BIM prove

BUILD
SMARTER.
CLEANER.
CHEAPER.

WHITE PAPER
on Digital Twins and Data Integration in the AECO Sector

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Index

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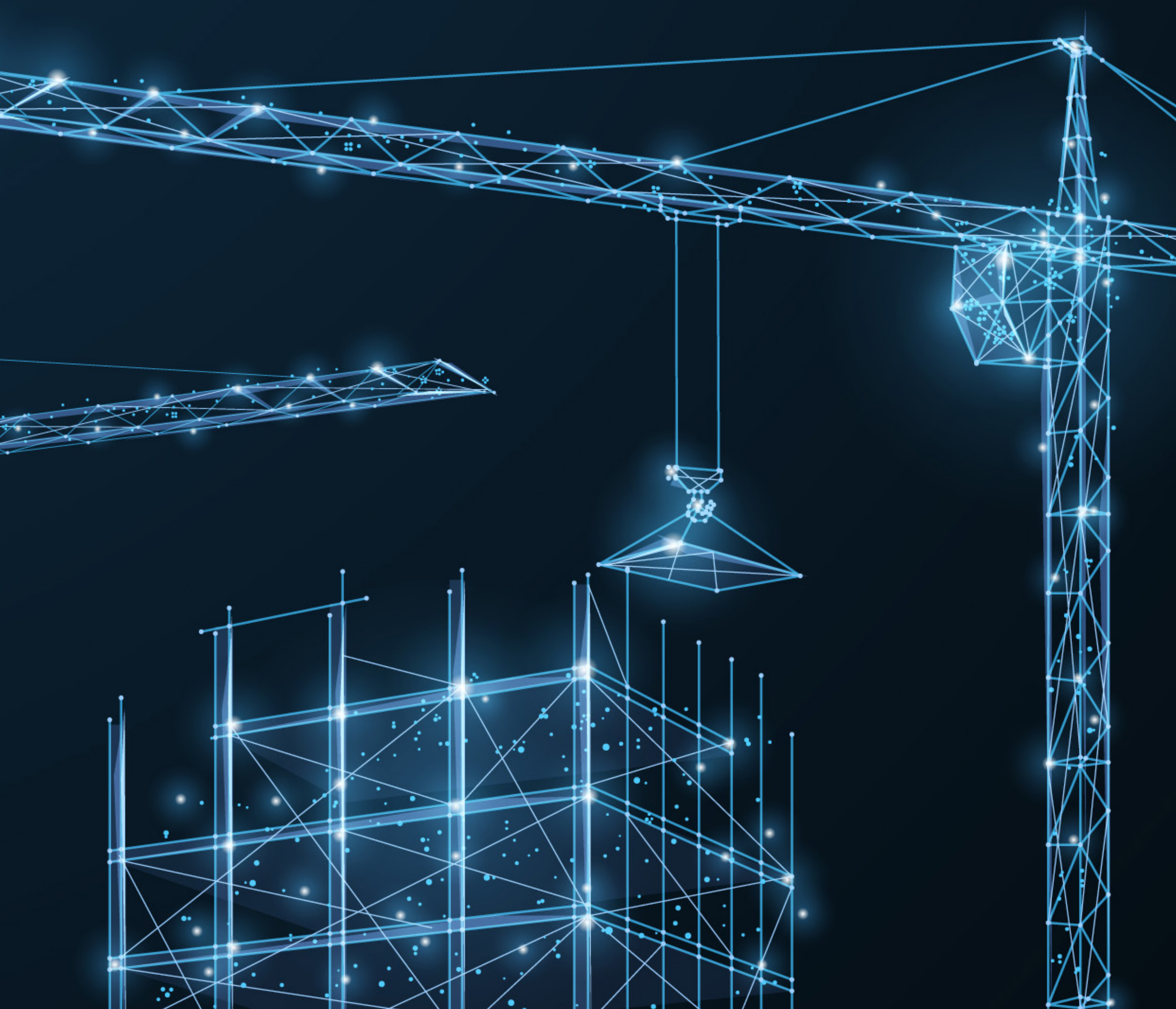
Abstract

This White Paper describes a proposal for a technology concept that will open the door to greater digitalisation within the construction sector, the core of which is a digital twin associated with a given building under construction. The proposal addresses the management of the highly heterogeneous environment inherent in the construction industry, and during the construction process in particular.

The *BIMprove* project *(Improving Building Information Modelling by Realtime Tracing of Construction Processes)* is intended to demonstrate how key processes can be automated and how the digital twin concept, representing a dynamic and expanding image of a real building asset, can benefit the management of a building throughout its life cycle.



Introduction

Digital twins will determine our future in all areas of technology.
The future starts now, and we are inviting you to join us on an exciting journey through the opportunities that digital twins are offering the construction industry.

In October 2018, a Fortune article [1] was already predicting the rise of the use of digital technologies in the architecture, engineering, construction and owner (AECO) industries. In the light of high cost pressures and international competition in a high-risk industry with tight profit margins, the AECO sector is finally getting to grips with the large-scale application of digital technologies.
But what does all this mean, and how will the adoption of such technologies transform AECO businesses?

For some time now, the use of Building Information Modelling (BIM) by the AECO sector has represented a major step towards the digitalization of building construction planning. There is already no question that the use of BIM is essential to the planning process.
But what comes after the planning phase?
It is well known, especially in the construction industry, that planning and reality tend to diverge as the actual construction process proceeds. A ventilation duct is introduced where it was not planned, pipes have to be re-routed, weather delays require resource replanning. There is no end to the reasons why something may go wrong. Moreover, certain risk factors are assigned different weights during construction due, among other things, to hazards on construction sites that were impossible to predict during the planning phase.

Currently, such situations are handled in site offices and at the construction company on a case-by-case basis as the need arises. Regular construction site inspections and a lot of manual work, carried out by many highly competent and experienced people, are required to monitor construction work. Nevertheless, it is easy to lose sight of the big picture. Details may go unnoticed and errors may occur during the transfer of measurement data.

