BIM prove

# D3.6 – Benchmarking, Evaluation & Demonstration

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 958450. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

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| **Project Title** | Improving Building Information Modelling by Realtime Tracing of Construction Processes |
| **Project Acronym** | BIMprove |
| **Grant Agreement No** | 958450 |
| **Instrument** | Research & Innovation Action |
| **Topic** | Industrial Sustainability |
| **Start Date of Project** | 1st September 2020 |
| **Duration of Project** | 36 Months |

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| **Name and Number of the deliverable** | 3.6 – Benchmarking, Evaluation & Demonstration |
| **Related WP number and name** | WP 3 - Integration, testing & piloting |
| **Deliverable dissemination level** | Public |
| **Deliverable due date** | 30 June 2023 |
| **Deliverable submission date** | 30 June 2023 |
| **Task leader/Main author** | Antonio Lopez-Rios (HRS) |
| **Contributing partners** | All |
| **Reviewer(s)** | Chiara Zarna (SINTEF) |

**Abstract**

This deliverable document the installation process on site, observation of problems, errors and possible improvements as well as metric control for benchmark. The documentation process is carried out by all industrial partners, as final users of the result of this research project.

**Keywords**

Installation process, Use-cases, Benchmarking, Industrial relevance

# Revisions

| Version | Submission date | Comments | Author |
|---|---|---|---|
| v0.1 | 1.5.2023 | Initial version | Antonio Lopez-Rios (HRS) |
| v0.2 | 17.5.2023 | Corrections | Kaj Helin (VTT), Dag Fjeld Edvardsen (CATENDA), Matthias Aust (FhG-IAO), Ruprecht Altenburger (ZHAW), Manuel Menéndez (VIAS), Øyvind Kjøllesdal (AFG) |
| v0.9 | 9.6.2023 | Submitted for internal review | Antonio Lopez-Rios (HRS) |
| v1.0 | 30.6.2023 | Approved, final version | Chiara Zarna (SINTEF) |

# Disclaimer

# Acronyms and definitions

| Acronym | Meaning |
|---|---|
| **PUC** | Pilot Use Cases |
| **IFC** | Industry Foundation Classes |
| **PCL** | Point Cloud |
| **API** | Application Programming Interface |
| **HMI** | Human-Machine Interface |
| **BIM** | Building Information Modelling |
| **BLE** | Bluetooth Low Energy |
| **IoT** | Internet of Things |
| **GUI** | Graphical User Interface |
| **BCF** | BIM Collaboration Format |

# BIMprove project

In the past 20 years, productivity in the European construction industry has increased by 1% annually only, which is at the lower end compared to other industrial sectors. Consequently, the sector has to step up its digitization efforts significantly, on the one hand to increase its competitiveness and on the other hand to get rid of its image as dirty, dangerous and physical demanding working environment. Construction industry clearly needs to progress beyond Building Information Modelling when it comes to digitizing their processes in such a way that all stakeholders involved in the construction process can be involved.

The true potential of comprehensive digitization in construction can only be exploited if the current status of the construction work is digitally integrated in a common workflow. A Digital Twin provides construction companies with real-time data on the development of their assets, devices and products during creation and also enables predictions on workforce, material and costs.

**BIMprove** facilitates such a comprehensive end-to-end digital thread using autonomous tracking systems to continuously identify deviations and update the Digital Twin accordingly. In addition, locations of construction site personnel are tracked anonymously, so that **BIMprove** system services are able to optimize the allocation of resources, the flow of people and the safety of the employees. Information will be easily accessible for all user groups by providing personalized interfaces, such as wearable devices for alerts or VR visualizations for site managers. **BIMprove** is a cloud-based service-oriented system that has a multi-layered structure and enables extensions to be added at any time.

The main goals of **BIMprove** are a significant reduction in costs, better use of resources and fewer accidents on construction sites. By providing a complete digital workflow, BIMprove will help to sustainably improve the productivity and image of the European construction industry.

# Contents

# 1. Introduction

The goal of this document is to provide an overview of what has been developed in the frame of BIMprove from the perspective of the final users (industrial partners); including general feedback that can be used for the future evolution of BIMprove system capabilities. Most functions of the BIMprove system has reached a prototype stage by M24 (as planned) and testing of the overall system has been started on the three Pilot Use-Case locations.

First, we have summarized systematically, which are the elements that have been developed during the BIMprove research project and that have a direct connection to the original 6 objectives of the project.

This is followed by a description on how the 6 objectives are reached thanks to the new functionalities of BIMprove. In the same way, we also show the relationship between these functionalities and the three pilot use-cases of the project: Scheduling, Safety and Fire. On the other hand, we also describe how the three pilot use-case sites (Madrid, Oslo and Lausanne) have been equipped to use BIMprove technologies.

At last, the three industrial partners describe the most significant items that are considered to improve the project moving forward.

## 1.1. BIMprove components

BIMprove is a project which aim is to contribute with a solution for monitoring a construction site using digital data, in order to improve and automate the follow-up of the quality, scheduling and safety of the site. In short, BIMprove is able to compare and analyse a BIM model and different type of real-time data from the construction site, in order to create a digital twin of the worksite. The work carried out in the frame of BIMprove resulted in development of hardware, software as well as methods that are described in the following sections:

### 1.1.1. Hardware components

| Objective | Title | Description |
|---|---|---|
| Data capture | UGV to take photos, thermal pictures and 3D scanning | For capturing visual data we have further developed a ground robot prototype that can, both, visit the worksite capturing: pictures, 3D scan (to provide point-clouds) and thermal pictures. The first integration of Leica BLK360 in UGV application. Autonomous navigation based on planned mission. |
| Data capture | UAV to take photos, thermal pictures and 3D scanning | For capturing visual data we have developed a drone prototype that can both, visit the worksite and capture: pictures, 3D scan (to provide point-clouds) and thermal images. The path planning is based on .ifc data that is converted to an Octomap (3D-occupancy grid). So the drone can navigate fully autonomous on a worksite, an onboard depth camera detects obstacles and adds them to the octomap. A modified A* algorithm is implemented for the path planning. |
| Service | Controller for UGV | For being able to control the robot remotely and launch autonomous functionalities, we have been working in a 2.4gHz WiFi based new connection with a greater gain antennas so that this connection can be established from a greater distance. The command service can be used with a remote control and a tablet-like device. |
| Service | Base-station for UAV | The drone flying indoor does not have an absolute position and orientation. To solve this problem we developed a landing base for the drone, that is also modelled and stored in the BIM. With the help of this, |

