COGITO

CONSTRUCTION PHASE
DIGITAL TWIN MODEL

cogito-project.eu

D4.5 – Personalized Alerts, Prediction and Feedback Tools v1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958310

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Dissemination Level:	Public
Deliverable Type:	Demonstrator
Lead Partner:	AU
Contributing Partners:	Hypertech, RSRG
Due date:	31-05-2022
Actual submission date:	11-07-2022

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Version History

Version	Editors	Date	Comment
0.1	AU	01.06.2022	Table of Contents
0.5	AU, RSRG	14.06.2022	Draft Version Ready for Review
0.6	OLOD, ASM	17.06.2022	OLOD, ASM's Comments in v0.5
0.7	Hypertech	22.06.2022	Hypertech's Comments in v0.5
0.8	AU, RSRG	30.06.2022	Comments Addressed
0.9	Hypertech	08.07.2022	Final Quality Checks
1.0	Hypertech, AU	11.07.2022	Deliverable Submission to the EU portal

Disclaimer

Executive Summary

Construction accounts for up to 25% of all occupational fatalities in many countries. Many of the accidents in construction are struck by and caught-in/between objects or vehicles resulting from insufficient or delayed detection of pedestrian workers. Research has proposed detecting visibility-related close calls to alarm the involved personnel and prevent negative consequences at the earliest possible time. This deliverable focuses on an intermediate version of the personalized alerts, prediction, and feedback tool of COGITO's WP4 and its T4.3. It has three objectives: First, a comprehensive synthesis on close call reporting processes and individual warning/alerting, data gathering, reporting, and analysis technologies. Second, a sensor system focussing on (a) autonomous close call data generation from run-time proactive proximity detection and alerting technology and (b) Digital Twin-based data processing and visualization in building information models at run time. Lastly, field testing and demonstrations that the developed system reaches purposes for proactive decision making in safety management beyond the scope of existing safety decision making processes.

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List of Acronyms

Term	Description
2D	Two-dimensional
3D	Three-dimensional
BIM	Building Information Model
COGITO	Construction Phase diGItal Twin mOdel
DT	Digital Twin
DTCS	Digital Twin for Construction Safety
DTP	Digital Twin Platform
GNSS	Global Navigation Satellite System
KLM	Keyhole Markup Language
OWL	RSRG smart sensor system for safety coordination
PPE	Personal Protective Equipment
ProactiveSafety	Proactive Safety Application
RTK	Real-time kinematic
SafeConAI	Preventive Health and Safety Application
UAV	Unmanned Aerial Vehicle (aka. drone)
VR	Virtual Reality

1 Introduction

Most occupational safety and health administrations worldwide pursue “zero accidents” visions to protect workers' life, health, and well-being [1-3]. According to laws in most industrialized countries, a safe workplace must be provided before any employee can start working [4]. As injury and fatality rates rise or decline by economic activity, however, well-articulated standards and processes related to construction safety, health, and well-being safety standards [5] alone may not adequately prevent dangerous working conditions. Many of these have proven inadequate upon execution in the field [6-8] or are challenging to change concerning the ongoing digitalization efforts in all industries. For example, contact collisions between pedestrian workers and heavy construction equipment still occur in large numbers [9]. Therefore, even industry leaders observe that further reductions of accident numbers are very hard to achieve [10]. In their case, numbers of reported human-machine interactions, unfortunately, stay flat [10].

A problem leading to this situation is that risk, so far, has been categorized by severity. During construction equipment operations, multiple levels of consequences can result from incidents: low, medium, or high [11]. Respective examples are minor collateral property damage, a bodily injury, or a fatality. While any of these highly depend on a human assessment, one of the contributing and repeating factors is pedestrian workers being too close to the heavy machinery and not being detected in time. Therefore, from the equipment operator’s point of view, limited or no visibility causes disturbance of workflow, increases the risk of accidents, and stresses the affected persons negatively.

Current best-practice techniques rely always-on passive measures such as back-up beepers on machines and personal protective equipment (PPE) on construction personnel. Wearing a hard hat and reflective safety vest [12], for example, is required by law to improve visibility in hazardous proximity incidents. They exist every day on construction sites between workers and heavy construction equipment. These passive measures by themselves, unfortunately, are incapable of recognizing a danger (aka. hazard), do not predict future accidents, and do not warn personnel proactively.

The Digital Twin (DT) is an up-to-date digital counterpart of the physical entities in a system [13]. The physical entities in construction include objects and processes in a construction project. The vast potential of digital twins for various applications such as construction safety, progress monitoring, resource allocation and decision making is yet to be explored. Seamless data collection and transfer through DT is possible with state-of-the-art sensing technologies. The information from digital twins can significantly improve proactive safety in many aspects. Compared to the conventional warning or alerting techniques that often fail and lead to fatalities in construction, run-time sensors and data received, offer much more insight into root causes and contributors of risky actions. However, sensing technology is hardly ever applied and if so only in the most basic functionality (e.g., rear-view cameras installed on heavy equipment) provide a visual extension and combined with sonar sensors issue beeping-alerts upon proximity to objects).

An alternative approach to tackle this problem is to gather data, analyse it, and educate accordingly the workforce that reduces the chances for accidents. Technology that aids in these tasks requires identifying, registering, and reviewing hazardous conditions that might lead to an incident, for example, an accident or so-called close calls. Therefore, a close call (aka. near miss) is a subtle event in the chain leading to a potential accident that remains unrecognized but should be treated like an accident [14]. The required investigation and feedback to such incidents have so far been always a reactive measure. Although one may find the root cause that led to the event and prevent it from happening again instead, preventive or (better) predictive measures should be used to plan for and maintain a safe working environment in the first place [15]. In short, to further improve construction safety performance, it is necessary to understand the underlying causes of its accidents in much greater detail [16,17]. Here, again, technology can assist.

