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A BIM-Based IoT Approach to the Construction Site Management

KEYWORDS: BIM-based technologies, IoT, construction site management, sensorization, actuators

BIM-based technologies can be strongly beneficial for construction sites management through platforms collecting data and providing analytics. These can be used to manage and control the people, materials and vehicles flows which create the complex organization of a medium and big construction site. IoT enables monitoring, controlling and actuating devices that are crucial to manage the site. Different typologies of sensors are available and some experimentations about how to simulate and thus predict critical issues in the construction site have been conducted. The experimentations, that are not presuming to be exhaustive, consider both indoor conditions and external situations verifiable through standard procedures. In the paper, four tests, developed in the virtual environment. The adopted workflow assumes the connection of the BIM (Building Information Modeling) authoring tool through a VPL (Visual Programming Language) to a database where data coming from the sensors are stored. The simulations shows the possible actuation of specific devices to correct possible critical situations that are commonly recurrent in construction sites and in the advanced one are implemented. The virtual experimental setups are show how to accomplish the work steps organization and how to visualize alerts and signals enabling the optimization and control of the construction site in a BIM environment. The advantages of this approach are strongly connected to risk and clash reduction in the construction site, increased safety for the workmen and environmental quality. Moreover, the possibility to control the warehouse conditions is highly beneficial to reduce the number of deteriorated materials with economic gains.

INTRODUCTION

The BIM (Building Information Modeling) methodology is radically and irrevocably changing the Construction sector, since it allows a coherent and holistic vision of the project throughout its supply chain. In this sense, there is an increasing awareness of how the information component is the real red thread that connects the phases of the life cycle of an asset from the starting phase of programmatic definition to the disposal. The emergence of this awareness is the Disruptive Force of Digital Transition for the AEC industry.

At this very important moment in history for IoT (Internet of Things), data is essential to support decision-making. In this sense, the partial automation of processes is a key feature of the concept of Industry 4.0. The use of BIM in construction processes provides stakeholders with the opportunity to understand and support decisions through a computational approach. The most recent legal provisions also impose a new way of operating in the building sector: for example, European Directive 2014/24 suggests an assessment of public works no longer limited to the design and construction phase, but extended to the entire useful life, favouring the adoption of information modelling, since it offers the possibility of controlling the overall progress of the project. After transposing European legislation, the Italian legislator went further with Ministerial Decree 560/2017, which established the transition to a BIM approach in public procurement, through a gradual soft-landing process of transition to digital, starting with the most important and strategic works with the objective, by 2025, to extend it to all the contracts. In order to start with this process, it is necessary to enable the direct contact of the client with the BIM methodology.

This crucial operational change is also impacting the construction companies, called upon to change their structure and produce useful data for the building management. However, in order to achieve a real change of approach, the available data should be used for tangible processes innovation and performance control, which means a not typical method for the AEC sector companies. In fact, they usually carry out only the final assessments. This paper aims at highlighting the benefits that the construction site can gain from the adoption of the BIM methodology and the BIM-based technologies, getting the definition and mainly the management of smart site. In particular, the following sections will emphasize the benefits of integrating detection technologies (i.e. sensors) in order to implement the digitization of the site and related processes. In the following paragraphs some simulation experiences conducted during the educational programme of the course Construction Site Organization at the University of Brescia are described and some critical aspects are also unveiled and suggested.

Digital transition: from projects to increasingly correct construction sites

In recent years, buildings and construction sites in general reveal a common denominator: being more and more complex. It is difficult to have for each of them an overall view of the processes, their relationships and the particular spatial-temporal context in which they take place. This complexity also increases the probability and propagation of errors during the whole process from design to construction phases. Although many studies investigated the causes of errors, less is known about the real costs associated with them, it is difficult to establish how to estimate and measure these costs and their effects over the life cycle of the work. Bijen (2003) states that errors in the construction sector account for up to 10% of the total investment for the construction of a work. Lopez (2012) claims that errors in tender documents alone can affect up to 5% of the contract value. According to the Building Research Establishment, in the United Kingdom, at least 50% of errors in the construction and life of the asset are attributable to design. By using BIM, on the other hand, it is possible to considerably reduce these errors, thanks to the continuous control of interdisciplinary design interferences, ensuring a consistent result. Traditionally, designers often work nearly independently of each other, making decisions without considering their impact on the other disciplines.