Photo by Drazen Lovric @ **istockphoto.com**

But, **what if:**

- everything could be measured automatically?
- all details were clearly recognizable?
- a direct transfer of the as-built state into a digital equivalent could enable an automated comparison with the BIM plan?
- subcontractors could be remunerated based on current construction progress?
- hazards could be recognized before they occur, and construction site personnel warned in good time?
- weather reports could be included automatically in advance planning, and if resources could be managed optimally in the medium term?
- construction site personnel could contact each other and site suppliers in real time using easy-to-use communication systems?

We propose that all these challenges and many others like them be addressed by means of the real-time digital twinning of entire construction sites!

Perhaps you are sceptical?

An EU-funded R&D project called ***BIMprove*** is bringing the concept of **digital twins** to the AECO sector, and by doing so is creating an **entirely new way of working** on building sites and in construction offices **throughout the entire life cycle of a building.**

Do you want to know more?
Check out this paper and visit our website at https://www.bimprove-h2020.eu/

Digital twins in the AECO sector

All industrial sectors would like to achieve higher levels of efficiency, less idle time, and better performance. While most sectors are currently enjoying the benefits of automation and digitalization, the AECO sector continues to struggle with this transition.
The sector still relies on human intervention in decision support throughout its building asset life cycles. The process of 'capturing' these decisions, which can be achieved by the digitalization of AECO processes, is complicated by the complex and diverse dynamics inherent within the sector.
As a result, there is no one-size-fits-all solution to the problem.
A wide range of ever-evolving industry standards are in place, such as the ***BIMprove Impact Master Plan*** [2], which regulates requirements related to building assets, but the industry's practical, hands-on experience remains 'embedded' in individuals such as architects, engineers, facility managers, site managers and foremen.

A comparison of the life cycle of a building asset to a product in the manufacturing sector results in the development of a product prototype, which must function for the next 100 years. This encapsulates very well the challenges and zero failure requirements facing the AECO sector.

Why do we need digitalization and digital twins in the AECO sector?

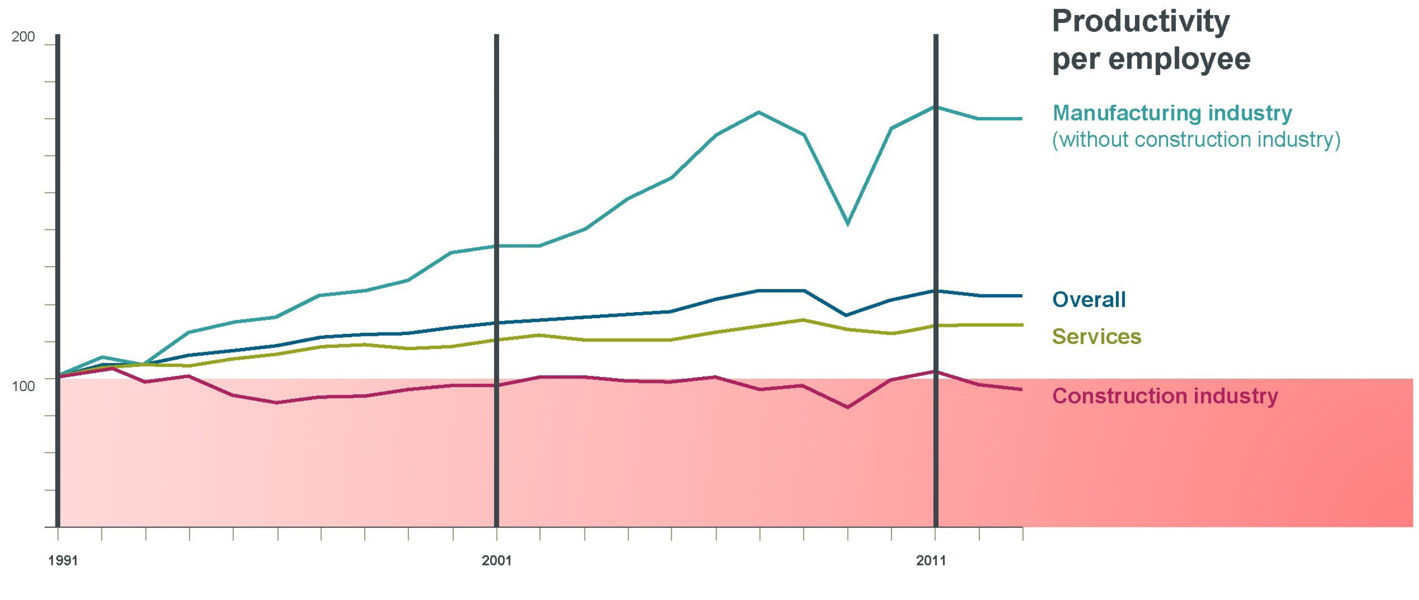


Figure 2.1 Productivity per employee in different industrial sectors [3].

Fig. 2.1 demonstrates that productivity increases within the AECO sector will not be achieved without automation and digitalization.

Digitalization supports decision making at many stages. It provides faster and more precise production forecasts; it reduces deviation detection times and long-term storage, and promotes learning following errors. These are just some of the most important benefits. The AECO sector has introduced digitalization in the form of Building Information Modelling (BIM), but this tool benefits only a very limited aspect of the building asset life cycle. BIM has become the ***de facto*** standard for the building design and operation phases, but its impact on construction and deconstruction is questionable.

BIM adheres to the same standard (ISO 10303 [4]) as the manufacturing industry when it creates a digital version of a building asset. This enables the AECO sector to benefit from the best practices now being applied in the ongoing industrial revolution in the manufacturing sector (Industry 4.0), and to accumulate knowledge on how to establish digital twins that can represent building assets.

While BIM enables the standardisation of information sharing and exchange, the loss of information that occurs during the 'transformation' of models from their native modelling language to BIM represents a major bottleneck. Initiatives are currently being developed to counteract this limitation, but we are still awaiting reports of success.

However, BIM cannot, and never will, be able to capture information that is not originally intended to be incorporated as part of a building asset, such as the simulation results from HVAC tests. In most cases, such information is given to facility managers and stored in some form of long-term storage system for use only when thorough checks are required after an error has been detected. Moreover, ad hoc changes related to new calculations and weather conditions, especially during the construction phase, which may be highly useful information in the operations phase, may go unrecorded. In most cases, BIM models are updated with so called 'as-built' information that reflects, but does not copy, reality, once the construction phase is completed.

