Optimal Construction Management & Production Control

# D1.2: Definition of the digital workflows for the construction process

WP1 – Digital Building Twin Process

Version 1.0

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## BIM2TWIN Key Facts

| | |
|---|---|
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## BIM2TWIN Consortium Partners

| | Partner | Country |
|---|---|---|
| 1 | CSTB: CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT | FR |
| 2 | TECHNION: ISRAEL INSTITUTE OF TECHNOLOGY | IL |
| 3 | UNIVERSITY OF CAMBRIDGE | UK |
| 4 | TUM: TECHNISCHE UNIVERSITAET MUENCHEN | DE |
| 5 | INRIA: INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE | FR |
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| 16 | IDP INGENIERIA Y ARQUITECTURA IBERIA SL | ES |
| 17 | AARHUS UNIVERSITET | DK |

## DISCLAIMER

## EXECUTIVE SUMMARY

*BIM2TWIN is conceived with the objective of applying the digital twin concept to the building construction process through a complete and holistic approach. This will be possible thanks to the design and creation of a digital twin platform of the construction process that will have a set of applications that allow the management of the construction and can provide a complete knowledge of the real situation of the work. The BIM2TWIN platform will bring together multiple data sources from the construction site to provide information on the status of the construction process. Knowing what is really happening on site will allow optimizing construction management. The development of the Digital Twin of the construction process on site will focus on the most relevant activities for the construction phase, such as the control of the execution and quality of the works, the planning and control of the necessary equipment and resources, and the safety of the workers.*

*In this report an optimal digital workflow framework is presented, which addresses the main issues identified in the as-is process analysis done in Task 1.1 and the requirements expressed by construction companies in relation to their processes and construction sites. It leverages an efficient integration of Digital Twin, Open BIM workflows and on-site data capture processes in a hybrid approach (user-driven and automated processes relying on artificial intelligence).*

*The analysis done focuses on how the data merge and interpretation technologies provided by different partners in the project fit together in holistic and integrated workflows, but goes beyond, by envisaging a future fully automated and digitalized scenario where BIM2TWIN concept could be extended to other non-covered domains, or even integrated to an ecosystem of Digital Twins.*

*This report, together with the KPI framework definition and the dashboard requirements (addressed in other tasks) sets the ground for the Digital Building Twin Platform implementation.*

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## ABBREVIATIONS

| | |
|---|---|
| AI | Artificial Intelligence |
| AP | Alternative Plans |
| API | Application Programming Interface |
| B2T | BIM2TWIN |
| BDTA | Building Digital Twin Association |
| BIM | Building Information Model |
| BPMN | Business Process Model and Notation |
| bSI | BuildingSMART International |
| CDE | Common Data Environment |
| DB | Database |
| DBT | Digital Building Twin |
| DBTP | Digital Building Twin Platform |
| DT | Digital Twin |
| DTaaS | Digital Twin as a Service |
| DTC | Digital Twin in Construction |
| ER | Exchange Requirement |
| EU | European Union |
| GA | Grant Agreement |
| GPS | Global Positioning System |
| IDM | Information Delivery Manual |
| IFC | Industry Foundation Classes |
| IoT | Internet of Things |
| IPP | Inspection Points Plan |
| JSON | JavaScript Object Notation |
| KPI | Key Performance Indicator |
| LOD | Level of Development |
| MVD | Model View Definition |
| OHS | Occupational Health and Safety |
| PaaS | Platform as a Service |
| PDCA | Plan–Do–Check–Act (or Adjust) |
| PII/PIM | Project Intent Information/Model (as opposed of PSI/PSM) |
| PPE | Personal Protective Equipment |
| PSI/PSM | Project Status Information/Model (as opposed of PII/PIM) |
| PtD | Prevention through Design |
| QA | Quality Assurance |
| REST | Representational state transfer |
| RFID | Radio Frequency Identification |
| UML | Unified Modelling Language |
| WBS | Work Breakdown Structure |
| WP | Work Package |
| XML | Extensible Markup Language |

# 1 INTRODUCTION

## 1.1 Scope and Objectives

The objective of the BIM2TWIN project is the creation of a Digital Building Twin Platform (hereinafter DBTP) to improve the efficiency in the management of building construction processes. BIM2TWIN proposes a comprehensive and holistic approach for the application of the Digital Twin concept to building construction. It will enable the involved agents to know the real-time status of everything happening on site and throughout the supply chain: the current progress and quality of the work, the current location of workers, equipment and materials, safety conditions, etc. Additionally, it will provide simulation tools to predict the impact of deviations detected and compare and prioritize alternative plans.

The DBTP must be able to capture the physical state of the building and the state of the construction process as it is. It must correspond directly to both, the building design, and the defined construction plan, so that everyone involved has access to reliable, accurate, real-time information on the status of the project, essential information for coordinating their work with others. This will ensure that everyone has a thorough understanding of the status of the project and the awareness of the implications of any change or deviation.

To achieve the objectives established in the project, it will be necessary to conceptualize the ideal Digital Building Twin Process, considering these three main pillars:

- Holistic: different vertical domains and use cases (safety, progress and quality control, equipment optimisation and process efficiency, waste management, supply chain, etc.) must be considered in an integrated approach, detecting, and modelling the interdependencies.
- Digital and open: the process must rely on open and standard data formats and ontologies (e.g. IFC) and foster the use of Open APIs for exchanging information.
- Automated: manual and user-driven processes must be progressively replaced by automated services to process information and extract knowledge (based on Artificial Intelligence).

The main objective of this deliverable is to propose an optimal construction process framework followed by the previous three principles and initially focused on the vertical domains addressed in BIM2TWIN but identifying the extension mechanisms for other domains or even multi-site management. Thus, DBTP workflows for the construction process will be presented using IDM (Information Delivery Manual) and BPMN (Business Process Model and Notation) standards. Based on the inefficiencies on site and barriers to digitization and the requirements collected in deliverable “D1.1 As-is practices analysis and end-user requirements”, and with the final objective of providing a real knowledge of the situation of the on-site process and allowing proactive actions to anticipate present and future problems, the optimal workflows have been created to overcome the identified barriers and allow the implementation of the Digital Building Twin concept.

The second objective of this deliverable is to identify the agents involved in the work and relate them to a profile and level of information of the work. It will also be necessary to identify all the required tools and services as well as the necessary data exchange, laying the groundwork for the development of the digital twin platform and the connected tools in the following work packages.

All the work collected in this document gathers all the activities carried out within Task T1.2: “Definition of the digital workflows for the construction process”. The result of this task will show the complete process description of the optimal construction process through the design of the digital workflows.

## 1.2 Relation to other Work Packages

This deliverable provides the basis for achieving the WP1 objective of developing the conceptualization of the optimal Digital Twin and will be used for the development of the other deliverables of this work package, as well as for the other work packages of the project.

The results collected in this document and in the other WP1 deliverables will define the end-user requirements and specifications with which to develop the innovative workflows in the Digital Building Twin platform (DBTP) and to define the data models in WP2.

All the process and platform specifications collected in this WP will have a direct relationship with the developments done in WP3, WP4, WP5, WP6 and WP7, as they will define the on-site data collection requirements for the tools to be developed in those work packages. While D1.2 describe holistic high-level and ideal workflows for the upcoming future, WPs 3 to 7 focus or zoom into specific use cases which are going to be implemented and validated on-site. Thus, their level of detail must be higher.

The results collected in this document will fuel the work for the future work packages. Because it links the users' needs, through the insight of pilot sites with the necessary developments for the DBT Platform, strongly considering the user´s perspective in the design.

Figure 1 shows the relation between WPS.

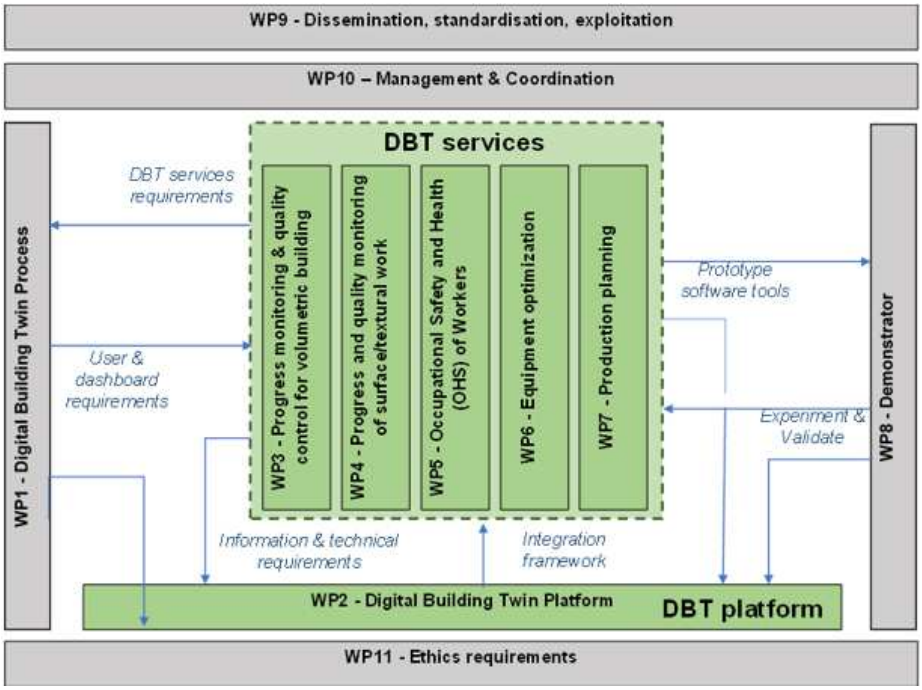


**Figure 1. Project scheme and relationship between work packages**

Figure 2 summarizes the relationship between T1.2 and other tasks in the project.

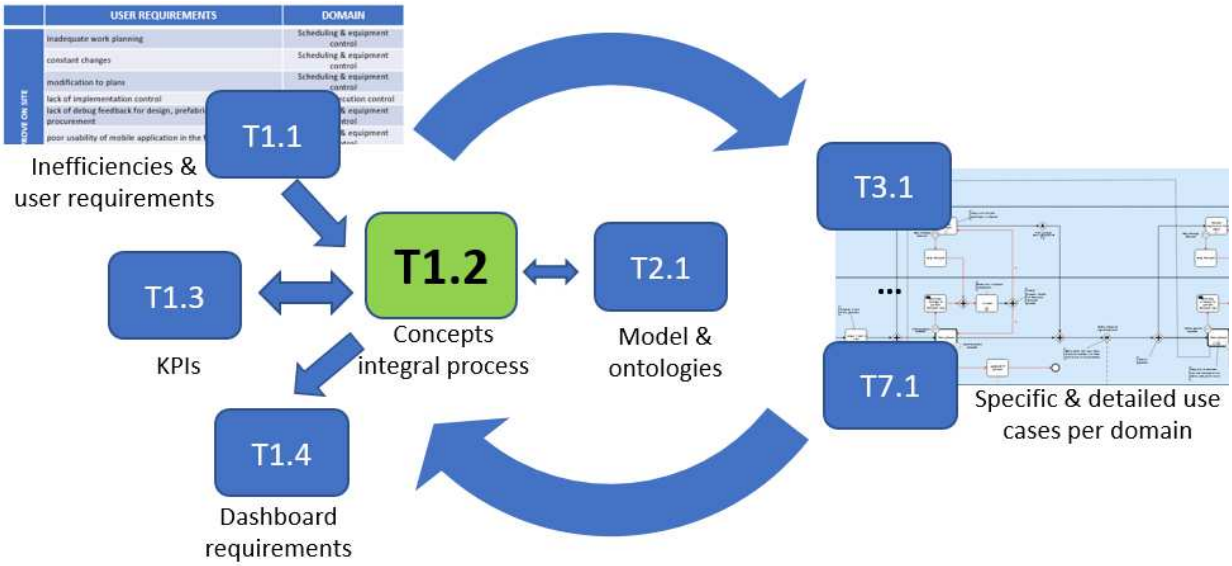


**Figure 2. Relationships of T1.2 with other tasks in the project**

- It takes the outputs from T1.1, in particular the user requirements per contractor and pilot site.
- It has close relationships with T1.3 (KPI definitions) and T1.4 (dashboard requirements).
- The preliminary concepts identified herein are being developed in detail as data models and ontologies in T2.1 (WP2)
- There is a bidirectional feedback between the holistic high-level use cases from T1.2 and the detailed specific use cases for each vertical domain described in the different tasks related to describe the system design (Tx.1, i.e. the initial task in each Work Package from WP3 to WP7).

## 1.3 Structure of the Deliverable

Section 1 presents an overview to the project in general, particularly focusing in task 1.2, identifying all the relationships with different Work Packages.

Section 2 introduces some basic concepts which are the basis for BIM2TWIN project, such as the PDCA (Plan, Do, Check, Act) cycle and BPMN concepts and the underlying principles of BIM2TWIN, which will help in better understanding the rest of the deliverable.

Section 3 captures the main outputs from deliverable D1.1, mainly the list of user requirements, and proposes a harmonized list of functional and non-functional requirements for the DBTP, as an input for the platform development (WP2).

Section 4 presents a high-level approach of the main semantic concepts and relationships extracted from the previous steps, organized according to the PDCA cycle, and mapped to each domain addressed in the project.

Section 5 proposes a harmonized BPMN template for all BIM2TWIN use cases, providing specific examples for each PDCA stage, both considering a generic, ideal scenario (beyond the scope of BIM2TWIN) and specific realizations within BIM2TWIN use cases.

Finally, Section 6 summarizes the main outcomes and extracts the most relevant conclusions and future insights.

# 2 BASIC CONCEPTS AND DEFINITIONS

## 2.1 The BIM2TWIN concept

BIM2TWIN proposes a global and complete approach for the application of the digital twin concept to the construction of buildings that allows the optimization of the on-site construction phase. The development of a Digital Building Twin platform (DBTP) based on the conceptualization and implementation of a Digital Building Twin (DBT) process will allow the involved stakeholders to know the status and everything that occurs on site in real time, to know the current progress and quality of the work, the current location of the workers, the status of materials and equipment and the safety conditions among other aspects.

On top of the core DBT model a set of construction management applications and services are provided which, by means of Artificial Intelligence techniques as well as automated image, video, point cloud and geometry postprocessing, will enable to boost the automation in real-time knowledge extraction, This information is called the Project Status Model (PSM), which represents both the as-built product and the as-performed process. The PSM is the current status of the Digital Building Twin and shows a current time snapshot of the status of the Physical Building Twin.

The DBT must also relate directly to the project design and construction plan. Therefore, its component information objects must relate to Building Information Model (BIM) objects, objects that represent not only the product design but also the construction process as planned. The as-designed and as-planned states. the project's as-designed and as-planned states are the record of the design and construction intent at the times when they were archived.

The conceptual design of BIM2TWIN (Figure 3) is the design of the on-site construction process supported by a digital building twin, which allows not only the storage of construction data and information but also the processing of that information.

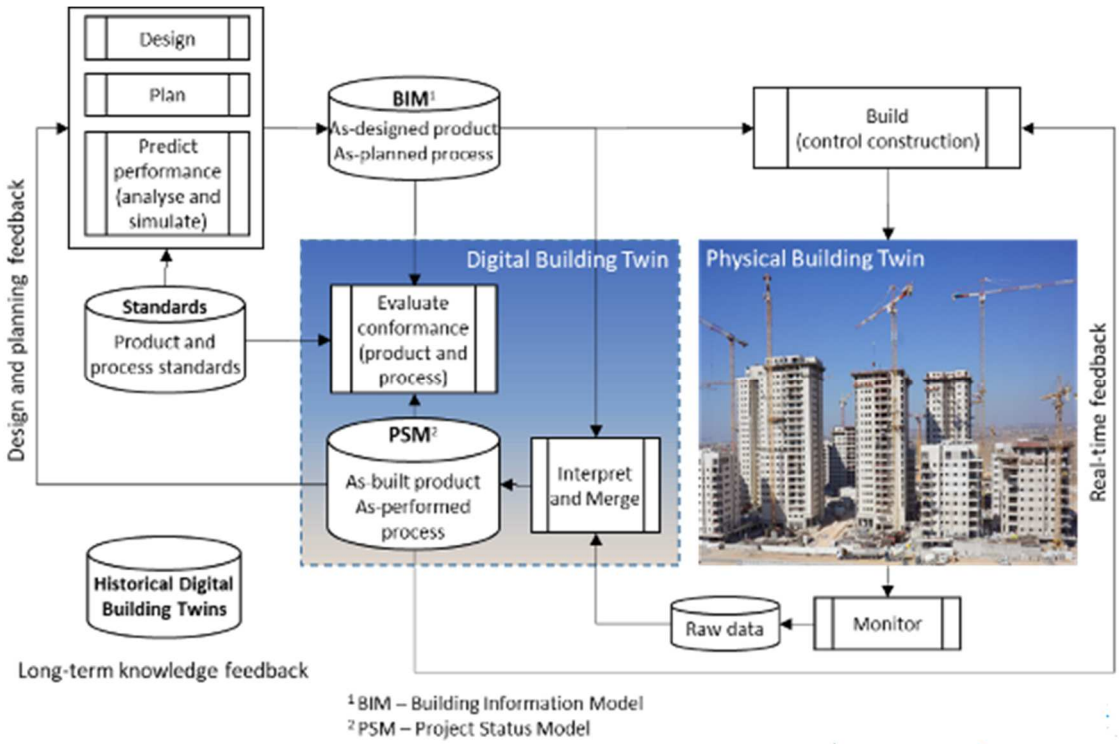


**Figure 3. BIM 2 TWIN digital building twin system architecture**

At this point, the key aspect is that all the interactions between domain applications and the core platform will be done though a set of open APIs based on widespread technologies such as RESTful web services and federation of different data standards and ontologies through a common property graph representation, being IFC a core component. This will foster the future extensibility of the platform to other non-yet covered vertical domains and applications towards a full digitalization of the building construction process. The application programming interfaces (APIs) required to compile all the modules are an inherent part of the digital building twin platform. Thanks to them, data from the construction site can be interpreted to provide information, and the information will be processed to obtain knowledge.