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| | | the drone is always located in the correct frame and on-board measuring devices are aligned with the global frame. Secondly the base station has charging capabilities such that the drone is recharged automatically after landing. |
| Data capture | Worker's presence detection | Activity, in terms of presence of number of workers, in all working zones can be logged, and it can be live shown in Bimsync with a compatible model. There are two central hardware elements in this system:<br>1. “Mobile beacons” are wearable Bluetooth tags mounted inside each worker's helmet. These tags are actively advertising over BLE.<br>2. “Stationary beacons” are Bluetooth BLE receivers mounted in the ceiling centrally in the zones they are to cover. Each stationary beacon listens for advertisements from the mobile beacons, and conveys the time, mobile beacon ID, and RSSI associated with each advertisement upwards in the tracking system.<br>To support and maintain reliable zone association of workers, a software system for reliable tracking based on a zone connectivity graph have been developed. For the sake of scalability to large sites with hundreds to thousands of zones, a distributed system architecture has been chosen. |

### 1.1.2. Methods

| Objective | Title | Description |
|---|---|---|
| Processing point clouds | Automatic alignment of the point cloud with the IFC coordinates system | A clear workflow was developed to align measurements with the BIM model. Functionality of given software (Pix4D, Leica Cyclone) was extended in a way such the alignment of the model and the measured data needs very few interaction by the user. It uses the newly developed markers that are standardised in the CEN workshop agreement.<br>In the case of Pix4D point clouds, the process is fully automated, in the case of the Leica cyclone software few interaction (aligning BW-markers to specific points) is needed. |

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| Comparing point-cloud with IFC model | Automatic comparing process of geometries from point clouds and IFC models | Automatic comparing process between the geometry of the BIM model and the point-cloud. Input is a BIM-model and a point cloud, output is a BCF issue describing the result. The end user considers this and makes a decision. |
| Comparing point-cloud with IFC model | Automatic comparing process of IFC elements existing on the point cloud and the executed due date of each element | Based on a BCF issue with links to the model and the comparison part of the point cloud, the user can as part of the daily decision process decide that work is delayed (or in theory ahead of time). If so the user can assign the issue to the scheduler (if this is a different role) and as that the task covering this in the schedule is updated. |
| Standardization | Use of targets during scanning to align point cloud with the local coordinates system | Definition of Markers with machine readable coordinates which can be measured by surveyors. The markers enable an automated alignment of the point cloud with precise coordinates both in real-time and in post processing. Tags for VR glasses or drone orientation can also be part of the markers. The definition of the markers is developed in a CEN Workshop, a pre-standardization initiative by CEN which results in a so-called CEN Workshop Agreement (CWA) and aims to be a future standard. |
| AI for pictures | Image recognition | Risk Object Visual Analysis System (ROVAS) for automatic detection of safety measures, especially safety nets, from photographs and 3D point clouds captured at construction sites. |
| Decision | Daily Decision Cycle | A schedule and a set of BIM models exists and are kept up to date. Each day the BIMprove operator looks at tasks that are supposed to be completed today and creates a “high level scan request” to the robot and/or drone operators. They scan and send back the results using BCF. The decision maker (a role) looks at the scans and decides if the conclusion is (1) Good result, |

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| | | accept (w) Not enough info, scan again, (3) send a person to check, (4) Done, but not perfect quality - rework must be done and scheduled, (5) Done, significant difference from the plan, but might be to expensive to correct - ask client if it is acceptable together with other compensation. |
| Picture | Pictures including Exif data field | Embedded Exif field with position and pose of the camera for machine learning and image classification |

### 1.1.3. Software functionalities

| Objective | Title | Description |
|---|---|---|
| Data capture | Definition of a capture mission with BCF | Drone: A dedicated application has been developed such that a semi-automatic data capturing workflow is executed. It first starts with the user defining a waypoint as a BCF issue for a drone scan, then the application obtaining that specific waypoint and sending it to the drone for a mission. All data captured will be transferred through the workstation via the application automatically after the drone is done with the mission. Then, thermal data post-processing will begin to analyse the captured data whether there is a risk in term of thermal issue or not. If yes, the application will create a BCF issue and upload/link all the problematic data to the specific BCF issue created before sending out an alert via SMS to the dedicated numbers or responsible persons. |
| 4D viewer | Create BCF issue board from MS Project | An MS Project file can be imported and based on this a BCF issue board is created. The benefit is that BCF is an open standard and that changing it is easy allowing the schedule to be more dynamic and accessible. BCF also have many nice attributes, like being made for linking with the BIM model. |
| 4D viewer | 4D simulation viewer | When the BCF-backed schedule tasks are linked with BIM-objects, playing back the schedule is possible with a timeline animation. When the date where a task is worked on is shown, the 3D viewer shows the related objects appearing. |