Contractors often receive incomplete or incorrect documentation, especially when there are tight deadlines to accomplish. Also the contractual forms and the methods of awarding the works have a significant influence on the level of coordination, communication and flow of information between designers. Love (1998) notes that the separation in use between design and construction has led to an ongoing lack of collaboration between those who deal with the work at different times. In contrast to this trend, BIM supports a full and uninterrupted collaboration between all the involved figures (i.e. clients, designers, and, if desired, contractors and others still called upon to give their contribution). BIM requires a unique strategy (Love et al., 2010), which revolves around shared information content, from the beginning to the end of the collaboration. The digital transition pushed by regulations and organized as described above, leads to a combination of digital project and reality. This merge is constantly increasing, thanks to the development of technologies to support the BIM methodology in this regard. Many researches are in fact evolving applications to convey the project to the several stakeholders. This means as first of all, among the designers, for example in the form of visualizations designed to facilitate the communication between themselves and other actors involved in the work, helping the share of design questions and/or executive details to be discussed and approved.

In any case, even during the execution phase, the project developed by means of information modelling permits, on the one hand, greater control of the works and, on the other hand, it facilitates the supervision of the site by the works management office (WMO), the operational managers, the site inspectors and the works manager. In this way, it is possible to achieve a free of errors construction design, or almost. The validation of these models, however, is very complex, especially if no solid rules of modelling are shared. Otherwise, every design structure, as often happens, produces models that are not able to provide added value for the client, but only two- or three-dimensional representations. Although the methodology favours a greater congruence between the documents, the projects drawn up may contain errors and, therefore, must be subject to three different phases of control: (i) validation of the BIM model, (ii) analysis of interference by clash detection and (iii) control of compliance by code checking. Once the project has been validated through these three phases, it can be placed on a competitive basis. The represented design is used by the selected company to carry out an evaluation of the construction methods that is most suited to the realisation of the work. They are responsible for checking the materials used on-site to ensure that they meet the design requirements and for carrying out the work correctly. The different design verifications are only possible if the use of information modeling is accompanied by a systematization of the data, which is, correlating the parameters of the project with the intended use of the methodology. This means that, as PAS 1192-2:2013 argues, in structuring a process, it is in fact necessary to "start with the end in mind": this statement indicates that, during the first phase of the project, the objectives of the project and, consequently, the contents of the specific information modeling must be defined. In this sense, the use of this methodology on site is only possible if it has been established in the preparation of the process that the information modeling should also be used in the construction phase. Therefore, the evolution of the worksite towards the smart, or beyond, towards the cognitive worksite requires a robust methodological basis, a greater attention to the management and formalisation of information by all the actors involved in the process.

MANAGEMENT OF THE SMART AND COGNITIVE CONSTRUCTION SITE

If the project operators are now aware of the urgency of the digital transition, i.e. of the adoption of the BIM, the construction managers are also experimenting its advantages in various ways. In particular, more and more scientific experiments are dedicated to the management of materials, time, equipment and employees. The adoption of a BIM model shared with all the actors of the work, on the one hand encourages the exchange of information, creating an uninterrupted flow between the world of design and that of companies, construction and / or management, without excluding the customer, on the other hand creates the conditions for obtaining a lean process (Lean) (Womack et al., 2003). In order to transfer this production model from the manufacturing sector to the construction sector, which has remained at a standstill for too many years, it is needed to act on the information side of the BIM methodology, an aspect that is often left in the background compared to the graphic one.

Being able to manage a large amount of data allows us to develop increasingly complex reasoning on the product, which often go beyond the individual disciplines involved and find a synthesis in the best allocation of processing time and overall costs, which means the sum of those necessary for supplies, equipment and employees. Through this approach, (i) an optimal planning of the activities, inside and outside the site, as a result of the analysis of alternative procedures, is now possible mostly as a preventive measure; (ii) a reduction in waste, both in terms of processing time and costs, including those for safety; (iv) a continuous monitoring of the current situation, which, if necessary, can be gradually corrected to respect time and costs. These issues are becoming increasingly complex as the size of the project grows, requiring a systematic approach to information on-site. The smart site is a connected site through devices and actuators that can optimize, speed up and increase the productivity and safety of the procedures. The cognitive site goes beyond and applying machine learning algorithms could learn by the data and predict issues and propose solutions increasing to a higher level the autonomization of the procedures.