The underlying principles (Figure 4) emerge from previous researches on the topic of Digital Twin in Construction or DTC (e.g. Sacks R. et al. [1]), where the building construction process can be split into:

- Product vs process. The final delivered building will be a decomposition of products, but each product can be described as a sequence of processes with associated resources and dependencies to assemble and integrate them into the building.
- Physical vs virtual. The first denotes the real building under construction and all the elements and people onsite, and the latter denotes the digital counterpart of these models.
- Intent vs status. The first denotes the products as-designed (e.g. from a BIM modelling tool) and the processes as-planned (e.g. from a 4D scheduling environment, linked to the BIM), i.e. the "future". The latter denotes the really performed work and delivered products (i.e. the "past") which could not coincide. Note that during the process evolution, as a consequence of various re-designs and re-planning, we will end up with several versions of intent or "future" (but only one consolidated reality or "past"). All this accumulate versions and changes can be stored for long-term decision-making and KPI extraction and to serve as a knowledge base for learning.

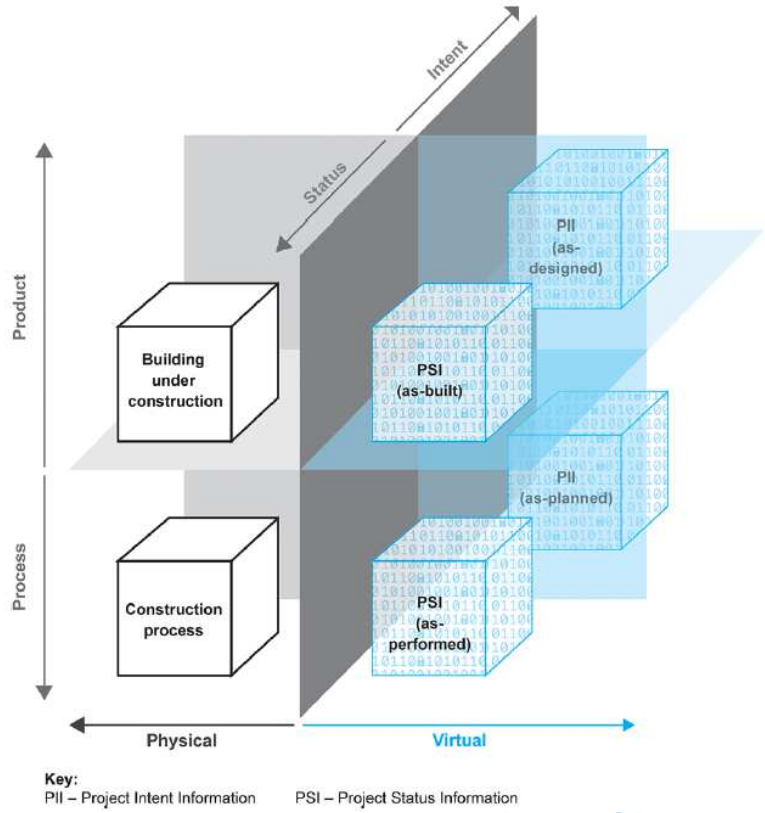


**Figure 4. Dimensions of the construction process**

## 2.2 The PDCA cycle

PDCA (plan–do–check–act or plan–do–check–adjust) is a systematic process for gaining valuable learning and knowledge for the continual improvement of a product, process, or service. Also known as the Deming Wheel, or Deming Cycle, since it was proposed by W. Edwards Deming as part of the modern Quality Control theory, although originally named PDSA (S=Study instead of C=check) [2]. It has been adopted in many disciplines, for instance in Lean Construction.


**Figure 5. PDCA cycle scheme**

The different stages of a DBT-driven construction process can perfectly fit with this model, thus, throughout the document it will used to depict the different workflows and processes.

**Table 1. Correspondence of PDCA cycle with BIM2TWIN and construction processes**

| | |
|---|---|
| Plan | Create the as-designed BIM model with the required level of detail and the as-planned activities (scheduling), along with other information such as safety planning, site zoning, etc. |
| Do | Carry out the construction activities and day-to-day management. |
| Check | Verify that the as-built products and the as performed process match the expected (plan). A nuclear part of BIM2TWIN project will be devoted to providing automated methods to perform this matching and detect deviations in the most relevant domains: progress and quality control, safety and process optimisation and use of resources, with special focus on heavy equipment. |
| Act | When deviations are relevant, modify the models and scheduling to adapt to the as-built/as-performed reality. BIM2TWIN also provides tools for what-if simulation of alternative plans according to user preferences and targets. |

Figure 6 illustrates how the information varies in BIM2TWIN Platform according to the outcomes of several PDCA cycles. The “DO” is the time arrow which moves dividing past from future. At each timestamp of the “DO” the captured status is checked against the planned and if deviations are detected and are considered significant an “ACT” process will trigger creating a new branch for “PLAN” (only to the future, since all past planned events will be locked and stored for future analysis.

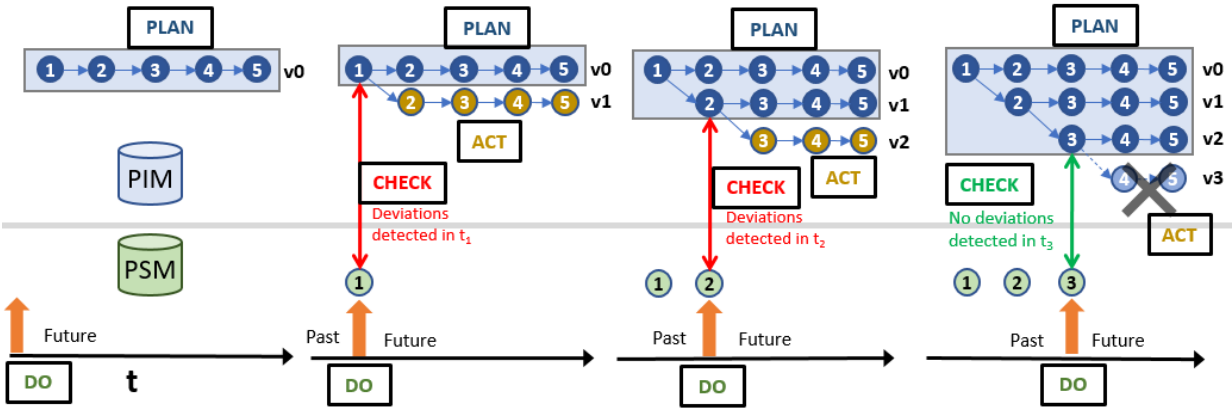


**Figure 6. PDCA cycle in different instants**

## 2.3 Introduction to BPMN

Business Process Model and Notation (BPMN) [3] is a standard way of modelling business processes, using a common graphical notation. It uses a flowcharting technique which resembles activity diagrams in UML (Unified Modelling Language). The aim is to support the communication between technical users and business experts, by providing a notation that is intuitive to business users, yet able to represent complex process semantics. Processes could even be simulated by automation engines, such as Camunda Platform [4].

buildingSMART International (bSI) [5], as part of the Information Delivery Manuals (IDM) standard [6], already adopted BPMN (widely used by BIM experts) for representing BIM processes. Thus, for the purpose of BIM2TWIN, BPMN will also be used for modelling and describing the proposed ideal DBT-driven construction process.

The following table describes some of the most relevant BPMN concepts used within this report. For a complete list, the official BPMN specification [3] can be checked.

**Table 2. Most relevant BPMN concepts used in BIM2TWIN**

| | |
|---|---|
| Process Map | The whole BPMN diagram which visually represents all the information and process flow between participants in a business process |
| Swimlane | A graphical container for partitioning a set of activities from other activities. Two different types of swim lanes are available: “Pool” and “Lane” (see below) |
| Pool | Participant in a collaboration process. Graphically, a container for partitioning a process from other Pools/Participants. A Pool is not required to contain a Process, i.e., it can be a “black box” |
| Lane | A partition that is used to organize and categorize activities within a Pool. A Lane extends the entire length of the Pool either vertically or horizontally. Lanes are often used for such things as internal roles (e.g., Manager, Associate), systems (e.g., an enterprise application), or an internal department (e.g., shipping, finance). |
| Process | A sequence or flow of Activities in an organization with the objective of carrying out work. In BPMN, a Process is depicted as a graph of Flow Elements, which are a set of Activities, |

| | |
|---|---|
| | Events, Gateways, and Sequence Flow that adhere to a finite execution semantics. Processes can be simple processes (no further specialization), collapsed (they contain sub-processes which are detailed in a separate diagram or expanded (they are detailed with internal sub-processes in the same diagram) (see Figure 7) |
| Data exchanges | They represent the data which each exchanged between two actors or processes, using the data object symbol, sometimes grouped in a single swim lane. The detailed description of the data contents is provided through a specification of Exchange Requirements, i.e.:<br>• The actor or system producing/sending the information<br>• The actor or system receiving the information<br>• Type of exchange: email, manual, file (in this case the format could be specified)<br>• Data contents: description of the data. It could be a formal/detailed description of data types (text, numeric…), cardinality (one, many…), mandatory/optional… or when we cannot reach such detail a plain human-readable description is provided.<br>The IDM specification [3] from buildingSMART already provides Word templates for specifying exchange requirements |
| Events | Represented as circles, they encapsulate actions that trigger or finalize processes. We can have start, intermediate or end events, which could be further specialized in timers (events that occur periodically), messages, conditional events and much more<br>  <br> |

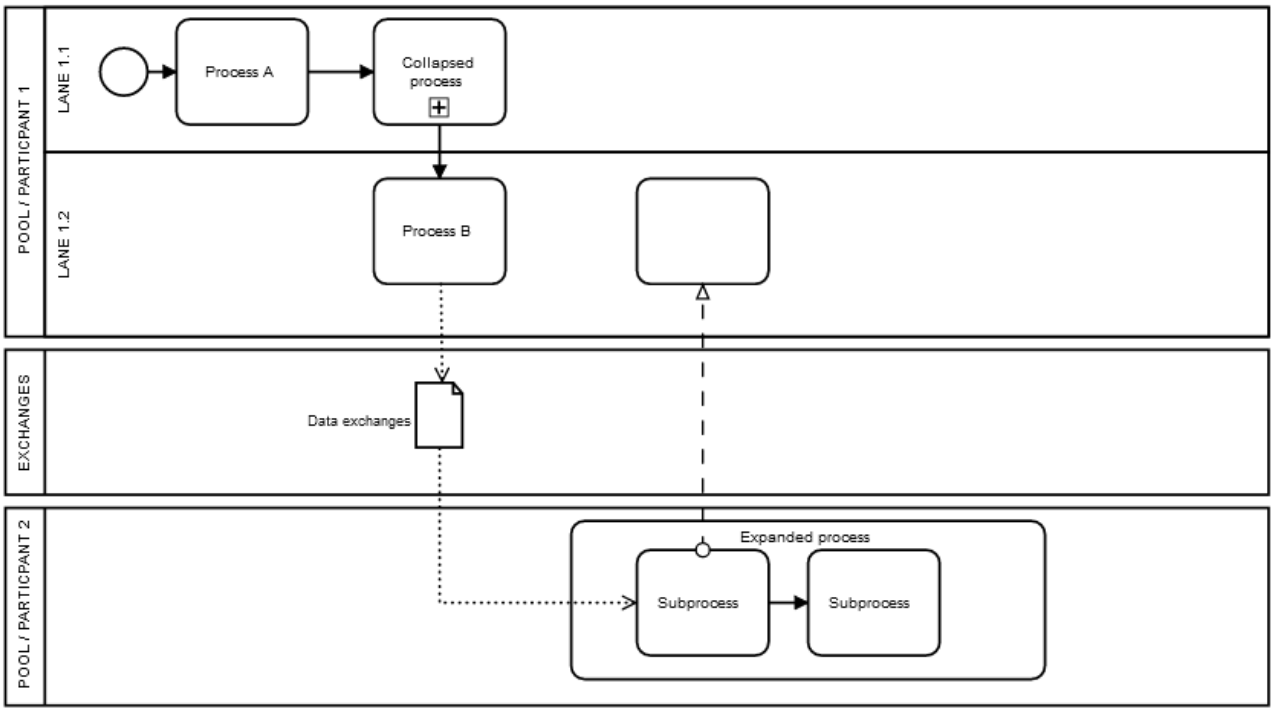


**Figure 7. Sample BPMN process map**

# 3 PRELIMINARY ANALYSIS AND CLASSIFICATION OF USER REQUIREMENTS

In this section, based on the work carried out in deliverable D1.1, in which a first approximation to the general user requirements was defined, according to the result of the analysis of the main inefficiencies and improvement points of the on-site execution process, the end-user requirements for the digital twin construction platform have been established.

Based on the first approximation of the high-level user requirements made for each pilot from the user's perspective, it has been possible to determine the final requirements that will lead to the subsequent definition of the technical specifications of the DBT platform.

As described above, with the objective of the DBT platform to optimize the on-site construction process, the PDCA (Plan, Do, Check, Act) method has been used to define the user requirements. This method allows a better control of the quality of a process, through a circle that starts with the Plan, continues with the DO, continues with the Check, and ends with the Act. Translating this methodology to the onsite process, the platform requirements have been categorized into these four groups, PLAN, DO, CHECK and ACT.

PLAN establishes the requirements and needs that will be necessary before the start of the work in the BIM model, such as the level of detail, detailing the specifications of the expected results, defining the activities necessary to achieve the platform's objective, establishing the objectives and processes necessary to achieve the necessary results, etc.

DO collects the necessary requirements during the work phase, indicating the different information to be displayed on the platform in real time or in specific time periods for the correct development of the construction process.

CHECK collects the specifications and requirements of the platform necessary to verify and control the correct development of the work on site, and thus, if it has not been achieved, it will be necessary to plan again.

Finally, ACT collects the requirements related to the necessary actions to be taken after the analysis of the control results, and to make the necessary changes to ensure the correct development of the work.

To facilitate the definition of user requirements, each of them has been related to the domains of the project to which they refer, and the WP(s) to which they are related. In this way it is possible to identify in a simple way which of these user requirements concern a specific WP or are related to all of them.

To optimize the classification of the defined user requirements, the exercise of relating each of them to the user profiles they will affect has been carried out. In this way, it can be determined which information or activities should be accessible to each of the user profiles.

To facilitate the structuring of the DBT platform information, four user levels or profiles have been defined, namely:

- Director/management
- Middle Management
- Technical Staff
- Workmanship

To reach these profiles, the information and work developed in T1.1 was taken as a basis. One of the activities carried out in this task was to analyse the current practices in the construction process and to analyse the differences between the construction processes in the different selected countries. As a result of this analysis it has been possible to identify the different profiles and stakeholders involved in the construction process in each of the countries. Based on this information, a single definition has been established to refer to them, since in each country a different term is used to refer to each stakeholder.

Once all the actors and stakeholders involved in on-site construction had been defined, an exercise was performed to relate each of these agents and the needs they have in the construction phase to one of the four BIM2TWIN profiles defined. The result of this work is shown in the following table.

**Table 3. BIM2TWIN Profiles**

| ROLES | | | PROFILES | |
|---|---|---|---|---|
| FINLAND | FRANCE | SPAIN | **COMMON DEFINITION** | **BIM2TWIN** |
| Employer | Project Owner | Owner | **Project Owner** | **Director / management** |
| Architect | Architect | Architect | **Architect** | **Technical Staff** |
| Engineers | Engineers | Engineers | **Engineers** | **Technical Staff** |
| | Surveyors | Quantity Surveyors | **Quantity Surveyors** | **Technical Staff** |
| Fire safety consultant | Technical control | Fire safety consultant | **Fire safety consultant** | **Technical Staff** |
| Health & Safety coordinator | Health & Safety specialist | Health & Safety coordinator | **Health & Safety coordinator** | **Technical Staff** |
| | | Project designer (Dirección de obra) | **Project designer** | **Director / management** |
| General contractor | General contractor | Main Contractor | **General contractor** | **Director / management** |
| Sub-contractors | Subcontractors | Subcontractors | **Subcontractors** | **Middle Management** |
| Suppliers | Suppliers | Suppliers | **Suppliers** | **Technical Staff** |
| production engineer | worksite managers | Production manager | **Production manager** | **Middle Management** |
| | Tender manager | | | **Middle Management** |
| Foremen | Foreman | Site Foreman | **Foreman** | **Middle Management** |
| Site engineer | Topographic surveyor | | **Topographic surveyor** | **Technical Staff** |
| | Chief Operational Officer | Technical office manager | **Chief Operational Officer** | **Technical Staff** |
| Workers | Coworkers | Workers | **Workers** | **Workmanship** |

For the definition of end user requirements, a series of requirements related to the necessary knowledge bases and related KPIs have also been included. Also, a series of requirements have been included that affect the possible scalability of the platform in the future. Finally, there is also a series of user requirements focused on the training and use of the platform by the personnel.

From all this, it has been possible to classify the user requirements to be implemented in the DBT platform. The classification of the different requirements, their relationship with the developments of the other WP(s) of the project, and their link with the defined user profiles is shown in the following table.