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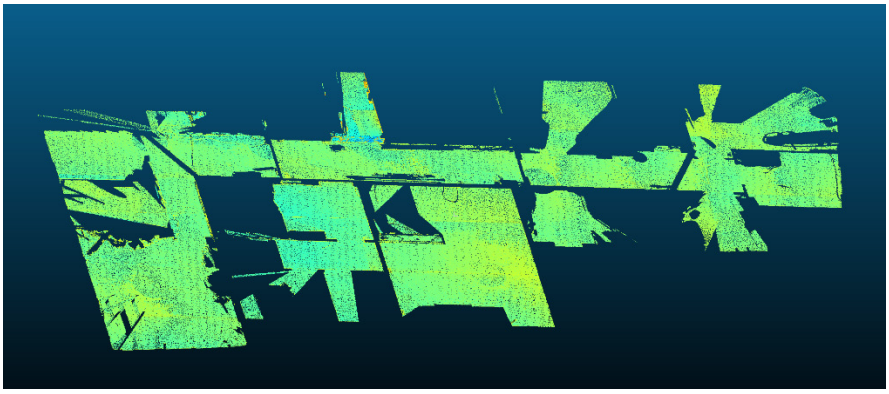
| | linked with IFC | |
| 4D viewer | 3D/4D viewer of delays | Comparation between the geometry of the point cloud and the BIM model (plan vs scan) is part of the consideration when updating the schedule and capturing delays and measures taken. |
| 3D viewer | Workers' presence viewer | Heatmap visualizing the position of workers with wearables. Workers use wearable trackers, and we can visualize in 3D how many people are at each location. To protect privacy, only the number of workers per zone is visualized. |
| Point cloud processing | Point cloud comparison (IfcEntity ↔ Pointcloud) | pyBIMprove compares each IfcEntities with data from a point cloud. The entities to be compared against can be controlled through a selection of GUID'S. Comparison works by trying to minimize point distance to mesh surface (best fit), resulting in a offset for the placement if the ifcEntity. From the comparison there is generated several filtered coloured point clouds, where the colour are either natural or coloured as a heatmap. There is also defined a feature set to try to estimate the success of the comparison, these result can be extract as a pure JSON-format. Here are some example of heat maps, from Fyrstikkbakken 14 BC, 9th floor.<br>  <br>*Heatmap for selection of floor slabs individually compared after best fit, shows geometrical difference on a single Entity (blue is -2 cm , red is 2 cm and green is 0 cm)* |

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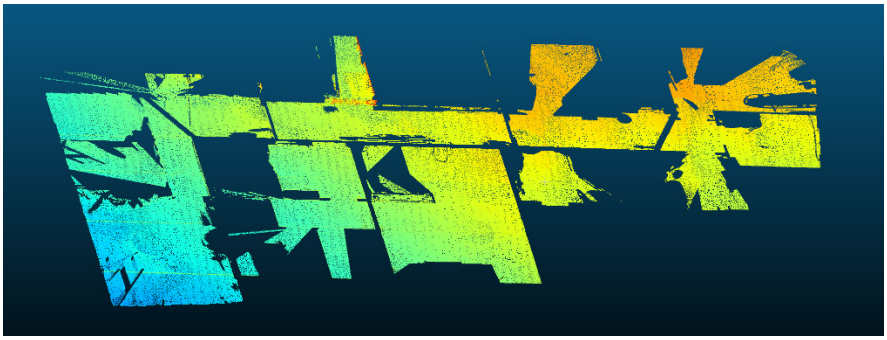
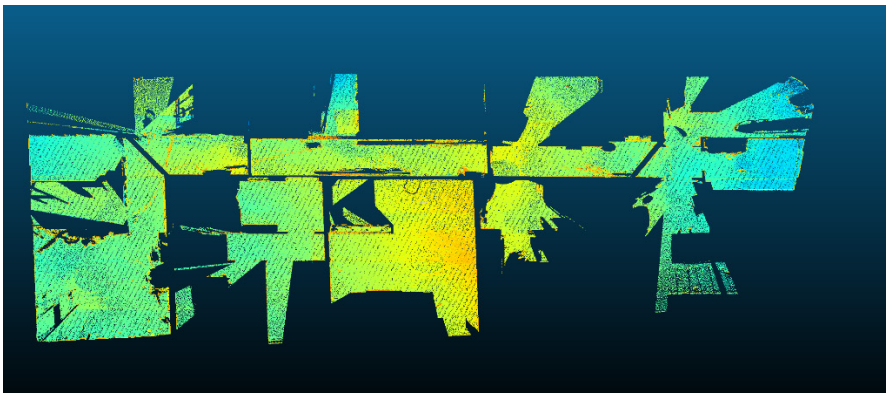
| | |  <br>*Heatmap for selection with no re-placement of IfcEntity, shows direct relation between planned and built (blue is -10 cm, red is 10 cm and green is 0 cm)*<br>  <br>*Heatmap for best fit detection against all IfcEntities in selection, shows geometrical deviation over multiple entities (blue is -2 cm , red is 2 cm and green is 0 cm)* |
| Visual inspections | Virtual reality | Before the project FhG-IAO and USTUTT had already developed a single-user VR software called XR-Visualizer. Its main feature was the easy loading and integration of 3D-models into VR. This software was built upon and greatly improved throughout the BIMprove project. The BIMprove XR Viewer is now a Multi-user Virtual Reality* environment to visualize IFC files and point clouds as well as communicate with BCF files (marking, issue creation). It has been installed and tested at the PUCs in Lausanne Bussigny and Madrid. (*There is also desktop-PC-version with which to join (VR-)sessions.) |
| Visual inspections | Augmented reality | BIM@Construction AR tool allows user to visualize the BIM model at the construction site. The main features of AR-tool has been developed and improved during BIMprove. Main development environment has been Unity3D and it could be exploited in Microsoft HoloLens 2 and high-end android tablet. AR tool includes several tools, which user can use in 1st person mode, like notes, measure tools, warning signs etc. BIM@Construction has been tested at the |