1.1 Scope and Objectives of the Deliverable

The overall objective of T4.3 is the prototype implementation of personalized alerts, prediction and feedback using technology that aids but not replaces human skills. The corresponding deliverables D4.5 and 4.6 aim to develop the tool called ProactiveSafety. This tool, based on data it receives from the IoT Pre-processing Module through the COGITO Digital Twin Platform, generates proactive alerts, logs relevant data, and further processes it to information so personalized learning becomes available., for example, of personnel directly involved (personalized learning) but as well outside of the incident (corporate level learning). Therefore, personnel at multiple organization levels can directly avoid accidents and enhance their understanding of risks contributing to accidents. Proactive safety is expected to be mutually beneficial for the Digital Twin Platform (DTP) and support periodic reviews and adjustments of construction safety planning and management. This deliverable describes work conducted between M10 to M19 for developing ProactiveSafety application and the conceptual components behind the development.

1.2 Relation to other Tasks and Deliverables

This deliverable builds upon D2.4 COGITO System Architecture v1 and mainly draws as-built 3D BIM from the Digital Twin Platform (DTP) (D7.9 and D7.10). The 3D BIM enhanced with safety information (safe BIM) is used to overlay the model with the experienced safety performance data. Therefore, this deliverable is also dependent on the Preventive Health and Safety Application, called in earlier reports SafeConAI (D4.1 and D4.2).

1.3 Structure of the Deliverable

The rest of the document is organized as follows:

- Section 2: Overview of the Digital Twin for Construction Safety (DTCS) and integration of ProactiveSafety;
- Section 3: Detailed description of ProactiveSafety and its components;
- Section 4: Conclusion of the work done for this deliverable.

2 Overview of Digital Twin for Construction Safety

The overall architecture of the Digital Twin for Construction Safety (DTCS) developed for the COGITO ecosystem is illustrated in Figure 1 [18,19]. The DTCS has four principal components: prevention through design and planning, conformance checking, right-time analysis and mitigation, and dynamic virtual reality (VR) training. Figure 1 illustrates the information flow between various components and how (a) run-time alerts are created, (b) appropriate measures are applied, and (c) generated information is shared, as needed, with project participants and with the DT (and its relevant components). By basing actual site safety data on project status knowledge (as-built and/or as-performed), it is possible to generate/simulate alternative safe(r) plans for planning more safely on the current and similar future projects. Each component of the DTCS is briefly described in the following subsections.

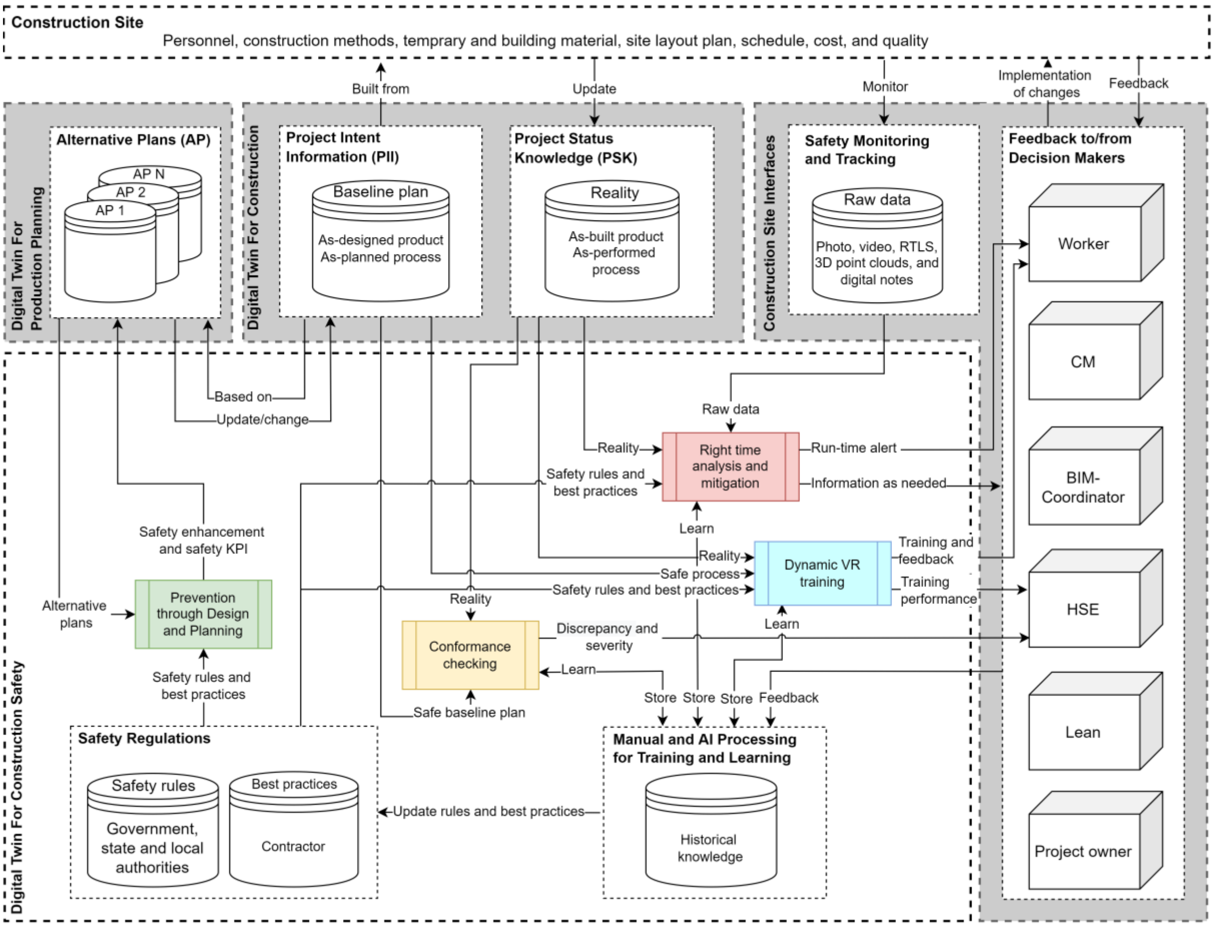

Figure 1. The architecture of the Digital Twin for Construction Safety (DTCS) and interaction between various components; the dynamically updated VR training module is presented in blue