## Table 4. BIM2TWIN user requirements

| CATEGORY | ID | REQUIREMENT | EXPLANATION/EXAMPLE | DOMAINS | | | | | BIM2TWIN Profile | | | | Main Skills |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | WP3 | WP4 | WP5 | WP6 | WP7 | Director/ Management | Middle Management | Technical Staff | Worker | |
| PLAN | REQ_PLN_01 | The BIM model should be detailed into the maximum level of detail which enables the assignment of resources (trade, equipment and material (LOD 400)* | The elements of the BIM model must present at least a LOD 400. In addition to being defined geometrically in detail, its position, belonging to a specific construction discipline, it will have assembly information in terms of materials and labour required and also allows the possibility of including non-graphic information linked to the element. | | | | | | | | X | | BIM |
| | REQ_PLN_02 | A work breakdown structure (WBS) of the whole project must be provided, specifying the required resources (trade, equipment, material) for each final task | Each task must allow the association of quantity of human resources (trade), materials or necessary equipment. Also, these tasks must allow define the start and end of task, and the deadline for changes | | | | X | X | | X | X | | Scheduling |
| | REQ_PLN_03 | In shorter term periods, the WBS granularity can be increase by splitting a task into more granular subtasks related to intermediate or temporary processes | It is allowed within an activity to create intermediate or specific processes that facilitate the control of the execution and planning of an activity or subtask (for example, "empty the containers"). | | | | | X | | X | | | Scheduling |
| | REQ_PLN_04 | Any object in the BIM Model must be mapped to a product (Assembly/part) and consequently in tasks in the WBS | This information should define the start and end points of the task and thee deadline changes. Thus, the changes to the design identified, will be included in the execution on site plan in terms of cost/quality/delay. | X | X | | | X | | | X | | BIM |
| | REQ_PLN_05 | There should be a deadline defined after which modifications in the design are not possible (they impact in cost/quality would be very relevant) | This information should define the start and end points of the task and thee deadline changes. Thus, the changes to the design identified, will be included in the execution on site plan in terms of cost/quality/delay. | | | | | | X | X | | | Scheduling |
| | REQ_PLN_06 | Tasks should have a clear definition of dependencies | To guarantee the execution of each task it is necessary to know if the precedent task is finished, if the necessary material is on site, etc. | | | | | X | | X | X | | Scheduling |
| | REQ_PLN_07 | An Inspection Points Plan (IPP) must be defined for QA and it must be possible to link any product (BIM object) to a task and a point/milestone in the IPP and include instructions for QA process steps | The tasks are relationship with the element of the BIM model, so the IPP associated must allow checking of quality control of this product associated to BIM model.. e.g. for the execution control of a column, a point cloud should be made after the execution on site and built with the BIM model. Or a surface scan should be performed to detect possible execution flows. | X | X | | | | | X | X | | QA control |
| | REQ_PLN_08 | Provide more intermediate milestones for control of the work executed and quality monitoring | For each task or activity, intermediate control milestones shall be defined to facilitate the detection of time deviations or execution failures (e.g. link them to shorter tasks in the WBS). | X | X | | | X | | X | X | | QA control |
| | REQ_PLN_09 | Each required resource for a task must be mapped to orders to a provider (subcontractor or supplier) and scheduled well in advance | The resources required for the execution should be scheduled and ordered, depending of the time of tasks, the relationship with other tasks, the execution phase, etc. thus These planification time must be defined a short time and longer time | | | | | X | | | X | | Scheduling |
| | REQ_PLN_10 | The construction site (possibly a 2D map) should be correctly divided into different spatial zones according to the activity performed (circulation of heavy machinery, storage…) well in advance | Depending on the development of the execution of the work on site, the changes of work zones that will be generated on site must be foreseen sufficiently in advance. In the initial stages of the project, the revision of the spatial zoning of the work site will be done every week, in later stages it will be enough with a revision/modification of the zones monthly, and there will come a point in the development of the work, in which these zones will no longer be modified until the end of the work. | | | X | X | X | | | X | | BIM |
| | REQ_PLN_11 | All tasks should have a definition of the safety risks associated and the required measures and equipment (collective and/or individual) | e.g. For the concreting of a pillar on an elevated floor, the need for collective protection nets at that height, the need for PPE for the workers must be indicated; | | | X | | | | | X | | S&H |

| | | | | DOMAINS | | | | | BIM2TWIN Profile | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CATEGORY** | **ID** | **REQUIREMENT** | **EXPLANATION/EXAMPLE** | **WP3** | **WP4** | **WP5** | **WP6** | **WP7** | **Director/ Management** | **Middle Management** | **Technical Staff** | **Worker** | **Main Skills** |
| | REQ_PLN_12 | A model checking functionality should warn if inconsistencies or missing data is found (tasks not planned, products not linked to tasks, etc.) | It should be possible to identify the existence of unplanned tasks, tasks or activities that are not associated with human or material resources, etc. | X | X | X | X | X | | X | X | | Scheduling |
| **DO** | REQ_DO_01 | Show resources needed (subcontracting/equipment/material) for on-going/next tasks | To guarantee the correct planning of the execution of the work, every task must have related the resources that will be needed. | | | X | X | X | | | X | X | Scheduling |
| | REQ_DO_02 | Show resources available on-site (subcontractors/equipment/material) and status (in-use, waiting…) | It should be possible to identify on a site plan/model (control panel), the location of the materials or equipment needed to perform a task, identifying if they are available or not. e.g. I am going to have to carry a pallet of bricks to a high floor of the building, I should know where the material is stored, and if the crane will be available when I need to perform that activity. | | | X | X | X | | | X | X | Scheduling |
| | REQ_DO_03 | Show safety equipment needed for ongoing tasks | At all times it must be possible to identify all the collective safety measures and PPE that are necessary for the tasks and activities that are currently being carried out on site. | | | X | | | | | X | X | S&H |
| | REQ_DO_04 | Show safety equipment available on-site | It should be possible to locate on a map or in the BIM model the health and safety equipment that is available on site as much collective as individual systems | | | X | | | | | X | X | S&H |
| | REQ_DO_05 | Show the status of ongoing orders and deliveries | To avoid deviations in the flattening, a control of the status of the orders of material and equipment that will be needed on site should be available, e.g. to know when a pallet of material will arrive on site, or at what time the concrete mixer trucks will arrive. | | | | X | | | | X | | Scheduling |
| | REQ_DO_06 | All resource flows (materials, equipment, etc. entering/leaving the site) should be registered and time-stamped for traceability purposes | A control of all material and equipment stored on site should be carried out, in order to know if there is material available for the execution of an activity, or if the necessary equipment for a task has left the site for a revision and is not available. | | | | X | X | | | X | | Scheduling |
| | REQ_DO_07 | Provide access to an updated task calendar in real-time | A calendar should be available that shows which activities should be executed on site each day, so that all site workers know which activities should be executed and can better control the correct development of the work and detect possible deviations and delays. | | | | | X | | | X | X | Scheduling |
| | REQ_DO_08 | Show the localization of on-going tasks | It should be possible to identify and visualize on a site plan or BIM model all the activities that are being executed on site in real time. | | | | | X | | | X | X | Scheduling |
| | REQ_DO_09 | Provide access to documentation (QA plans & other certifications) according to IPP | There should be a repository where all documentation on quality control plans and other certifications that can be reviewed by the agents involved in the control of the work on site should be stored. | X | X | | | | | | X | | QA control |
| **CHECK** | REQ_CHK_01 | Automatic alerts when any of the needed requirements is not met (required materials or safety equipment not present, deliveries not arrived, etc.) | A system of alerts should be created to warn when the materials or safety equipment required for the execution of a task are not available, e.g. to warn that the materials necessary for the execution of a task that was planned for this week have not yet arrived at the site, or that a series of activities cannot be started in an area of the site because the necessary collective safety measures have not been installed. | | | X | X | X | | X | X | | Scheduling |
| | REQ_CHK_02 | Automatic conformity checking of collective safety protection | It must check and report that all safety measures are correctly installed. e.g. a safety net has been dismantled and not reinstalled, due to an accident a safety equipment has been damaged and needs to be replaced. | | | X | | | | | X | | S&H |
| | REQ_CHK_03 | Automatic detection of potential risks (e.g.: fall from heights) | With the development of the construction site, new risks will arise that must be automatically detected and addressed. E.g. fall from height during a task, etc. | | | X | | | | | X | | S&H |
| | REQ_CHK_04 | Automatic calculation of quantities of work executed | By means of the use of the technologies, it should be possible to control the real progress of the work, thus being able to have a real monitoring of the quantities executed. | X | X | | | | | X | X | | QA control |

| CATEGORY | ID | REQUIREMENT | EXPLANATION/EXAMPLE | DOMAINS | | | | | BIM2TWIN Profile | | | | Main Skills |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | WP3 | WP4 | WP5 | WP6 | WP7 | Director/ Management | Middle Management | Technical Staff | Worker | |
| | REQ_CHK_05 | Provide a tool for entering QA inspection results (photos, notes...) according to IPP | A system should be in place to control and manage the results of quality control inspections, and to allow traceability of the information. | X | X | | | | | | X | | QA control |
| ACT & MODIFY | REQ_ACT_01 | For each modification (e.g. due to issues, defects, corrections….), control the workflow of changes (who modifies, who validates...) | E.g. Modification of the schedule due to problems, defects, or necessary corrections, it must be indicated who will make the changes, who must validate them, etc. | | | | | | | | X | | Scheduling |
| | REQ_ACT_02 | Know at any time the deviation WRT as-planned (quantities, duration…) | It will be possible to check the deviations produced on site, both the deviations that affect the deadlines and planning of the work, as well as the deviations in the use of materials and equipment associated with an activity. | X | X | | | X | X | X | X | | Scheduling |
| | REQ_ACT_03 | Automatic update of planning according to executed work (as-performed vs as-planned progress deviation) | The planning of the work, both the activities to be carried out and the material and human resources required, must be updated according to the real progress of the work on site. | | | | | X | | X | X | | Scheduling |
| | REQ_ACT_04 | All affected stakeholders should automatically receive updates on design/planning changes (new start/end of task, modified quantities, materials...) | If a task planned don´t be executed, all the affected stakeholders must be informed in order to reschedule the work on site. E.g. If due to a delay on site, concrete pouring must be delayed, all stakeholders responsible for this activity as well as the suppliers must be informed well in advance in order to reschedule the work on site. | | | | | X | X | X | X | X | Scheduling |
| | REQ_ACT_05 | Understand the impact of each modification in cost and schedule and be able to reallocate resources onsite | An estimate of the costs and delays that a modification may cause in the work schedule should be available to facilitate decision making. | | | | | X | X | X | X | | Scheduling |
| | REQ_ACT_06 | Automatic update of associated resources (e.g. material, equipment, people) per task when a drawing (BIM model) is modified | Changes in a task (due to schedule or to products delivered) may imply different quantity and type of resources needed | | | | | X | | | | | Scheduling |
| | REQ_ACT_07 | It should be possible to update task status and reallocations onsite from a mobile device, including checking of proper performing (product/subassemblies) and quality steps | The smartphone is the device that everyone on the construction site has, and the one that offers the greatest ease of work | | | | | X | | | X | X | scheduling<br>Scheduling |
| KNOWLEDGE BASE & KPIs | REQ_KB_01 | Information about defects, delays, safety incidents, etc. should be stored for a better insight and a more efficient problem solving | The defect and delay of task, the root causes of them, the frequency of affected tasks, etc. should be stored in a databases, to analyse later and used the conclusion to optimize problems solving. E.g. information related to the root causes of defects or delays, the severity of defects or delays, or the frequency of affected tasks should be stored so that it can be analysed and used to optimize problems solving. | X | X | X | X | X | X | X | | | Scheduling |
| | REQ_KB_02 | Feedback about defects, delays, etc. should be reported to designers & suppliers for continuous improvement | This information could help in supplying better quality products in the future and learn from detected mistakes | X | X | | | X | X | X | X | | QA control |
| | REQ_KB_03 | Calculate the performance of subcontractors and the work performed | Depending on the real progress of the work, it must be possible to check the performance of the subcontractors in order to make decisions. | X | X | | | X | X | X | X | | QA control |
| | REQ_KB_04 | Use the historic information (previous experiences) of subcontractors' performance, quality, and defects, etc. to efficiently take the best decisions (manage the bids, select products…) | This information will be very useful for future projects and decision making. | | | | | X | X | X | | | Scheduling |
| SCALABILITY & | REQ_SF_01 | The platform should be designed to allow vertical scalability (include in the future other aspects or vertical domains) | For example, to include other domain such as waste management | | | | | | | | | | |

| | | | | DOMAINS | | | | | BIM2TWIN Profile | | | | Main Skills |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CATEGORY | ID | REQUIREMENT | EXPLANATION/EXAMPLE | WP3 | WP4 | WP5 | WP6 | WP7 | Director/ Management | Middle Management | Technical Staff | Worker | |
| FEDERATION | REQ_SF_02 | The platform should be designed to allow horizontal scalability (extend it from single site to multi-site management) | For example, to be able to manage the resources of two sites simultaneously | | | | | | | | | | |
| | REQ_SF_03 | It should allow in the future bidirectional connectivity to other Digital Twins through Open APIs (e.g. obtain traffic information from a City DT) | Integration in future data ecosystems, by sharing knowledge | | | | | | | | | | |
| OTHER | REQ_OTH_01 | Information should be centralized (e.g. a Common Platform or Data Environment as a "Single Source of Truth") in order to avoid errors, defects… due to not up-to-date or incoherent information | Everyone must rely on the information provided by the Digital Twin | | | | | | | | | | |
| | REQ_OTH_02 | Improve the communication/collaboration between stakeholders onsite (e.g. problem solving as a team) | Have a common vision of the construction site | | | | | | | | | | |
| | REQ_OTH_03 | Easy-to-use tools, fast learning curve, adapted to each trade (manager, operator…) | To ensure that the tools are used on site, they must be user-friendly and easy to use. Otherwise, there will be a rejection of their use by the site workers. They must see the use of these tools as an aid to their work, and not the opposite. | | | | | | | | | | |
| | REQ_OTH_04 | Simplified interfaces for on-site/mobile use | To ensure that the tools are used on site, they must be user-friendly and easy to use. Otherwise, there will be a rejection of their use by the site workers. They must see the use of these tools as an aid to their work, and not the opposite. | | | | | | | | | | |
| ADOPTION & TRAINING | REQ_TRA_01 | Train the workers in the use of new technologies & DBT | | | | | | | | | | | |
| | REQ_TRA_02 | Provide clash management meetings | | | | | | | | | | | |
| | REQ_TRA_03 | To demonstrate and convince the gain or the improvement brought by the change | | | | | | | | | | | |
| | REQ_TRA_04 | Changes must be incremental and very progressive | | | | | | | | | | | |
| | REQ_TRA_05 | to provide constant and regular meetings between the different parties | | | | | | | | | | | |
| | REQ_TRA_06 | To demonstrate and convince the gain or the improvement brought by the change | | | | | | | | | | | |

# 4 Elicitation of main semantic concepts for the Digital Construction process

As a result of the preliminary analysis of the construction process and the classification of user requirements done in the previous chapter, the first identification of the main semantic concepts to be handled has been done.

To be consistent with the approach presented before, the next analysis has also been structured according to the PDCA cycle stages. Various iterations with the developers of the Data Model of the Platform (WP2) and technology providers in WP3 to WP7 have been done for aligning the terminology.

It must be highlighted at this point that the upcoming lists are a preliminary analysis to better orient the real development, they are not meant to be an exhaustive list of concepts and attributes (which, as a result of implementation activities, will be more detailed and could still vary).

After this analysis, a compiled list of concepts has been produced (see Table 6).

## 4.1 Concepts for PLAN

The initial modelling/planning phase comprises the list of concepts depicted in Figure 8. We must note that not all the information is provided in a single stage. Rather, we could have an initial information level, which can be further detailed afterwards (we cannot have a perfect project definition from time t=0). Thus, purchases and subcontracting can be defined in shorter loops (or even tasks can be split into detailed subtasks in shorter loops).

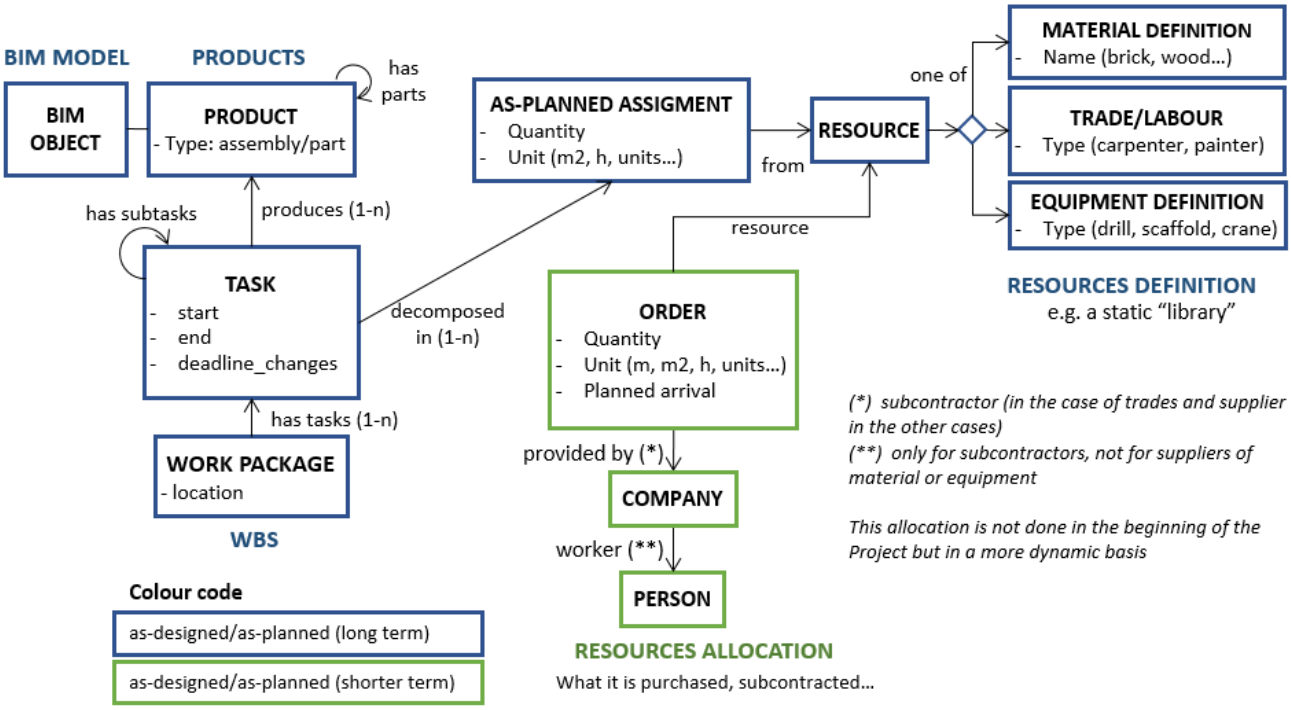


**Figure 8. Preliminary entities (PLAN use case)**

Additionally, tasks must have a clear identification of dependencies among them and with other factors (Figure 9). This is critical for being able to assess the impact that any change or deviation in any task has in the rest of the project.