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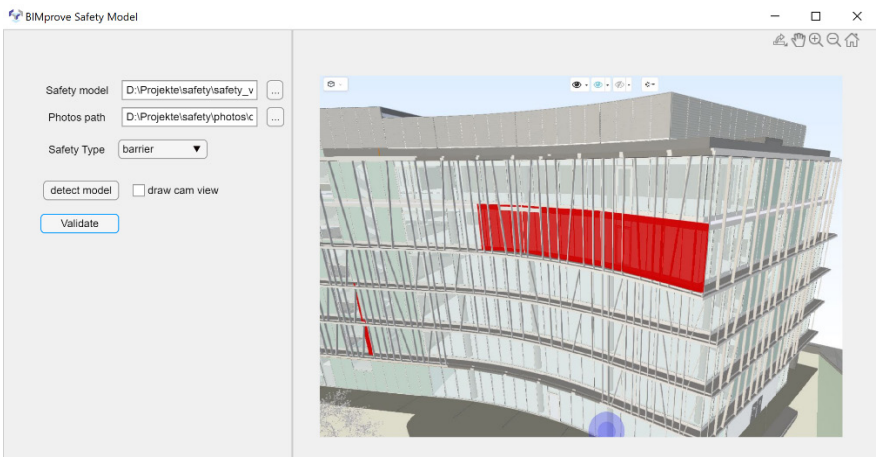
| | | PUCs in Lausanne Bussigny and demonstrated in Madrid. As tool is proof of concept it could be future developed and provide Software as a Service.<br>  <br>*Left: View from AR tool. Right: End-user is testing AR tool in Lausanne Bussigny* |
| Image processing | Software service for detecting safety elements on pictures | Machine learning based computer vision model is trained for detecting risks or risk countermeasures at the construction sites. The model's detection capabilities are provided as a service through a suitable REST interface. It can load the model and uses it to analyse the images send to it by HTTP POST. The detection results are returned as JSON text and described in the deliverable D2.4 Detailed Description of the Safety Functionalities and Worker Notifications. |
| Image processing | Picture + detection → IfcElement in Safety model |  <br>The starting point is a geometry model and the definition of safety elements (here: barriers). Data acquisition with UGV/UAV is actually intended for geometry surveying. However, the data can also be processed with the ROVAS system and additionally with additional information (where and at what angle was the image taken). Together with the detection of e.g. barriers, this can now be compared with the safety model and checked whether these facilities are present where required. |

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| 3D viewer | Viewer of photos with thermal images | Based on the stored Exif data in the taken thermal pictures, the system can automatically present on the BIM model, where the photo was taken and from which angle.<br>  |
| Visual inspections | Model & point cloud delivery for XR | Semi-automised conversion of IFC- and point cloud files for VR and AR.<br>The software consists of scripts for the semi-automised utilisation and parameterisation of pre-existent third-party software. As of now, its utilisation can be offered as a service by FhG-IAO. The workflow has been described in earlier Deliverables of the project such as D2.7, D2.8, and D3.1.<br>  <br>*Visualisation of converted geometry (BIModels and point clouds) in multi-user VR.* |
| User interface | Human-Machine Interface for UGV | The original HMI for the Summit-XL mobile ground robot has been extended with new embedded functions. Such functions cover the control of 3D scanner, autonomy properties and path following capabilities. |

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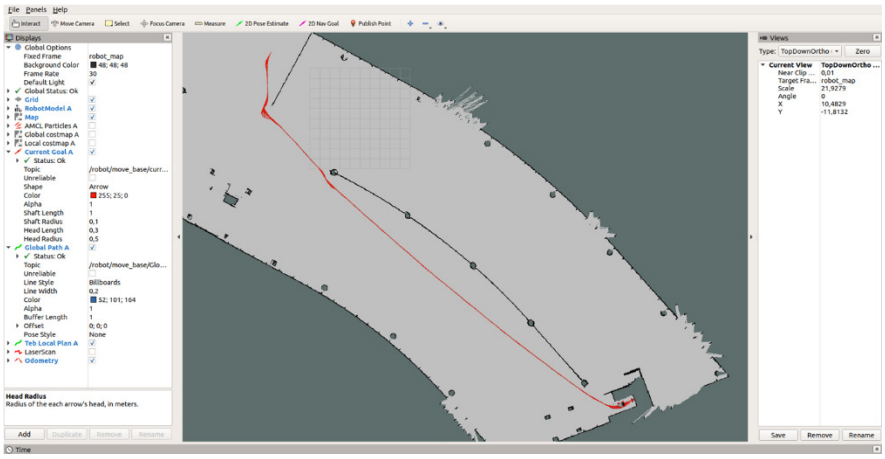
| 3D viewer | Path-planning for UGV | An automated tool to generate the shortest path in an IFC model from the current position to an emergency exit is developed.  |
| Data capture | Capability for automatic scan with UGV | The Summit-XL mobile ground robot has been extended and integrated with RS-Lidar 16, Flir Ax8 and BLK 360. The integration description can be found in D3.4. Prototype System Description and Test Results. |

# 2. Benchmarking

<table>
<tr><th colspan="2">Objective 1 — Develop a digital twin for building constructions, based on BIM</th></tr>
<tr><td>Initial proposal</td><td>Implementation</td></tr>
<tr><td>Challenge: BIM can store a wide variety of information related to the construction phase, but there exists no off the-shelf solution to automatically update this information, as construction progresses. Furthermore, BIM is a static model, where the information is stored and used as reference, and it does not act as a two-way communication tool.</td><td rowspan="2">Development: BIMprove creates the digital twin using the following information:<ul><li>Initial BIM model of the design phase</li><li>Real geometry of executed elements (represented by point clouds)</li><li>Dates of when elements have already been executed (date from the point cloud capture)</li><li>Real-time position of workers</li><li>Photos, including the thermal pictures</li></ul>A drone and a ground-robot receive a specific mission (with a defined path) to capture data: pictures and a point-cloud of the construction site. The point cloud is uploaded on the platform “BIMprove cloud” where the “digital twin” information is available.<br>In the same way, sensors of presence detect the position of workers. This information is also available on “BIMprove cloud”.<br>BIMprove cloud can be accessed here: https://cloud.bimprove-h2020.eu/</td></tr>
<tr><td>Proposition: Digital twin of a building construction can extend the use of BIM in new application fields. A digital twin, like in BIMprove, enhances the productivity, progress monitoring, quality assurance of the construction site, with connecting real-time data to the static BIM. While BIM is still used as a refence for the execution of the construction, additional comfort functions arise with the use of digital twins (scheduling, safety, analytics, etc.).</td></tr>
<tr><td>KPIs: number of use-cases demonstrated in realistic environment</td><td>Results (number of carried out demonstrations):<br>Comparing point-cloud with BIM model<ul><li>Oslo: 1</li><li>Madrid: 1</li><li>Lausanne: 1</li></ul></td></tr>
</table>

