However, it is worth pointing out that priorities and plans for digitization of bridges will be deployed by owners according to the available resources. Some assets will require sophisticated twinning whereas others, will not.

4.1.2.3 Construction of an office building - Demo 6 ("case study 18") – Office building, Spain, Barcelona[8]

a. General information

Typology: Office building

Location: Barcelona, Spain

Asset owner: Private owner

b. Main use of the DT

Research is based on a case study of an office building that has been used as a testbed for developing an exemplary version of a digital twin of the entire construction process. The digital twin prototype is designed to mirror the physical building and its systems, enabling real-time monitoring and analysis of various parameters during construction. In particular, the research project was granted access to a specific module of the whole compound.

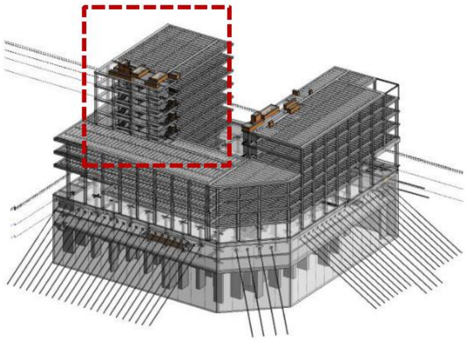

Figure 8 Accessed module of the RC structure

c. Description of the DT

The case study is a RC building located in the Barcelona district of Poble Nou. BIS structures, a Barcelona-based structural engineering office, together with many other stakeholders, agreed upon collaborating with ASHVIN by facilitating access to MILE – a Business Campus project construction site. MILE is an office buildings project of 38.093 m^2, divided into three complexes: MILE Badajoz, MILE Llull, and MILE Ávila. The access was provided for one specific module, a cast-in-place reinforced concrete building of long-spanned post-

[8] Relevant documents and links:
Conference papers:
Posada, H.; Chacon, R.; Ungureanu, L.; Garcia Carrera, D. (2022). Closing the gap between concrete maturity monitoring and nonlinear time-dependent fem analysis through a digital twin. Case study: post-tensioned concrete slab of an office building, Barcelona, Spain. International Symposium on Automation and Robotics in Construction. Bogotá, Colombia.
Jungmann, M.; Ungureanu, L.; Hartmann, T.; Posada, H.; Chacon, R. (2022). Real-time activity duration extraction of crane works for data-driven discrete event simulation. Winter Simulation Conference. Singapoure.
Journal papers:
Rolando Chacón, Hector Posada, Carlos Ramonell, Manuel Jungmann, Timo Hartmann, Rehan Khan, Rahul Tomar. "Digital twinning of building construction processes. Case study: a reinforced concrete cast-in structure". Submitted for publication to the Journal of Building Engineering.

tensioned slabs, consisting of eight levels, and a total area of 16.524 m^2. Access to MILE was granted for the study within the premises of a specific module of the building, during the erection of the concrete frame (approximately 6 months).

Figure 9 Office building render, finished building and developed dashboard

d. <u>Main improvements beyond the state of the art</u>

The DT the varied nature of data in construction sites as well as the importance of proper data channelling to enable effective decision-making using the digital twin. Overall, the use case provides insights into the development and implementation of a digital twin for an office building, highlighting its potential to improve productivity, resource efficiency, health and safety in construction environments.

One interesting achievement and improvement is related to including different data-collection techniques and to developing different automated information pipelines during construction. Figure 11 summarizes the implemented pipelines. From sensors to assessment (using performance indicators), these pipelines erect the frame of the whole DT in Standard construction processes or RC buildings.