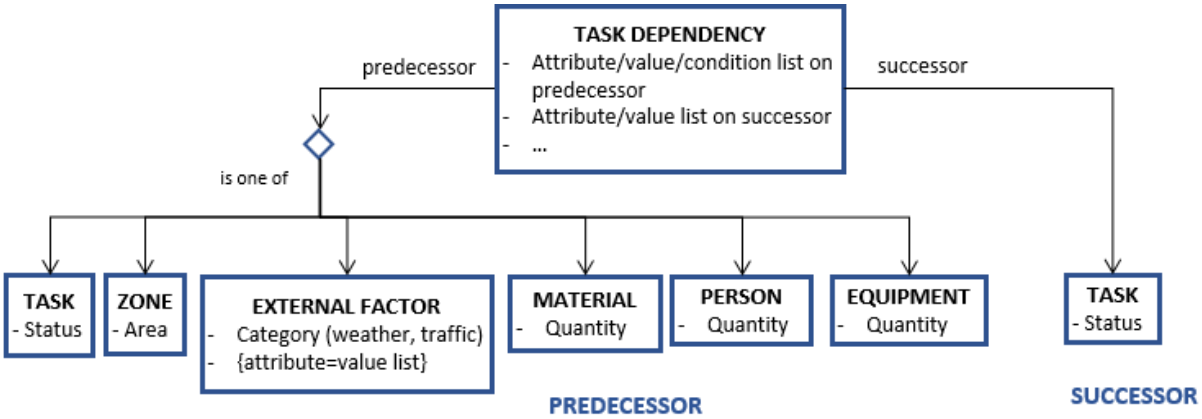


**Figure 9. Task dependencies**

Possible types of dependencies between two tasks:

- Finish to Start: Predecessor must finish before Successor can start (wall must be erected before cladding can start).
- Start to Start: Predecessor must start before Successor can start.
- Finish to Finish: Predecessor must finish before Successor can finish.
- Start to Finish: Predecessor must start before Successor can finish.

The following figure shows the above mentioned four types of dependencies, from left to right: Finish to Start, Start to Start, Finish to Finish and Start to Finish.

| **Example 1: "Task A must finish before task B starts"** | **Example 2: "Task A requires wind speed < 60m/s"** |
|---|---|
| - Attribute of predecessor: "Status"<br>- Value on predecessor: "Finished"<br>- Condition of predecessor: "Equals"<br>- Attribute of successor: "Status"<br>- Value on successor: "Started" | - Attribute 1 of predecessor: "Category"<br>- Value 1 on predecessor: "Weather"<br>- Condition 1 of predecessor: "Equals"<br>- Attribute 2 of predecessor: "Wind speed"<br>- Value 2 on predecessor: "60m/s"<br>- Condition 2 of predecessor: "Less than"<br>- Attribute of successor: "Status"<br>- Value on successor: "Started" |

It is also required to model in advance how different tasks and external factors are associated to certain risks, and these in turn must define the safety measures to be applied in terms of collective or individual safety equipment (Figure 10), which should be also part of the BIM model (in line with the ideas of Prevention through Design or PtD).

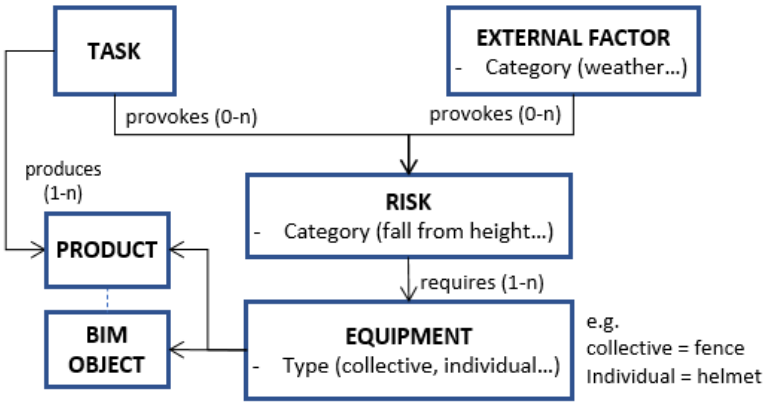


**Figure 10. Definition of risks and planning of safety measures**

## 4.2 Concepts for DO

The functionalities of the DBTP in the DO use case will be mostly related to querying information about upcoming activities or receiving proactive information/notifications (see Table 4 and Section 5.2.2). Thus, the information managed will be essentially the same as for the PLAN use case and there is no need to go further on that.

## 4.3 Concepts for CHECK

The concepts to be considered in the CHECK use case can be considered a mirror of the PLAN case (see Figure 8). In fact, most of the concepts are applicable and some new concepts (in red in next figure) are just a mapping as follows:

**Table 5. Plan/check concept mapping**

| PLAN | CHECK |
|---|---|
| Product | Completed work |
| Task | Operation |
| Order | Delivery |
| As-planned assignment | As-performed consumption |

In the case of resources, we can see that in addition to which is assigned to a task and which is allocated to a supplier or subcontractor we have also the real resources present on-site (linked to the Project Status Model). The orange concepts in the bottom-right corner of Figure 11 depict this on-site instantiation.

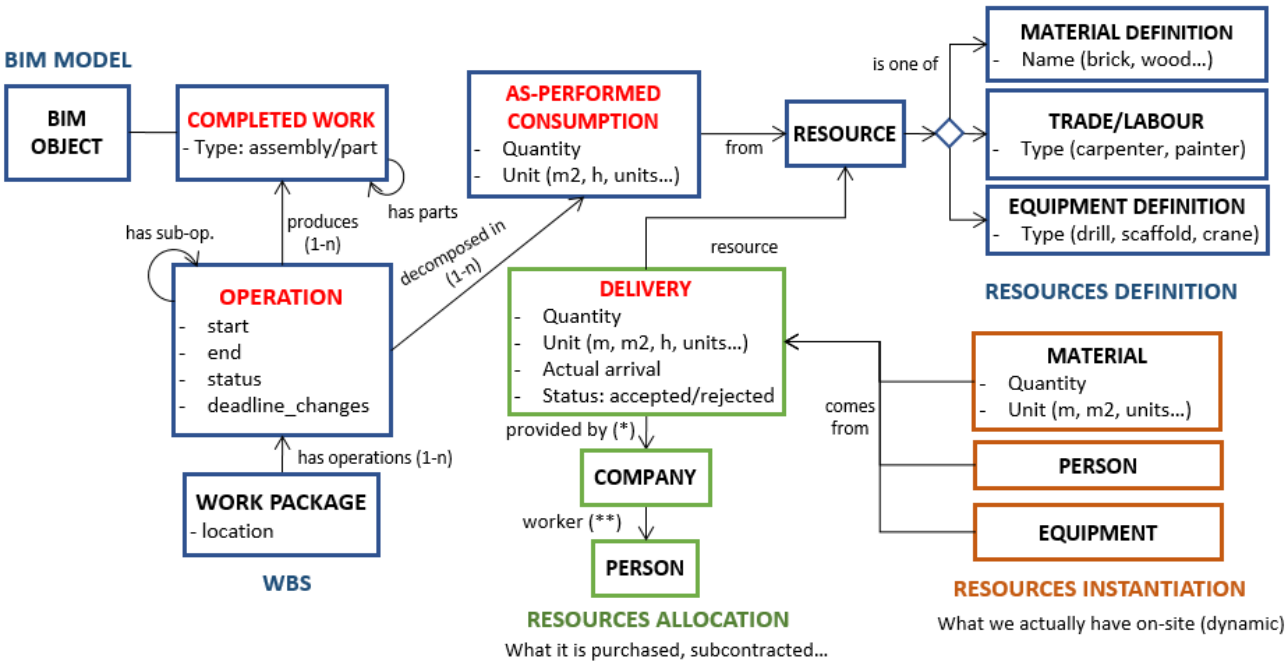


**Figure 11. Preliminary entities (CHECK use case)**

Additionally, the CHECK use case is one of the cores of BIM2TWIN, since most of the technical developments will be oriented to automatically capture and extract the knowledge about what is happening on-site. Thus, the action of checking the current status and reporting issues and deviations also imposes the need for some extra concepts.

First, to inspect the correctness of the performed work can be considered as a kind of task on its own (planned inspection), which is then realized on-site, with a potential workflow associated (person who inspects, who validates, who is responsible for corrections…).

Also, the concept of issue is very relevant. It denotes any kind of deviation with respect to the ideal plan. Issues can be categorized (delay, defect…), spatially located, associated to a task/product, assigned a severity and impact, and caused by another “concept” (person, task, etc.). In the long term, the analysis of all the stored issues will enable the extraction of KPIs for the whole process and serve as a training repository for machine learning techniques.

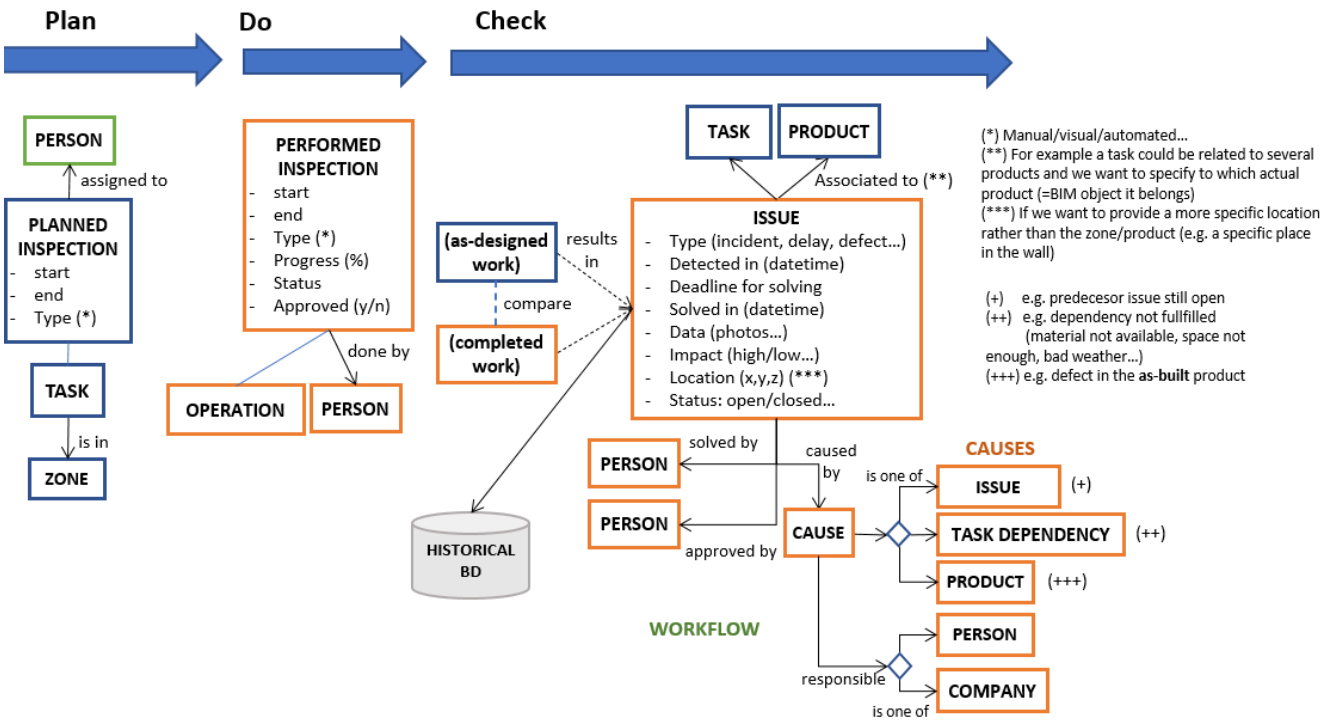


**Figure 12. Preliminary entities (CHECK use case – Progress/Quality Control)**

In the specific case of monitoring the status related to safety and equipment aspects, the following relationships appear (Figure 13), which mostly deal with checking the location of people and equipment and proximity between them and in the case of equipment the status (in use, idle…).

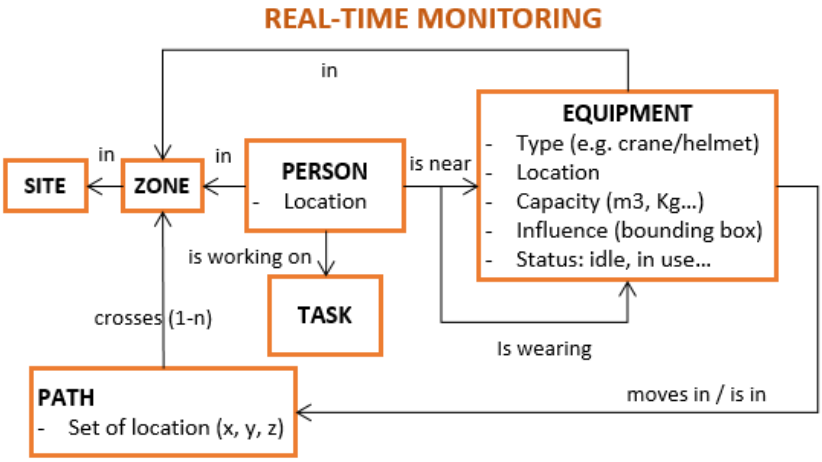


**Figure 13. Preliminary entities (CHECK use case – Safety & Equipment detection)**

The issue handling for safety and equipment can also be covered by the model depicted in Figure 12. Examples of equipment issues can be a failure in a machine, or use exceeded from the recommended duration. Examples of safety issues could proactive (detection of misplaced/not present guardrails) or reactive (an actual incident that has happened).

## 4.4 Concepts for ACT

The ACT use case mostly deals with tasking decision about how to handle the detected deviations. Mainly, to select the best re-planning alternative for the project (changes in products, resources, or scheduling). As such, it will mainly consist on generating new versions of the PLAN entities, with their respective timestamp, so no additional concepts are required.