Platform and technologies

The management of the cognitive site is a complex operation that must be regulated in order to keep under control all the processes that take place in situ. In order to control the entire process, a platform must be used (Benammar, 2018) that allows different stakeholders to access it with different levels of permits.

The use of a stand-alone management system would involve the implementation of only one aspect of the site, creating redundancy of incompatible and not interconnected systems. For this reason, the use of a single, possibly web-based platform would ensure that the actors in the process use a common basis for data exchange. In this way, the instruments used to manage the various aspects of the site (such as safety, material management, interference, etc.) would be optimized and perform multiple functions. It is in this direction that many companies are moving to set up platforms (such as BIM 360 layout, STR Vision Team Work, Evolvea, Tekla BIM Sight) able to manage and verify the compliance with the requirements on safety and coordination of workmen by monitoring in real time, with wireless sensors, the onset of risk factors and compliance with prescriptions. These multi-level architectures are able to record and analyse data in order to obtain statistics on site behaviour and, finally, provide monitoring and final reports. This structure acquires data from the field infrastructure, which connects and locates sensors, tags and badges, developing data management and storage in the Cloud. In this way, the surveys are analysed in real time, identifying and proactively reporting risk situations (Toole, 2002, Zou, 2009) and non-compliance with prevention and protection procedures.

Users can only access data using credentials connected to a user profile such that certain information is made available depending on the level of the person and the affiliation. The interface allows to manage three-dimensional monitoring with all the information required for the geographical location and progress of the activities. In this way, it is possible to simultaneously control multiple sites located in areas that are also very distant from each other, optimising the use of staffs responsible for managing warnings and anomalies in the construction sites. These structures are able to locate in real time, both indoors and outdoors, people, equipment, means of work, as well as materials with presence control and access authorisations to the various construction site areas. This approach can identify and monitor operational interference that exists between workmen in the same area or by means of vehicles, indicating hazards with respect to moving vehicles. On a cognitive site, the aspects listed above are just some of the possible uses in terms of safety and resource management, which are made possible by the introduction of sensors and actuators. The extensibility and scalability of these systems allow the customization of the system contents according to the needs of the construction site the idea of cognitive includes machine learning algorithms to introduce a responsiveness related to behaviours. In a smart construction site to close the control loop information are delivered back to machines or people in the form of locations of other objects or instructions for movement, in a cognitive concept the machines and materials can implement their intelligence through data analytics and machine learning to introduce predictive logics.

In particular, it’s worthy to underline as that certain controls such as, for example, the humidity level in a work area are not necessary, or superfluous, on a civil construction site, but in the case of a tunnel construction it is a very important factor. The purpose of this document is to explain the possible uses and integrations of this system. In particular, we can identify sensors for (i) tracing people or property, (ii) environmental detection (e.g. air quality, noise levels, etc.), (iii) access to areas and (iv) environmental adaptation. The use of sensors on site is made possible by an interconnection network that can detect the presence of new devices and insert them into the monitoring system. In the same way, the removal and movement of network devices is also extremely easy and therefore suitable for temporary installations. The positioned devices connect autonomously to the others to configure a radio coverage of the chosen zone. All data is conveyed to and from one or more gateways, connecting the network to the Internet and then to the servers and clients of the platform (Valero, 2016). However, it should be pointed out that the use of tools to trace people oversteps the personal privacy of workmen, which is why these tools entrust each workman with a user with certain characteristics that he or she possesses (such as qualifications, IPR, patents, etc.), but does not allow system administrators to view the identity of the person. Only in situations of danger (i.e. in the presence of accidents) is the administrator allowed to link the workman's identification with his/her real identity.

METHODOLOGY

The adopted methodology pursues to connect data coming from IoT devices such as sensors that could be used to locate materials, people and machines. The method adopted uses VPL to realize a workflow of interconnection between data collected and the BIM model which is the virtual environment of control of the construction site (digital twin). Inside the virtual environment controls are structured by colour codes and actuations could be implemented towards the communication architecture pervading the construction site. The main methodological workflow is depicted in Figure 1: sensors data are simulated and written in a database such as an excel file, and then translated to the BIM model by a dynamo script and actuation or a control system about environmental conditions, workmen' safety and machineries location is implemented.