2.1 Prevention through design and planning

This component is termed SafeConAI (D4.1 and D4.2) in COGITO System Architecture v1. Alternative construction plans are handed to the prevention through the design and planning module (shown in green) of the DTCS and enhanced with safety, based on the safety regulation of the construction site. The system analyses the hazard spaces identified in the design and hazard spaces identified in the process (e.g., pedestrian crews working simultaneously in overlapping or directly adjacent workspaces (near equipment or underneath loads attached to it), creating hazard zones in terms of being struck by a vehicle or an object from it. The safe alternative plans are returned to the Digital Twin for Production Planning (DTPP) for decision-makers' (stakeholders of the project) selection, consequently updating the baseline plan from which the construction site is built. As such, COGITO focuses on application in infrastructure projects which often deploy heavy construction equipment throughout the project lifecycle phase. Such (and already identified) use cases deserve special attention.

2.2 Conformance checking

The conformance checking module (shown in yellow) should find and classify discrepancies, including severity level, between the plan and reality. This information should be stored on the construction site, and when the HSE expert has visited the problem, s/he can update the PSK and provide new information on the correctness of the output (in terms of both incident classification and its severity). This information the HSE provides eventually is used to update the historical knowledge and turns into one of the best safety practices that an organization may apply in addition to following governmental/local safety rules and regulations. An example of an updated best safety practice is to separate the walking pathway of pedestrian personnel from vehicles lanes of heavy construction equipment. Another example in railway construction is to avoid pedestrian workforce to enter neighbouring (live) rail tracks where workers might get hit from running trains.

2.3 Right-time analysis and mitigation

The right-time analysis and mitigation module (shown in red) perform complex event processing and classification based on the reality of the construction site, the raw safety monitoring data, historical knowledge, and safety regulation. This module is termed as ProactiveSafety (see D4.5 and D4.6) in the COGITO System Architecture v1. There, the workers and equipment operators are alerted to prevent both accidents (i.e., fatalities, serious injury, and minor injury) and incidents (i.e., close calls) before they occur. The module subsequently performs data logging, reporting, and analysis. The investigation into the root cause/s that lead to the incident or accident can be further examined (e.g., utilizing the HSE's expertise) to prevent similar events from happening in the future.

2.4 Dynamic Virtual Reality training

The dynamic VR training module (represented in blue) includes updating serious games and periodic education and training of construction project personnel (i.e., including also apprentices and management staff) using the latest information from the DTCS. By feeding the model from SafeConAI enriched with the accident type and the area, the smart VR environment can produce relevant scenarios for each incident fed into the system. This will be done based on the location and type of hazard. Both colliders and data collection capabilities will be automatically created from this scenario before a training session is conducted. The workforce and the digital twin mutually benefit from this. The worker receives training, and the digital twin receives knowledge such as the safety performance of an individual and a group of workers that can be utilised when other prevention approaches are used.

3 Right-time analysis and mitigation

3.1 Factors affecting safe equipment operation and accident reporting

Construction sites are different from work environments in the maritime [20-24], airline [25,26], agricultural or manufacturing [15,27] sectors, perform activities in a defined but continuously evolving workspace. This means safety issues can emerge dynamically and require attention at the right-time [12].

While several conditions are adversarial to a safe working environment (Figure 2) [30], equipment operator blind zones and reach into unsafe work zones are among the most adverse aspects. These zones are a frequent cause of visibility- and contact-related fatalities. Although software based on machine data (i.e., from 3D design), enhanced field-of-view through use of mirrors, camera-monitor-system and/or work lights are used to design out blind zones [28], more than plenty of these remain [29].