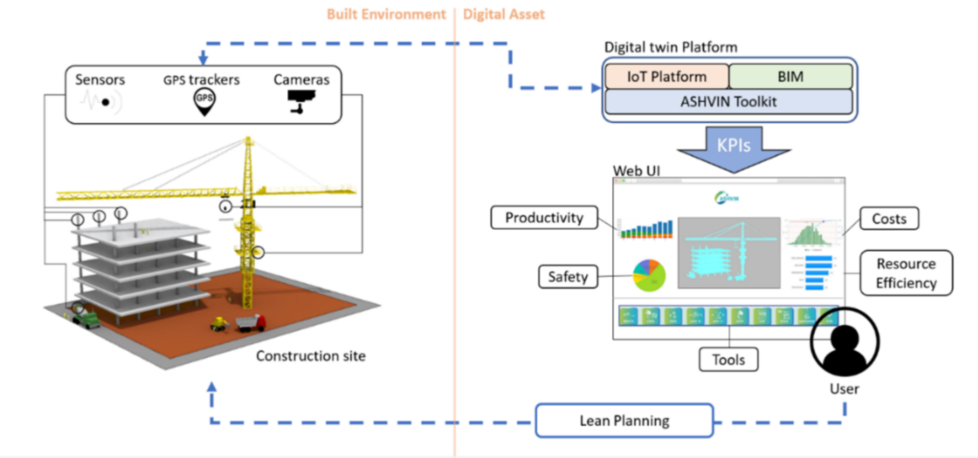

Figure 10 Information layers organized for end-users

Name	Data collection	Stakeholders	Simulation	Application	Performance indicator
PCL	Spatial position of the crane load. IMU sensors	Crane operators/ Construction managers/ Concrete supplier	Discrete Event Simulation	Analysis of the sequence of concrete casting. Identification of bottlenecks and potential improvement	Construction duration, Worker's productivity, Crane productivity, Utilization rate crane, safety factor and personnel costs
LS	Longitudinal strain during slab post-tensioning	Post-tensioning suppliers/ Construction managers	Structural analysis of the tensioning process	Timely analysis of adequate tensioning of the slabs. Component properties	Integrity of structural components, strength of structural components, productivity
SD	Slab deflection using laser scanning	Formwork staff/ Construction managers	Point cloud analysis	Timely control of the slab deflection.	Percentage Plan Complete, Productivity, Strength of structural components
CM	Temp. of fresh concrete	Concrete suppliers/ Construction managers	Nonlinear time-dependent structural analysis	Advanced analysis may allow to reduce formworks and accelerate unshoring	Integrity of structural components, strength of structural components, productivity
AV	Acceleration during vibration	Concrete suppliers/Casting staff/Constructio n managers	Signal processing of the measurements	Identification of adequate vibration time (energy-wise, quality-wise)	Productivity, adequate concrete vibration, energy consumption and percentage plan completed
CPM	Construction progress monitoring	Construction managers	Prediction of construction performance	Evaluation of the expected project's progress and performance	Productivity, percentage plan completed

Figure 11 Information pipelines implemented during twinning of the building

e. <u>Replication potential</u>

The potential of digital twinning of buildings during construction is considerable yet very varied in nature. This particular use case focused on twinning structural behaviour of the asset during construction as well as on logistics. This was due to the boundary conditions presented by the construction firms as well as the owners. However, it is worth pointing out that priorities and plans for digitization of buildings will be deployed by owners and constructors according to their needs and expertise.

4.1.2.4 Load Tests in Railways Bridges - Demo 1 ("case study 19") – Railways infrastructure, Spain, Extremadura[9]

a. General information

Typology: Railways infrastructure

Location: Extremadura, Spain

Asset owner: ADIF (Administración de Infrastructuras Ferroviarias, SPAIN).

b. Main use of the DT

Load tests represent a routine episode for all bridges. Presently, its report is a pdf document. The objective of the DT is the generation of a calibrated DT for use during operation. The DT includes measurements, simulations, IFC-based geometry and analysis with seamless matching connections between all information sources.

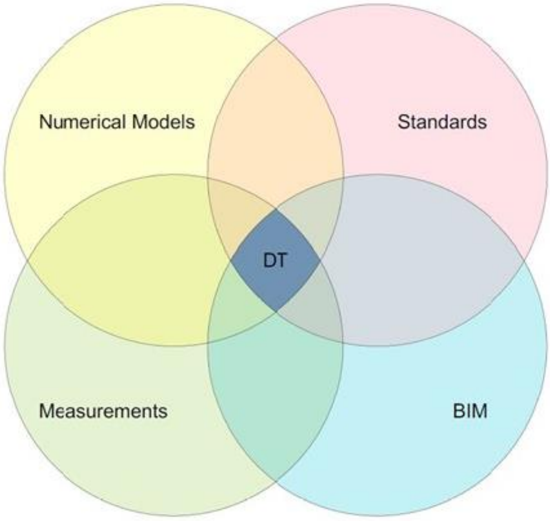

Figure 12 Layers added to the digital twin

c. Description of the DT

A series of railways bridges were tested systematically by ADIF and DRACE (formerly GEOCISA) in 2021. Access to five bridges was granted to ASHVIN researchers under the form of collaboration. These bridges represented testbeds that allowed conceptualizing needs and thus, developing DTs with

[9] Relevant documents and links:
Conference papers:
Ramonell, C.; Chacon, R. (2022). Towards automated pipelines for processing load test data on a hs railway bridge in Spain using a digital twin. International Symposium on Automation and Robotics in Construction. p. 231-237
Chacon, R.; Posada, H .; Ramonell, C.; Sierra, P.; Rodriguez Gonzalez, A.; Koulalis, I.; Ioannidis, K.; Vrochidis, S.; Tomar, R.; Freitag, S.; Wagmeister, S.; Teodorovic, M. (2022). On the digital twinning of routine load tests in railway bridges. Case study: high speed railway network, Extremadura, Spain. International Conference on Bridge Maintenance, Safety and Management. DOI: 10.1201/9781003322641-98
Dissemination video: https://www.youtube.com/watch?v=8BTwK6iKuzc
Journal papers:
Rolando Chacón, Hector Posada, Carlos Ramonell, Pablo Sierra, Rahul Tomar, Christian Martinez de la Rosa, Alejandro Rodriguez, Ilias Koulalis, Konstantinos Ioannidis, Stefan Wagmeister "Digital twinning during load tests of railway bridges. Case Study: High Speed Railway Network, Extremadura, Spain". Accepted for publication in Structure and Infrastructure Engineering. September 2023.

realistic needs. Measurements, simulations, and assessment were put together. Two viaducts (Valdelinares and la Plata) were twinned in detail.

Figure 13 Valdelinares Viaduct, 8 simply supported spans, and La Plata Viaduct, 4-spanned continuous concrete beam

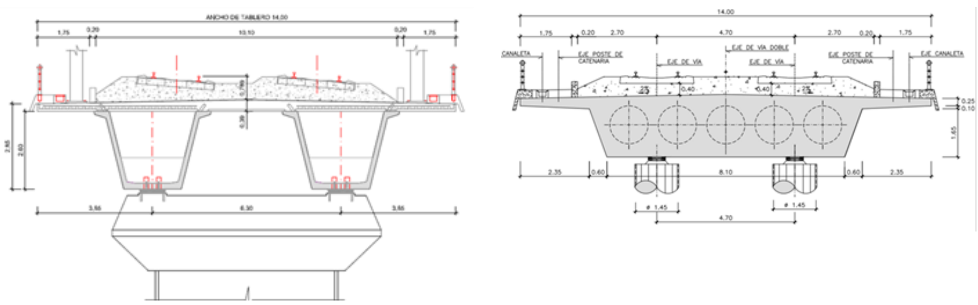

Figure 14 Structures under study

d. <u>Main improvements beyond the state of the art</u>

Presently, valuable information gathered during a load test is collected in pdf forms. Access to this information in a geometrically meaningful way is not yet commonplace. The DT would represent an ideal starting point with calibrated models and properly gathered information for future control of those infrastructure systems. In this particular case, KPIs related to the accuracy of the models, the digital knowledge of the asset (geometry, material) as well as other singularities of the asset can be also computed.