Current analytical tools use BIM (either 'as-designed' or 'as-built') as a basis for suggesting improvements and plan changes, and to run a variety of simulation scenarios. Since these calculations are based on a snapshot of the building asset (an exported BIM file), it is clear that they have inherent limitations.

It is very important to separate the concept of digital twins from simulation.
Simulations are essentially static processes, providing a visual overview and calculations based on pre-recorded data. Digital twins, on the other hand, are dynamic entities that are fully connected to a construction site, providing a full digital representation of all its chaotic complexity.

Digital twins offer the key to higher productivity in the AECO sector, especially in the construction phase. Currently, quality control, scheduling and logistics during the construction phase are in most cases performed on the basis of the experience of humans. Knowledge is transferred between specific construction projects only via the individuals who participated in them. Digital twins enable the recording and analysis of data, and offer a key tool for safeguarding long-term learning from the actions taken throughout the building asset life cycle.

Why now?

The evolution of the ISO 19650 standard [5] for information models in the construction sector, first published in 2018, has highlighted the needs and opportunities related to the organization of information management.

During the life cycle of a building asset, an enormous amount of information is generated and lost during transfer among the various stakeholders.

The more widespread use of BIM, and the option to establish a common data environment (CDE), may serve to address this problem. The interconnection between the various ISO standards underpinning this effort is shown in Fig. 2.2.

Figure 2.2 Relation of the ISO 19650 Information Management standard using building information modelling [5].

While this need was identified by the manufacturing industry as early as in 2003, and reflected in the publication of the standard ISO 14649 (Industrial automation systems and integration) [6], the task has proved to be much more challenging for the AECO sector, as previously described.

Moreover, the manufacturing industry has recently established the standard ISO 23247 (Automation systems and integration – Digital twin framework for manufacturing) [7], which may act as motivation for the establishment of a **digital twin standard for the AECO sector, expected by 2033.**

Some of the key developmental events and their dates are shown in Fig. 2.3.

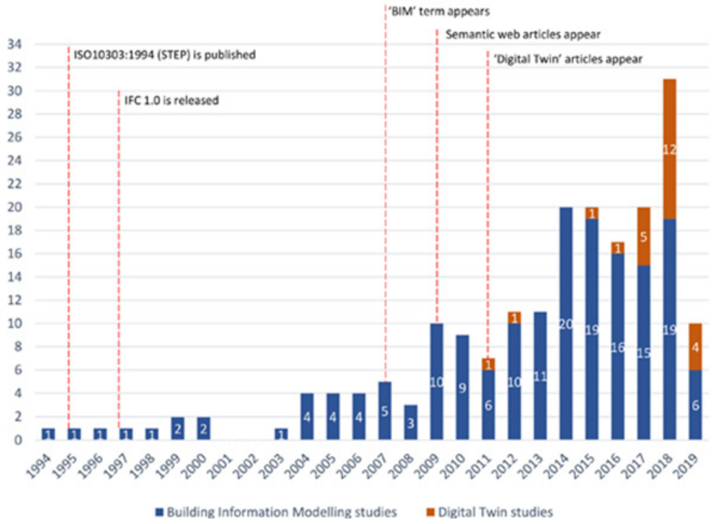


Figure 2.3 Timeline for BIM and digital twin [8].

Why a digital twin and not BIM alone?

While BIM exerts its main impact during the design phase, digital twins are designed to reduce the overall costs involved in producing a building asset. BIM-based workflows and analysis may be useful in preventing expensive design changes during the construction phase. However, they cannot speed up the detection of deviations or help to reduce rework or waiting costs.

A digital twin can be regarded as part of a site manager's subconscious.

The well-known MacLeamy Curve, shown in Figure 2.4, shows that the digital twin's contribution can be visualized in terms of lower overall costs and reduced effort. This is because the twin enables the long-term storage and re-use of experience in a variety of different building asset projects.

The difference between the use of a digital twin and BIM alone can be explained as follows: while BIM provides a snapshot of a building asset at a given point in time, **the digital twin provides both the history of, and future predictions related to, the building asset.**

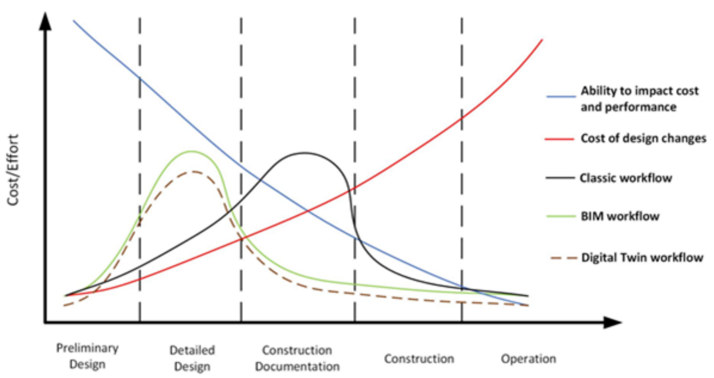


Figure 2.4 MacLeamy Curve showing the impact on costs and effort of using BIM versus digital twin workflows [9].

In the following sections we will examine these differences and discuss the opportunities and solutions provided by the use of a digital twin as opposed to the classical BIM representation of a building asset.

The AECO ‘scenario space’ as a 3D structured layer

In addition to the technical challenges, the design of a digital twin commonly raises communication issues among stakeholders who do not possess a software engineering background. Such stakeholders may include AECO professionals, business people, lawyers, politicians and software engineers with no knowledge of the industry.
Since all of these stakeholders have to be involved, they need a tool to document their requirements and by which to exchange their ideas and expectations as to how the digital twin will help to resolve the problems facing the AECO industry.

To this end, we propose a widely-used approach based on ***scenarios*** [10]. A scenario describes a problem as an interaction script that functions both between the users and the digital twin, and between the digital twin and other systems.
Both software and non-software engineers have to be able at least to read, review and comment on the scenarios, and finally to agree on them as the starting point of scenario development.

In larger projects, involving increasing numbers of scenarios, scenario organization can become unwieldy. Software engineers, who need a holistic picture of a system in order to design it, thus require an ***abstraction*** – a way of representing scenarios in a concise and compressed way.
The abstraction should enable a clear and immediate representation of the purpose of a scenario and its context.

