INTEROPERABLE APPROACH IN SUPPORT OF SEMI-AUTOMATED CONSTRUCTION MANAGEMENT

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ABSTRACT: Construction progress monitoring has always been a major concern for managers. Several are the advantages provided by a reliable approach in this field, among which we cite efficient project performance control and quality control, timely on-site inspections, better control of health and safety prescriptions against job injuries and fatalities, which are still too high. This paper addresses the development of a semi-automated approach for construction management, based on two main features: on one side a project management oriented re-organization of project's information based on interoperable BIM (Building Information Modeling) and 4D modeling protocols, which aims to facilitate the control at the execution phase; on the other side a monitoring platform for real-time collection of data, relative to work progress and resources usage, by means of low intrusive technologies. Preliminary experiments on the capability by the low intrusive and real-time monitoring system to acquire and filter the data collected on resources usage are carried out. In addition, a general framework implementing several high-level logics is proposed. Its application would lead to seamless production of reports, to a semi-automated control of materials procurement, that is to say with limited or no human intervention. Preliminary application cases are shown, too. Among the expected benefits, not only economic savings for builders, but also better quality of recorded data and real-time availability of information have been pointed out.

Keywords: *Construction management, construction progress, interoperability, real-time monitoring.*

1. INTRODUCTION

Building processes has an information intensive nature that must be properly taken into account in order to avoid information overload: term that has become popular in the last few years for its negative effects. Information overload occurs when the available information exceeds the capabilities of the management system (either human or machine). An efficient management may be hindered by time wasted in information retrieval, by poor structuring and delayed communications [1]. These and other similar evidences led to the birth of a series of research projects on the application of novel IT tools for improved information management and automated control of project performances [2]. The latter being a tough goal, due to the intrinsic difficulties in the wished automated estimation of the various project performance indicators, regarding cost, schedule, labour productivity, materials procurement etc...

The basic idea is that collecting low level field data (e.g. locations of workers, materials and facilities) in real-time and inputting them into interpretation algorithms, progress control and deviation analysis can be inferred with no human involvement. Past experiments demonstrated that workers' tracking and comparison with the project's baseline can be used to assess the activities in progress, and related preliminary prototypes provided an accuracy error lower than 20% [2]. Extending the concept towards automated activity progress monitoring, successful findings have been reported in the field of earthmoving control [3], supply management [4], road construction [5]. Several papers in literature maintain the higher the work standardization the less complex applying automated procedures.

The whole approach requires to develop new technologies and intelligent procedures. Technologies should act as data acquisition systems for tracking and sensing (e.g. movements and vibrations sensors etc..). Algorithms should be able to interpret how the site is evolving and reliably compare it with the project's baseline, in order to progressively update the actual performance indicators.

This paper describes first a possible framework, based on BIM modeling, that may be adopted to organize information at the design phase, such that next progress evaluation is facilitated. Then a first prototype of a platform providing resources tracking and automated production of daily site reports (DSR) is described.

2. THE SUPPORT PROVIDED BY BUILDING INFORMATION MODELLING (BIM) TOOLS

The adoption of a shared IFC (Industry Foundation Classes) building model has been appreciated to support collaborative design, which provides the indisputable benefits of quick decision-making and more effective multi-disciplinary approach [6]. In particular, BIM provides the opportunity to archive both geometric and non geometric data (e.g. typology of structure, construction phase) in the project. Hence it can assist in the tasks of documentation production and data retrieval about the model [7, 8]. In addition, BIM based software tools also provide the capability of 4D visualization, that have been used in some trials even for construction management [9]: it assists in the creation of daily reports, according to the entries provided by site inspectors and foremen, who may either input the actual progress and obtain the scheduled work organization or input the WBS's tasks under execution and receive information about the work progress. Special tools for conflict resolutions and safety assessment may be programmed as well [9]. In addition, once every piece of a precast construction is marked by a tag with a unique ID, 4D visualization of the work progress can – in principle – automatically run [10, 11].

In this paper, we propose to use BIM models to properly organize project's information, in order to make automated updating of the project's construction progress feasible, irrespective of the specific technology. The proposed approach also relies upon a protocol to be followed by foremen or crew leaders and upon a non-invasive monitoring system. This approach may be easily adaptable to several types of construction technology.

3. PROCEDURE FOR SEMI-AUTOMATED CONSTRUCTION MANAGEMENT

Estimation of performance indices needs collecting data regarding activities progress and resources allocation over time, to be used as inputs. The proposed procedure makes such a process semi-automatic in the sense that only a small portion of data collection asks for the involvement of human operators. In particular, it is first suggested the use of BIM protocols at the design stage, to manage project information in a systematic way. At the execution phase a non invasive monitoring system and the application of procedural protocols, in charge of foremen or crews leaders, are used for resource and work progress tracking. Finally, the collected data are filtered to automatically produce daily site reports and other structured information.