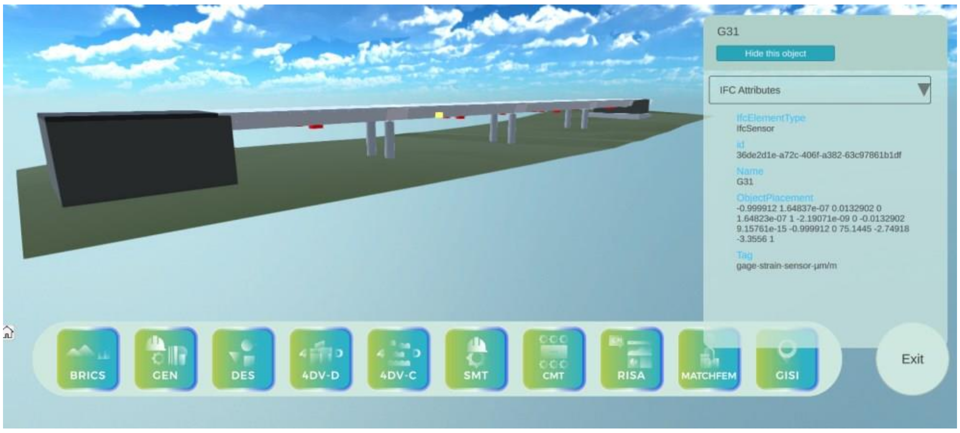

Figure 15 La Plata Viaduct featured in the developed platform

e. Replication potential

The potential of digital twinning of railways bridges during load testing episodes is considerable. Load tests are performed yearly and routinely in Europe by the hundreds. Presently, considerable efforts on logistics, measurements, models, and analysis are put while testing. The additional effort related to digitization adds a considerable value to the load test but not necessarily, a considerable cost.

4.1.2.5 Planning and optimization of maintenance activities on airports using unmanned aerial vehicles (UAVs) ("case study 21") – Airport, Croatia, Zadar[10]

a. General information

Typology: Airport

Location: Zadar, Croatia

Asset owner: 55% owned by the Republic of Croatia, Zadar County with 20%, the city of Zadar also with 20%, and the municipality of Zemunik Donji with 5%

Building Digital Twin (BDT) manager: ASHVIN

b. Main use of the DT

Implementing the ASHVIN digital twin in the airport focuses on digitalization of airport infrastructure with the purpose of optimizing maintenance and operational planning. The main idea for this demonstration project is the use of images of operational areas of the airport collected with unmanned aerial vehicles (UAVs) which is then used for planning and optimization of maintenance activities.

c. Description of the DT

DT is developed containing detailed structure information about the runway layout, materials, drainage systems and signage. It will be combined with the Airport Operational Database (AODB) and inspection data performed with Unmanned Aerial Vehicles (UAVs). Two interdependent tools were developed to enable establishment of a risk-based predictive maintenance planning, a riskbased status assessment tool with KPI dashboard and a GIS integrator for digital twin-based asset management.

[10] Relevant documents and links:
Stipanovic I., Skaric Palic S., Ramon Casas J., Chacón R., Ganic E., 'Inspection and maintenance KPIs to support decision making integrated into Digital Twin tool', EUROSTRUCT 2023 – 2nd Conference of the European association on quality control of bridges and structures.

Figure 16 Airport, Croatia, Zadar - Use of images of operational areas of the airport collected with unmanned aerial vehicles (UAVs)

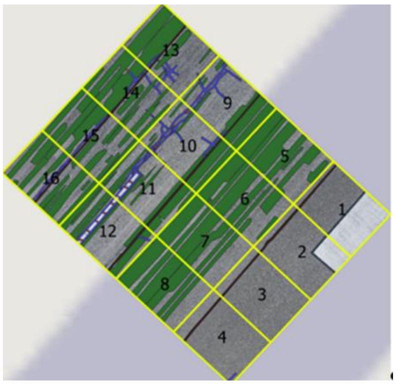

Figure 17 Airport, Croatia, Zadar - Drone-based images for the automation of the visual inspection and damage detection and classification procedures of operational areas of the airport

d. <u>Main improvements beyond the state of the art</u>

The developed methodology for digitalization and automation of inspection and monitoring processes of operational areas, are integrated into GIS based predictive maintenance tool. Deep machine learning techniques are applied on drone-based images for the automation of the visual inspection and damage detection and classification procedures. Collected data is transformed into single safety KPI related to the condition and structural safety. Based on that KPI, consequence analysis is performed which includes other KPIs, like productivity, costs, resource efficiency and health and safety, which are then finally implemented into risk-based maintenance planning. The use of UAVs is also integrated into regular inspection procedures for the monitoring of the airport infrastructure.

Current airport practice includes visual assessment of the condition of operational areas with the aim to detect new damages, snow covered areas, wet areas etc., performed manually by person walking or most common driving in the car. This is performed several times per day, usually without registering any damages and purely based on the naked eye of the inspector. Introducing automatization into the process allows registering of changes on the operating surface (pavements, fences, equipment, ...) before major damage occurs and potential detection of friction problems (changes in microstructure on the surface) through detection of changes in quantity of tire marks on the pavement surface.