Problems related to more general software systems are usually unbounded, both in problem space and solution space. This is due to the nature of software. A system is often designed to solve problems that it was not possible to solve ***previously***.
However, the digital twin presented here is designed to address specific problems associated with the AECO sector. Unlike general systems, the problems solved by a digital twin are well-defined by established best practices, regulations and standards.
Such problems are not arbitrary, so a general abstraction of the possible problem space is not required. Instead, the dimensions of any given problem must be captured in a common structure, called a ***scenario space.***

We approach this by constructing a three-dimensional scenario space in which a scenario is abstracted as a volumetric entity within the space, enabling the user immediately to understand which problem subspace is being addressed by the scenario (see Figure 3.1).

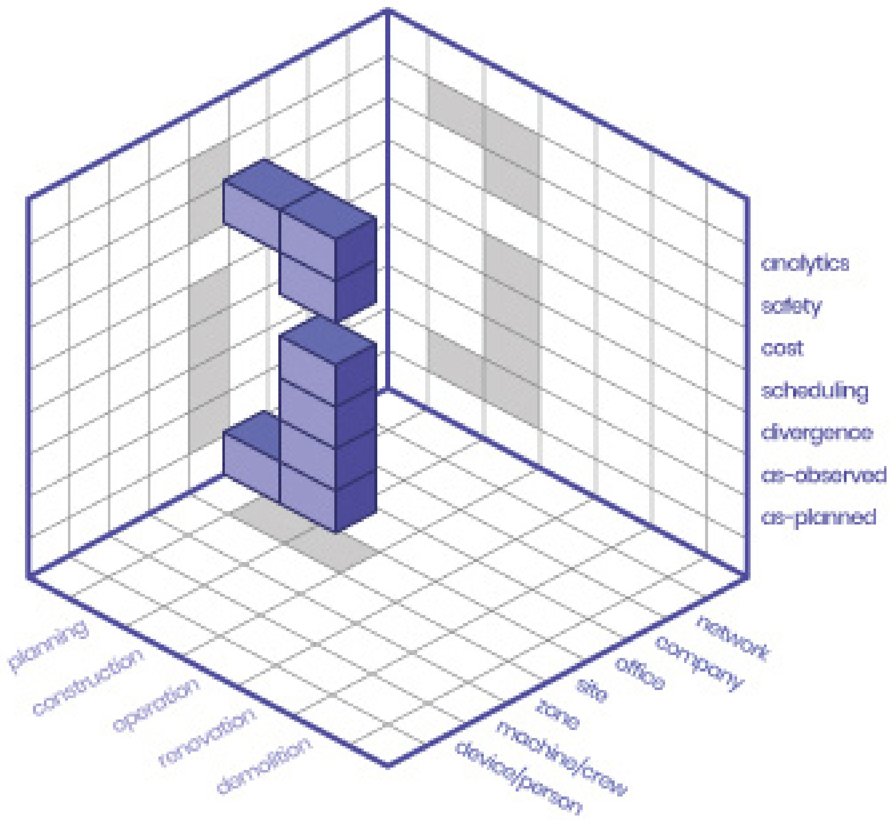


Figure 3.1 The scenario 'Risk Management' incorporated in a digital twin and illustrated as a volumetric entity in the scenario space. A summary of the scenario is given in Table 1.

The following three dimensions are proposed to represent a scenario space:

- **a layer**, i.e., the aspect of a problem
- **a phase** in the building life cycle
- **a level** in the hierarchy

The scenario space is defined in such a way that any AECO process can be mapped within these three dimensions.
A system fulfilling the complete scenario space is thus capable of processing upcoming real-world events, such as the correction of a building structure, rescheduling, the implementation of security measures, etc., within the system.
Consequently, the system design and its implementation become easier to model and can be traced back explicitly to the scenario space.

It is noteworthy that not all possible scenarios are defined in advance.
Additional scenarios can be added and incorporated into the scenario space as the project progresses.
In order to establish an overview, the scenarios are brought in as volume elements and put together in the scenario space just like Lego bricks.
This enables the user both to visualise the parts of the problem space that are still missing, and to see which subspaces should deliberately be ignored.

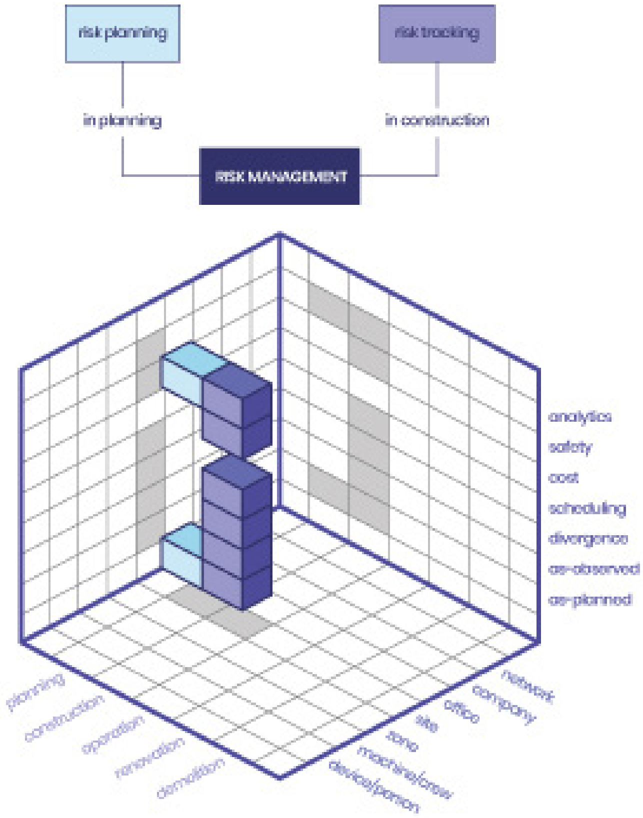


Figure 3.2 Dissection of a scenario called 'Risk Management' (see Figure 3.1 and Table 1b) by the dimension 'Phase' into two scenarios called 'Risk Planning' and 'Risk Tracking'. The scenario 'Risk Management' addresses the specific problem by positioning the volumetrics of the underlying scenarios in the scenario space.