## 4.5 Summary of all identified concepts

**Table 6. Alphabetical list of concepts**

| Concept | Definition | Description / relationships / constraints[1] |
|---|---|---|
| **As-planned assignment** | The last level of detail of a Work Breakdown Structure (WBS). It defines the amount of resources required for a product | Links a **task** with a **resource** (specifying amount and units). In the as-performed process it is mirrored into the **as-performed consumption** |
| **As-performed consumption** | The actual assignment of resources incurred in an executed task | As opposite of **as-planned assignment**, which refers to the planning phase |
| **BIM object** | A physical object as designed in a BIM modelling software.<br>A BIM object will be modelled as a subtype of *IfcProduct*. | A virtual representation of a **product** in BIM. The same way a product can be composed by product parts a BIM object can be an aggregation or container of smaller objects (e.g. in the case of IFC through an *IfcRelAggregates* relationship) |
| **Cause** | The origin of an issue | An **issue** can have different causes or originators: person, equipment (wrong/misplaced…), company (underperforming), product (with defects), etc. |
| **Company** | Represents either the constructor or any of the subcontractors/suppliers | |
| **Completed work** | Any as-built element, part of the final building | It represents the as-built counterpart of an as-designed **product** |
| **Delivery** | An order which has been executed | See **order** |
| **Equipment** | An instantiation of an equipment definition (i.e. which is onsite) | An equipment will be on a **zone**, assigned to a **task**, have a status (in use, idle…), move through a **path**, etc. |

[1] In bold, references to other concepts

| Concept | Definition | Description / relationships / constraints[1] |
|---|---|---|
| **Equipment definition** | Generic definition of an equipment (any auxiliary means used, which is not a final product of the building) | They include temporary elements, safety devices, both individual (helmet…) or collective (fence…), heavy vehicles (truck, crane) and small devices (drill…) |
| **External factor** | Anything which influences the progress of the construction and is not part of the project | It should be categorized (weather, traffic…), assign some attributes… |
| **Inspection** | Any activity carried out to assess that the as-built and as-performed matches the as-designed and as-planned | All **tasks** should be associated to an inspection, which will be assigned to a **person** and could product a list of **issues** |
| **Issue** | Any deviation from the as-designed and as-planned with respect to the as-built and as-performed, also including safety issues | An issue could be associated to a **product** and have a list of **persons** associated in a workflow (the ones who create, solve, approve… it).<br>An issue will have a cause: a precedent **issue**, a not fulfilled **task dependency** (for progress), a not fulfilled **order** (e.g. delayed delivery or has been delivered with defects) a **product** with defects (for quality), an **equipment**, **person,** or **product** (for safety), etc. |
| **Labour (crew, trade)** | Human resources required for a task | It must be categorized: carpenter, electrician, mason, truck operator… |
| **Material** | It represents the actual quantity of a given material onsite, i.e. an instantiation of a material definition | Associated to a **material definition** by specifying a quantity (which will dynamically vary) |
| **Material definition** | Generic definition of a material (a physical constituent of the final product) | They must be categorized: wood, mortar, cement… |
| **Operation** | An executed task | The as-performed counterpart of an as-planned **task** |
| **Order** | An allocation of a given resource by assigning it to a company (link with the supply chain) | In the case of labour the order will consist on a subcontracting (e.g. hire 10 carpenters to company X)<br>In the case of equipment or material it represents a purchase or hiring of goods (100 kg of concrete, 2 trucks)<br>In the as-performed process the order is materialized into a **delivery** |

| Concept | Definition | Description / relationships / constraints[1] |
|---|---|---|
| **Path** | A set of sequential locations where a vehicle or person moves on site | A path is within or crosses a **zone** |
| **Person** | Any human participating in the process | It belongs to a BIM2TWIN profile (e.g. workmanship, management…, see Table 3).<br>In the case of workmanship, they belong to a **task**, will be in a **zone**, and will be wearing protective **equipment** |
| **Product** | Can represent either<br>- a whole unit to be installed (a wall, a stair…)<br>- a part (e.g. a layer of a wall, a finishing, a frame…) | A product of type = "part" must always be child of a product of type = "assembly"<br>A product of type = "assembly" could be decomposed in products of type = "part" or be atomic (not decomposed) |
| **Resource** | The tangible inputs required to perform a task | In the context of building construction processes, we can specialize resource into more specific concepts: **labour**, **equipment,** and **material** |
| **Risk** | Anything that endangers the operational health and safety | It should be categorised (fall from heights, explosion, etc.). It will be produced by **tasks** or **external factors**, and require the use of certain **equipment** (personal or collective) |
| **Site** | The physical location or area where the construction activity occurs | |
| **Task** | A certain activity in the WBS with a given start/end dates, use of resources and responsible, which delivers a product | A task uses **resources** (**material**, **equipment**, **labour**) to create/install **products** (probably as assemblies of **product parts**)<br>Implies some **risks**<br>Has some constraints modelled as **task dependencies** |
| **Task dependency** | It models the dependencies of a given task (i.e. the requirements for that task to be executed) | |
| **Work package** | High level grouping of related tasks (excavation, structure…) within a Work Breakdown Structure (WBS) | |
| **Zone** | Spatial divisions of the site according to the phase or to the tasks performed | Site zoning will vary during the project execution several times |

# 5 BIM2TWIN HIGH LEVEL WORKFLOWS THROUGH BPMN

## 5.1 Holistic BIM2TWIN approach

In section 2.1 the overall BIM2TWIN concept has been presented, which seeks to provide a process status awareness by integrating various knowledge extraction and merging techniques based on Artificial Intelligence and targeting different domains. The concept will be applied to three different construction sites which represent different building typologies and countries/construction practices.

However, we should not limit ourselves to considering BIM2TWIN as a "single-site" management platform, and we can envisage a future with multiple BIM2TWIN replicas are used in some location.

**From single site to multi-site**

In the first place, we can imagine a construction company which manages a portfolio of construction sites, which can even run in parallel and in nearby locations. For this scenario, we could imagine the proposed DBTP not as an isolated single-site platform, but a multi-site management platform that can aggregate and coordinate the information of various construction sites manged by a contractor (see Figure 14).

Each BIM2TWIN instance is composed by three logical layers (the physical twin, the digital twin, and the service layer). A DBT broker would coordinate the information exchanges between multiples sites.

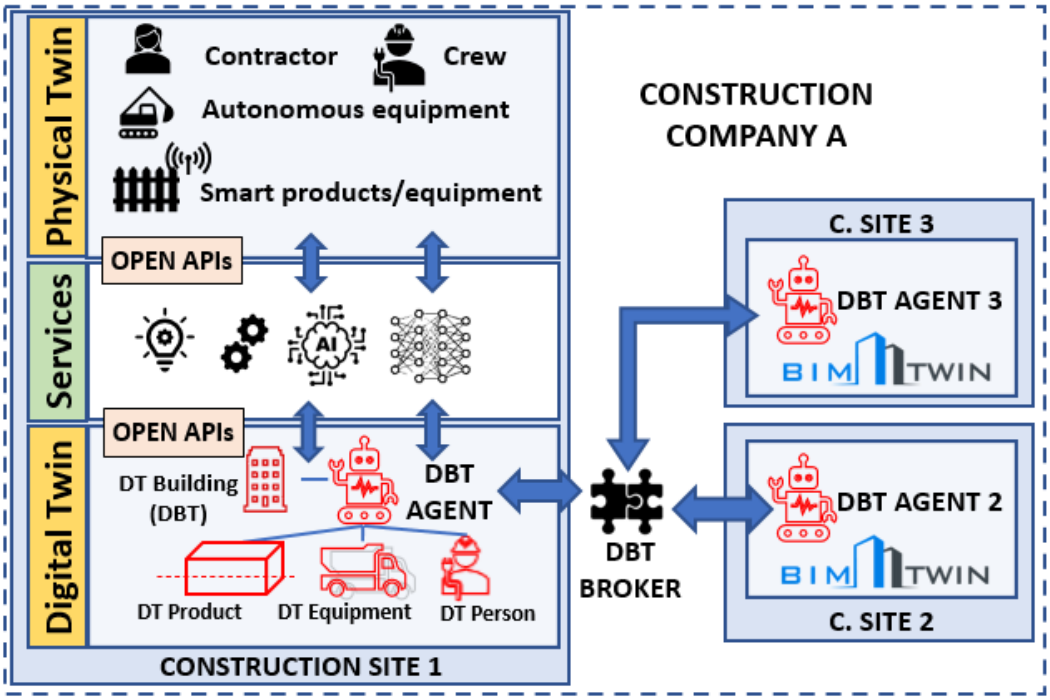


**Figure 14. Multi-site management as an evolution of BIM2TWIN Platform**

The lowermost layer consists on the individual models or Digital Twins for each entity, e.g. the digital twin of a product, a piece of equipment or even a person. Some Digital Twin models could be simpler, following a rule-based approach, while others could require more complex simulations.

A DBT agent would encompass the knowledge model of the whole building (as a product and as a process) by aggregating the information provided by individual entities, and would communicate through the API

layer with the physical counterparts, which will send and receive information to the platform. Thus, we could have:

- People with different roles (contractor, designers and crew from different trades and subcontracting companies). Communications can be on demand or proactive (e.g. a safety alert sent by the DBT to the operator's smartphone due to a detected risk).
- Autonomous equipment. In a future scenario, more and more equipment and vehicles will act on their own, e.g. send to the DBT their location or their status (idle, occupied…) and receive from the DBT orders ("pick up material from location A to B") or even act in a closed loop without directly interacting with the DBT. We could also have drones which are programmed or instructed from the DTB Agent to perform a point cloud collection with no human interaction.
- Smart products and equipment. In a similar way, the massive adoption of IoT solutions will pave the way for smart materials, smart buildings, and smart sites, so a fence could inform the DBT when it has been misplaced or opened. Sensors and RFID tags could also be used by equipment and materials to inform about their status or location.

Following the same logic, the DBT Agent would not only interact downwards, but also upwards, with other construction sites of same company which have deployed BIM2TWIN instances. That could be achieved through a middleware or central broker (see Figure 14) that coordinates different DBT Agents. That would allow cross-site optimisation of resources envisaging scenarios such as:

- If I have idle workers in site A today, I can send them to site B, if an equivalent task is foreseen there
- If due to some unexpected delay in the supply chain delivery, I am short of material in site A, but I have available stock in site B which is not estimated to be used today, I can move it from site B to A.

The service layer consists on the knowledge extraction services and applications that process the raw data generated on regular basis to extract the information about problems, delays, bad performance of processes, safety issues, etc. This information will be reported to the platform for calculating the various KPIs and trigger (when necessary) new versions of the planning (closing the loop of the PDCA cycle).

This approach is in line recent proposals of the DTaaS concept (Digital Twin as a Service) [7] although in a broader sense, not only for construction, but for industry in general.

**From Digital Twin Platform to Digital Twin ecosystem**

We could bring the previous line of reasoning one step forward and think of a coordination not only between the various DBT instances, but with other types of heterogeneous Digital Twins at different spatial scales and technical domains (city, infrastructure, etc.). The challenge here is even greater, since multiple digital twins from different organisations and from different domains must agree on a common way of sharing knowledge for optimising the real-time management, but also for benefitting from historical data for learning, benchmarking and self-tuning purposes.

A research from Boje C. et al [8] advocates for future semantic and intelligent construction platforms. On the one hand, the semantics are boosted by providing common agreed vocabularies and APIs, where standards such as IFC have a relevant role to play, all complemented with an integration layer through semantic web technologies.

On the other hand, the intelligence is ensured by leveraging AI for prediction and optimisation applied to various vertical services (some of them also considered herein, such as real-time safety detection, automated progress monitoring or optimised scheduling and resource allocation). The concept of AI-enabled agents is suggested.

As the authors above mention: “building does not live in isolation and should therefore be regarded from the perspective of the city district level. Interactions with its immediate environment (city traffic, pollution, social events, etc.) should be considered for a larger construction site management context”.

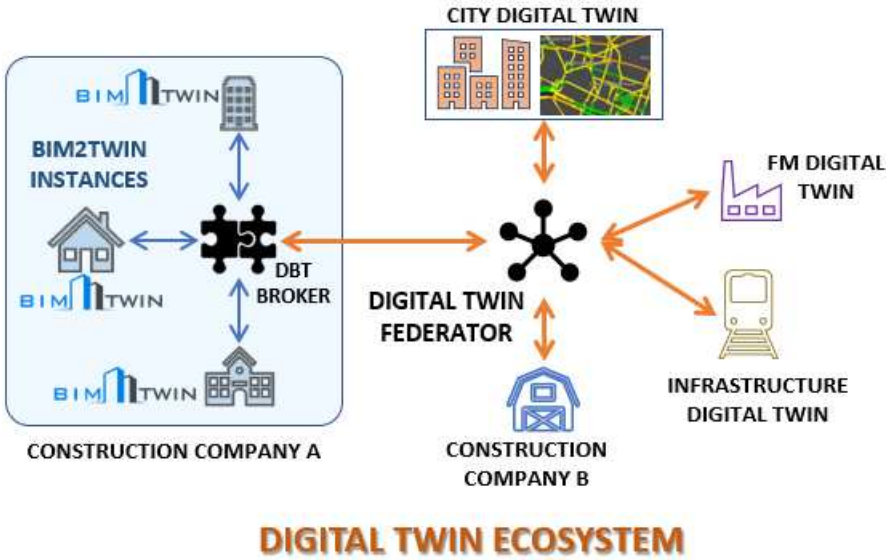


**Figure 15. Vision of BIM2TWIN as part of a Digital Twin ecosystem**

This is totally aligned with current initiatives at international level. For instance, buildingSMART and The Centre for Digital Built Britain [9] already introduce the concept of an Ecosystems of Digital Twins, as aggregated systems of systems in a federated approach [10][11][12]. The rationale behind is that the value of data exponentially increases when it is shared across organisations and scales (product, system, building, city). In the United Kingdom the concept of National Digital Twin is also in place. For those scenarios to happen, it is mandatory to rely the interconnections on secure and trusted exchanges, based on open APIs and ontologies. Also, in the United States the Digital Twin Consortium [13] has established technical guidelines and taxonomies and a series of requirements and new standards to maximize the benefits of digital twins, demonstrating the value of this technology.

Similarly, the ongoing Horizon 2020 project SPHERE [14] also aims at envisaging a Platform as a Service (PaaS) architecture for Digital Twins deployment in a Common Data Environment (CDE) [15] and standardising some key definitions [16] and in the project framework is remarkable the report "The White Book of Digital Twin. Definitions for building", which aims to be a starting point for the creation of a standardized work environment. The role of ontologies and commonly agreed vocabularies for the building domain is crucial, which has led to setting up the Building Digital Twin Association (BDTA) [17].

It is also aligned with other documents that develop the concept of the digital twin, for example ARUP [18]. This report presents the current state of the digital twin in the built environment and explores ideas about what might be possible in the future by presenting the various definitions of digital twins in the industry and defining the digital twin and its ecosystem with the goal of better decision making, learning and autonomy.

## 5.2 BPMN templates proposal

In the following section, the concept reflected in Figure 14 and Figure 15 is translated to a harmonized BPMN template, which will be used in each of the PDCA stages.

This set of BPMN templates depict a holistic vision of the whole construction process and how it could look like in a nearby future thanks to the potential of process automation. As such they cover a wide range of situation, but without going into deep details. On the other hand, specific process maps (also in BMPN) developed as part of technical requirements in Tasks T3.1, T.1, T5.1, T6.1 and T7.1 can be seen as specific implementations or "instances" of this global BPMN. They do not cover the full automation potential described herein, only some selected use-cases for implementing and testing on-site, but these use cases are detailed more in deep since they are the entry point for software implementation specifications.

The following figure shows the different pools and lanes into which the template is structured. Note that for better readability, it has been rotated 90 degrees (pools and lanes are horizontally displayed in BPMN).


**Figure 16. BPMN template for BIM2TWIN**

The following conventions have been followed from top to down (from right to left in Figure 16).

- POOL: Construction site. It models everything happening in the actual construction site, potentially including office or design activities and groups internally the different actors in lanes:
    - LANE: Person. We should have a lane for each individual role considered in the process map, e.g. contractor, worker (which could be even further specialized if needed).
    - LANE: Autonomous equipment. All equipment that could act on its own (e.g. a construction robot or a self-driving vehicle equipped with GPS and vision cameras). Some equipment could even have a local-loop logic (e.g. for safety purposes).
    - LANE: Smart equipment/product. Any element that can be tagged and can emit or receive information, e.g. material stock or equipment with an RFID tag that informs about its properties or can be tracked. Another example can be a fence with a contact sensor that "informs" when it has been opened.
    - LANE: Data capture and store. All devices that capture what is happening onsite (e.g. video or surveillance cameras and the local deployment which stores all this raw data, as well as the data captured by people or by other smart equipment. This massive storage will be a temporary buffer, only relevant information (issues or high-level knowledge extracted from here) will be sent to the Digital Twin Platform.
- POOL: Services. It encompasses all the services developed for extracting valuable information and insight from the bulk data generated in the construction site. In the context of BIM2TWIN, all the data merge and interpretation services based on Artificial Intelligence (AI) related techniques (point cloud segmentation and object detection, computer vision, machine learning, etc.). Ideally, these services should run in an automated way, with minimum user interaction.
- POOL: API Layer. For a better understandability of the information flows between physical and digital pools, all exchanges are grouped into a specific lane. In the actual implementation of the DBTP, these exchanges will be mapped to specific web service specifications (e.g. a JSON content, a file content, or a list of parameter inputs within a REST API call).
- POOL: Digital Twin Platform. It represents the digital or virtual counterpart of the construction site. Two main lanes are considered.
    - LANE: DBT Entities. It represents the backbone representation of the Digital Twin concepts identified previously in Section 4, modelled as data objects in BMPN. We could imagine them as Digital Twins of individual concepts (people, products, processes, and equipment). All entities will have the representation of is intended or planned status (probably in different versions) and the representation of past status and performance.

- LANE: DBT Agent. By interlinking and analysing the various DBT Entities we can derive the Digital Twin of the whole building (both as a set of products and a set of processes). The DBT agent models this high-level knowledge and orchestrates the information flows to and from each entity. The vision is that it could talk to other DBT agents for coordinating and exchanging information in a future Ecosystem of Digital Twins using open APIs.

This approach has been further split in four BPMN templates covering each step of the PDCA cycle, which are detailed in the following pages. For each stage, two diagrams are described: the generic one and the specific one which is the specific use case defined for BIM2TWIN project, considering the vertical domains addressed.

### 5.2.1 *BPMN template: PLAN*

#### 5.2.1.1 Generic case

The planning phase will consist of the creation of the as-designed data model (products).

**Table 7. BPMN template for PLAN**

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Person** | [P1] Provide as-designed & as-planned data | Generation of the BIM model and scheduling with the level of detail required. This is usually done through external modelling/planning software and possibly not at a single stage but in iterative steps, with increasing detail |
| **Services** | [P2] Data validation | A quality control check of the generated data. If it fulfils the requirements from the DBT perspective (if the attributes and relationships between objects, tasks, risks… are properly modelled). Some 4D planning tools already offer some of these capabilities. In the future, we could envisage as a built-in feature of the platform, supporting a Model View Definition (MVD) [19] of IFC created for that purpose. |
| **API Layer** | As-designed & as-planned | The input data received by the platform in the agreed format(s) (IFC, XML…). |
| **DBT Agent** | [P3] Update as-designed & as-planned | Create (or update) the objects corresponding to the as-designed/as-planned, as well as their mappings and relationships (see Table 6 for a preliminary list of objects, to be further refined in the DBTP Data Model in WP2). |

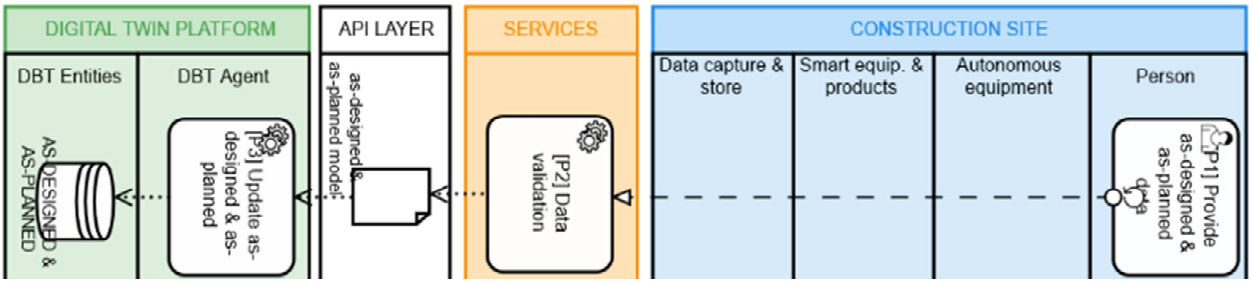


**Figure 17. Generic BPMN template for the PLAN phase (rotated)**

This generic concept is translated into a high-level BIM2TWIN use case as follows.