GIS tool allows the visualization of condition assessment results using safety PIs. The risk tool uses the results of numerical modelling and GIS tools as a KPI for the assessment of infrastructure performance.

Selection of maintenance strategy can vary from no maintenance and just monitoring, to minor or major repair and finally replacement. The risk tool takes into account consequences of different maintenance options and illustrates the risk for different maintenance strategies. Once the risk is calculated by applying the RISA tool, the result is then returned into the numerical modelling and GIS tool to visualize impacts on the safety in the 2D or 3D model.

e. Replication potential

UAVs have demonstrated a significant potential for usage in the inspection and assessment of different infrastructure assets, including airports. In comparison to conventional inspection techniques, the use of UAVs for condition assessment of airport operational areas has shown to have several advantages, including increased accuracy, speed, and cost-effectiveness. The use of UAVs for risk-predictive maintenance for different types of infrastructure assets has a high replication potential. In reality, a variety of businesses and organizations, including those in the energy, transportation, and telecommunications sectors, have already begun deploying UAVs for asset inspection and monitoring. Predictive maintenance models can be created using the data gathered from UAV inspections, allowing for the early identification and prevention of possible problems before they propagate. Risk predictive maintenance planning using UAVs data collection on various types of structures increases productivity, decreases human effort and downtime, and improves workers safety. It is important to stress that proper training, certification, and regulatory compliance will be required for the use of UAV technology for infrastructure asset inspection and maintenance. The usage of UAVs must be done in accordance with regional rules and regulations as well as appropriate safety precautions to guarantee the efficient and safe functioning of these systems.

4.2 New Work Item Proposal NWIP "Digital twinning of bridges during diagnostic load testing"

4.2.1 Procedure of development

Based on the standardization workshop result on idea 3 "Load tests of bridges in a digital way (demo site 1)" (see 3.3) but also on the work on the use case/case study for the ongoing standardization project on CEN/TR 18077 (see 4.1.2.4) it was decided to continue work on the feasibility of a NWIP "Digital twinning of bridges during diagnostic load testing".

Already in 2022, this potential topic for future standardization was presented by UPC (Rolando Chacón) to the Technical Committee "Load test for bridges" (CEN/TC 250/SC 1, Eurocode 1: Actions on structures) at the IABMAS (International association for bridge maintenance and safety) conference. This consortium sees great potential for the applicability of a suitable standard due to the enormous amount of construction and maintenance work on bridges across Europe and worldwide.

By founding CEN/TC 442/WG 9 in 2022, now there is also a responsible committee existing that could take care of future development.

In 2023, in parallel to the contributions to the CEN Technical Report (CEN/TR 18077), intensive work was carried out on the completion of the NWIP (see Annex A) and a basic paper[11] which is used as a concept for the further procedure (UPC and ASI). The aim was to present the project to the future responsible working group. In December 2023 ASHVIN consortium was asked for comments on the proposal.

At the beginning of 2024, the project idea for the NWIP was presented in the first step to the convenor and the secretary of the responsible working group (CEN/TC 442/WG 9) and in the second step to the entire working group. The aim was to create understanding and attention for this idea so that (in the best case) the working group itself do the official act "Submission of a NWIP to CEN/TC 442" in March 2024. The discussion so far in the WG 9 working group suggests great interest. The potential and advantages of such a standard project were understood and noted favourably (e.g. tackling operation and maintenance of bridges more efficiently, productively, and safely, streamlining operations and reducing costs, ensuring the safety and structural integrity of the bridge by simulating various load conditions).

4.2.2 Main content of the NWIP

Complete content is given in Annex A.

Scope: *This proposal for a Technical Specification (TS) focuses exclusively on diagnostic load testing of bridges, a critical aspect in assessing and ensuring the structural integrity and safety of these infrastructures. The core of the proposal is the standardization of information delivery in several key areas,*

[11] Journal paper:
Rolando Chacón, Hector Posada, Carlos Ramonell, Pablo Sierra, Rahul Tomar, Christian Martinez de la Rosa, Alejandro Rodriguez, Ilias Koulalis, Konstantinos Ioannidis, Stefan Wagmeister "Digital twinning during load tests of railway bridges. Case Study: High Speed Railway Network, Extremadura, Spain". Accepted for publication in Structure and Infrastructure Engineering. September 2023.
https://www.tandfonline.com/doi/full/10.1080/15732479.2023.2264840?src=

utilizing up-to-date measurement technologies and established industry standards to optimize and streamline bridge assessment processes:

- *Standardization of information delivery concerning measurements obtained.*
- *Standardization of information delivery relating to the geometry of the bridge. This can be achieved using open BIM data such as Industry Foundation Classes (IFC), an established data model intended to describe building and construction industry data.*
- *Standardization of the delivery of information related to the simulations of the asset, specifically in the context of structural analysis. This involves establishing common protocols and formats for presenting and exchanging simulation data, thereby ensuring that the simulations are based on consistent and verifiable data. This standardization is crucial for accurate modelling and for understanding how the bridge will behave under various stress scenarios.*
- *Standardization of information delivery for comparisons between models and real-world measurements using Key Performance Indicators (KPIs).*

How Stakeholders benefit:

This proposal presents a comprehensive framework enabling asset owners to digitally harness information throughout the service life of their bridges. The digitization and standardization of data collection and analysis procedures, as outlined in this proposal, offer several significant advantages for various stakeholders involved in the lifecycle of a bridge.