CASE STUDIES

The field of application of IoT to BIM is wide and in this paper a short introduction has been given in the previous sections. The objective of the paper is to describe some case studies about how to use the data gathered in the construction site through a BIM model to control, enable and implement advanced features for the construction site. Four case studies are described in the following sections:

1. Control of environmental conditions in the areas of a construction site;
2. Dust control in the different areas in the construction site;
3. Man down safety control in the areas of a construction site
4. Localization of machines in the areas of a construction site.

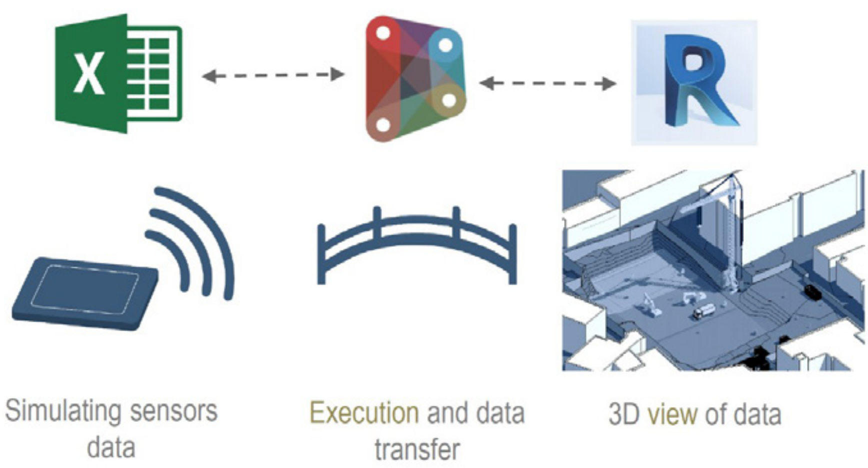


Figure 1: Workflow between the data collected by sensors in the construction site and the BIM model in Autodesk Revit where 3D data are shown to perform controls and actuations.

RESULTS AND DISCUSSION

In the following sections the four case studies about IoT and BIM connection for construction site are described and possible applications highlighted.

Control of environmental conditions in the areas of a construction site

The first case study has been performed to simulate the indoor condition for the construction site considering specific thresholds for the adopted parameters. The possible applications of this approach are wide considering the data that can be gathered by sensors installed and the environmental control parameters such as: temperature; relative humidity; smog/pollution; dust particulate; pressure; smoke; noise; VOC levels. The same concept could be implemented to monitor and decrease fire outbreaks, water leaks and claims. In the present case, the indoor air temperature and relative humidity have been used as main control parameters and values have been identified to simulate the data collection by sensors and the verification of the indoor conditions. The thresholds are defined in compliance with standard safety and comfort values (UNI EN ISO 7730) such as: 18°C < air temperature (T) < 22°C; 65% < relative humidity (H) < 75%. The reported ranges state the correct conditions and thus the colour code "green" is displayed, while the values are lower or higher than the thresholds the values are reported as not compliant and consequently combined with a "red" colour code. The data have been collected and organized in an excel file as repository as shown in Table 1.

In Figure 2 the result of the simulation is presented. It is thus possible to envisage in the BIM model the critical areas and promote a tailored service to relocate resources which could have problems with indoor and storage conditions or increase the comfort for the workmen in the construction site areas.

Sensor code	*Floor*	*Air temperature*	*Relative humidity*
P0.02	*Ground*	*17.73*	*71.17*
P2.05	*Second*	*17.79*	*74.04*
P1.13	*First*	*21.39*	*77.28*
P2.20	*Second*	*21.04*	*69.28*
P0.07	*Ground*	*21.05*	*75.27*
P0.06	*Ground*	*20.61*	*75.23*
P1.14	*First*	*17.75*	*67.24*
P2.18	*Second*	*20.57*	*74.11*
P2.23	*Second*	*20.36*	*68.56*
P2.09	*Second*	*20.87*	*76.03*
P2.11	*Second*	*18.32*	*77.15*
P2.15	*Second*	*22.71*	*73.73*
P-1.03	*Underground*	*20.08*	*89.33*
P0.03	*Ground*	*19.60*	*75.92*
P2.14	*Second*	*20.74*	*75.40*
P-1.04	*Underground*	*32.54*	*74.16*