<table>
<tr><th colspan="2">Objective 2 — Automate progress and quality reporting of building constructions</th></tr>
<tr><th>Initial proposal</th><th>Implementation</th></tr>
<tr><td>Challenge: Progress and quality checks/reporting is in most cases executed by manual labour with use of site survey equipment. The result is than analysed, compared and evaluated in order to give an overview of the day's/week's progress. Quality assessment is not always quantitative, and harder to evaluate. In order to express quality in finishing of a construction phase (e.g. position of an electrical outlet), combined analysis of executed task and result is needed. In both cases, the evaluation result could result in 1) acceptance; 2) update in the building drawings; 3) rescheduling of tasks; 4) re-work of the given step; 5) cost re-calculations. These previously mentioned actions, in a BIM based construction, require manual labour and are cumbersome.</td><td rowspan="2">Development:<br>Once the point-cloud has been uploaded on “BIMprove cloud”, there is an automatic process to check the progress and quality of the construction thanks to comparing both geometries (point cloud and BIM model) and creating automatically-sent messages (BCF) to notify where are:<ul><li>the differences of geometry</li><li>the differences of planning (dates of execution are linked to the BIM model’s elements)</li></ul></td></tr>
<tr><td>Proposition: BIM based building construction, gives the possibility to control progress in a digital way. The static BIM needs extension toward a digital twin (like in BIMprove) in order to establish the necessary services, which checks, updates or replaces the as-planned BIM with as-built information. As-built information is gathered with use of stationary, mobile or flying robots. Information from these robots are then processed to a format, which BIMprove can understand and evaluate the differences/similarities. The layer structure of BIMprove clearly identifies the roles of different services and open new business opportunities for digital data providers. Early</td></tr>
</table>

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| detection of deviations allows better control of scheduling and higher quality results. | |

**KPIs:** construction site ground survey in m2/hour, construction site volume survey in m3/hour

| Pilot Use case | m2/h survey capture | m2/h drone capture | m2/h ground robot capture | m3/h ground robot capture |
|---|---|---|---|---|
| Lausanne | 157m2/h (with Faro Focus 3D) | 7200 m2/h (indoor scan with ZHAW custom drone) | 75,7 (with Summit-XL robot using BLK360) | 227,7 (with Summit-XL robot using BLK360) |
| Oslo | | 3550 m2/h (facade scan with DJI Mavic 2 Pro) | 240,93 (with Summit-XL robot using BLK360)<br>674,6 (with Summit-XL robot using BLK-ARC, while moving) | 722,69 (with Summit-XL robot using BLK360)<br>2023,8 (with Summit-XL robot using BLK-ARC, while moving) |
| Madrid | | 3185 m2/h (facade scan with DJI Mavic 2 Pro) | 1676,05 (with Summit-XL robot using BLK360) | 11145,8 (with Summit-XL robot using BLK360) |

## Objective 3 — Improve worker safety

| Initial proposal | Implementation |
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| **Challenge:** Workers in the construction sector are continuously exposed to some danger. The major sources of the danger are 1) work task type; 2) location; 3) time of execution; 4) cooperation with other workers 5) unexpected events; 6) wrong/unexpected material. In order to limit exposure to danger and increase safety: trainings and protective equipment is used. However, these cannot take into consideration the points 2), 4) and 5). | **Development:**<br>The position of workers can be identified thanks to the use of captors and wearable chips for workers. If workers are wearing wearable trackers, we can visualize in 3D how many people are at each location.<br>If any specific location has been identified as a dangerous area (thanks to the safety BIM model), because there is any unsafe situation, workers can be notified. |

<table>
<tr><td>Proposition: Worker's location can be monitored for safety purposes. This allows BIMprove and its digital twin to provide comfort functions to the workers, increasing overall safety of the workers. BIMprove can anonymously track workers and schedule their activities at the construction site to minimize hazards. Additionally, the BIMprove user interfaces can support workers' situational awareness and safety (for example a smartwatch for tracking and context-specific notifications; worker privacy will be protected). In case of BIMprove robots, safe and pleasant human-robot interaction will be ensured in the concept and implementation practices, in which the locations of persons and robots will be utilized. Further on, machine learning to predict safety risks, based on existing historical data and real-time inputs and human-centric design to help identify places where these are most needed.</td><td colspan="3"></td></tr>
<tr><td rowspan="4">KPIs: amount of accidents happening during building construction, fires happening during building constructions</td><td>Pilot Use case (as 1/6/2023)</td><td>Nº of accidents</td><td>Nº of fires</td></tr>
<tr><td>Oslo</td><td>0</td><td>0</td></tr>
<tr><td>Madrid</td><td>10</td><td>0</td></tr>
<tr><td>Lausanne</td><td>5</td><td>1</td></tr>
</table>