#### 5.2.1.2 BIM2TWIN use case: PLAN

This BPMN Diagram shows the first steps in the beginning of the construction process. In this point of the workflow is where the as-planned information is generated.

The main participant is the Constructor in its different ambits where he/she has responsibility (Scheduling, Safety and Quality Control). Some of them require BIM modelling skills.

Figure 18 reflects the high-level BIM2TWIN use case for the PLAN stage, where different subdomains or disciplines as depicted with different colours.

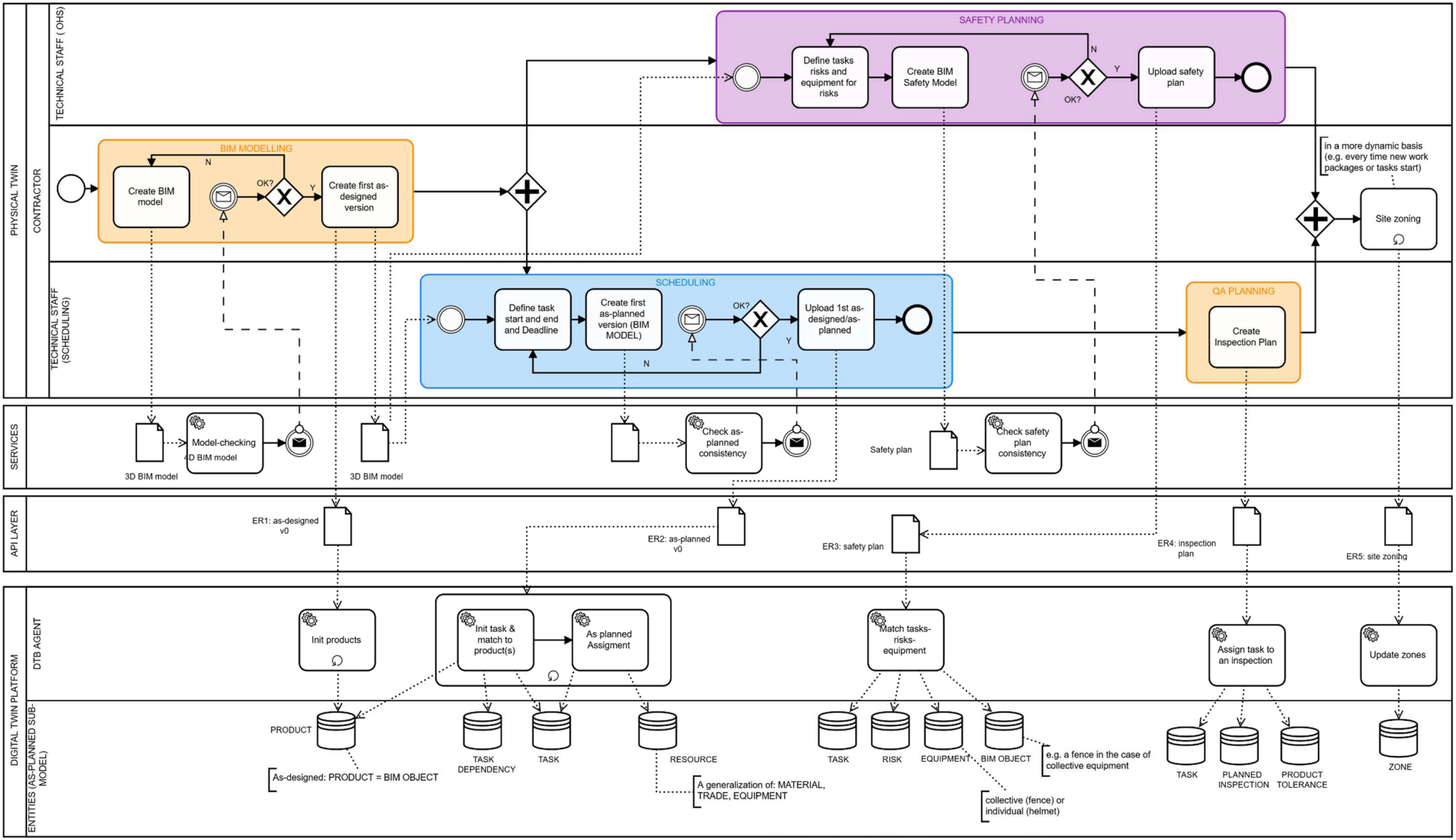


**Figure 18. BIM2TWIN use case for PLAN**

**Table 8. BPMN template for use case PLAN**

| Actors | Tasks / Data objects | | Description |
|---|---|---|---|
| **Person [Technical Staff]** | [P1] Provide as-designed & as-planned data | BIM MODELING. CREATE BIM MODEL- | Generation of the BIM model and scheduling with the level of detail required. This is usually done through external modelling/planning software and possibly not at a single stage but in iterative steps, with increasing level of detail. |
| | | SCHEDULING | A sequency of Activities managed by the technical staff of contractor, specialized in scheduling, with the objective of generation the initial scheduling of the construction.<br>In this process, for each product of BIM Model, it will be defined the task in different aspect (start, end and deadline, dependency into task, etc.). In addition, in each task will be identify the resources necessary to develop it (material, trade, equipment, etc.) |
| | | QA PLANNING | This task is managed by the technical staff of contractor, specialized in scheduling and Quality Control, with the objective of creating the initial Inspection Plan.<br>In this process, the planned inspection will be developed for each product and how it will be checked in each task. Also, it will be defined the allowed tolerance to admit an executed task. |
| | | SAFETY PLANNING | A sequency of Activities managed by the technical staff of the contractor, specialized in Health and Safety, with the objective of create the initial Safety Plan.<br>In this process, the first step is to define the risk associated to each task and the risk of the equipment necessary to make the task. After that, it is necessary to create the BIM safety model which must be checked to verify the safety plan consistency. |
| **Services** | [P2] Data validation | BIM MODELING. CHECKING | It will be necessary to check the BIM Model contain all the necessary information to build. |
| | | CHECK AS PLANNED CONSISTENCY | It will be necessary to check the consistency of the scheduling to be able create the as-designed /as-planned information in the DTB. |
| | | CHECK SAFETY PLAN CONSISTENCY | It is necessary to create the BIM safety model which have to check to verify the safety plan consistency. |
| **API Layer** | As-designed & as-planned | ER1-as design | The required information is the BIM model for execution/construction (in a higher LOD than the design model). If the execution project contained a BIM model, it will be necessary to modify and to adapt it to the reality of the construction site. The data exchange is the information the as-design product, based in the BIM Object of the BIM 3D Model.<br>The information included in this 3D model, is the data of the beginning point of the process.<br>This data object represents the data grouped into a specific exchange between contractor, who represented the Physical twin, |

| Actors | Tasks / Data objects | | Description |
|---|---|---|---|
| | | | and the Digital twin platform, about the fist as-design version BIM Model. |
| | | ER2-as planned | The required information is the as designed BIM Model. The data exchange is the information as planned.<br>This data object represents the initial plan of the all task necessary to executed and the match with the products defined in the BIM Model. In this task are included not only the start, end, and deadline of them but also the interdependency between the tasks and the resources to execute them (material, trade, equipment, etc.). |
| | | ER3-safety plan | The required information is the as-designed BIM Model and the data exchange is the safety plan.<br>This data object represents the information grouped about the safety planning where include the risk associated to task, the individual and collective equipment necessary to reduce the risk and how the task, the risk and the necessary equipment are related. |
| | | ER4-inspection plan | The required information is as-planned information which include the detailed of each task. The data exchange is the inspection plan.<br>This data object represents the aggregated information about the quality control planning including the inspection plan and how it relates to the task. |
| | | ER5-site zoning | The required information is the as-planned information and safety plan. The data exchange is the zoning of the construction site.<br>This data object represents the information about the on-site zoning according to the safety plan and as-planed task. Thus, the update frequency of the zoning will be higher than the BIM model (e.g. every time new tasks start or change from location)<br>It could be a 2D map or other format, but it should be referred to the same coordinate system as the IFC model |
| **DBT Agent** | [P3] Update as-designed & as-planned | Initial product | The data exchange is the information the as-design product, based in the BIM Object of the BIM 3D Model. The information included in this 3D model, is the data of the beginning point of the process. |
| | | Initial task &match to products | The as-planned information contains the detailed task, the task dependency, and the resources. |
| | | As planned assignment | |
| | | Match task-risk equipment | In the safety plan, is matched the task defined in the execution plan with de risks, the risk of equipment used in the task and the collective and individual equipment necessary to minimize the associated risk with each task. |

| Actors | Tasks / Data objects | | Description |
|---|---|---|---|
| | | Assigned task to an inspection | The inspection plan contains the detailed point of inspection and the description of who, when, how must do the inspection process. Also, there are definition about the tolerance to accept a product. |

### 5.2.2 *BPMN template: DO*

#### 5.2.2.1 Generic case

This workflow reflects the usage and information flows of the DBTP when performing the real onsite activities. To be more precise, it is meant to be implemented in a proactive manner, i.e. the information requirements and workflows to be supported before a task runs.

**Table 9. BPMN template for DO**

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Person** | [D1] Information requests | Any information request launched on-demand by an end-user participating in the process, e.g. "list of tasks assigned to me today", "list of equipment required for today/tomorrow", etc. The requests allowed (and responses received) could depend on the user role (worker, site manager…), as well as the way to display the results (table, 2D map…) |
| | [D6] Receive notifications | In addition to on-demand request, each user should be able to receive proactive notifications or alerts form the platform, e.g. "New task start planned for tomorrow" or "Not enough material for the tasks planned for today" (see [D5] Notify, below) |
| **Autonomous equipment** | [D7] Receive notifications | Same as [D5] applied to autonomous equipment (e.g. a scanning robot which receives orders from the DBTP, like: "Please perform a point cloud scanning of the second floor at 17:00") |
| **Smart equipment or product** | [D8] Receive notifications | Same as [D6], [D7] applied to smart equipment/product |
| **API Layer** | Info request | The requested information by the user |
| | Info response | The response sent back to the user |
| | Next/ongoing tasks | Receive the list of next/ongoing tasks in which the requesting user is involved, with all the required metadata (start, end, location, required resources…) |
| | Quality info | The report of the quality check performed in [D4] in the specified format |
| | External request | Information request sent to another site |
| | External response | Information received from another site |
| **DBT Agent** | [D2] Perform query | Perform the request query to the DBT model (as-planned & as-designed entities) |
| | [D3] Check ongoing & next tasks | It checks which tasks are ongoing or due to start in order to inform the affected stakeholders |
| | [D4] Check information quality | For tasks detected in [D3], it checks if the existing information level and quality in the DBT model is the required one for the processes to run, e.g.: |

| Actors | Tasks / Data objects | Description |
|---|---|---|
| | | • Check if a product (BIM object) is split in layers, with definition of colours/materials/textures before requesting a scanning for texture detection<br>• Check if materials needed for a task starting tomorrow have been ordered to a supplier and its status (arrived, on the way...)<br>• For a task starting tomorrow, check if it is associated to a spatial zone and the risks have been defined and modelled in the DBTP |
| | [D5] Notify | Notify the affected user (or autonomous or smart equipment) of next/ongoing tasks and associated information.<br>Additionally, notify to the relevant person potential lacks or defects in the information quality<br>Note that this action can also be triggered by external events (e.g. a sudden change in wind speed could trigger a safety warning like "you cannot start the works in the roof in these weather conditions") |
| | [D9] Coordinate with external DBTs | Some tasks or some situation could require multi-site coordination. For example, if we don't have enough material for today/tomorrow, the DBT Agent could request to other nearby sites if they have spare material |
| | [D11] Handle external requests | The inverse of [D9], a DBT agent can be receiving external requesting and sending back requested information |
| **DBT Broker** | [D10] Multi-site optimisation | Manage and orchestrate the information request between different sites (DBT agents) |

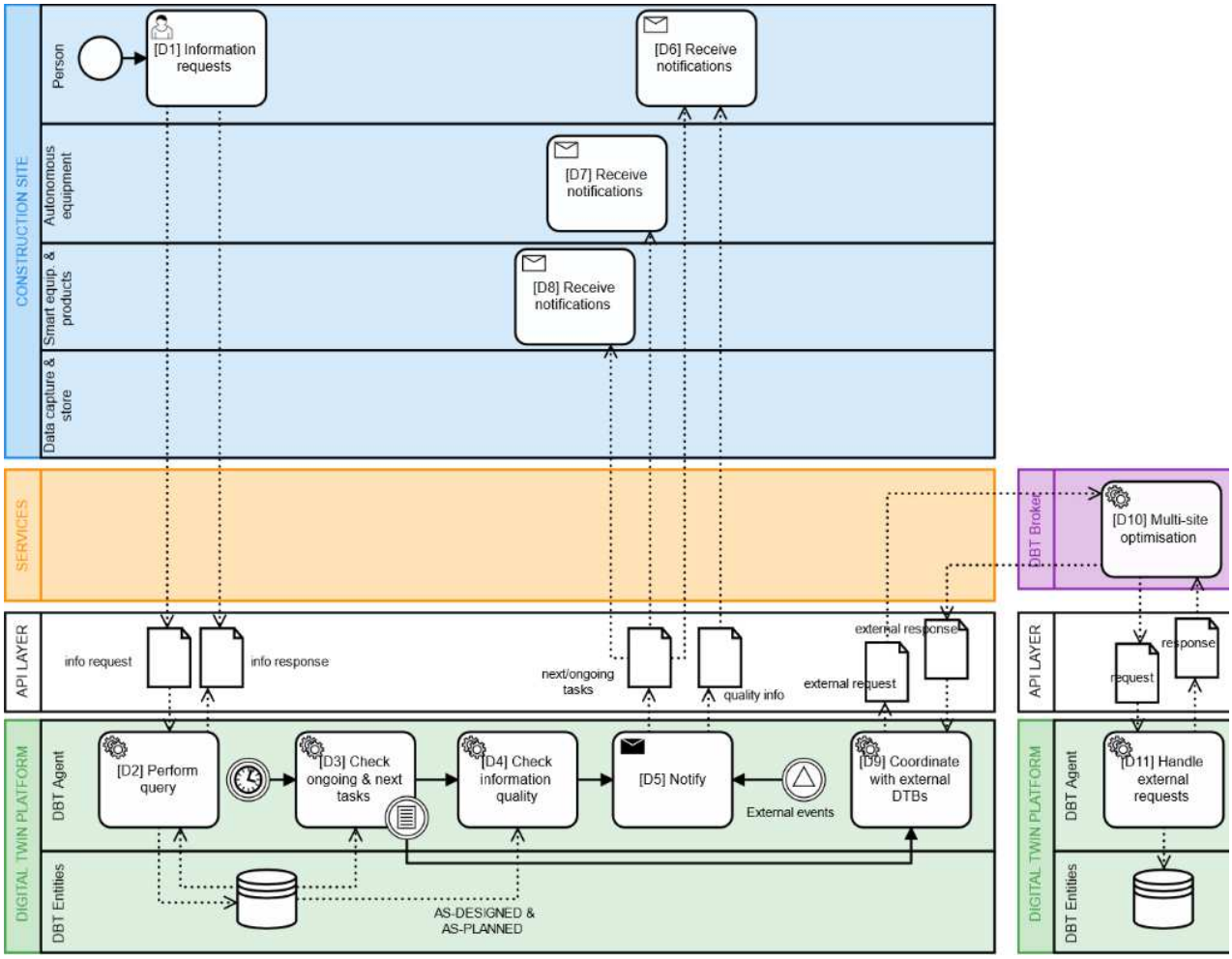


**Figure 19. Generic BPMN template for the DO phase**

#### 5.2.2.2 BIM2TWIN use case: DO

In this case, no specific diagram for a concrete use case has been created, because the flow it is very similar in all of them. In general lines, the different actor who works in the ambits of constructions (Health and Safety, Scheduling, control quality, etc.) request information necessary , the digital twin platform works performing different query, checking ongoing and next task, checking information quality, etc. and finally the result of these process is notified to the actor. This result could be sent directly to the actors or to other elements as smart equipment or products or autonomous equipment.

Each agent in function of their role in the construction process, will visualize and manage the information in different formats and levels of detail. This analysis is addressed in D1.4 Dashboard Requirements, which goes into more detail about how the information is presented to different stakeholders.

When the digital twin is part of a digital twin ecosystem, the result of checking the ongoing or next task, could be coordinate with external DBT to optimize multisite tasks.

### 5.2.3 *BPMN template: CHECK*

The check phase reflects the activities oriented to check that the executed work (as-built products and as-performed tasks) corresponds to the planned one (as-designed products and as-planned tasks), in terms

of scheduling, quality and resources employed, among other factors. In the case of BIM2TWIN it represents the core part of the data merge and interpretation processes developed in WP3 to WP6.

As Figure 20 shows, any progress checking activity starts with capturing onsite data which will be further postprocessed. This data capture can be initiated in 4 different ways in the most generic case:

- Manually by a person: worker performing an inspection either visually (and entering data in a tool) or using scanning devices.
- Automatically by an autonomous equipment (e.g. a robot programmed to perform scanning of an area or the whole site every day).
- Automatically by fixed cameras or sensors, which populate a raw database.
- In response to some event by smart products (e.g. a fence which reports itself when it has been moved).