Layers

The dimension 'Layer' addresses a particular aspect of a multi-layered scenario. Layers are based on the existing higher dimensions ('5D', '6D', etc.) of the BIM [11]. Here, these BIM dimensions are generalized in order to extend over a broader category of systems, such as data governance systems, cyber-physical systems (including digital twins), etc., as follows:

- **As-planned**: this layer of the scenario captures building plans and planned activities, both in space and over time.
- **As-observed**: this layer specifies the observations of the physical world that have to be stored and managed by the system (both in space and over time).
- **Divergence**: this layer documents which deviations between the plans (from as-planned layer) and observations (from as-observed layer) are relevant, and how they should be computed in this layer.
- **Scheduling**: this layer specifies how the system should capture the logical order of activities, and how changes in this order affect the overall schedule.
- **Cost**: the cost layer reveals aspects of the problem related to costs and expenditures.
- **Safety**: this layer addresses and documents which risks are important, and how the system should assist in the planning, tracking and mitigation of these risks.
- **Analytics**: this layer specifies the analytics to be computed by the system. These will include technical analytics, such as pipe routings and static and dynamic re-calculations, as well as business-related analytics such as KPIs.

Table 1 below illustrates how the three different scenarios address the various layers.

A ***Truck Guidance***: external truck drivers arrive at the construction site to deliver components.

As-planned	The deliveries are specified as tasks
As-observed	The driver's device tracks the truck's GPS location
Divergence	The device guides the driver to the delivery location
Scheduling	Unmet deadlines are pushed as issues
Analytics	Delivery delay statistics are reported

B ***Risk Management***: various risks are planned and tracked on the site.

As-planned	The Risk Manager manages the risks
As-observed	The Risk Manager orders focus spots for recording
Divergence	The preventive resource visually inspects the recordings
Scheduling	The Risk Manager inspects the risks linked to the tasks
Safety	The Risk Manager flags hazardous tasks
Analytics	The system tracks escalated risks per category

C ***Cost Tracking***: planned costs are tracked against expenditures.

Cost	Planned costs and expenditures are related to tasks
Analytics	Task costs that exceed budgets are reported

Table 1. A summary of three different scenarios related to an AECO digital twin. The scenarios are further analysed according to the layers in the scenario space.

Phases in the building life cycle

A large project usually consists of a multi-phase building life cycle. In order to avoid ambiguity, the user should always be aware of context, with a clear reference to the relevant phase. We propose the following phases:

- **Planning**
- **Construction**
- **Operation**
- **Renovation**
- **Demolition**

Our choice of phases is based on experience from the industry. However, alternative phase listings, such as those of the SIA [12], HOAI [13] and RIBA [14], etc., may also be applicable. Thus the phases used in the scenario space depend on the project, or the company, national and international best practice in question.

Hierarchy

In a complex AECO setting, stated requirements commonly refer to different levels of detail, which in turn follow a natural hierarchical organization of the people and material involved in an AECO operation. People are organised into crews, and a site unit is responsible for crews, etc. Motivated by the hierarchy used in the RAMI4.0 reference framework for smart manufacturing [15], we propose the following hierarchy of levels of detail[1]:

- **Device or Person** (e.g. an excavator shovel or an electrician)
- **Machine or Crew** (e.g. an excavator or a team of electricians)
- **Site unit** (e.g. a defined zone on the construction site)
- **Site**
- **Site office**
- **Company**
- **Network of companies**

[1] We chose to represent the levels of hierarchy in this way as a matter of convenience. More intricate structures are possible in the form of branching hierarchies or complex graphical representations such as ontologies. In our opinion, such intricate structures are much harder to communicate and visualize, while providing only limited improvements in clarity.

Requirements analysis and engineering in the AECO sector

As previously described, digital twin development requires harmonious communication between two groups of stakeholders: 1) AECO professionals and other non-software engineers, and 2) software engineers. The former knows ***what*** problems they want to solve, the latter knows ***how*** to solve them.

The substance of a software project is usually considered in terms of ***requirements***. In such a setting, non-software stakeholders and software engineers have to achieve agreement on the kind of digital twin they wish to develop, the AECO-related problems they wish to address, and any aspects that are technically infeasible. Although such requirements are commonly incomplete (because completeness is either infeasible or too costly), and often change over time, they will still serve as a basis for system development.

Thus, both sets of stakeholders have to be able to read, review and approve the documented requirements. Scenarios are proposed with the aim of capturing the activities that take place between the digital twin and its users (both humans and other systems). Instead of free-form scenarios, we propose a well-defined scenario space that situates the scenarios in their respective contexts.

The following two sections illustrate firstly the ***perspective*** that a scenario should take (a system rather than a user perspective) and, secondly, the ***formal language*** that is best suited to the AECO sector in situations where the scenarios require formalization.

System scenarios

Digital twins interact directly with the physical world. This idea is fundamentally different to many of the typical information systems employed in the AECO sector.
For example, data governance systems are used to manage collaboration between BIM models, but have no immediate impact on the physical world.
The interactions of a cyber-physical system differ significantly from those of a data governance system because they are interconnected to other machines (devices, computers, vehicles, etc.), and human-computer interaction represents only a fraction of its requirements.

In a digital twin, the focus of the requirements analysis is shifted from the user to the system. Instead of describing user interactions in a user scenario, activities at module and system level are described in terms of ***system scenarios***.

This shift of focus is crucial to a successful requirements analysis in the context of digital twin application in the AECO sector. Previous focus on the user has caused us to overlook a number of key ***system-related*** details. While many problems appear to be consistent and feasibly resolved from a user perspective, the same problems suddenly become practically infeasible and underspecified from a system perspective.

For example, from a user perspective, there is no need to know where our data comes from, or how, when, and how often they need to be processed. It is usually sufficient to note which data the user needs to see. However, a system perspective will reveal deeper issues, such as the reliability of the source of the data necessary to solve a given problem.
A system perspective addresses such questions as: do domain experts agree about data validity (sensor accuracy)?
Or does resolution of the problem in hand require a large or a small amount of data?
Such questions have an enormous influence on downstream development and should be clarified as soon as possible. So, while user scenarios are certainly important, and should not be ignored, system scenarios are indispensable.