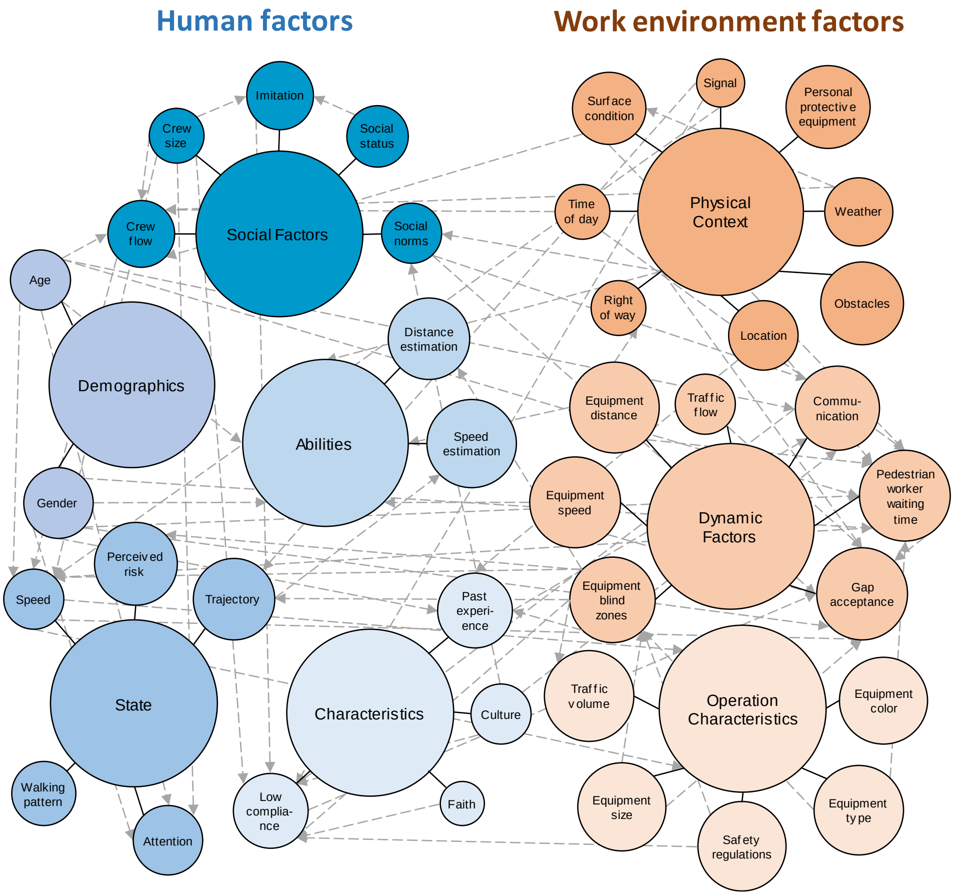

Figure 2. Factors involved in pedestrian worker decision

Workers being in a blind space of heavy construction equipment or "not seen because of obstructions" were mentioned in 56% of all visibility-related fatalities in construction [31]. Researchers also concluded that equipment that deviates from their usual paths of operation increases the likelihood of accidents [32]. Other research found that decreasing vigilance results from workers engaged in specific tasks while ignoring distracting noises [31]. When a truck or piece of machinery is reversing (in about 75% of all equipment-related accidents), a worker can be easily distracted by focusing on the assigned work task alone. Workers are probably also more vigilant at the beginning of a project. Then, they may pay more attention to alarm signals. Alarms can quickly become routine to the workers, and over time, the noise is processed more as an annoyance that tends to be ignored.

Illumination factors are another vital aspect of visibility; however, they are frequently not recognized in accident descriptions [17]. Therefore, they also play a minor role in research. When an accident occurs, the typical response is to attribute the cause to the most apparent agent. For example, a worker is in a blind zone may be struck by and killed by a vehicle. Conventional industry procedure is to classify this incident as a "struck-by" fatality, and the assumption from this occurrence is that equipment is dangerous. While this may be a "struck-by" accident, but closer examination of the root cause may reveal that vision impairment was the primary factor, and the equipment, because of its proximity, size, and weight, was a secondary factor. Research showed that lighting was the primary contributing factor in about 7% of all visibility-related cases [31]. Overall, standards and guidelines in reporting accident and fatality events can be improved to conduct more thorough root cause analyses.

In consequence, additional tools are needed to issue preventive warnings or alerts to pedestrian workers and equipment operators to mitigate dangerous situations.

Sticking to the use case that is pursued in COGITO WP4, the existing close call reporting and feedback practice that is common in the construction industry requires an extension. The framework for the development and implementation of right-time analysis and mitigation in the ProactiveSafety application is explained next and illustrated in a conceptual way in Figure 3. The figure includes: (a) the legacy process, as illustrated using solid arrows and boxes; and (b) the proposed process, as represented using dashed arrows and boxes (NB: the proposed process augments but does not replace the existing manual close call reporting and follow-up process).

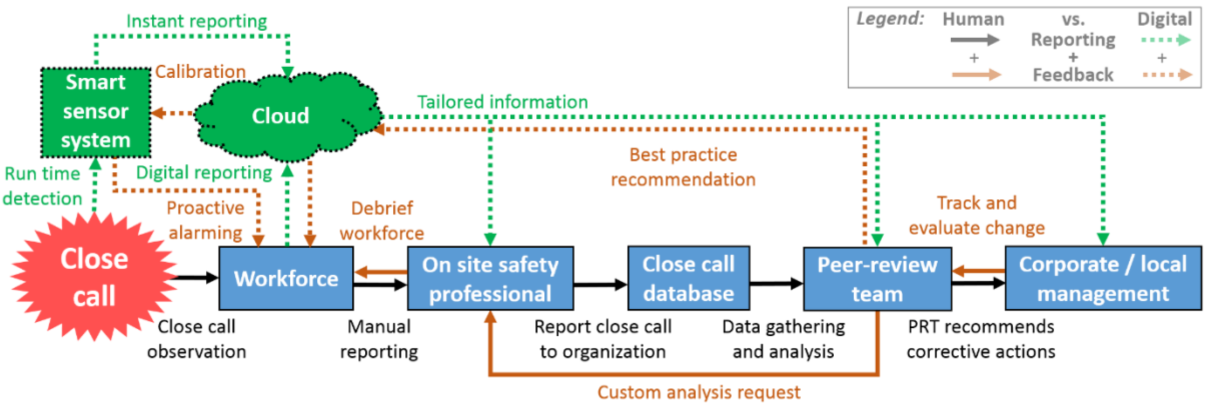

Figure 3. Close call reporting and feedback processes Towards a digital close call detection, reporting, analysis, and personalized feedback process

To underpin our previously articulated WP4 objectives (T.4.3), we provide a brief discussion on the state-of-the-art process of close call reporting and feedback that will aid us in developing the needed tool ProactiveSafety. In addition to the existing process, we present our proposed approach that takes advantage of the previously reviewed sensor-based systems (D4.3) in conjunction with a cloud-based close call data management system (aka. the DTP). The following paragraphs accompanying Figure 3 explain the existing practice and proposed approach in-depth.

Any workforce member (i.e., a pedestrian worker or persons operating equipment) can have a close call incident. This happens, for example, when both worker and machine interact in too close range to each other.