In essence, the proposed approach revolutionizes the way information is used in the lifecycle of bridge infrastructure. From the initial design and construction phases to ongoing maintenance and eventual decommissioning, every stage is enhanced by the availability of standardized, high-quality data, leading to safer, more efficient, and cost-effective bridge management.

4.2.3 Further steps

At the last meeting of CEN/TC 442/WG 9 (March 5, 2024), the official handover of the proposal to CEN/TC 442 was discussed (UPC and ASI attended).

During this meeting it was agreed that UPC and ASI would present the project idea at the next plenary meeting of CEN/TC 442. An official vote can then be initiated among the CEN members. Of course, it remains to be seen how CEN members will vote in the official vote on the NWIP.

Rolando Chacón (UPC) is committed to lead the project as a Task Leader within CEN/TC 442/WG 9.

5 STANDARDIZED PROCESSES – ASHVIN USE CASES

ASHVIN Use Cases (see D7.2) have been developed and documented, based on Information Delivery Manual (IDM) standards (EN ISO 29481-series[12]), to aid standardization practices and open accessibility within the industry. Use case approach was used to transparently document and communicate to industry the implementation process of ASHVIN platform and tools on demonstration projects. The use cases were developed based on the template provided by the BuildingSMART[13] (www.buildingsmart.org, https://ucm.buildingsmart.org/) using IFC (industrial foundation classes) as a neutral and open specification for BIM.

This process of documentation of the demonstration activities is based on ISO 29481-1: 2016 (Building information models - Information delivery manual) and it ensures a common language and a uniform understanding of BIM/digital twin applications (use cases) within the entire construction and real estate industry. Standardized use cases enable the capture and specification of exchange and actors involved in a unified manner, to ensure the implementation of best practices, which are accessible to all members within the built industry. A list and detailed description of the developed ASHVIN use cases with related tools is provided in D7.2.

6 CONCLUSIONS

Through the chosen process of standardization workshops (generating, evaluating and prioritizing potential standardization ideas), condensing the topics into “deep dives”, feedback from ASHVIN’s Advisory Board and finally active engagement with and participation in the CEN/TC 442/WG 9 working group, it was possible in this task T6.2 to help shape essential standard content as part of the development of CEN/TR 18077 and thus to make essential results from ASHVIN in the form of use cases/case studies for digital twins known and accessible to a wide range of users in the near future and, on the other hand, to initiate an NWIP for a Technical Specification (CEN/TS) on the subject of "Digital twinning of bridges during diagnostic load testing".

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Ramonell C., Chacón R. (2023). Seasonal analysis of a 846 long steel box girder bridge using Terrestrial Laser Scanners (TLS) and FE-models. Proceedings of the Annual Stability Conference Structural Stability Research Council. AISC-SSRC. North Carolina, USA.

Chacon, R.; Ramonell, C.; Puig-Polo, C.; Mirambell, E. (2022). Geometrical digital twinning of a tapered, horizontally curved composite box girder bridge. International

[12] EN ISO 29481-series:
EN ISO 29481-1 "Building information models - Information delivery manual - Part 1: Methodology and format (ISO 29481-1:2016)"
EN ISO 29481-2 "Building information models - Information delivery manual - Part 2: Interaction framework (ISO 29481-2:2012)"
EN ISO 29481-3 "Building information models - Information delivery manual - Part 3: Data schema (ISO 29481-3:2022)"

[13] BuildingSMART is an international organisation which aims to improve the exchange of information between software applications used in the construction industry.

Colloquium on Stability and Ductility of Steel Structures. Aveiro, Portugal. p. 52-58. DOI: 10.1002/cepa.1727

Rolando Chacón, Hector Posada, Carlos Ramonell, Manuel Jungmann, Timo Hartmann, Rehan Khan, Rahul Tomar. “Digital twinning of building construction processes. Case study: a reinforced concrete cast-in structure”. Submitted for publication to the Journal of Building Engineering.

Chacon, R.; Posada, H .; Ramonell, C.; Sierra, P.; Rodriguez Gonzalez, A.; Koulalis, I.; Ioannidis, K.; Vrochidis, S.; Tomar, R.; Freitag, S.; Wagmeister, S.; Teodorovic, M. (2022). On the digital twinning of routine load tests in railway bridges. Case study: high speed railway network, Extremadura, Spain. International Conference on Bridge Maintenance, Safety and Management. DOI: 10.1201/9781003322641-98 Dissemination video: https://www.youtube.com/watch?v=8BTwK6iKuzc

Rolando Chacón, Hector Posada, Carlos Ramonell, Pablo Sierra, Rahul Tomar, Christian Martinez de la Rosa, Alejandro Rodriguez, Ilias Koulalis, Konstantinos Ioannidis, Stefan Wagmeister “Digital twinning during load tests of railway bridges. Case Study: High Speed Railway Network, Extremadura, Spain". Accepted for publication in Structure and Infrastructure Engineering. September 2023.

Rolando Chacón, Hector Posada, Carlos Ramonell, Pablo Sierra, Rahul Tomar, Christian Martinez de la Rosa, Alejandro Rodriguez, Ilias Koulalis, Konstantinos Ioannidis, Stefan Wagmeister “Digital twinning during load tests of railway bridges. Case Study: High Speed Railway Network, Extremadura, Spain". Accepted for publication in Structure and Infrastructure Engineering. September 2023. https://www.tandfonline.com/doi/full/10.1080/15732479.2023.2264840?src=

Posada, H.; Chacon, R.; Ungureanu, L.; Garcia Carrera, D. (2022). Closing the gap between concrete maturity monitoring and nonlinear time-dependent fem analysis through a digital twin. Case study: post-tensioned concrete slab of an office building, Barcelona, Spain. International Symposium on Automation and Robotics in Construction. Bogotá, Colombia.