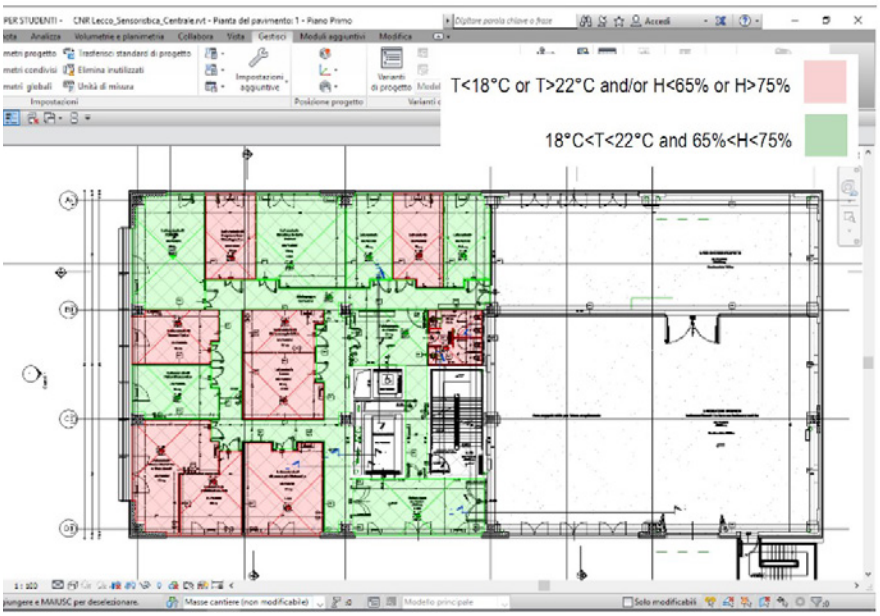


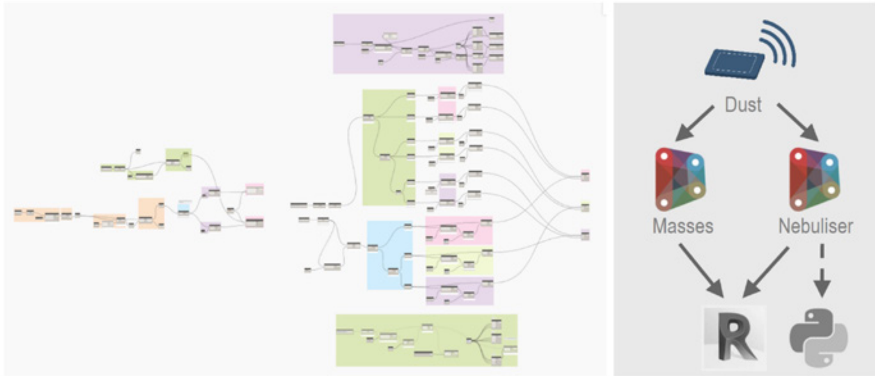
Table 1: Example of data of air temperature and relative humidity collected by field sensors in the construction site.
Figure 2: Colour code to underline the levels of temperature and relative humidity.

Dust control in the different areas of the construction site

The second simulation is about the measurement and control of dust in the construction site related to different areas. In this simulation the BIM model of the construction site has been realized with different section corresponding to masses and the sensors referred to the values of the excel repository. The main task is to monitor the environmental condition but a step forward is to endorse the actuation of a nebulizer to reduce the presence of dust. A dynamo script has been executed to read the excel data virtually coming from the sensors and write the parameters in the BIM model in the Autodesk Revit authoring software (Figure 3). A colour code has been applied to the construction site areas to define thresholds to activate the nebulizer (Figure 4). In Table 2 the organisation of the BIM model in the simulation is shown including the values of dust.

The simulation allows to understand how to define the conditions of different areas in the construction site however it is critical to define the different areas and the relevance of the various processes and location. The masses that define the area in which the dust control is empowered have been defined in correlation to the excavation areas however the areas could change during the progress of the work. It is worthy to note how the information model should be correlated with the organisation of the construction phases of the site to avoid methodological discrepancies or inconsistencies.