In today's existing construction site practice, close call reporting and following up (shown with solid lines and shapes in blue colour in Figure 3) is done manually by participants observing the incident. They are registered by on-site safety professionals within a close call database. A peer-review team would then analyse the close call database periodically and inform the corporate or local management about potential practices changes. It would prevent a similar close call from happening again. The local management would finally initiate the feedback via the peer-review team and the on-site safety professional to the workforce.

The process so far involves several stakeholders. Many are likely operating at different locations and not available any time soon. Feedback to or debriefing the workforce is relatively slow or non-existent. Unfortunately, new close calls or even accidents can occur in the meantime.

3.1.1 Advocating for digital data from sensors

In addition to the human efforts of reporting close calls and following up, we take advantage of digital means (shown with dashed lines and shapes in green colour in Figure 3). The proposed approach incorporates the DT (a cloud-based system) utilizing digital reporting and sensor information to register and manage close calls either by, respectively: (a) a personal observation that is digitally reported (e.g., only if the work environment permits using an application of a smartphone or tablet), or (b) a specialized Smart Sensor System (SSS), in COGITO (similar to the prototype Owl as supplied by COGITO partner RSRG).

ASSS is a decentralized (edge computing) unit based on sensor inputs (*run-time* detection) analyses hazardous incidents and instantaneously notifies the workforce. The term *run time*, as compared to *real-time*, in this context refers to data of an event occurring at some point in time and being gathered, communicated, processed in the execution of the application or program (e.g., as fast as possible the involved technology permits or as user demand it; often, but not always in real-time, e.g., high-frequency rates such as 30 frames per second).While the individual signals from the sensors are fused, reported, and reacted upon later, most importantly, the SSS provides an assistive warning signal (pro-active alarming feedback) to the individual workforce that is sent instantly (not requiring any cloud processing). This helps to prevent potential accidents from happening. Based on such run-time analysis performed in the SSS, the workforce is proactively alarmed about appearing close call incidents before they turn into an accident.

The information to the automatically recorded close call is sent to the cloud where on-site safety professionals, the peer-review team, and the corporate/local management have access and can review the information concurrently and at any given time. The cloud connects all the stakeholders to the, in their view, important information. It also connects the system components, e.g., computation units, to the data. It is, therefore, an entity that ties together the system. The information in the cloud should be tailored towards the individual stakeholder's interest to make sure that this is significantly informative and does not drown in the insignificant. This information improves the best practice in place.

Based on the relevant information that becomes available in the cloud, debriefing of the workforce happens as soon as possible. Additionally, future machine learning techniques will assist in identifying recurring or new patterns in close call reports. Then close call reports can include – aside from the general observations that include the location, observer, participants involved in the close call, its timestamp, severity, cause, and measure – newly available details such as equipment trajectory and velocity.

Based on the latest available information, there should happen a two-way calibration. The SSS data, along with labelled close call incident, should be uploaded for further computation of:

- Long term prediction, analysis, and information gathering,
- Parameter optimization, and
- Data access from stakeholders.

The updated parameters should assist the SSS to improve the analysis capabilities. Over time and with large amounts of data in the future, a system like the proposed can make more accurate predictions than humans might be able to perform by themselves.

3.1.2 Applying proactive and passive measures

Unfortunately, as explained in COGITO D4.3 no single sensor system for use in current proximity sensing is suggested for implementation because each one comes with benefits (e.g., identification, a visual extension of danger zones) and limitations (e.g., range, functional security measures). Our focus is on the entire time sequence: from early hazard detection, rapid application of a proactive measure, and finally analysis of data gathered along this chain with appropriate (if possible: personalized) feedback.

Then, warnings/alerts by sensors can be experienced in passive and active modes. Passive because a sensor may provide no additional information than the raw data. A bird's view camera-mounted system, for example, provides a video stream on a small screen inside the equipment cabin. This would still require the operator's attention to recognize and react to hazards that eventually become visible on the screen. It could rather distract the intent of manoeuvring the heavy construction equipment. Therefore, active alerting (e.g., a voice, a blinking light in the view of the operator) that responds automatically could offer alternative, probably a better assistance when alerting. A radio system can do this in run-time, instantly and without sending/receiving data to/from the DTP. This is a key advantage, as it operates in this project locally (on the construction site where pedestrian workers and heavy construction equipment interact dynamically). The system further records and reports safety data and reports it to the IoT pre-processing module and DTP where the data is further processed (right-time, not necessarily in real-time) and feedback to the relevant project stakeholders is shared afterwards (as needed). In brief, the prompt reaction upon the closeness of an encountered danger would still be required instantly. In such situations, sounding a horn, applying the equipment brake, or starting an obstacle avoidance manoeuvre are common ways of reacting because a pedestrian worker with low awareness might not have a 'second chance'.

3.1.3 Demanding data reasoning and feedback

While active sensors detect, react, and warn from hazards, they yet lack, as discussed in the literature [33, 34], "realistic modelling and visualization of risk in safety management". Golovina et al. [14] have shown from a practical perspective why knowledgeable personnel in charge of construction safety rarely can measure or evaluate site-specific safety data. Some obvious reasons are lack of available time because they often manage multiple projects at the same time. Other more technical reasons are that sensors create large data sets, and software for meaningful data reasoning and feedback hardly exists.

3.1.4 Cloud-based close call reporting and analysis

The sensor and data communication network in development and furthermore to be defined for the close call reporting and analysis process includes generally:

- an operator display,
- a data logger for close call incidents,
- a positioning sensor, and
- software for data recording, communication, and analysis.