M. Jungmann, L. Ungureanu, T. Hartmann, H. Posada and R. Chacon, "Real-Time Activity Duration Extraction of Crane Works for Data-Driven Discrete Event Simulation," 2022 Winter Simulation Conference (WSC), Singapore, 2022, pp. 2365-2376, doi: 10.1109/WSC57314.2022.10015250.

M. Jungmann and T. Hartmann, “D4.2 Discrete Event Simulation Formalism for Productive, Resource Efficient, and Safe Construction Planning” Deliverable 4.2 ASHVIN. 2022, https://doi.org/10.5281/zenodo.7220125

Jungmann, M.; Ungureanu, L.; Hartmann, T.; Posada, H.; Chacon, R. (2022). Real-time activity duration extraction of crane works for data-driven discrete event simulation. Winter Simulation Conference. Singapoure.

Ramonell, C.; Chacon, R. (2022). Towards automated pipelines for processing load test data on a hs railway bridge in Spain using a digital twin. International Symposium on Automation and Robotics in Construction. p. 231-237

Stipanovic I., Skaric Palic S., Ramon Casas J., Chacón R., Ganic E., ‘Inspection and maintenance KPIs to support decision making integrated into Digital Twin tool’,

EUROSTRUCT 2023 – 2nd Conference of the European association on quality control of bridges and structures.

ANNEX A: TEMPLATE NWIP "DIGITAL TWINNING OF BRIDGES DURING DIAGNOSTIC LOAD TESTING"

New Work Item Proposal	
* to be attached to the CIB	
CEN/TC 442 – Building Information Modelling	
Secretariat:	Proposal documented in N xx
Date of circulation:	Closing date for voting:
Decision reference:	Decision date:

Proposal

0. This proposal relates to

☒ the adoption of a New Work Item in the committee's work programme (stage 10.99)

☒ the adoption of a Preliminary Work Item in the committee's work programme (stage 00.60)

☐ the activation of a Preliminary Work Item in the committee's work programme (stage 10.99): PWI *XXXXX*

1. Deliverable

☐ European Standard (EN)

☒ Technical Specification (TS)

☐ Technical Report (TR)

2. This item corresponds to

☒ A new project

☐ An amendment to the EN *XXX*

☐ The revision of EN *XXX*

☐ The conversion of TS *XXX* into an EN *XXX*

☐ The revision of TS *XXX*

☐ The revision of TR *XXX*

2.1 - Only for WIs of CEN/TCs (not applicable to CEN-CLC/JTCs WIs): if this item corresponds to an amendment/revision of an EN indicate if:

☐ the scope will change (weighted vote required - select the right option in the CIB)

☐ the scope will not change (simple majority vote required - select the right option in the CIB)

3. Explain the purpose and give a justification for this proposal (max 4000 characters). This text should provide information on technical topics to be discussed.

Bridge load testing can answer a variety of questions about bridge behaviour that cannot be answered otherwise. Load tests for bridges are broadly categorized into diagnostic load tests and proof load tests. Diagnostic load testing aims to evaluate and refine analytical models used in bridge design and assessment. In the case of new bridges, it helps confirm that the bridge performs as expected. For older bridges, it's useful for updating models that inform decisions like load ratings or special load permits. On the other hand, proof load testing is conducted to verify that a bridge can safely support loads as per the standards set by relevant codes or specifications. This involves applying a load that matches the combination specified in the governing codes to the bridge. If the bridge sustains this load without showing distress, the test is deemed successful, indicating the bridge's compliance with the specified load-bearing requirements. Most bridges require diagnostic load testing before entering the service stage. Proof load tests are "only" performed in limited special cases.

Load tests are required in both road and railways bridges but there is a difference between both types of assets:

- A road bridge is a structure constructed for the purpose of carrying varied load traffic. Roads cover countries, regions, cities, and rural areas. The traffic on road bridges depends on many factors ranging from importance of the infrastructure system to its location. Road bridges are managed by a large variety of owners ranging from public city councils or Ministries to large private investors. Management of road bridges is seldom concentrated on a single institution.

- A railroad bridge is a structure constructed for the exclusive purpose of carrying railroad traffic across an obstruction. Railways infrastructure systems are generally more centralized, and their management involves maintenance in close relationship with the operation of the railways network.

The development of load tests presumes the use of controlled loads (trucks, locomotives, wagons) under controlled scenarios and it also implies deploying a considerable amount of sensors and data acquisition systems. Deploying such tests on real assets is costly, time-consuming and requires careful planning. It represents a major episode on the asset in which logistics, measurements and comparisons with existing analytical models are put together by multidisciplinary teams. The result of the test is generally a standardized report (based on Eurocodes an additional "National Annexes" on Eurocodes) with written information about the asset's behaviour.

One question arises: Can load tests be also used as the episode the digitalization of bridge assets?

Since considerable physical efforts are put on these assets by stakeholders, creating a comprehensive set of standardized information to feed a vast-scoped digital twin of the asset seems to be cost-effective. During a load testing episode, stakeholders may leverage all efforts related to costs, logistics and planning. The result of the load test can be not only a written report but also, a useful digital asset for maintenance purposes by owners and managers that can be retrieved at any time but most importantly, adequately updated along its lifespan.