## Objective 4 — Provide better control of building constructions

| Initial proposal | Implementation |
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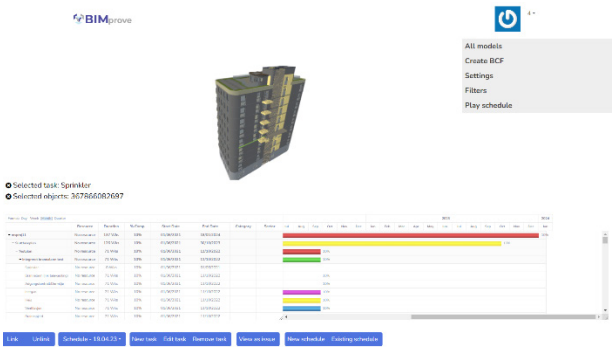
**Challenge**: Efficiency in building construction site is less than 50%. This is due to waiting time for other processes (e.g. construction tasks) to be finished, waiting for raw material, waiting for construction equipment, re-building or correction of errors. Construction control (e.g. quality or quantity) is usually not instant. Workers needs to wait for approval, or they risk creating accumulative errors, with even bigger cost for correction. Site managers ensure the timely execution of the work, with physical interaction (measurement, survey, etc.) of the workers. The more time they spend on the construction site, the less time they have, to log the progress and record/introduce the changes to the as-built BIM

**Proposition**: To increase efficiency, better management is needed, and workers need to have access to updated plans and progress reports. BIMprove allows instant access to information (e.g. BIM), schedules, location of equipment instantly. The BIMprove digital twin updates schedule based on progress monitoring, can proactively reassign tasks, notify workers or site managers. This result: better scheduling, better allocation of resources and optimization of equipment usage.

**Development:**

As a first input on BIMprove, users upload the BIM models and a planning of the execution progress. This planning is related to the BIM objects using the BCF format files. After scanning the construction site, BIMprove is automatically comparing the geometry of elements from the BIM model with the point cloud of that given date. BIMprove will notify when an element which should have already been built (regarding the initial planning) has not still been executed.




**KPIs**: prediction accuracy of simple construction tasks, efficiency of a building construction site.

**Results:**

Construction tasks can be monitored and checked, when these are supposed to start and end. The users are notified in case of deviations with BCF.

Compared to classic, manual survey including comparison to detect need for re-work or errors

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| | (approx. 1 week) the BIMprove Daily Decision Cycle provide results of the quality control within 24 hours. |

| **Objective 5 — Support standardization activities and industrial adoption of BIMprove** | |
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| **Initial proposal** | **Implementation** |
| **Challenge:** The construction sector is labour intensive and uses digital tools in a limited matter. While BIM was launched as an industrial standard, it is still in many places in early adoption phase. Digital construction sites are pre-requirements for BIM based construction, which still does not exist in most countries. In addition, the market is unlikely to adopt solutions that are not standardized. | **Development:**<br>The standardization activities carried out by BIMprove partners concern the 3D scanning process, which is the main source of data to monitor the construction site. The proposed CWA is titled: position markers for digital applications on construction sites, structural monitoring and BIM-applications. The CWA aims to provide digital technologies with measured position data from surveys in a secure manner.<br>For the industrial adaptation an open access dataset (BIM models, point cloud scans and pictures) from the project has been published.<br>Open access dataset available at https://bitbucket.org/sintef-manufacturing/openaccess |
| **Proposition**: BIMprove builds on BIM and could provide the necessary push to BIM to be more widely adopted. BIM itself has a limited effect on the construction site, on the other hand: the BIM methodology, digitalization, which makes the boost for productivity and efficiency. BIMprove digital twin as a tool in the construction phase, can highlight the direct benefits of BIM based construction. BIMprove recognizes standardisation as a potential instrument to transfer project findings directly into the market: standardisation activities will be fully integrated within the project. Open and transparent process of standardization will | |

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|---|---|
| ensure that all relevant stakeholders can participate in project standardization activities leading to a higher acceptance by the market. | |
| **KPIs**: number of developed layers, services and architecture of BIMprove | **Results:**<br>1 CWA in preparation<br>1 Open access dataset (both layer service description (D2.8) and Open Research Data Pilot (D2.9)) |

## Objective 6 — Apply digital twins in building constructions

| Initial proposal | Implementation |
|---|---|
| **Challenge:** Digital twins are present in manufacturing sector and in material science already, where the environment or the processes are structured and static. However, application of digital twins in construction sector is more challenging: the environment is dynamic, unstructured and the presence of human labour results in complex systems. To apply digital twin in building construction, continuous tracking of equipment and workers, automated progress reporting and quality check is necessary. | **Development:**<br>All the developments have been tested in the laboratory of each partner, and then tested at least at one the three pilot use-case site: Oslo, Madrid or Lausanne. |
| **Proposition:** Research and development carried out in BIMprove will help to establish digital twins in building constructions with the help of leading academic, industrial and research partners. BIMprove digital twin is designed and planned to be applicable in building constructions. The development cycles ensure the necessary iterations and adaptation | |

<table>
<tr><td>to user requirements. BIMprove will be tested in laboratory and in realistic environment at industrial partners.</td><td colspan="4"></td></tr>
<tr><td rowspan="2">KPIs: number of use-cases demonstrated in realistic environment</td><td colspan="4">Results:</td></tr>
<tr><td>Pilot Use-cases</td><td>Oslo</td><td>Madrid</td><td>Lausanne</td></tr>
<tr><td></td><td>BIMprove components tested (total of 21)</td><td>17</td><td>13</td><td>10</td></tr>
</table>

# 3. Use cases

In BIMprove there are three Pilot Use-cases that have been defined and that are using the BIMprove digital twin thanks to its functionalities.