In all cases, data is stored in a local raw database deployed on-site. Only selected and curated information derived from this database will be uploaded to the DBTP.

#### 5.2.3.1 Generic case

**Table 10. BPMN template for CHECK**

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Person** | [C1] Data capture | It denotes the action of capturing data using some device (smartphone, handheld scanning device, etc.) |
| | [C2] Manual inspection | It denotes the action of visually performing an inspection, the result being manually entered in a tool |
| | [C3] Report issue | Manually reporting an issue (e.g. a problem identified in a visual inspection) |
| | [C11] Receive notifications | Receive a relevant notification, either in a closed loop (e.g. safety risk detected and notified to a smartphone) which must be immediately sent or a notification by the platform for any other issue (see [C20] and [C21]) |
| **Autonomous equipment** | [C4] Data capture & report status | An autonomous machine (construction robot, scanning robot, self-driving vehicle...) equipped with cameras, GPS, etc. which continuously monitors its environment and sends to the raw DB the captured data (images, its location through GPS coordinates…). It could even report its status (stopped, moving, idle…). |
| | [C5] Report issue | When a relevant issue is detected (e.g. safety risk) it can directly by sent to the DBTP |
| | [C10] Receive notifications | Receive a relevant notification, e.g. a stop order, due to a safety risk |
| **Smart equipment or product** | [C6] Report status | e.g. a smart product that reports its status when changes are detected (opened, closed, moved, etc.) |
| | [C7] Report issue | Same as [C5] |
| **Data capture & store** | [C8] Data capture | Capture periodically data (images, video streams, temperatures, wind speed) and send to the local storage |
| | [C9] Send notifications | Send notifications directly to people or equipment onsite, without going through the DBTP (in some cases, we don't need this level of detail in the platform) |

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Services** | [C12] Request information to DBT Platform | It denotes any information request sent to the platform by a generic data merge & interpretation service |
| | [C16] Data merge & interpretation -> knowledge | It denotes the process of converting captured data to knowledge by applying data fusion and AI techniques |
| | [C17] Update information in DBT Platform | Update the as-built & as-performed information in the DBTP because of [C16] |
| | [C18] Report issue | Report an issue to the platform when the outcomes of [D16] represent a deviation |
| | [C21] Report information issue | Report an issue to the end-user when the information quality in the platform does not meet the requirements for running a given service |
| **API Layer** | Requested info | Information requested by a given service |
| | Response | Response sent by the platform to the previous request (when the information stored meets the required quality, see [C13]) |
| | Status | The update in the as-built / as-performed status generated by the services |
| | as-built/as-performed issue(s) | Issues due to deviations in the as-built/as-performed issue(s) in relation to the as-designed / as-planned |
| | Information issue | Issues related to inadequate information quality in the DBTP with respect to the required by the services |
| **DBT Agent** | [C13] Check information quality | Checks the information quality level for the associated request |
| | [C14] Provide information | Provides the requested information to the requesting service (see [C12]) |
| | [C15] Update status | Updates the status of a given entity in the as-built or as-performed |
| | [C19] Create issues | Creates an issue in the platform with the required metadata (type, severity, timestamp, etc.) |
| | [C20] Report information issue | Reports an information issue to the requesting service, which in turn will send it to the end user (see [C21]) |

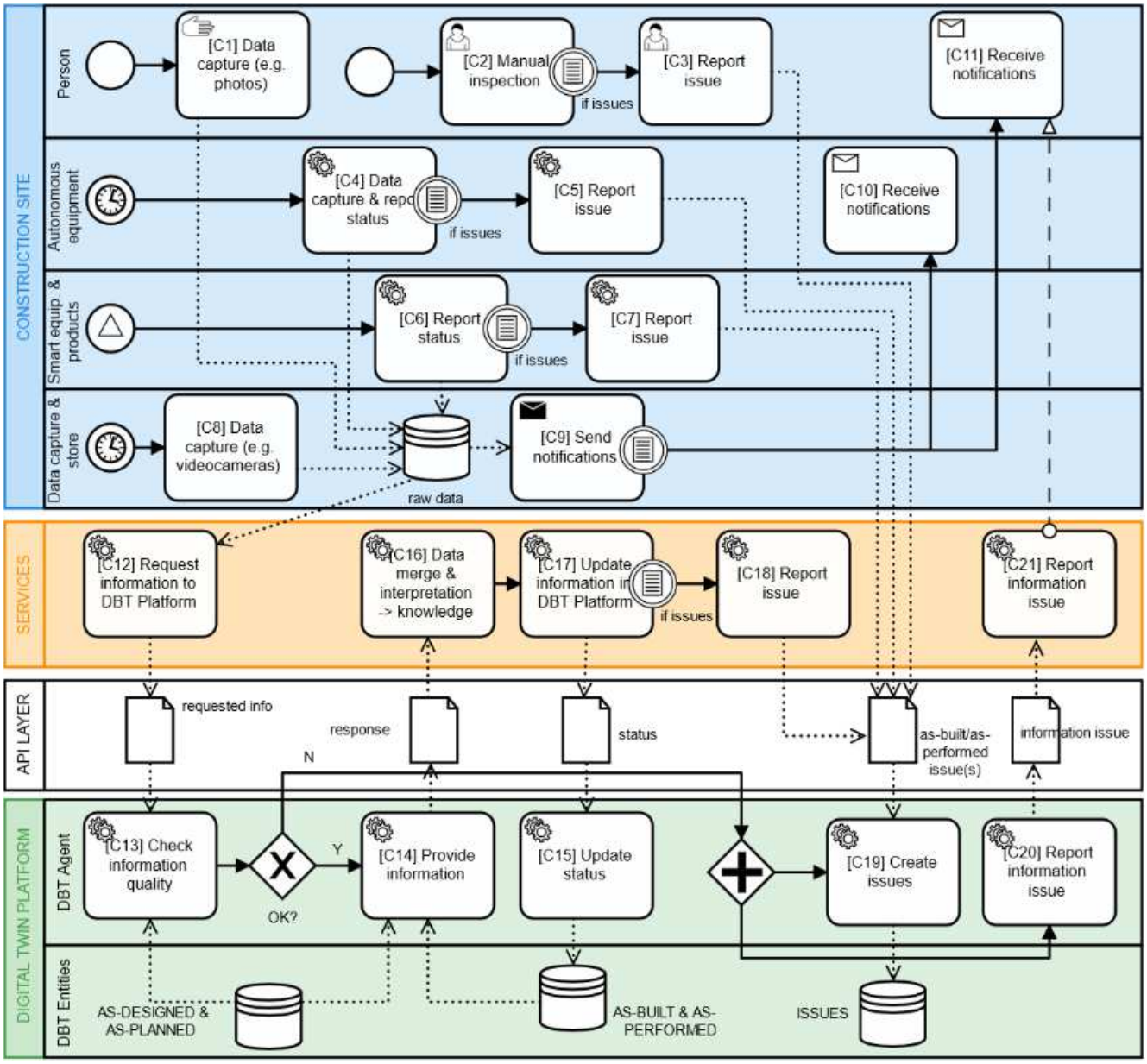


**Figure 20. Generic BPMN template for the CHECK phase**

### 5.2.3.2 BIM2TWIN use case: CHECK PROGRESS & QA

The BPMN Diagram in Figure 21 shows the activities oriented to check that the executed work (as-built products and as-performed tasks) corresponds to the planned one (as-designed products and as-planned tasks), in terms of Scheduling and Quality Control. In this diagrams, as well as the next diagrams in this document, a colour coding has been applied to map the different vertical domains and developments addressed in BIM2TWIN project to the BPMN, so that the interactions and holistic view can be easily identified at a glance.

The checking activity starts with capturing onsite data (point Clouds and Images) which is stored in a local raw database deployed on-site (Data Store). The process start will ideally be triggered by DBTP proactive notifications (list of upcoming tasks/products to be checked).

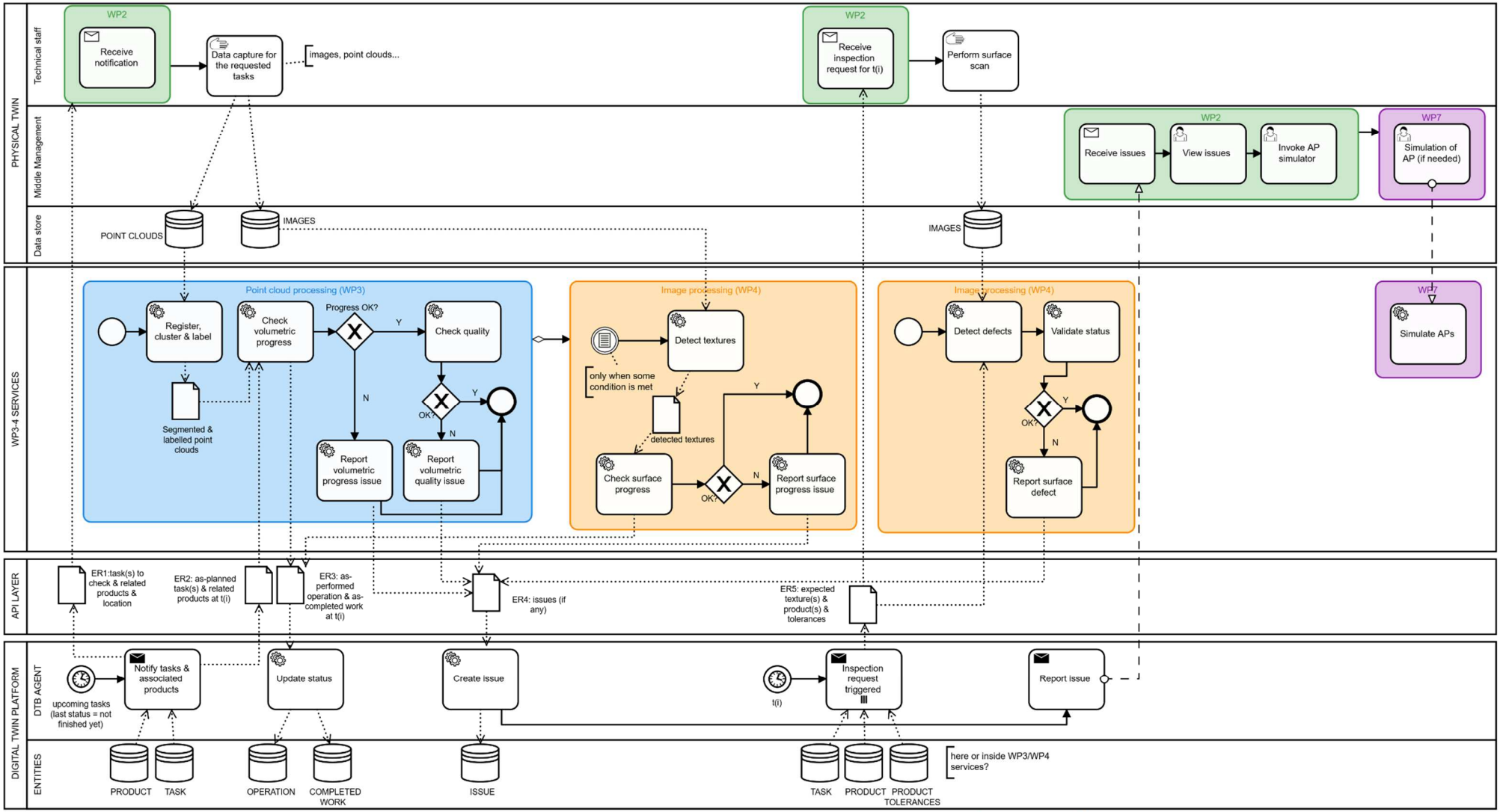


**Figure 21. BIM2TWIN use case: CHECK PROGRESS & QA**

**Table 11. BPMN template for CHECK progress & QA**

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Person** | [Technical Staff] Data capture | When a notification is received, the data capture will start for the requested tasks (which in turn are related to objects) with the required equipment (scanner or smartphone). The notification could come from a trigger due to an upcoming task or due to a programmed inspection. |
| | [Middle Management] Receive notifications | When the Middle Management receive an issue, they review them and activate the AP simulator |
| **Services** | Point cloud processing | First, request information (Point Clouds) from a DB deployed on site. Secondly, registering, clustering, and labelling of point clouds. Afterwards, check the volumetric progress comparing the segmented, labelled point clouds with as planned and related products (ER2). If the progress is according to the planification, then the following step is to check the quality and also update information as-performed & as completed work (ER3).<br>But, If the outcomes represent a deviation, then a volumetric progress issue is reported (ER4). |
| | Image Processing to detect progressing | If the condition is needed, then detect textures from image stored in the DB developed on site, and check the surface progress, if the progress is according to the planification then update information as-performed & as completed work (ER3).<br>But, If the outcomes represent a deviation, then report a volumetric progress issue (ER4). |
| | Image Processing to detect defect | If the agent receives an inspection request, then checking the image from DB developed on site with expected textures and products tolerance (ER5). The following step is validating the status and when the outcomes of comparation represent a deviation, then an issue to the platform is reported (ER4). |
| **API Layer** | Requested info | ER1: task to check & related products and location (including their geometry). Information requested by technical staff<br>ER2: as planned task and related products (including their geometry). Information requested to checking volumetric progress<br>ER5: expected textures & products & tolerance. Information requested to checking defects |
| | Status | ER3: The update in the as-built / as-performed status generated by the services |
| | as-built/as-performed issue(s) | ER4: Issues due to deviations in the as-built/as-performed issue(s) in relation to the as-designed / as-planned |
| **DBT Agent** | Notify task & associated products | Provides the requested information to check the volumetric progress |
| | Inspection request triggered | Provides the requested information to detect defects |
| | Update status | Updates the status of a given entity in the as-performed operation &as completed work |

| | | |
|---|---|---|
| | Create issues | Creates an issue in the platform with the required metadata (defect, volumetric quality, etc.) |
| | Report information issue | Reports an information issue to the requesting service, which in turn will send it to the end user |

#### 5.2.3.3 BIM2TWIN use case: CHECK OHS

This BPMN Diagram shows the activities oriented to check the safety conditions. This use case represents the proactive real time risk monitoring and detection.

As before, the colour coding reflects how other domains and developments in BIM2TWIN are related to this use case (mainly equipment optimisation and alternative plans simulations).

**Table 12. BPMN template for CHECK OHS**

| Actors | Tasks / Data objects | Description | |
|---|---|---|---|
| **Person** | [C1] Data capture | Image | The Middle Management takes images to check the required inspection |
| | [C2] Manual inspection | Visual Scan | The Middle Management does the Visual Scan to check the required task. |
| | [C3] Report issue | The Middle Management reports the issue if they detect with the visual scanning an issue. | |
| | [C11] Receive notifications | If the system detects an issue about a personal risk, an alert will be sent to his/her mobile device | |
| | | The Middle Management receive a notification of safety uses and if It is necessary launch a simulation of AP and check the safety KPI and the recommendations, | |
| **Autonomous equipment** | [C4] Data capture & report status | Equipment location | The equipment has a GPS system which reports the position, and/or the status (opened, closed, moved, etc.) when changes are detected to the local storage |
| | [C1] Data capture | Person location | The person has a GPS system which reports his/her own position to the local storage |
| | [C10] Receive notifications | Receive stop signal | Receive a relevant notification, e.g. a stop order, due to a safety risk |
| **Smart equipment or product** | [C6] Data capture & report status | Person location | The person has a GPS system which reports own position to the local storage |
| **Data capture & store** | [C8] Data capture | Continuous video ¬image capture | An autonomous machine Captures periodically data (images, video streams, temperatures, wind speed, position etc.) and send to the local storage |
| **Services** | [C16] Data merge & interpretation -> knowledge | PROACTIVE REAL-TIME RISK MONITORING | Process of get input of data (image, video, position, etc.) from local data base in streaming and interpretation of the data with the OHS requirements of person. Next, the risk is calculated, checking the |

| Actors | Tasks / Data objects | | Description |
|---|---|---|---|
| | | AND DETECTION | real-time data, with the OHS requirements which should be onsite (personal and collective equipment). |
| | | SAFETY KPI | Process to calculate the Safety KPI from the simulate APS |
| | [C18] Report issue | Report Issues | Report an issue to the platform when the outcomes of PROACTIVE REAL-TIME RISK MONITORING AND DETECTION represents a deviation with the safety requirements |
| | [C21] Report information issue | Send preventive warning an alert | If a risk is detected, an issue will be reported and will send a preventive warning and alert to the implicated person. In addition, If the risk is caused by a machine and it's safe to stop, it will send a stop signal to stop the equipment. |
| **API Layer** | Requested info | ER1: OHS requirements | Information requested by an OHS service about the OHS requirements in the personal and collective equipment which should be onsite |
| | Response | | Response sent by the platform for the OHS service |
| | as-built/as-performed issue(s) | ER2: Safety issue, detected risk, timestamp, task, severity | Issues due to identify risks on site in relation to the required safety measures |
| **DBT Agent** | [C14] Provide information | Check for required safety measures | Provides the requested information to the requesting service about requirement of the personal and collective equipment which should be on site |
| | [C15] Update status | Check for potential risk | Updates the status of a given entity in the as-built or as-performed about the potential risk based on external factors as weather condition. |
| | [C19] Create issues | Create issue & assign to task product | Creates an issue in the platform with the required metadata about safety issues, detected risk, timestamp, task, severity, etc. |
| | [C20] Report information issue | Sent notifications | Reports an information issue to the Middle OHS Management by sending a notification |