4. Titles

English title: Digital twinning of bridges during diagnostic load testing

5. Scope of the proposed work item (max 4000 characters)

This proposal for a Technical Specification (TS) focuses exclusively on diagnostic load testing of bridges, a critical aspect in assessing and ensuring the structural integrity and safety of these infrastructures. The core of the proposal is the standardization of information delivery in several key areas, utilizing up-to-date measurement technologies and established industry standards to optimize and streamline bridge assessment processes:

1. Standardization of information delivery concerning measurements obtained.
   (Note: Ideally, this information delivery should be based on adequately secured Internet of Things (IoT) technologies. By harnessing IoT devices for data collection, information can be leveraged by other stakeholders when needed. However, the vast amount of data generated by IoT sensors necessitates a structured and standardized approach to data handling and analysis. This standardization will not only improve data accuracy and reliability but also enhance the interoperability of data across different platforms and stakeholders.)

2. Standardization of information delivery relating to the geometry of the bridge. This can be achieved using open BIM data such as Industry Foundation Classes (IFC), an established data model intended to describe building and construction industry data.
   (Note: IFC provides a universal language and structure for describing the complex geometries of bridges, ensuring that the geometric data is consistent, accurate, and easily shareable among the various professionals and software environments involved in bridge analysis and maintenance.)

3. Standardization of the delivery of information related to the simulations of the asset, specifically in the context of structural analysis. This involves establishing common protocols and formats for presenting and exchanging simulation data, thereby ensuring that the simulations are based on consistent and verifiable data. This standardization is crucial for accurate modelling and for understanding how the bridge will behave under various stress scenarios.

4. Standardization of information delivery for comparisons between models and real-world measurements using Key Performance Indicators (KPIs).
   (Note: KPIs offer a quantifiable measure of performance over time for a specific objective, making them an ideal tool for comparing the results of simulations with actual measurements. By standardizing the use of KPIs, the proposal ensures that comparisons are made using consistent criteria, thereby enhancing the credibility and usefulness of the assessments.)

6. Digital aspects

☐ The deliverable is intended to be developed using the Online Collaborative Authoring platform

☒ The deliverable is intended to include non-Word/PDF content, e.g. audio files, XML schemas, machine-readable formats or software.
Please provide details of the non-Word/PDF content:

☐ None of the above.

If yes to either of these questions, CCMC will contact you for feasibility and organizational aspects.

7. Stakeholder categories immediately affected by the proposal

☒ Industry and commerce	☐ Societal consumer groups	☒ Standards application
☒ SMEs	☐ Labour	☐ Non-governmental organization (NGO)
☒ Government	☒ Academic and research bodies	☐ Environmental stakeholders
☐ Consumers		
☐ None of the above categories		

8. How will these Stakeholders benefit from or be impacted by the proposed deliverable?

This proposal presents a comprehensive framework enabling asset owners to digitally harness information throughout the service life of their bridges. The digitization and standardization of data collection and analysis procedures, as outlined in this proposal, offer several significant advantages for various stakeholders involved in the lifecycle of a bridge.

- For asset owners, this approach provides the capability to utilize digital information effectively during the service period of the bridge. This real-time, data-driven insight into the bridge's condition allows for more informed decision-making regarding maintenance and safety measures. Additionally, owners can formulate tendering processes for diagnostic load testing with clearly defined, detailed requirements. By specifying these requirements, asset owners ensure that the bidding companies adhere to high standards of data collection and analysis, thereby enhancing the overall quality and reliability of the diagnostic tests.

- Bidding companies, in response to these well-defined tender requirements, are expected to deliver more transparent and accurate information regarding measurements, geometry, and simulations of the bridge. While this might entail a greater initial effort, it is an investment that pays dividends in the long run. Standardized, high-quality data leads to better-informed decisions, fewer errors, and potentially lower long-term costs due to more efficient maintenance and fewer unexpected repair needs.

- For design offices and bridge contractors, this standardized information schema becomes a valuable resource from the outset. It allows them to refine their models in alignment with the specific needs and conditions of the bridge, right from the design and execution phases. This proactive approach in model updating can significantly reduce the likelihood of future discrepancies between the designed model and the actual behaviour of the bridge.

- Maintenance planners stand to gain considerably from this approach as well. With access to accurately gathered and standardized information, they can effectively incorporate this data into the future digital twins of the bridges. These digital twins then serve as comprehensive, dynamic replicas of the physical bridges, enabling maintenance planners to simulate various scenarios, predict potential issues, and plan maintenance activities with a higher degree of precision.

In essence, the proposed approach revolutionizes the way information is used in the lifecycle of bridge infrastructure. From the initial design and construction phases to ongoing maintenance and eventual decommissioning, every stage is enhanced by the availability of standardized, high-quality data, leading to safer, more efficient, and cost-effective bridge management.

9. Document developed in drafting body ☒ Existing drafting body *(please give name and title)*: CEN/TC 442/WG 9 "Digital twins in the built environment" ☐ New drafting body *(please give name and title)*:
10. Proposed Project Leader (including contact details) - *Optional*
11. United Nations Sustainable Development Goals (SDGs) **Please select any United Nations Sustainable Development Goals (SDGs) that this document will support. For more information, please visit the SDG section of the CEN website (currently under development).** ☐ **GOAL 1:** No Poverty ☐ **GOAL 2:** Zero Hunger ☐ **GOAL 3:** Good Health and Well-being ☐ **GOAL 4:** Quality Education ☐ **GOAL 5:** Gender Equality ☐ **GOAL 6:** Clean Water and Sanitation ☐ **GOAL 7:** Affordable and Clean Energy ☐ **GOAL 8:** Decent Work and Economic Growth ☒ **GOAL 9:** Industry, Innovation and Infrastructure ☐ **GOAL 10:** Reduced Inequality ☐ **GOAL 11:** Sustainable Cities and Communities ☐ **GOAL 12:** Responsible Consumption and Production ☐ **GOAL 13:** Climate Action ☐ **GOAL 14:** Life Below Water ☐ **GOAL 15:** Life on Land ☐ **GOAL 16:** Peace and Justice Strong Institutions (N/A **GOAL 17:** Partnerships to achieve the Goal) ☐ None of the above Proposed rationale for the selected SDG(s)- (optional):
12. Accessibility aspects *See CEN-CENELEC Guide 6:2014 'Guide for addressing accessibility in standard'* ☐ Accessibility aspects are relevant for this NWI *(please indicate which ones):* *See the 'protocol' to help you decide when accessibility following a Design for All approach is relevant:* https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/accessibility/design-for-all/ ☒ Accessibility aspects are not relevant for this NWI *Please provide a written explanation detailing why accessibility aspects do not apply to the current proposed WI:*
13. Environmental aspects