Number	*Name*	*Dust level*
1	*Mass 1*	*55*
2	*Mass 2*	*75*
3	*Excavation area*	*5*



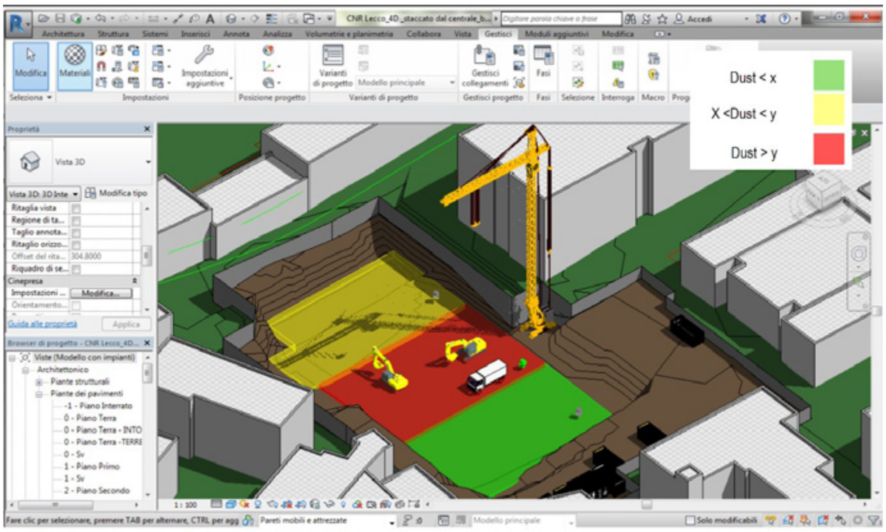


Table 2: Example of data of dust collected by field sensors in the different areas in the construction site.
Figure 3: Dynamo script and workflow from sensor to model to monitor and control the dust.
Figure 4: Simulation of control of dust through BIM model masses and IoT approach.

MAN DOWN SAFETY CONTROL IN THE AREAS OF A CONSTRUCTION SITE

The man down and PPE (Personal Protection Equipment) are crucial for safety procedures in the construction site. The application of the IoT to BIM connection are referred to security and safety applications and access control to restricted access areas. The two sensors related to the worn PPE and man down signal converge to the dynamo script who transfers to the BIM model the information related to the colour code.

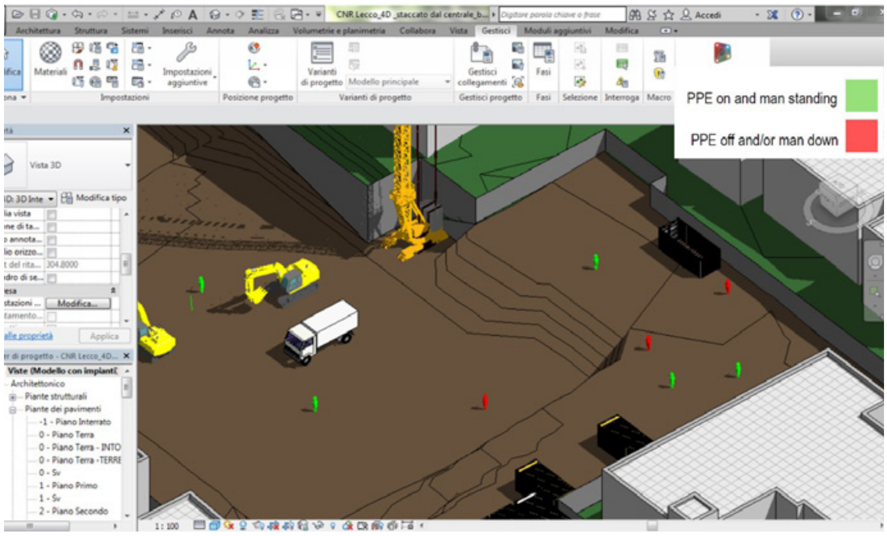
The colour code is assigned for the PPE on (worn) and man standing as "green" light or correct procedure and "red" light and alert signal for the PPE off and/or the man down signal as shown in Figure 5. The association of the two information could bring to a same emergency level however it could be differ for safety procedure.