The network consists of the individual parts (these will be further explained in the following sections):

- a Digital Twin Platform (DTP) with a safety module that tries to design out hazards embedded in the work environment in the first place (e.g., based on COGITO's SafeConAI and other common project data shared in the DTP),
- a Real-time Location Sensing (RTLS) device (e.g. RTK-GNSS, BLE, and/or camera-vision based monitoring systems and if included, already existing AI-components) that detects and reports positioning data of pedestrian workers and heavy construction equipment continuously to the DTP,
- a run-time proactive proximity detection, warning, and alert system (e.g., the SSS would (a) operate locally to issue instant alerts, but also (b) log close call events and communicate these to the DTP and its IoT pre-processing module),
- a machine control system (optional; and only if available and accessible on the heavy construction equipment; in very rare cases) to avoid an accident if the human equipment operator or pedestrian worker would not react in time,
- a visualization element for later close call data processing, e.g. creation of heat maps, in a BIM-viewer software (example shown in Figure 4) that will be used in personalized feedback to stakeholders (e.g., continuing safety education and training, toolbox meetings), and
- management reports in the form of tables or graphs to share feedback with involved stakeholders at all levels.

Figure 4 displays the concept of a close call heat map visualization in a BIM software viewer interface: (a) left: simplified process to visualize a close call heat map; and (b) right: locations of reported close calls are visualized in the form of colorized boxes in run time on a building information model (BIM), which itself is superimposed on a 3D terrain model that was captured by an unmanned aerial vehicle (UAV).

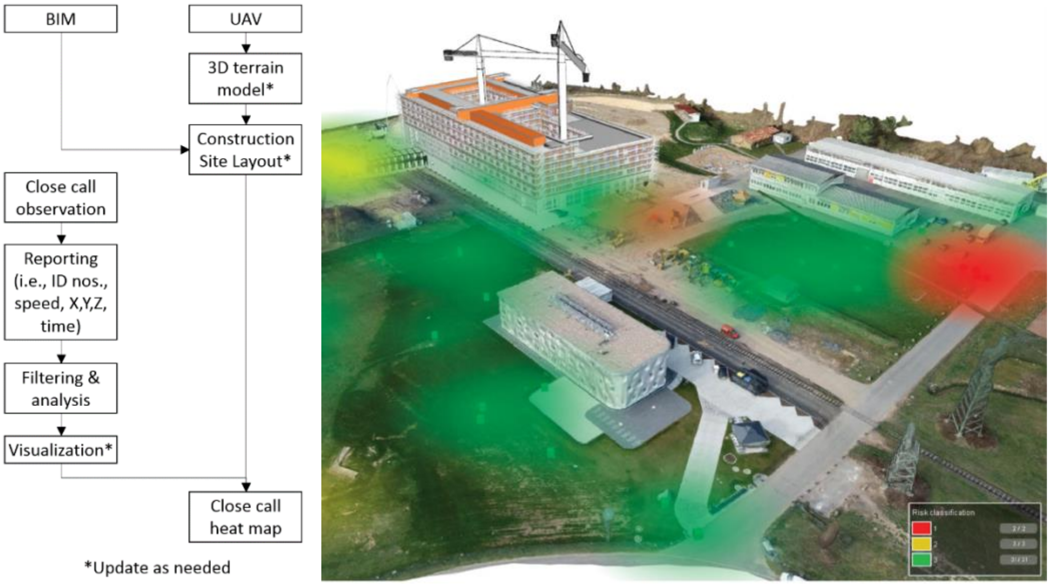

Figure 4. Concept of a close call heat map visualization in a BIM software viewer interface and an example

The network reports all relevant event data (i.e., equipment ID, personal tag ID, timestamp) to an intermediate (local) server. Here, these events give the current position and timestamp in the local coordinate system. The synchronized information is sent in real-time via ProactiveSafety (the construction site safety management system) to the DTP to the IoT Pre-processing Module through the COGITO Digital Twin Platform, a service that operates on COGITO's project data-sharing platform. It collects, pre-processes, and finally, analyse the reported close call events and visualize report in a contractor's BIM software application.

Further (optional) data came from a georeferenced 3D terrain model using an Unmanned Aerial Vehicle, called drone [35]. While the raw point cloud data does not need to be processed to an object-oriented representation, any newly generated information of the as-built status of the construction site and its layout increases the realism of the visualized safety model. A user, for example a knowledgeable person in charge of safety on-site or an off-site peer-review team, now has access to previously unavailable safety information (e.g., timestamped location data and heat map on close calls) from anywhere and anytime.

3.2 Technology Stack and Implementation Tools

The following section describes the concept of the Smart Sensor System (SSS) and how it should look like.

For the Smart Sensor System to provide the location and position data of equipment and staff a similar software system like the prototype Owl of RSRG could be used.

The system uses GNSS tracker (Dual Frequency Smartphones and RTK base station and antennas) for locating the relevant objects on the construction site. Figure 5 shows an example for a construction site with all tracked objects and areas on a two-dimensional (2D, plan view) map.