The PUCs are given the following naming:

- “Scheduling” - PUC AFG - Fyrstikkbakken (Oslo, Norway)
- “Safety” - PUC VIAS - Las Tablas (Madrid, Spain)
- “Fire” - PUC HRS - CoteGare Bussigny (Lausanne, Switzerland)

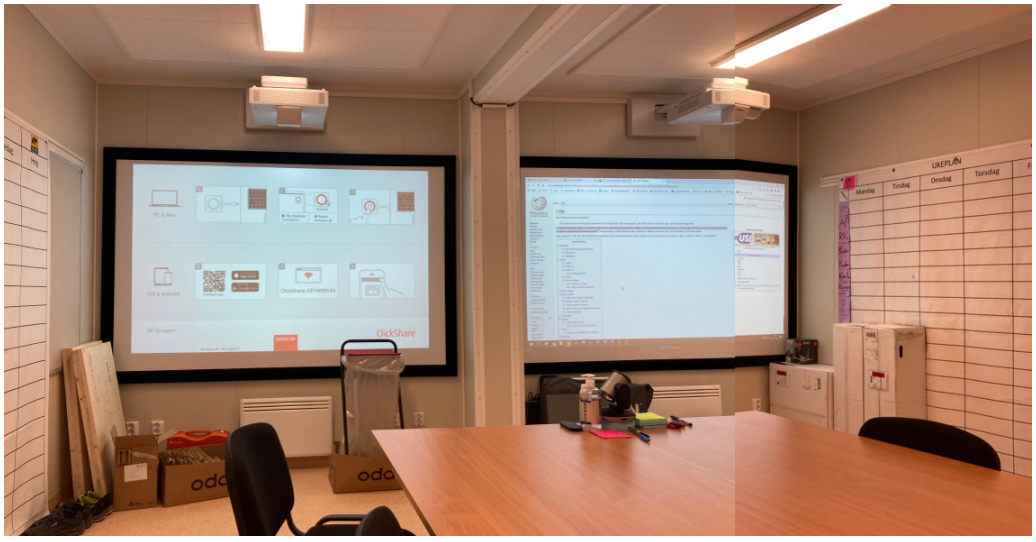
In the following table we provide some details of each use case:

| BIMprove components | Scheduling | Safety | Fire |
|---|---|---|---|
| UGV to take photos, thermal pictures and 3D scanning | x | x | x |
| UAV to take photos, thermal pictures and 3D scanning | x | x | x |
| Worker's presence detection | | x | |
| Automatic alignment of the point cloud with the IFC coordinates system | x | | |
| Automatic comparing process of geometries from point clouds and IFC models | x | | |
| Automatic comparing process of IFC elements existing on the point cloud and the executed due date of each element | x | | |
| Use of targets during scanning to align point cloud with the local coordinates system | x | x | x |
| Image recognition | x | x | x |
| Daily Decision Cycle | x | x | x |
| Pictures including Exif data field | x | x | x |
| Definition of a capture mission with BCF | x | x | x |
| Create BCF issue board from MS Project | x | | |

| | | | |
|---|---|---|---|
| 4D simulation viewer linked with IFC | x | | |
| 3D/4D viewer of delays | x | | |
| Workers' presence viewer | x | x | |
| Point cloud comparison (IfcEntity ↔ Pointcloud) | x | x | x |
| Virtual reality | | x | x |
| Augmented reality | x | | |
| Software service for detecting safety elements on pictures | x | x | |
| Picture + detection → IfcElement in Safety model | | x | |
| Viewer of photos with thermal images | | | x |

# 4. Installation at the construction site

## 4.1. AF Gruppen

| Pilot Use Case: Oslo | |
|---|---|
| Prototype description: | The construction site has been provided with twin screens for facilitating BIM and integrated scheduling processes. |
| Equipment: | 2 Epson projectors, including Deco frame and video conference equipment:<br>• Epson EB-800F UST Laserprojector, 1080P/5000 ANSI lumen<br>• Decoframe 32:9 , 464x142cm, Flex White CI<br>• CX-30 Barco ClickShare CX-30,<br>• CSE-200 Barco ClickShare CSE-200<br>• VS-62H Kramer Matrix 6x2 HDMI Auto UHD 4K60<br>• RC-308/EU-80/86 Kramer ControlPanel<br>• LOGITECH Rally Plus Ultra-HD ConferenceCam |
| Photos: |  |

## 4.2. VIAS

| Pilot Use Case: Madrid | |
|---|---|
| Prototype description: | The construction site has been provided with hardware for the BIM@SiteOffice prototype. |
| Equipment: | • 1 Computer ( AOURUS 15P YD-74ES244SH INTEL CORE i7-11800H/32gb/1TB)<br>• 1 Touch screen (Optoma 3751 RK -75")<br>• 1 VR goggles (HTC Vive Pro 2 (Full Kit) head mounted display)<br>• 1 Tablet (TABLET SAMSUNG GALAXY TAB ACTIVE 3EE)<br>• 1 L1+L5 RTK device for OTG on Android system . (RTK-15D) |
| Photos: |  |

## 4.3. HRS

| Pilot Use Case: Lausanne | |
|---|---|
| Prototype description: | The construction site has been provided with hardware for the virtual reality. |
| Equipment: | • 2 computers:<br>  ○ laptop: Acer Nitro 5<br>  ○ Desktop PC: Joule Force Strike<br>• 2 screens: AOC Q27G2U/BK, 27”<br>• 2 VR goggles (HTC Vive Pro 2 (Full Kit) head mounted display) |
| Photos: |  |

# 5. Feedback from Industrial partners

On this chapter we describe the main points that industrial partners consider important to enhance the project.