A universal language

A system scenario has to capture domain knowledge that enables software engineers to understand the problem in hand and evaluate its resolution. While free-form human language may suffice to describe a scenario in theory, the invention of relational terminology for every new problem or project is a tedious process, which can be avoided by re-using an existing language with well-defined terms. Such an approach can save a lot of work and avoid many misunderstandings [16].

Finding such a language is not a trivial task. It has to be understood by both domain experts and software engineers. The latter are familiar with general graphical languages, such as Unified Modelling Language (UML), but these are obscure to domain experts. Process languages, such as Business Process Model and Notation (BPMN) and Information Delivery Manual (IDM), are often too detailed, specific and elaborate for describing typical system scenarios.

While languages such as UML, BPMN and IDM can be used in situations where there is an explicit need for highly formal problem descriptions, there also exists an easier option – the Building Information Model (BIM), which is currently widely used in the AECO sector. Since BIM is increasingly universally mandated in the sector, including by public authorities, a growing number of domain experts are familiar with its entities and relationships.

Since BIM is widely recognised in the industry and already used as a modelling language, we see no reason why it cannot also be used as a universal language in relevant system scenarios. BIM offers a natural language for the description of system entities and their relationships within AECO-related processes.

BIM circumvents the communication barrier resulting from the formalisms so enamoured by software engineers, but from which domain experts shy away. BIM thus offers an attractive compromise that is formal enough to prevent ambiguity and familiar enough to enable domain experts to participate in the discussion.

Figure 4.1 below provides an example of a requirement that is narrowly specified using BIM.

Performance history is defined as an instance of `IfcPerfromanceHistory`, and lives in the model `bim_extended`.

Cost is an instance of `IfcCostItem` living in the model `bim_extended`. It can be linked to tasks through GUIDs and `IfcRelAssignsToControl` (where the task is the related object).

Expenditure is an `IfcCostItem` living in the model `bim_extended` together with its relations.

To distinguish it from estimated costs, expenditures are explicitly linked to a performance history through `IfcRelAssignsToControl` (where performance history is the control and expenditure the related object).

Figure 4.1 An example of elicited requirements using BIM as the formal language. While it is possible to deduce these entities without BIM, BIM nevertheless enables us to employ a rich library of terms that are comprehensible to both AECO experts and software engineers.

Data exchange in *BIMprove*

As outlined in the previous sections, a digital twin is not simply a static database containing a vast amount of data. It also enables two-way data exchange and data visualization, both in near real time. The process of making a digital twin can also be referred to as 'twinning', by which information flows are mapped from a dynamic construction site, where verbal agreements between involved parties are transformed into processes, and by which major and formal revisions are communicated from clients to site managers.
Every step of formal or informal data exchange must be understood, and translated into a (preferably) standardized language that enables automation and digitalization.

The aim of the project ***BIMprove*** is to establish processes, inputs and outputs with this aim in mind, and some of the processes are described in the following subsections. We refer also to the article on the 'Digital Twin ***BIMprove***' [17].

Interoperability using current systems

BIMprove builds on and expands existing workflows, such as BIM Execution Plan. Many such workflows will be digital, but some will require human intervention, such as the manual entering of data into the system. There also exist a number of proprietary systems, but unfortunately there is no widely-used open standard for data exchange between these systems.

In other situations, several competing open standards exist, and ***BIMprove*** will have to take this into account, supporting as wide a range of standards as possible. Where this is possible and meaningful, open standards will be preferred for entering and accessing data to and from the system. We refer to the ***BIMprove Impact Master Plan*** [2].

The *BIMprove* data architecture

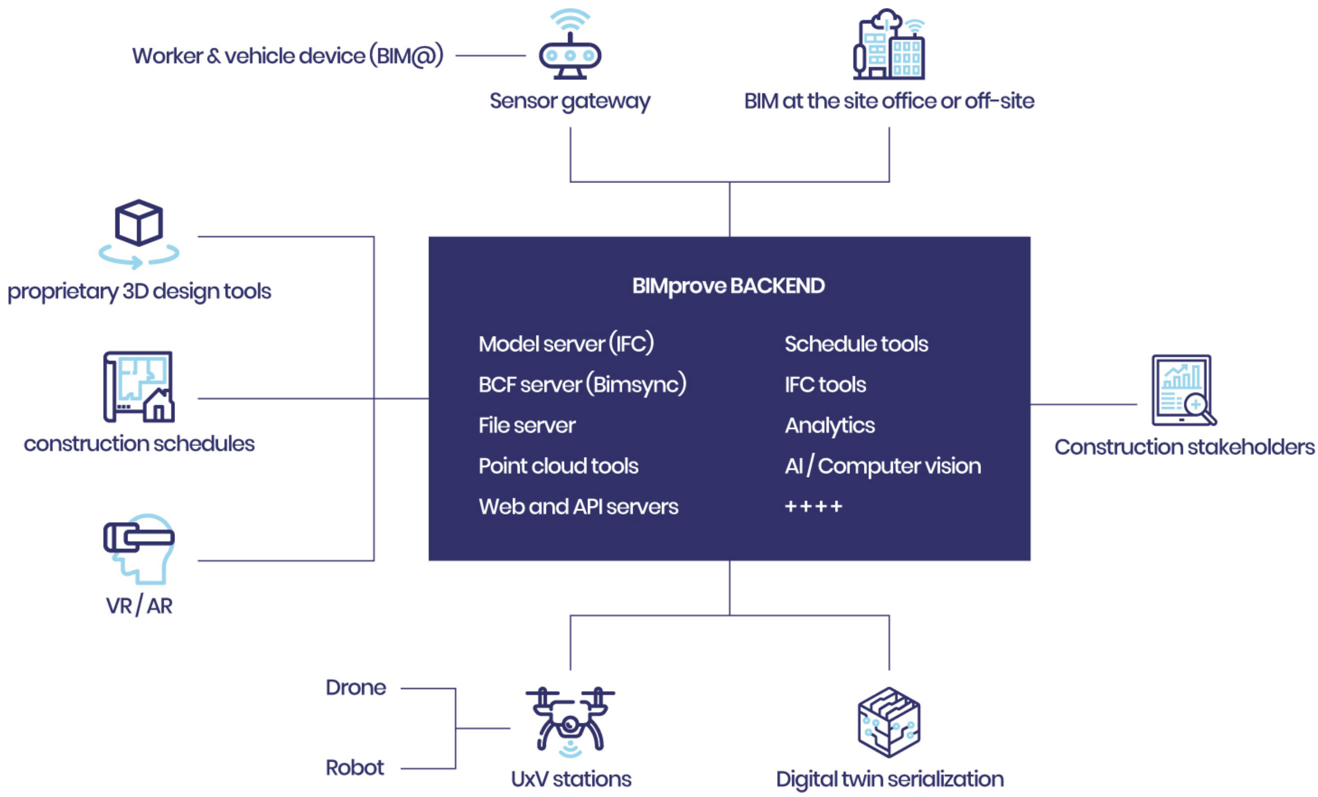


Figure 5.1 The main components of the BIMprove data architecture.