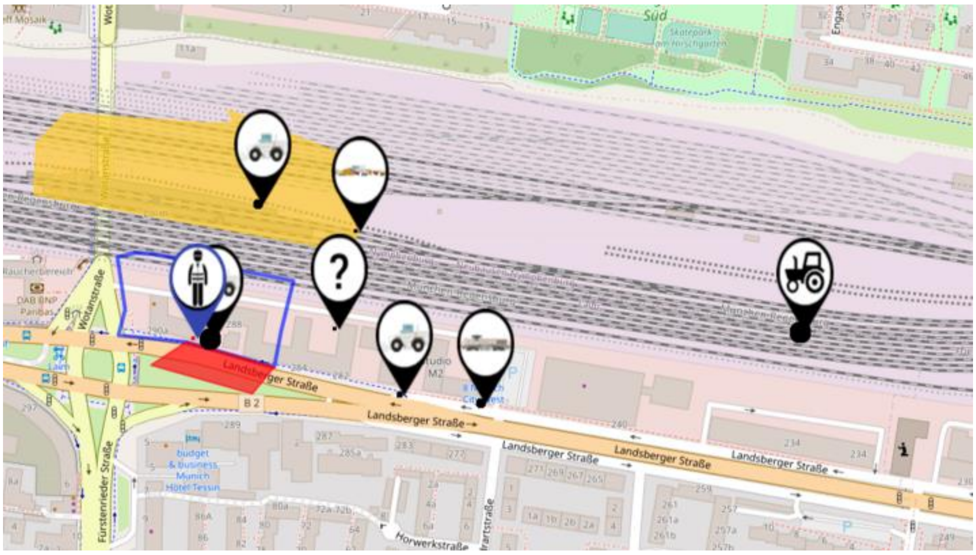

Figure 5. Example of object tracking visualized on actual construction site layout map.

The tracking devices are sending their position (respective location coordinates) within a one-second sequence (timestamp). In the Owl System, user-defined areas created in the COGITO System can be imported as KLM (Keyhole Markup Language, is an XML notation for expressing geographic annotation and visualization within 2D maps and 3D Earth browsers) files or directly be drawn in the dashboard map.

In the concept, three types of Areas are distinguished:

- *Warning/Danger Areas are marked in red on the map.* If a person (or the operator of a piece of equipment) enters a dangerous area, s/he receives a corresponding notification. Objects (e.g., construction machines, rail vehicles) can also represent a warning area by means of a radius.
- *Working Areas are displayed in the map with a blue border and represent the working area.* If a person / device enters or leaves the corresponding area, this data point is logged accordingly.
- *Information Areas are marked yellow on the map.* If a person / device enters the area, a corresponding notification is sent.

Areas can be switched active or inactive. The information such as name, type, roles, and notification per area are entered or adjusted in the dashboard. Visual markers with no active tracking on site can also be included into the visualization (like warning signs or parked machines).

Persons are marked accordingly with an icon in the map. The position of the icon in the visualization represents the georeferenced position received from the location tracker on the construction site. Construction machines or rail vehicles are marked accordingly with an icon in the visualization. Based on the selected role, a safety radius can be set around the vehicle. If another device or person is detected in the safety zone, a corresponding notification is issued.

The smartphone application is used to record the position of markers / persons on the corresponding construction site and to inform, warn or notify the persons in case danger is detected.

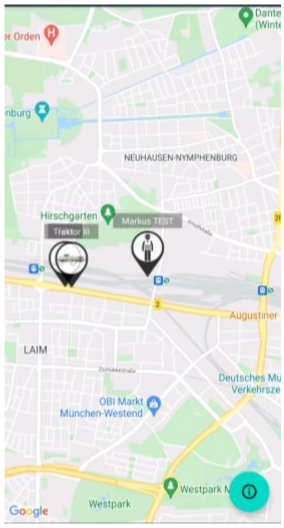

Figure 6. Mobile user application interface (aka. app).

The main screen (Figure 6) a user sees in the app shows the map of the construction site and the tracked objects. Likewise, the markers and zones are visualized that are set by the coordinator in the dashboard. If the tracked coordinates indicate that the device is in a *Warning/Danger Zone*, an alarm is triggered on the device. The user exposed to the danger is informed acoustically (using a warning tone), haptically (vibration), and visually (push notification and pop-up shown in Figure 7, left image). The interface allows the user and/or (more likely) the respective safety-responsible personnel to manually enter/annotate more detailed information to an incident (Figure 7, middle image). Secure access is finally provided in form of a protocol, for example, if the tracked coordinates determine that the device has been in a Warning/Danger, Working, or *Information Area*, the corresponding information is logged and displayed on the device of such a user. This user, which might not be present at the location and at the time of the incident, can be informed acoustically (warning tone), haptically (vibration) as well as visually in form of abbreviated textual information using a push notification and pop-up (Figure 7, right image).

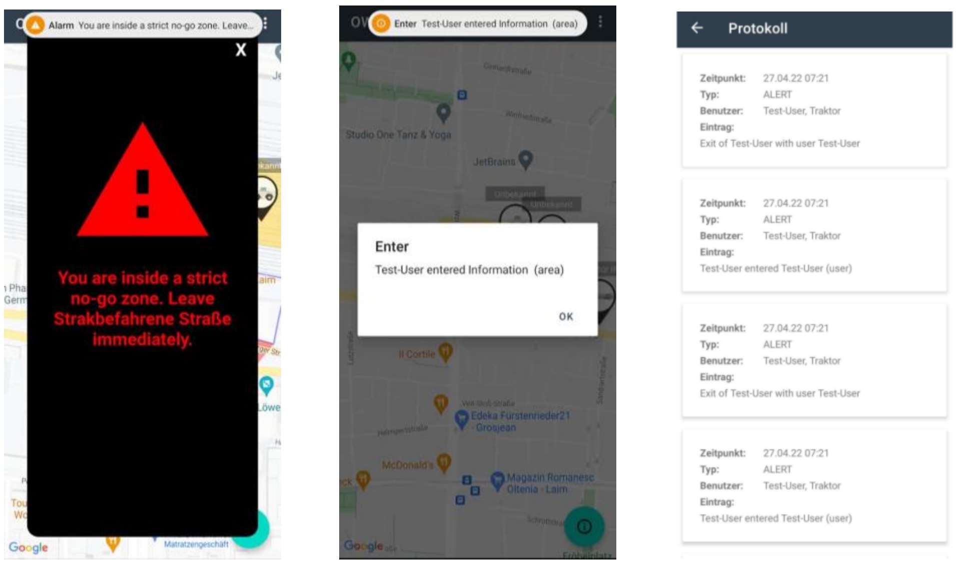

Figure 7. Push notification warning a user, manual data entry, and protocol (left to right images)

The libraries and technologies used in Personalized Alerts, Prediction and Feedback Tools are listed in Table 1. Please note, the current work on Prediction and Feedback tools are currently under development. These have been extensively explained (incl. user interfaces) in D4.3 – Proactive Real-time Risk Monitoring and Detection Methods v1 and are not repeated in this deliverable.