LOCALIZATION OF MACHINES IN THE AREAS OF A CONSTRUCTION SITE

The localization of the machines in the areas of the construction site is a very important issue and accidents and safety problems could be avoided and controlled by using sensors to delimit the areas (i.e. cones sensors as RFID Radio-Frequency IDentification) that are connected to the sensor in the machine (i.e. GPS Global Positioning System) used to identify its location. The aim of the experimentation is to know the number of machines in a specific area aiming at optimize the flows and the resources. The IoT to BIM workflow could be applicable to define density of machines in a specific area and density of workmen in the areas.

The process could be supported both outdoor and indoor. The actual coordinates of the machines are converted with a dynamo script in the BIM environment and then compared to the masses used to define the areas in the construction site. In this way it is possible to determine if a specific machine is in a defined area and verify

Number	*Name*	*PPE*	*Man down*	*Presence*
1	*Workman 1*	*Yes*	*No*	*No*
2	*Workman 2*	*Yes*	*No*	*Yes*
3	*Workman 3*	*Yes*	*No*	*Yes*
4	*Shipyard*	*Yes*	*No*	*Yes*
5	*Driver*	*Yes*	*No*	*Yes*
6	*Electrician 1*	*No*	*Yes*	*Yes*
7	*Installer 1*	*No*	*No*	*yes*
8	*Crane driver 1*	*Yes*	*No*	*Yes*
9	*Workman 4*	*Yes*	*No*	*Yes*
10	*Workman 5*	*No*	*No*	*Yes*



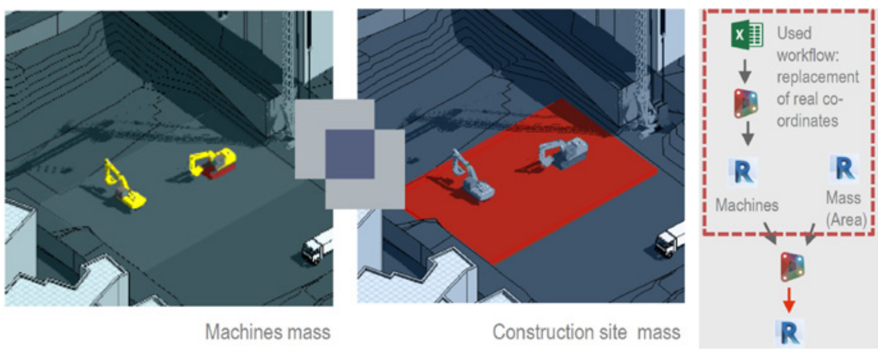


Table 3: Example of data for the man down and presence control of people.
Figure 5: Simulation of man down and PPE control in the construction site.
Figure 6: Masses for machines and mass for the areas in the construction site and workflow.

if there are incompatibilities and issues to solve.
The simulation could be used to enable processes of recognition of position for elements in the construction site such as pillars, beams, etc. adopting a control procedure and a colour code to highlight possible errors in the positioning of such elements. In this case it is also crucial to define the different areas of the construction site in a congruent and relevant manner to unveil issues. The concept of "start with the end in mind" continues to be core point for a BIM-enabled IoT optimization approach.

CONCLUSION

The cognitive construction site, enabled by IoT technologies and BIM methodology, allows to increase productivity and decrease time and costs. A lot of factors can increase of +80% the cost of a construction, for change in work plan, not available working areas, underestimated efforts, weather conditions, previous handoff incomplete, not available materials and labour. Most of these factors can be corrected by an IoT approach by sensing the procedures and materials, tracking machines and workmen to optimize flows and increase safety and compliance of optimized procedures. The paper shows some case studies where a workflow to connect data gathered by sensors that could be installed in the construction site enable to implement the control procedures: improving environment conditions, controlling and actuating actions to correct uncompliant conditions, increase safety and enabling emergency procedures, locate in the correct place of the construction site machines, workmen and elements that could be beneficial to be monitored in the work progress. The proposed workflow supports the project management and the use of data for statistical analysis providing a graphic visualization of the information in the same platform however the interconnection between different software is needed and automatization could be implemented through an interpreted, object-oriented, high-level programming language with dynamic semantics.

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Figure 7: Simulation of machines localization in specific areas in the construction site.

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