The ***BIMprove*** system is constructed from some loosely coupled data interfaces that each provide sporadic information updates, while the core element, referred to as a 'backend', provides highly integrated and near real time information exchange for use in data analytics and visualization services, as described in the ***BIMprove*** requirements list.

The main components of the BIMprove data architecture are visualized in Fig. 5.1 and described in the following:

Proprietary 3D design tools

Building asset designers (architects and engineers) will work using their own applications, such as Revit, ArchiCAD, Tekla, MagiCAD, DDS and Allplan, in the same way as they do today. In a ***BIMprove*** context, such tools will output in open BIM (IFC) models that illustrate the 'as-designed' appearance of the building asset that includes not only its 3D-geometry but also rich information on physical elements such as slabs, walls and windows, as well as non-physical elements such as rooms, building storeys, zones, systems and design layers. If any design changes are suggested from ***BIMprove***, these will be issued by BCF.

Construction schedules

Provided they exist, highly detailed (daily) construction schedules will be stored in a variety of highly heterogeneous ways, and may be exchanged using IFC (e.g. ***IfcTask***). However, such exchanges will only be carried out very rarely. ***BIMprove*** will enable data entry either manually or by another standardized approach, such as by using a predefined scheme.

VR/AR

Data visualization is one of the main benefits of digital twins. Geometry derived from IFC (with intact identifiers) can be presented on demand in VR and AR applications, and users can return tasks/issues to the backend using BCF.

UxV stations

Drones and mobile ground exploration robots are not directly connected to the backend, but communicate indirectly via intermediate stations, which obtain their data from the backend in order to plan their UxV reality capture paths. These paths are based on data from the future construction and its location, taken from the schedule and BIM models. The stations send back point clouds, aligned with the coordinate system of the BIM models, together with geometry derived from the point clouds and thermal photos.

Digital twin serialization

In contrast to a BIM file, a BIMprove digital twin cannot simply be exported from or transferred between construction sites. This raises the question of how a digital twin, representing the sum of all information, can be accessed after the project end date. We propose to develop a strategy for the serialisation of key data, including revisions and time stamps so that the content of the main data entities can be restored outside the system. Our aim is to achieve this as far as is practically possible using open standards such as IFC for BIM, open point cloud formats, open image formats, BCF for issue history, etc.

Construction stakeholders

The various stakeholders will be presented with the information that they have to consider and decide on. For example, a scanning function may be introduced to see if security protection is present when it should be. This will enable decision-makers to inspect the point cloud (perhaps accompanied by a system-generated suggestion), determine whether a deviation has occurred and, if so, decide what the next step should be.

BIM at the site office or off-site

It will be possible to visualise and analyse a wide range of information both at the site office and off-site. Information from scans, as-designed BIM, schedules, etc., will be made available from the backend and viewed on a big screen or in virtual reality. Questions and decisions that require human intervention can be sent to the backend using BCF.

Sensor gateway

Sensor data such as worker or truck positions are sent to the backend via the gateways. Urgent warning notifications, such as a truck reversing towards a worker, are sent directly to the worker or truck, and not via the backend.

BIMprove as a major contributor towards using real-time digital twins in the AECO sector

A digital twin in BIMprove is defined as an integrated, multi-scale, probabilistic simulation of a complex construction that employs the best available physical models (BIM), sensor updates, historical data, user inputs, etc. to mirror the life of its corresponding twin.
The main objective is to go beyond the static BIM approach and provide the dynamics necessary to track the life cycle of a building asset.
The main benefit of a digital twin in this context is its ability easily to monitor construction site status, enabling planning to be improved and resources optimally scheduled. It offers flexibility, safety and enhanced productivity.

The digital twin extends BIM capability with a rolling timeline that includes the following:

- **Changes made on a daily basis** can be tracked back to find out when and why they were made, and if said changes were approved.
- **Personnel and equipment** can be tracked, providing insights into levels of efficiency, utilisation and availability, in anonymised form.
- **Daily progress reports** will document all work carried out on the day in question.
- **Design changes** will be introduced in traceable form.
- **'Look-ahead' forecasts** will provide multiple scenarios based on planning data and available resources.

The digital twin extends BIM's accessibility to all stakeholders, as follows:

- **Information can be presented** according to a given stakeholder's requirements and function.
- **Access control and filtering** are offered as part of a single system.

The main difference between the static BIM model and the dynamic digital twin in ***BIMprove*** is the ability of the digital twin to store events as a continuum. While the BIM model always reflects the current situation, the digital twin encompasses the entire life cycle of the construction.

Transformation of the static BIM model requires the addition of continuity, as shown in the figure below.

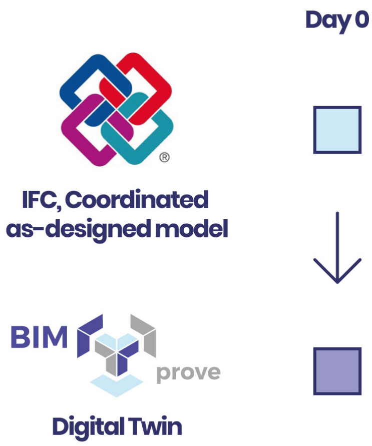


Figure 5.2 Transition from static BIM model to digital twin.

The BIM model includes scheduling information for the execution of construction tasks, such as the work plan, which in turn forms the basis of the digital twin.