☐ Discharges to soil ☐ Discharges to water ☐ Emission to air
☐ Heat ☐ Noise/Vibration ☐ Use of land
☐ Radiation ☐ Use of energy ☐ Other effects on biodiversity
☐ Use of material ☐ Use of water ☐ Waste
☒ Risk to the environment from accidents/misuse ☐ Chemicals

☐ Other:

☒ None of the above.

Please provide a written explanation detailing why these environmental aspects do not apply to the current proposed WI:

This proposal exclusively focuses on digital aspects, emphasizing the standardization and digitization of information related to bridge assets, from diagnostic load testing to maintenance planning. It involves digital tools and methods such as IoT for data collection, IFC for geometry representation, and the creation of digital twins for ongoing asset management. However, it's important to note that this proposal does not directly address environmental aspects. The scope is confined to enhancing digital methodologies and data standardization for bridge infrastructure, without delving into environmental impacts or sustainability considerations. The emphasis is on leveraging digital technology to improve efficiency, accuracy, and transparency in the management and maintenance of bridge assets, with environmental factors remaining outside the purview of this proposal.

14. How do you plan to address these environmental aspects?

☐ Bring in environmental expertise to the WG

☐ Contact EHD for help/support (cen.ehd@cencenelec.eu) and/or use examples from Environmental Framework
https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/environment-and-sustainability/environmental-helpdesk-and-trainings/

☐ Use of environmental checklist and guides (please visit the dedicated section in the CEN website
https://boss.cen.eu/reference-material/guidancedoc/pages/environment/

☐ Other**:**

15. Vienna Agreement (parallel procedure)

☒ No or Vienna Agreement with CEN lead proposed

☐ Yes – Vienna Agreement Parallel with ISO Lead

ISO project reference:
ISO project ID:
ISO/TC:

16. The project is based on

☐ No document from another organization

☐ An ISO or ISO/IEC document (not covered by a parallel procedure)

☐ Identical

☐ Non-identical

ISO/IEC project reference:
ISO/IEC project ID:
Publication date:

☒ A document from another organization than ISO or ISO /IEC:

Note: Please explain the purpose and give a justification for this proposal in Section 3.

☒ Journal papers

Rolando Chacón, Carlos Ramonell, Hector Posada, Pablo Sierra, Rahul Tomar, Christian Martínez de la Rosa, Alejandro Rodriguez, Ilias Koulalis, Konstantinos Ioannidis & Stefan Wagmeister (2023). Digital twinning during load tests of railway bridges - case study: the high-speed railway network, Extremadura, Spain, Structure and Infrastructure Engineering, DOI: 10.1080/15732479.2023.2264840
https://doi.org/10.1080/15732479.2023.2264840

Citation to the background document of the CEN/TC 443/WG 9 with Digital Twin examples needed (CEN/TC 442/WG 9_WI 00442049_ Building information modelling — Digital twins applied to the built environment — Use cases) – "CEN-TC 442-WG 9_N82_DRAFT - use cases for digital twins - final rev1"

17. Please indicate whether the proposed project is linked to a specific European Research and Innovation Project

☐ **No**

☒ **Yes**

Research and/or Innovation project code: *958161 – ASHVIN – H2020-NMBP-ST-IND-2018-2020 / H2020-NMBP-ST-IND-2020-singlestage*
Research and/or Innovation project acronym: *ASHVIN*
Research and/or Innovation project title: *Assistants for Healthy, Safe, and Productive Virtual Construction Design, Operation & Maintenance using a Digitial Twin ' – 'ASHVIN' ('action')*

18. Track

☐ Enquiry + Formal Vote (for EN)

☒ Vote on TS or TR by correspondence

19. Please provide the target dates for the below key stages.

19.1 – For ENs

This section applies only to WIs for homegrown CEN standards (excluding ISO adoptions), WIs under VA with CEN lead only and homegrown standards developed by a CEN-CLC/JTC (with CEN lead). This section does not apply to the adoption of PWIs. For JTCs also add the durations in week.

20. Related standardization request(s) (formerly mandate):

☒ No

☐ Yes *(please specify)*:

21. Related directive(s)/regulation(s)

☒ No

☐ Yes	Directive/ Regulation reference	Candidate for citation in Official Journal?
		☐ No ☐ Yes
		☐ No ☐ Yes

22. Relation to other legislation or established public policy.

☒ No

☐ Yes

Please specify which legislation or established public policy is/are in relation with the proposed project:

23. Is the proposed project covered by Intellectual Property Rights (IPR)?

Please indicate whether there is any knowledge of items covered by IPR(s), for instance patents, copyright, trademark, etc.

☒ No

☐ Yes

Please provide full information about these items and the identified IPR(s):

24. Commitment This section applies only to *CEN-CLC/JTC* To *be completed for NWI request to be approved by CEN and CENELEC BTs.*

The following members (at least five) are committed to participate in the development of the project: