D1.8 – Risk and safety assessment method

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Abstract

The construction industry shows high workplace accidents than other sectors, in Europe it is at the forefront of fatal and non-fatal accidents ahead of traffic.

One of the main points of action to reduce the accidents is to improve the prevention management by all the involve actors, the analysis tools and training are clue to get this objective.

A common risk detection methodology, related with fall and fire risk, is designed for the three demo sites based on the experience of the industrial partners, and supported by inspections made by robots and humans, that will let BIMprove to notify workers that they are exposed to different situation with different risk impact.

One of the main objectives of BIMprove is to significantly increase the safety of people on the construction site by tracking people and monitoring potentially dangerous conditions and it could be achieved through the identification and definition of risk and safety assessment methods that will be implemented in BIMprove, the methodology presented is based on a study that sum up all the possible situations that could merge into an accident related with fall and fire risk in a construction site.

Keywords
Risk identification, Falls, Fire, Risk assessment, Likelihood, Impact

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Disclaimer

Acronyms and definitions

Acronym	Meaning
BIM	Building Information Modelling
PTZ	Pan-Tilt Zoom
UGV	Unmanned Ground Vehicle
H&S	Health and Safety
H	High
M	Medium
L	Low
LS	Low Severity
MS	Medium Severity
HS	High Severity
T	Trivial
To	Tolerable
M	Moderate
S	Substantial
In	Intolerable
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
VDC	Volts of Direct Current
GPIO	General Purpose Input/Output
RS232	Recommended Standard 232 – *Serial connector*
RJ45	Registered Jack 45 – *Ethernet connector*
SBC	System Basis Chip
IR	Infrared
LIDAR	Light Detection and Ranging

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.

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1. Objective

The main objective of this report is to set a common risk detection methodology for the three demo sites based on their safety assessment, it should be flexible and customizable from certain inputs that the work technicians can configure at the beginning of the work, daily or when the environment conditions change.

In the methodology the following parameters will be defined, per each of the establish risks:

1. Risk identification,
2. Risk situation that can produce an accident,
3. Parameters to be monitored,
4. Technologies used
5. Risk assessment.

Once the risk has been analysed and evaluated, an alert level will be established to be send to the workers and a series of actions depending on their importance.

In BIMprove we are going to focus on two risk:

- Falls
- Fire

2. Risk identification

"Occupational risk" shall be understood as the possibility that a worker suffers a certain damage derived from work. To qualify a risk from the point of view of its severity, the probability of the damage occurring, and its severity will be jointly assessed.

A Hazard Identification is the Process of recognizing that a hazard, understood as a Source, situation, or act with a potential for harm in terms of human injury or ill health, or a combination of them, exists [1].

Figure 1 The risk identification scenario

In the same way, potentially dangerous fire-related scenarios will be those where prior measures and control over time is required in order to avoid hazard situations.

2.1. Falls

Here we will identified the different scenarios inside a worksite where a fall risk can be presented:

- By perimeter floor structure
- From scaffolds, shoring, formworks and step ladder.
- From vertical opening (facade)
- By holes in the floor structure
- From working platforms
- From covers
- From site elevator or forklift
- From precast walls

- From piles, slabs and desk
- In metal structures assembling
- From slopes and trench

2.2. Fire

The most frequent fire-related scenarios are:

- Unclean construction site
- Heat Sources or electrical components not supervised
- Potentially dangerous Tasks
- Managing negligence
- Untrained personnel
- Incorrect material warehouse
- Emergency exits and/or fire Brigade accesses blocked
- Adjoining Buildings or structures

3. Risk situation that can result in an accident

3.1. Falls

Work at height means work in any place where, if precautions were not taken, a person or an item could fall a distance liable to cause personal injury.

To avoid or reduce the consequences of falling people or objects from height, a series of preventive measures must be taken, so that by analysing the kinds of work to be carried out at height, the necessary data can be obtained to adopt most appropriate protection in each case.

The main risk situations that can merge into an accident will be cause by the non-existence or bad assembly of:

- Safety barrier fence.
- Vertical safety nets.
- Horizontal safety nets.
- Fall Protection Equipment, lifeline.
- Bad use of ……hand ladder

3.2. Fire

The majority of potentially destructive fires occur outside of business hours. These are mainly produced by:

- Heat sources or electrical devices unsupervised: Heaters on workers containers (winter season).
- Thermal loads due to improper material storage: Storage of cardboard or other flammable products in uncontrolled areas
- Performing heat-related tasks within the last two working hours: Some high-temperature tasks can store potentially dangerous heat, capable of starting a fire even several minutes after completion.

In addition, other relevant situations derived from the risks mentioned in Section 2.2 are:

- Blocking of emergency exits or fire brigade accesses due to negligent storage of materials, parking of trucks or machinery. This situation also includes the improper covering of relevant Information panels.
- Negligence of workers, including lack of training. For example, smoking, improper use of electrical sources, or performing dangerous tasks without the manager approval.

- Negligence or lack of foresight by Managers. For example:
    - To not control the state and situation of the fire extinguishers.
    - To not control implemented measures during construction works. (Does the scaffolding have an exit at max. 25m from any point? is the covering fire resistant? etc.)
    - To not control and compare the execution of dangerous tasks with position of flammable stored materials

4. Parameters to be monitored

4.1. Falls

These protections are divided into two groups: *collective* and *individual protection*.

The objectives of the collective protection is first to **prevent falls**, eliminating risks through integrated security or, when this is not possible, using collective protections, such as nets, railings ... and second to l**imit the fall**, if it is impossible to prevent the fall, it will be necessary to install collection surfaces that limit the fall, that is, protection nets as a means of collective protection, and finally when it is not possible to use collective protections, or the working conditions require it, it will be necessary to protect each worker by **individual protection**, that is, the use of seat belts and individual devices.

But if this protection is not well assembled or maintained, losing their safety properties, they must be considered as no protection so should be checked/detected:

Safety barrier fence

- Detect by element the presence of all of their parts, handrail, baseboards and intermediate rail
- Detect the continuity of the hold system around the perimeter to be protected.

Vertical safety nets assembly

- Check that the net is in its place covering all the perimeter that should be protected
- Check the continuity in the upper and bottom union around the perimeter to be protected

Horizontal safety nets assembly

- Check that the net is in its place covering all the hole perimeter that should be protected
- Check the continuity around the perimeter to be protected

Fall protection equipment assembly

- Check the continuity of the lifelines at the roof

Others

- Check that while all of these systems are on installing or on maintenance there should be a non-available area limited by a barrier.

4.2. Fire

Heat sources or electrical devices unsupervised

The pre-installation of the construction site is done using modular electricity sources. In this way, at the end of the work day it is possible to cut off the electricity of all those parts that are not essential. Disconnecting all possible connected and unsupervised devices. It is important to carry out prior planning to establish the necessary measures.

Thermal loads due to improper material storage

Periodic reviews and control in cleaning at the end of the tasks.

Performing heat-related tasks within the last two working hours

It is very important to carry out a scheduling of the tasks taking into account this scenario. It is not possible to perform this type of task at the last minute. In the same way, it will be necessary to check that the area is clean and that flammable products have not been stored near the area. It is convenient to analyse if in the area affected by the execution of the task, another task that could be incompatible will be parallelly developed.

Blocking of emergency exits or fire brigade accesses

It requires good planning of entry, unloading and exit of trucks. It affects logistics, but also the organization and execution of tasks. It should be communicated to the subcontractors, as well as the machinery drivers. The informative panels must be always visible and the checks by the manager must be periodic.

Negligence

The training of all workers is an essential point, even so there can always be distractions, accidents or even negligent acts. In order to avoid potentially dangerous situations, regular checks are essential. In this sense, the safety manager must check that dangerous tasks are not carried out without approval, that negligent behaviour such as smoking does not occur, or that electrical sources are used appropriately.

5. Detection technologies

5.1. Ground Robot

The ground robot, SUMMIT XL-HL [2], is a robotic platform for application development with great versatility and resistance. The rim mount wheels allow the platform easy switch between the indoor omnidirectional configuration and the skid-steering configuration, enabling an increased mobility and manoeuvrability and unmatched speed and agility.

The platform can navigate autonomously or teleoperated both indoor and outdoor, by means of a Pan-Tilt Zoom (PTZ) camera that transmits video in real time. The strong mechanical structure allows to carry heavy loads (up to 65 Kg). There are several suspension shocks possibilities. They can also be mounted at several positions to modify the robot clearance. The robot has skid-steering kinematics based on 4 high power motor wheels. Each wheel integrates a hub brushless motor with gearbox.

SUMMIT-XL HL can be configured with a wide range of sensors. It also has internal (USB, RS232, GPIO) and external connectivity (USB, RJ45, power supplies 5,12 VDC and battery) to add custom components easily.

The odometry is computed using the wheel speeds and a high precision angular sensor mounted inside the chassis.

Figure 2 Ground robot

5.2. Thermal camera

Ground robot will be carrying a PTZ camera for the visible spectrum, but not a dedicated thermal camera is expected to be carried by the UGV. On the other hand, due to the poor precision and further integration needs for navigation LIDARs in the digital reconstruction issue, a specific sensor for assisting the work is being studied in this regard, namely the Leica BLK360 [3]. Would such sensor be validated, not only the point cloud, but also visible and IR pictures will be captured during data capture. The inner thermal camera of the BLK360 could be then used for assessing abnormal situations with high temperatures in cables or installations. It is still to be tested if live streams of data can be captured and feed into the systems.

5.3. Drones

We will use a custom made quadrocopter with four 11.3" propellers in an x-configuration. The drone is equipped with an Arm-based flight controller, a Raspberry PI4 SBC for navigation and communication and different sensors for navigation and data acquisition. Navigation and path-planning algorithms are usable for both in-door and out-door navigation. The total weight is 2.2kg and a typical flight time is 20 minutes. The system can be run in a manual and totally autonomous mode.

6. Risk assessment

In the construction sites is very difficult to do the risk evaluation of every workplace, due to the ever-changing environment, the influence of different task in a same place and because of the mobility [4].

BIMprove will help to increase the preventive activity in the worksites.

6.1. Risk evaluation

The **likelihood** is based on the number of worker exposed, to the frequency and the exposure time, the use of the personal protective equipment's, the use of workplace tools, etc.

As the methodology should be flexible and customizable from certain inputs that the work technicians can configure at the beginning of the work, daily or when the environment conditions change, the H&S manager will be able to categorize in a table, see the Table 1, relation between likelihood and workers, for each risk and in a scalable way, both the number of exposed workers, as well as the number of times a risk occurs in order to determine the final classification of a risk.

Table 1 Relation between likelihood / workers

		Nº of workers	Nº time per day and per worker
High	(H)	6?	6?
Medium	(M)	4?	3?
Low	(L)	2?	2?

The **impact** has been determined based on the possible losses if an accident will happen (death, permanent disability, limb loss, injuries, minor cuts, etc ...), categorized into:

Table 2 Impacts definitions

		Description
Low severity	LS	Superficial damage: small cuts and bruises, eye irritation from dust. Discomfort and irritation: ex. headache, discomfort.
Medium severity	MS	Burns, concussions, major sprains, minor fractures. Deafness, dermatitis, asthma, musculoskeletal disorders, illness leading to minor disability.
High severity	HS	Amputations, major fractures, poisonings, multiple injuries, fatal injuries. Cancer and other chronic diseases that severely shorten life

Once we have detected all the hazards in the different tasks, we will analyse their likelihood and impact inserting them in the next double entry matrix that allows us to determine the magnitude of the risk.

Table 3 Risk evaluation

RISK EVALUATION		IMPACT		
		LOW SEVERITY (LS)	MEDIUM SEVERITY (MS)	HIGH SEVERITY (HS)
Likelihood	Low(L)	TRIVIAL (T)	TOLERABLE (To)	MODERATE (M)
	Medium (M)	TOLERABLE (To)	MODERATE (M)	SUBSTANTIAL (S)
	High (H)	MODERATE (M)	SUBSTANTIAL (S)	INTOLERABLE (In)

The risk levels indicated in the previous table are the basis for deciding whether to improve existing controls or implement new ones, as well as the timing of actions. The following table shows a suggested criterion as a starting point for decision making. The table also indicates that the precise efforts to control the risks and the urgency with which the control measures must be taken should be proportional to the risk.

Table 4 Risk definition

Risk	Action
Trivial (T)	No specific action will be required.
Tolerable (To)	The preventive action doesn't need to be improved, **but a communication should appear in the applicative.**
Moderate (M)	Some efforts should be done to reduce the risk, the measures should be implemented in a certain period of time, when the risk will be associated with a high severity impact a forthcoming action to establish with high accuracy the likelihood of the damage will be done to set the criteria to improve the control measures.
Substantial (S)	Work should not begin until the risk has been reduced. Some additional resources could be needed to control the risk, when the risk corresponds to a work that has been doing, the reaction time should be lower than moderate risk.
Intolerable (In)	The task should not begin neither continue until the risk has been reduced, if it´s not possible, the task should be forbidden.

6.1.1. Falls

Regarding falls we have define and resume in 14 scenarios that cover all the possible situation that can merge into a fall risk [5].

Table 5 Extract from fall scenarios evaluation

	Risk activity	Risk Situation						
		No protection	SAFETY BARRIER FENCE	Nets under floor		Nets floor to floor	SAFETY NETS V SYSTEM	
1.1	Falls from different level (floor level)	INTOLERABLE (In)	TOLERABLE (To)	SAFETY BARRIER FENCE	no SAFETY BARRIER FENCE	TOLERABLE (TO)	SAFETY BARRIER FENCE	no SAFETY BARRIER FENCE
				MODERATE (M)	SUBSTANTIAL (S)		MODERATE (M)	SUBSTANTIAL (S)
1.2	Falls from different level (1 m above the floor)	INTOLERABLE (In)	INTOLERABLE (In)	INTOLERABLE (In)	INTOLERABLE (In)	TOLERABLE (TO)	INTOLERABLE (In)	INTOLERABLE (In)

6.1.2. Fire

There are several situations that can cause a fire, here we can find different situation to be evaluated in site in order to avoid whatever situation that could be potentially dangerous related with fire.

Table 6 Fire scenarios evaluation

Fire	Escape routes		Fire prevention systems			Heat sources or electrical elements		Storage	
	1. Signage	2. Clear	1. Signage	2. Not in place	3. In place	1. Not properly sized or modified	2. Electrical appliances turned on without supervision	1. Inflammable materials/ inappropriate	
	Invisible	Material blocking	Invisible		Not ok			Close to a heat source	Close to dangerous task
	MODERATE (M)	MODERATE (M)	MODERATE (M)	INTOLERABLE (In)	INTOLERABLE (In)	INTOLERABLE (In)	SUBSTANTIAL (S)	MODERATE (M)	MODERATE (M)

6.2. Inspections

The risk assessment plan of each pilot case will be the one that will let us build our BIM safety model, which means how the place must be, and this model will be the base used to compare, thanks to the Safety digital twin, how the place really be, if anything related with safety has change in order to apply measures to keep the workplace as a safety place.

The safety elements will be consider as a unique element not as a set of them, that means, for example that a barrier will not be consider as a set of elements conform by a top, mid and toe bar, it is just a barrier that must be set in certain place depending on the stage of the works, in that sense the inspection systems, the UAV´s and the ground robot, will only identify if the safety element is place where it´s supposed to be, not if it is well set.

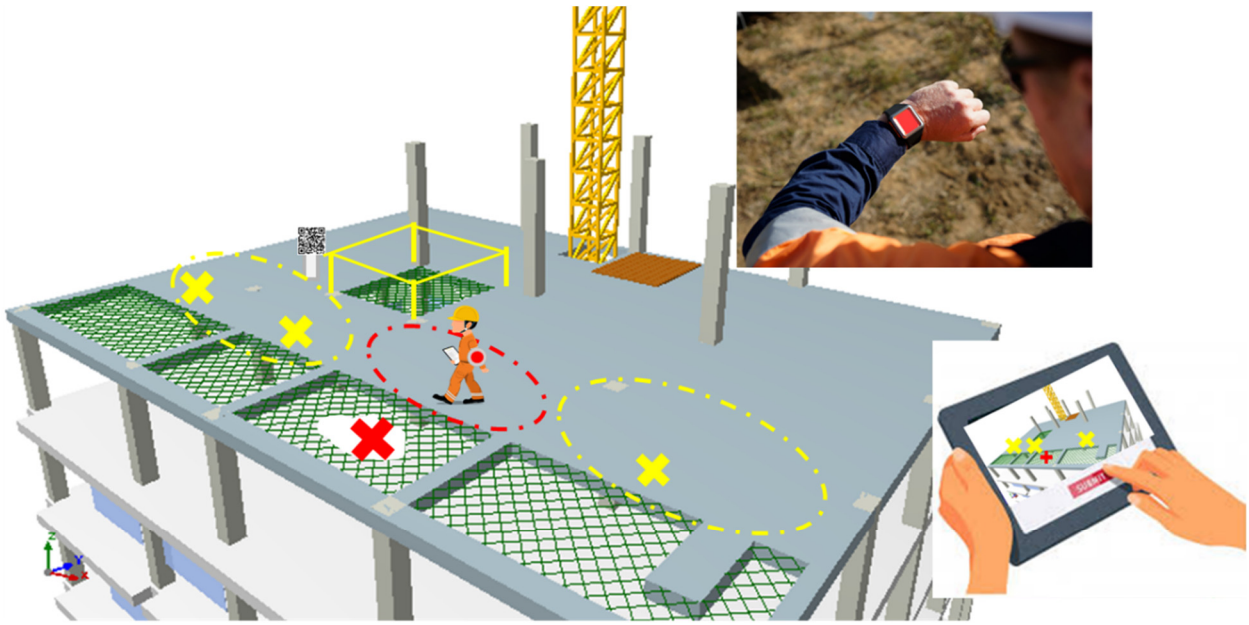
In that sense will be the Preventive Resource or the person in charge of safety the one that should inspect the safety systems in detail according to all the parameters established in Section 4.

Summing up, the Methodology will be based on two kind of inspections, the ones made by the sensors, ground robot and UAV´s, and the inspections made by the persons in charge of the safety.

6.2.1. 1st Inspections made by Preventive Resource

Every day and before the works start, the person in charge of the safety will register in the system that everything is ok or not, BIMprove will send notifications that will help to control or reduce the risk detected.

The risk evaluation will be made based the methodology describe in Section 6.1, where has been detected all the possible situation that can merge into a fall and fire risk.



	Risk activity	Risk Situation						
1.1	Falls from different level (floor level)	No protection	SAFETY BARRIER FENCE	Nets under floor		Nets floor to floor	SAFETY NETS V SYSTEM	
		INTOLERABLE (In)	Tolerable (To)	SAFETY BARRIER FENCE MODERATE (M)	no SAFETY BARRIER FENCE SUBSTANCIAL (S)	Tolerable (To)	SAFETY BARRIER FENCE MODERATE (M)	no SAFETY BARRIER FENCE SUBSTANCIAL (S)
1.2	Falls from different level (1 m above the floor)	INTOLERABLE (In)	INTOLERABLE (In)	INTOLERABLE (In)	INTOLERABLE (In)	Tolerable (To)	INTOLERABLE (In)	INTOLERABLE (In)

Figure 3 Fall scenario

6.2.2. 2nd Inspection made by robots/drones

When in the scheduling is planning to perform certain potentially dangerous tasks that could cause a fire, a continuous monitoring should be done in a static way, in that sense the thermal cameras could detect if certain temperature thresholds are exceeded, the inspection systems will be placed in a place that does not disturb until the task is finished.

Mainly, the inspection system will support the supervision in order to complete the inspection made by the Preventive Resource, in that sense the Health and Safety Manager could check from the office that everything runs ok vs the BIM model, detecting and planning needs that from site perspective would be difficult.

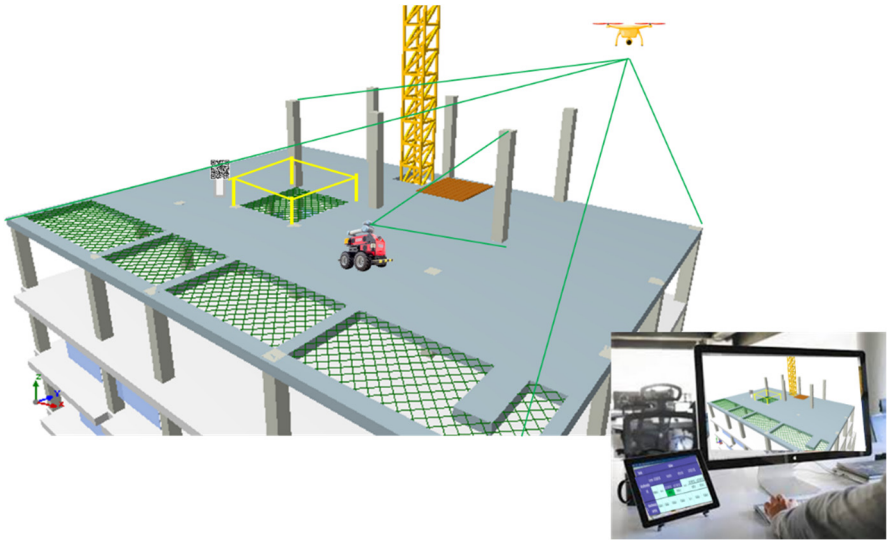


Figure 4 BIM@SiteOffice

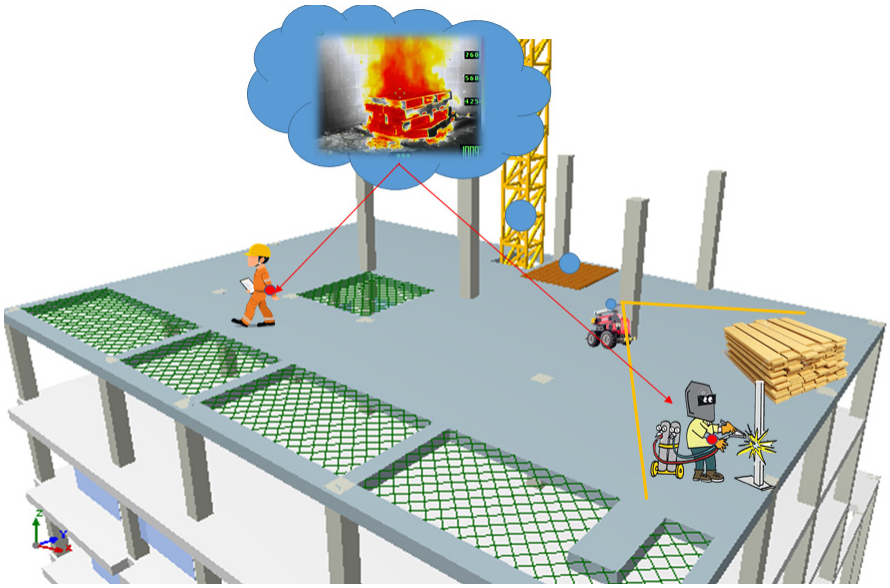


Figure 5 Fire scenario

6.3. Alerts

In order to minimize the risk, it is mandatory to know what risk and how it should be communicated to certain worker depending on their responsibilities.

BIMprove propose to use a combination of colours depending on the different risk impact, where all the actors involved in a task will know what happens and how to act.

First, it is mandatory to define the chain of command, it could be customizable depending on the different national legislation, as a beginning we are going to define three profiles, the Health and safety manager, Preventive resource, Worker.

Health and safety manager

Is the one who do the health and safety assessment, establishing what safety measures and resources will be needed to keep the place free of situation that can merge into an accident, is the highest authority in safety.

Preventive resource

They will have training in risk prevention at least of a basic level, is the one who has to ensure the safety of the workers in certain task.

Foreman

A worker who supervises and directs other workers.

Workers

Is the personal who perform a job within a task.

If the risk is **Trivial** or **Tolerable**, a message will be shown in the device notifying the risk to all personal in site, the background colour will be white.

If the risk is **Moderate**, a message will be shown in the device notifying the risk to all personal in site, an alarm will sound or the device will shake, this persons must confirm that they have received, the background colour will be green.

If the risk is **Substantial** a message will be shown in the device notifying the risk to all the personal in the site and related with safety, and alarm will sound or the device will shake, all the personal should confirm, work should not begin until the risk has been reduced, the alarm will be activated several times until the risk will be controlled, the preventive resource will be the person in charge, the background colour will be yellow.

If the risk is **Intolerable**, a message will be shown in the device notifying the risk to all the personal in the site and related with safety, and alarm will sound or the device will shake, all the personal should confirm, the background colour will be red. the worker must get out of dangerous area, task should not begin neither continue until the risk has been reduced, if it´s not possible, the task should be forbidden.

If the message **Evacuation** appear in the device all the personal in te site must leave whatever they are doing and go to the "meeting point" according with the evacuation plan, the background colour will be black.

Table 7 Alerts

INCIDENCE	Traffic light	ALERT TO			¿?	¿?	BIMprove
		H&S manager	Preventive Resource/Foreman	Workers			
Trivial (T)	.....				¿?	¿?	
Tolerable (To)	.....	X	x	x	¿?	¿?	The risk is shown
Moderate (M)	Green	X	X		¿?	¿?	+ALARM
Substantial (S)	Yellow	X	X	X	¿?	¿?	+ (CONTROL THE RISK)
Intolerable (In)	Red	X	X	X	¿?	¿?	++, PRESENCE IN THE AREA
Evacuation	Black	x	x	x	¿?	¿?	Alarm “go to meeting point”

The system will let to send notifications to the staff related with situations that can´t be evaluated, and although they are forbidden could happened, as for example:

"Smoking is not allowed in this area", "Do not modify a collective protective equipment" or "The use of Protection Personal Equipment is mandatory for workers", as well the system should have an option that let to order the evacuation of the area/building in a dangerous situation as could be a uncontrolled fire.

7. References

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