Table 1 – Libraries and Technologies used in Personalized Alerts, Prediction and Feedback Tools v1

Library/Technology Name	Version	License
OWL	0.4	Internal prototype
Dual frequency Global Navigation Satellite (GNSS) smartphone	Xiaomi Mi8	No license
Real-time kinematic (RTK) Global Navigation Satellite (GNSS) hardware	N/A	No license

3.3 Licensing

The ProactiveSafety application is offered in the form of a closed-source software component.

3.4 Installation Instructions

The ProactiveSafety application is available as a web-based application, thus no installation is required.

3.5 Development and integration status

The current technology for the ProactiveSafety application has been developed for a few participants in a controlled test environment. It is still under development and considered a prototype. There are two key elements that require further work. First, initial testing of the prototype leading to further input/output technology and user requirements, and secondly, integration of this module in the overall data architecture, incl. the IoT data Pre-processing Module and the COGITO Digital Twin Platform. These two main tasks will be explained next.

The existing use case must be applied and tested involving multiple pedestrian workers and equipment operators. The application components for runtime alerting, close call data collection and analysis, and personalized feedback need to be independently developed and tested. This includes common usability analysis, incl. system usability and net promoter scoring (SUS and NPS, respectively). These components are being integrated into realistic field trials on simulated (safe) and live construction sites. The immediate next step is expanding the current pool of sensor devices and creating rigid test procedures and test demonstration environment. Furthermore, integration of sensor data and linking the output after the initial data processing with the DTP is required.

While D4.3 and D4.4 present the inner-workings of the tool (from an algorithmic point-of-view), deliverables D4.5 and D4.6 (some are due later) provide an elaborate presentation of the developed tools along with the interaction(s) with other COGITO subcomponents and potentially its end-users (e.g., site managers). More particularly, future work that link with other COGITO WPs will detail the functionality and interactions with the DTP in more detail, including but not limited to, for example, JSON messages exchanged along with their format/structure. This should lead to, eventually, that relevant parts (termed “right-time safety”, meaning construction site safety analysis that is provided not necessarily in real- or run-time) of ProactiveSafety ultimately receive processed information from the IoT Pre-processing Module through the COGITO Digital Twin Platform. Other COGITO WPs will assist and start activities that further detail the exploration of data coming from other IoT devices for safety applications. This ultimately may lead to data fusion that generates the desired safety information. Likewise, a presentation of the ProactiveSafety tool itself will be worked, for example, a component diagram presenting ProactiveSafety subcomponents/submodules. This will further aid in completing the technology stack and implementation tools section (e.g., Tables in D2.4 and 2.5 containing relevant libraries and tools that are about to be used throughout the implementation will be more detailed to greater detail. Details to the application components for runtime alerting, close call data collection and analysis, and personalized feedback will be described in more detail (e.g., user interfaces) once the initial field trials in August 2022 are completed. The expected development progress can then be layed out how ProactiveSafety ties and integrates as a module to the DTP and its components.

3.6 Assumptions and Restrictions

The ProactiveSafety application is being developed for desktop computers and for access of users at various levels within organizations. The communication with the DTP and the rest of the COGITO components needs to be established and tested and the application must be modified based on the requirements.

4 Conclusions

This deliverable presents the functional components of ProactiveSafety application and their use for workforce alerting, close call data collection and analysis and personalized feedback. The information related to tools and technology for development of this application, and the overview of data exchange and integration with the Digital Twin Platform (DTP) are described.

Worker safety continues to grow in importance throughout the construction industry. Close calls are subtle events that put workers at risk and, likewise, should be treated like accidents. As previous work has shown, investigating close calls related to the proximity of pedestrian workers to heavy construction equipment is possible. This requires few known parameters that can be measured. For this purpose, the capabilities of SSS are used to enhance right-time understanding by demanding data gathering for reasoning and if needed, to give proactive feedback before an accident occurs.

Worthwhile suggestions for personalized feedback were made. For example, providing valuable close call information in the form of a heat map to the responsible safety personnel in charge of one of the construction sites proved that effective measures that were implemented reduced the close call rate. Despite the value of providing such information on close calls, WP4 may also need to strive for statistical significance, longer-term performance analysis, or user experience evaluations. Nonetheless, proximity detection and alarming technology combined with cloud-based data processing and visualization offer valuable data envisioned for accident precursor analysis.

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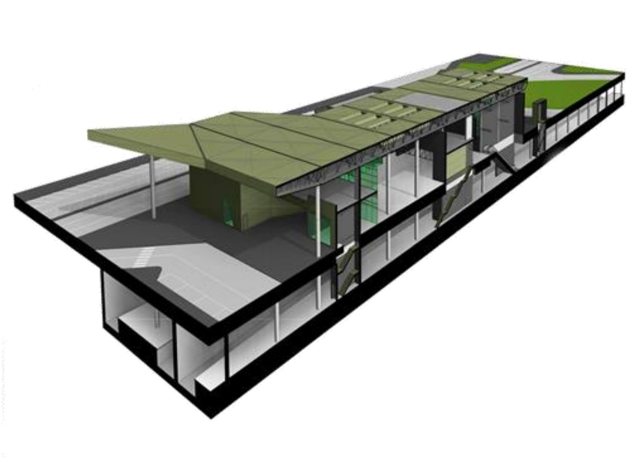

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958310