The digital twin's timeline is divided into discrete blocks, such as shifts or days, depending on requirements at the construction site in question.
Events that happen on any given day are stored with reference to the date in question. All days are defined with a start and end time, which can also be referenced to given events. It will also be possible to store continuous data, with appropriate start and end times.

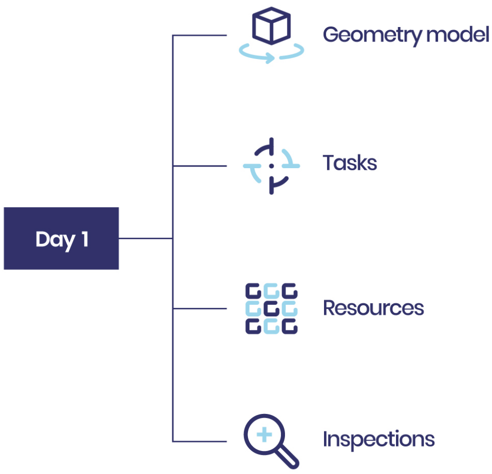


Figure 5.3 Time-based anchoring.

As well as the original 'as-designed' IFC entities, all elements necessary for construction are stored in the digital twin. These elements include:

- **Human workers**
- **'Smart' construction equipment**, such as trucks, machines and cranes
- **Robots and drones**

These do not form part of the 'as-designed' model, but are part of the digital twin, and are identified by 'DT - Unique ID' and presented in the as-design model with their respective positions.

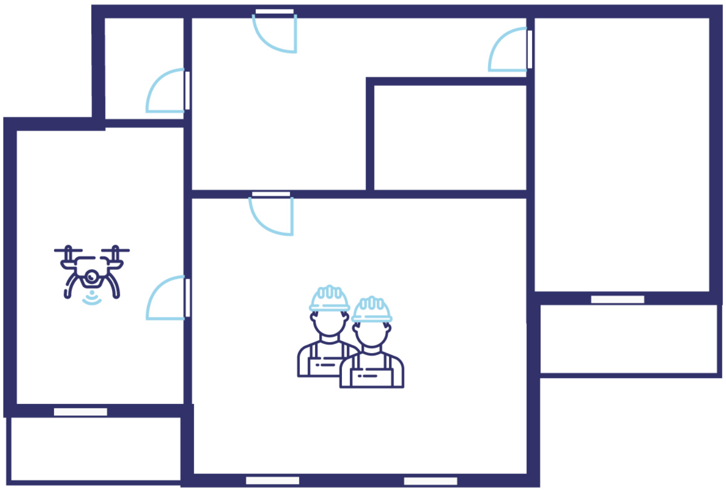


Figure 5.4 Visualization of 'DT - Unique ID' resources in a 2D plan.

About the *BIMprove* project

The consortium behind the project ***BIMprove*** intends to employ digital twin technology to develop a dynamic digital thread system for construction sites that goes beyond the static Building Information Modelling (BIM) process currently in use. The technology will introduce profound disruption to the construction sector, which has experienced prolonged stagnation and is ripe for digitalization.

The building construction market has experienced considerable growth during the last decade and is estimated to achieve revenues of EUR 7955 billion in 2022. However, sector productivity has failed to improve during this time, hindered by increased labour costs, inefficient working conditions and a declining interest in the sector shown by the younger generation. Moreover, jobs in the construction industry represent some of most dangerous in modern Europe. As the global population continues to increase, it is imperative that zero-energy buildings replace existing constructions. Improvements in the sector that promote safety and efficiency are crucial to Europe's future.

The aim of the ***BIMprove*** project is to invest effort in the development of a system that promotes fast-track productivity by cutting costs and improving working conditions. This will be achieved by employing 3D model-based BIM systems in combination with a digital twin technology to the construction sector, constituting a dynamic and multi-functional system based on real-time data. This new technology will consolidate the future development of the European construction industry and allow enterprises in the sector to optimize their performance. The technology will enable a real-time overview of current status on all construction sites, facilitating the early identification of errors and their remediation at the lowest possible cost. It will also be possible to control resource scheduling and transactions in real time, thus ensuring high levels of construction site security and efficient adherence to, and adaptation of, work schedules, according to need.

The overall objective of the ***BIMprove*** project is to go beyond the static BIM approach and create a digital thread that acts as a dynamic metrical building model, or digital twin. This will promote the easy monitoring of construction site status, effective resource scheduling and improved work planning. The new technology will offer greater levels of flexibility and safety, and enhanced productivity. The ***BIMprove*** project focuses on the building process on construction sites, once the erection or installation of a framework has been completed.

The technology is actualised using ground-based robots and unmanned aerial vehicles (UAVs) to monitor site status and detect deviations that can be used to update the digital twin and the underlying BIM model. It will facilitate the anonymous tracking of site personnel, thus enabling both the system and personnel supervisors to optimize resource allocation, personnel flow and worker safety. The ***BIMprove*** system will be easily accessible to all stakeholders in the form of various user interfaces, including the provision of notifications to site workers via wearable devices, and to supervisors via virtual reality (VR) visualizations. The system will be a cloud-based service with a layered structure, enabling the addition of future extensions, as required.

The ***BIMprove*** system will be developed in a series of six-monthly iterative cycles, which will ensure adequate time for the fine-tuning of system functionalities in order to meet the requirements of the consortium's industry partners. A proof-of-concept installation will first be implemented in an industry-oriented lab (TRL 5) environment before installation on industrial premises. At a later date, the ***BIMprove*** system will be demonstrated in realistic environments (TRL 6) and showcased as part of three real-world pilot use cases.

The goal of the BIMprove project is to achieve:

- 20% improvements in **schedule forecasting**
- Improved **resource allocation** and optimisation of **equipment usage**
- Reductions in the number of **construction site incidents**
- 20% reductions in **construction project costs**

The ***BIMprove*** project is being supported by a multi-disciplinary consortium composed of 12 partners drawn from Norway, Finland, Germany, Spain and Switzerland. The consortium includes two universities (USTUTT and ZHAW), three national research and technology centres (SINTEF, FhG-IAO and VTT), a standardization institute (DIN), two technology providers (Catenda and ROBI), a marketing expert (AUS) and three end-user companies (AFG, HRS and VIAS).

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