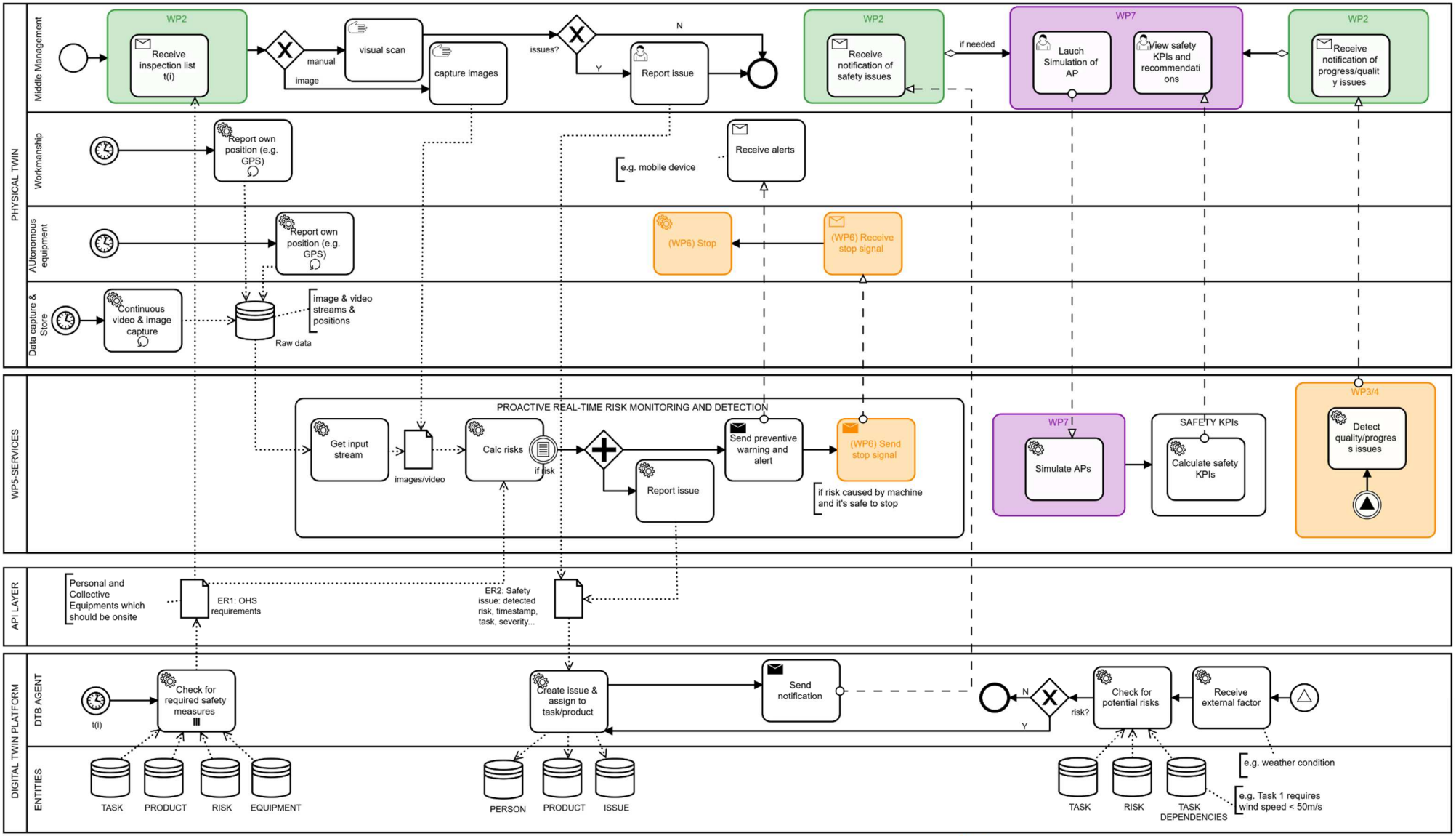


**Figure 22. BIM2TWIN use case: OHS**

#### 5.2.3.4 BIM2TWIN use case: CHECK EQUIPMENT

This BPMN Diagram shows the activities oriented to the optimization of the equipment and its use. This use case represents the monitoring of equipment and material required on site in real time.

As before, the colour coding reflects how other domains and developments in BIM2TWIN are related to this use case. As it can be seen, there are close interactions with proactive health & safety control.

**Table 13. BPMN template for CHECK EQUIPMENT**

| Actors | Tasks / Data objects | Description | |
|---|---|---|---|
| **Person** | [C11] Receive notifications | From WP5 receive warning | The person in risk (Workmanship) receive a relevant notification about safety risk detected, related to the equipment tracking and notified to a smartphone. |
| | | Manual stop | The equipment operator (Workmanship), receive a stop signal and must immediately stop the equipment. |
| | | From WP2 receive an issue | The person in risk (Workmanship) receive a notification related to the perform transport or equipment tracking and invoke the AP simulation if it is needed |
| **Autonomous equipment** | [C4] Data capture & report status | Report position | An autonomous machine (construction robot, scanning robot, self-driving vehicle...) equipped with cameras which continuously monitors its environment and sends to the raw DB the images |
| | [C10] Receive notifications | Perform Transport | Receive a relevant notification about an authorization of perform transport |
| | | Automatic stop | Receive a stop order. Only when the machine allows & there is not risk |
| **Data capture & store** | [C8] Data capture | Continuous video/image captures | Capture periodically data images and video streams, and send to the local storage (RAW DATA Images) |
| **Services** | [C21] Report information issue | Equipment tracking | Report an issue to the workers' phone, if a risk is detected or send a signal to stop the equipment when the equipment tracking is analysed.<br>In case of the machine allows and there is no risk, a signal to stop the machine automatically is sent |
| | | Perform transport | Report an issue to the workmanship if a risk is detected when it be calculating the transport path, or in the other hand, authorize the transport if there not be risk |
| **API Layer** | Requested info | ER3: resource list | Information requested by the equipment tracking to get resources list (potential risk) on path |
| | | ER4: site map | Information requested by the equipment tracking to get the site map |
| | Response | ER5: site map | Response sent by the platform when the task is starting and requiring movement of an equipment. This API selects the equipment closest to the task location, the one that has less travel, the one that is not going to be used in the near future, etc. |
| | Status | ER1: location and status | The update in the as-performed status generated by the service of detection equipment and location status |

| Actors | Tasks / Data objects | Description | |
|---|---|---|---|
| | | ER2: location direction | The update in the as-performed status generated by the service of request what is in path |
| | Information issue | ER6: Issue | Issues related to inadequate information about the equipment tracking or the perform transport with respect to the required by these services |
| **DBT Agent** | [C14] Provide information | Get resources on path | Provides the requested information about the what equipment is in path and send information about the potential risk detected after checking the equipment path with other equipment, personal or material. |
| | | Get map | Provides the requested information about the zones in the on site |
| | | Select equipment | Provides the requested information about site map of the equipment selected, according to the closest to the task location, the one with least path, etc. |
| | [C15] Update status | Update | Updates the equipment location and status of an equipment in the as-built or as-performed |
| | | Update status | Updates the equipment status (equipment and performed work) |
| | [C19] Create issues | Create issue | Creates an issue in the platform with the required metadata about the equipment tracking and performed transport (type, severity, timestamp, etc.) |

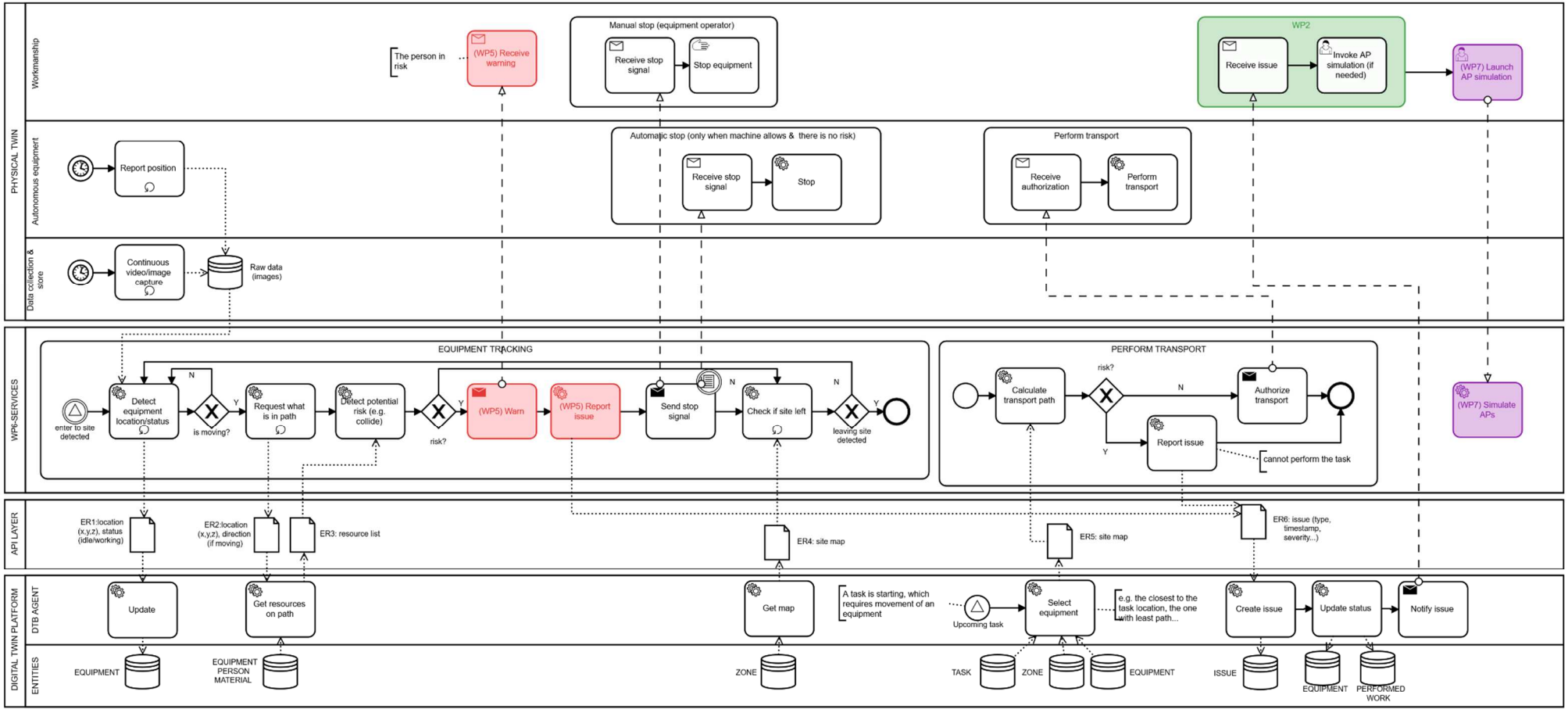


**Figure 23. BIM2TWIN use case: Equipment**

### 5.2.4 *BPMN template: ACT*

#### 5.2.4.1 Generic case

**Table 14. BPMN template for ACT**

| Actors | Tasks / Data objects | Description |
|---|---|---|
| **Person** | [A2] Receive notifications | It denotes the reception of a notification from the DBTP to an end user informing about a deviation detected in the (see [A1]) as-performed and as-built with respect to as-planned as-designed |
| | [A3] Launch alternative plans | A user launching the generation of alternative plans. This will be done through a specific tool/user interface with options to configure targets, priorities… |
| | [A5] Select alternative | The user will select which option to implement as a new version of the planning (see Figure 6) |
| | [A6] Update as-planned as-designed | The selected option will be implemented (using dedicated modelling and planning tools) and results uploaded to the platform |
| **Services** | [A4] Simulate alternative plans | It denotes the action of simulating different alternative plans considering the user specified configuration and the deviations or "delta" detected between planned vs performed |
| | [A7] Data validation | Similar functionality as the one described for the PLAN phase (see [P2]) |
| **API layer** | Deviations | The complete list of "deltas" or deviations for all as-built products and all as-performed processes |
| | As-designed & as-planned v(i+1) | New version of the as-designed / as-planned in the same structure as the defined for the PLAN phase |
| **DBT Agent** | [A1] Notify deviations | A notification which will be automatically triggered by the platform when a deviation is detected (the checking for deviations will be performed every time any service updates the status in the DO phase |
| | [A8] New versions of as-designed & as-planned | New versions of all the affected entities in the as designed and as planned will be created |

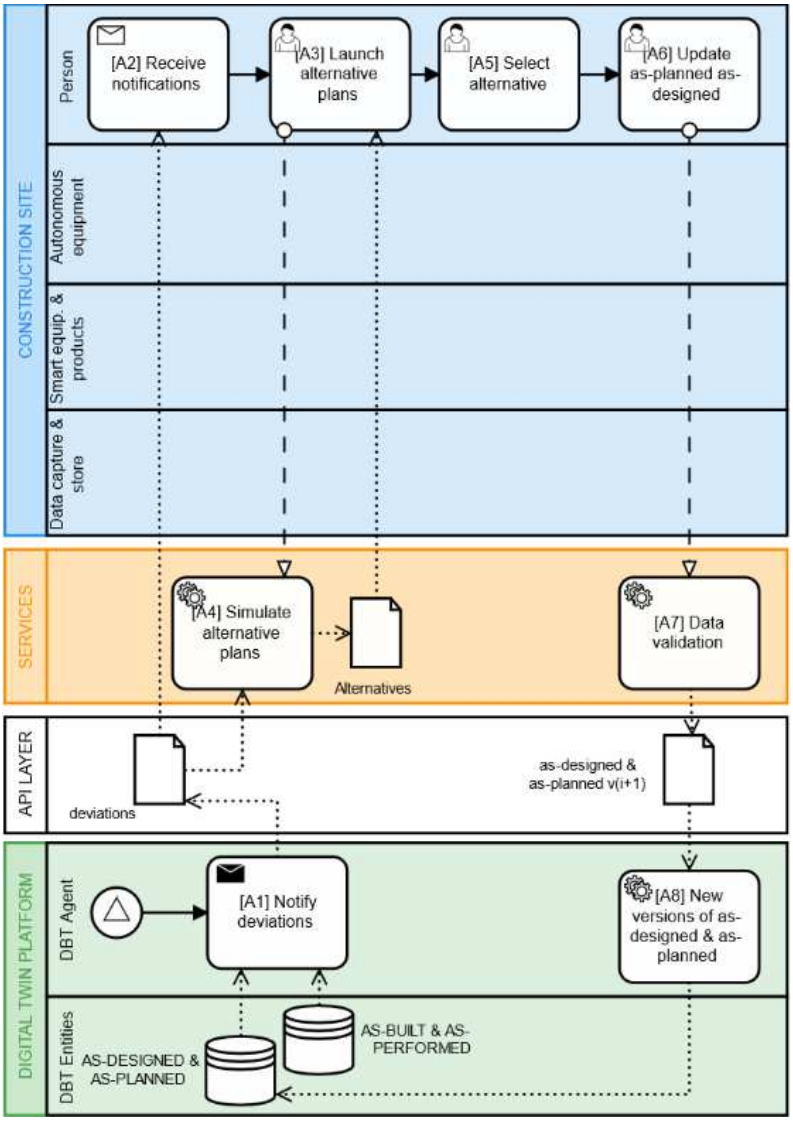


**Figure 24. Generic BPMN template for the ACT phase**

#### 5.2.4.2 BIM2TWIN use case: ACT

No specific use case for ACT has been developed, because it has been already included as part of the previously developed use cases (see references to alternative plans simulations in Figure 21, Figure 22 and Figure 23).

# 6 CONCLUSION AND FUTURE DIRECTIONS

The application of the Digital Twin concept to the Construction industry is still in early stages in comparison to other industries such as Automotive or Manufacturing, although recent progress is noteworthy. In any case, the State-of-the-Art applications are mostly oriented to building maintenance and operations, whereas its application to the building construction process is still in a very conceptual stage.

Starting from this conceptual framework, this report proposes an approach on how to describe how the ideal construction process should be, using the widespread IDM/BPMN techniques as a common language for this and very popular is modelling BIM processes. The main innovations addressed herein can be summarized in:

- Embed the PDCA cycle concept and lean construction principles in the workflows.
- Propose a standardize BPMN template, where actors both at the physical twin side and the digital twin side are represented.
- Propose a future vision of the construction site, where the physical actors could be not only human (the stakeholders of the process), but also any autonomous device/vehicle of smart products that can monitor the environment, capture data on their own or even react and extract some knowledge by interacting among them. In other words, we pave the way for the user-driven construction processes to hybrid processes, merging user activities and expert knowledge with artificial intelligence and computer vision algorithms which boost and optimize the process. This path-to-automation is already envisaged in various researches [20], in many cases applied to the same verticals as in BIM2TWIN (automatic progress monitoring, safety, workforce productivity, etc.).
- Additionally, a standardized set of digital entities is proposed, which model the virtual counterparts and are the basis for developing in other Work Packages the holistic data model through a property-graph representation and an open and extensible layer of APIs. The use of open standards (mainly IFC) in the information workflows and the property-graph representation is also a crucial aspect.
- From here, a set of use cases are presented which describe specific implementation of each BPMN diagram using the applications provided by BIM2TWIN, with special focus in the data collection and knowledge extraction in the selected vertical domains. The key aspect is the detection of how the different applications and use cases relate to each other in a common high-level workflow, while WP3 to WP7 will go into a deeper detail of each use case oriented to a given domain.
- Finally, this vision is put in a broader context of future scenarios, where a digital twin is not an isolated piece which manages a construction site, but could speak and coordinate with other sites or even to other domains' digital twin (city, infrastructure…).

The upcoming activities in BIM2TWIN project will be devoted to implement the DBTP prototype and develop AI-based services which will demonstrate the most relevant use cases presented in this report.

## APPENDIX: LITERATURE AND REFERENCES


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