## 5.1. AF Gruppen

| Development | Comment (problems, errors, improvements) |
|---|---|
| General: | The BIMprove ecosystem, where a live digital twin is available for the project, feeding with live data of progress, quality assurance, resource allocation, and avoidance of potential severe HSE issues, will give construction projects significant value. Even though the tools are still at a prototype level, and the different functionality are not fully integrated, the insight provided brings value to PMs, site managers, and foremen, when it comes to analysing and improving the everyday ongoing processes on site.<br><br>The adoption of the new tools on-site will require new roles as well as a shift of the traditional processes in a construction project.<br><br>The main improvements would be to automate more of the processes and integrate the different insights in a live updated dashboard and make both the data-capturing process as well as the analysed data easily accessible. |
| 01-Automated progress monitoring, automated quality assessment and analysis | The automated progress monitoring will monitor and verify that the completed work is according to the specifications and the schedule. In construction projects, consistency between the actual progress and the schedule will naturally often vary, which is why updated and consistent insights are of high importance. When the site managers are in a position of updated and accessible data, they're also able to use the data, by rescheduling, adding or moving resources, doing daily logistics planning and so forth.<br><br>The utilization of the scanning process, analysis, and accessing insights is not an autonomous process as of today. However, the data from the semi-manual processes in the pilot use case already contribute to better processes. |

| | |
|---|---|
| | The most important improvement will be to streamline all the processes of capturing and providing analysed data and to make these processes integrated parts of the daily site management protocols. |
| 02-Tracking daily changes | By tracking the daily changes in an updated “as-built”-model, will the site managers get updated info about the status of the progress at the construction site. Discrepancies, both when it comes to quality and schedule, will be detected, and issues could be handled before any following errors occur.<br><br>The main improvement will be to further develop technology for handling the capturing process, so this doesn't require much extra work. |
| 03-Resource allocation optimization | By dynamic prediction of workload and insights into where work crews are allocated, efficiency could be improved rapidly. Better live insights into where workers are located, and available areas for starting to work, could possibly hinder trades from working too closely, and give more space for the individual trades.<br><br>The sensors which have been tested so far seem to give insights and value. However, there might be some inconsistency in placement, and the installation of the sensors and equipment for indoor tracing requires some extra work.<br><br>The main improvement will be to find or develop sensor infrastructure that easily could be installed and moved during construction. |

## 5.2. VIAS

| Development | Comment (problems, errors, improvements) |
|---|---|
| 01-Risk and safety assessment methods | One of the main objectives of BIMprove was to increase the safety of construction site workers, through the BIM methodology, by tracking people and monitoring potentially dangerous situations that could merge into an accident, it´s true that the objective has been reached, but some improvements, according to the methodology develop in early stages of the project, should be done, as having a Safety BIM Model, with all the safety elements defined in deep, or having a system that could alert workers depending on the severity of the risk. |
| 02-Digital twin | The BIMprove digital twin was created with the inspection made by drones and ground robots, anyway to create a real digital twin these technologies have some limitations in buildings constructions as a continuous monitoring is needed, an unsafety situation can arise whenever.<br>This technology is perfect for linear infrastructures but for building, inspections devices as camaras fit better as they are less intrusive. |
| 03-VR/AR | BIMprove has shown a different way of working using virtual and augmented reality, for AR will be very interesting to test accuracies, in other to know if some task made by the surveyor can be made by whoever using this technology as to mark a drill. |
| 04-Scan to BIM | BIMprove made an automatic comparison between the geometry of the Point cloud, Bim Model and Scheduling, more test will be needed to check the degree of automation comparing with traditional control processes. |
| 05-General | BIMprove project is a good approach of what a digital twin should be in the construction sector, the technology used in the project create a digital representation of a real site, improving the collaboration between all the departments involve in the construction phase, the information access and decision making, thanks for the information gathered from the inspection systems.<br>BIMprove has been designed as a service platform, where different improvements will be needed in order to make it more friendly for the final |

| | |
|---|---|
| | user, maybe with a higher degree of automatization, as well BIMprove has laid the foundation for future developments relates with safety. |

## 5.3. HRS

| Development | Comment (problems, errors, improvements) |
|---|---|
| 01-Ground robot to capture photographs, thermal pictures and 3D scanning | This technology is more convenient for projects with few partitions and large surface per floor. For example, in housing buildings, walls, doors and materials stored represent important hurdles for the self-driven ground robot. |
| 02-Drone to capture photos, thermal photographs and 3D scanning | This technology is more convenient for projects with big volumes such as industrial, sports buildings or infrastructure projects (roads, railways, etc.) for example, otherwise the drone will find a lot of hurdles on its way. What's more, there is an undeniable potential for site managers to save time in projects including larger distances. |
| 03-Image recognition | It's important to detect on a picture the safety elements but it would also be good to identify the flaws on safety elements. |
| 04-Create BCF issue board from MS Project | It would be more efficient if some rule sets could be implemented for the process to link the tasks to the BIM models. For example, the task of building the 1st floor slab, could be connected to the IfcSlab which level is = N01. Some automatic processes could then provide more efficient tools. |
| 05-General: | BIMprove project is very focussed on capturing data, mainly the point cloud, to compare it against the BIM model. The three use cases are scheduling, safety and fire. Nevertheless, we have seen that the development of the project doesn't provide big changes to the fire security. However, there is a big potential for another use case, which is the "Quality Control". A bad quality control may have very important consequences on the planning, the economy and the results of the construction process. Same extra functionalities could be easily added on BIMprove in order to provide an added value to the product, and be more oriented to an use case that needs to improve its efficiency. |

# 6. Conclusions

The construction sector is one of the most dangerous sectors in Europe. With the use of digital tools we are able to make tomorrow's construction industry safer, more flexible and, not least, more productive. To achieve these goals, digital tools such as digital twins, VR/AR, drones and unmanned ground robots are being used. 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.

BIMprove demonstrated with the solutions presented in the deliverable, how to detect potential deviations in construction in an early phase.

Inadequate planning can often mean that you have set up something that was not planned or that has the wrong size or position. This in turn can lead to having to tear down the structure and then erect it again, which is a very expensive process, and entails increased risk for the workers.

By using unmanned (flying or ground) robots, errors can be detected early (outside work hours), while current solutions take about a week for error detection, BIMprove does this within approx. 24 hours.

In addition, fires, lack of protection and falls are direct causes of damage on the construction site, but attempts at efficiency and cost savings, as well as inadequate planning and coordination, can also lead to unwanted incidents on construction sites.

BIMprove components presented in this deliverable shows the possibility to reach these goals and ambitions. It is also worth mentioning that the components in themselves are not enough to make an impact in the construction industry. New workflows, roles and trainings to use the components are needed as well.