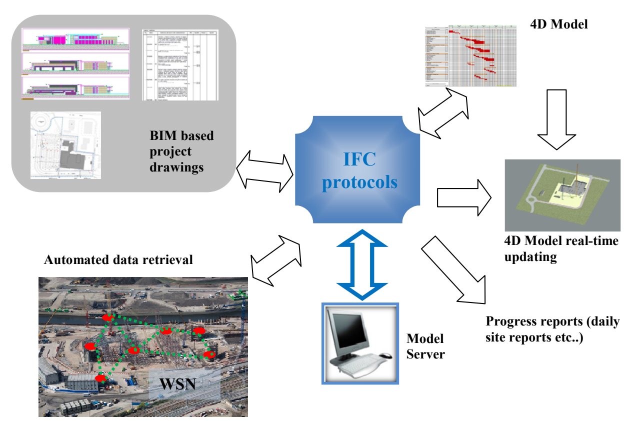


Fig. 1 General framework of the proposed methodology.

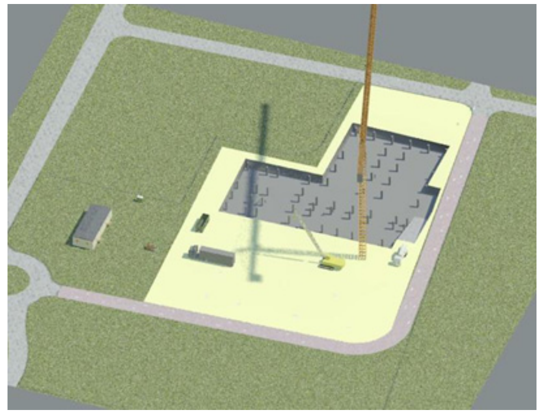
As shown in Fig. 1, the whole approach has the main objective of collecting information from the work progress at the construction site in real-time, to compare such information with the project baseline and to estimate performance indices. In order to accomplish that, project information will be created and organized using the BIM software language, which also includes the baseline. The same codes used to label construction elements in the BIM model, will then be encoded in the corresponding RFId devices, in order to identify the elements put in place. Thanks to BIM adoption, the corresponding actual 4D model could be updated progressively over the work progress, thus reducing the management effort.

3.1 BIM modeling

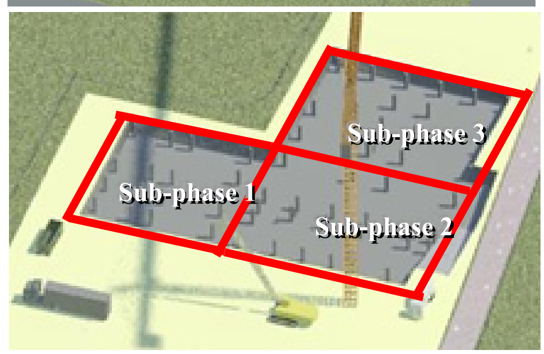
The main role of BIM modeling will be structuring information at an early stage (hopefully during design), in order to facilitate the next execution control phase. For the sake of easier understanding, we will present an example about one activity carried out in the construction of a shopping mall (Fig. 2). The easiest way to control work progress would be to embed sensors with localization capabilities inside each building element, so that once put in place, it will be able to automatically communicate its position. Hence the server would infer work progress according to the elements already assembled. Even if this is correct in principle, it is not completely feasible for two reasons. First, there are no cheap and accurate enough localization technologies to embed so many sensors in every building element, yet. Secondly, only precast elements can be equipped with sensors, instead another, more general approach, is needed for those activities regarding on-site shaped elements.

Fig. 2 3D view model of the shopping mall.

Let's take under consideration the phase of column erection (Fig. 3-a) on the first level of the shopping mall. At the design and planning stage it is required to decide how refined the control progress must be. In the case under consideration it was decided to split the column erection phase into 3 different sub-phases, each of them corresponding to one lot of level 1 (Fig. 3-b). All the columns included in each lot will be labeled with a specific code (e.g. LE1COLO1xxx), where xxx is a progressive id number of the columns on level 1, and LO1 identifies the specific lot. A map of the activity subdivision into lots will be transferred to the site foreman and crew leaders, in order to make them aware of the level of refinement required for work progress control. This information will be used as described in the following sub-paragraph 3.2 .



a)



b)

Fig. 3 Column erection at the 1st level (a) and its subdivision into 3 sub-phases or lots (b).

3.2 Work progress and resource monitoring

Work progress will rely upon the use of wireless sensors to easily generate and retrieve data. Fig. 4 provides a visual representation about how the procedure may be applied to the case of column erection. As soon as the crane puts in place the first precast concrete column, the crew leader or the foreman fixes one of the passive RFId tags labeled with the code relative to "columns" type (e.g. LE1COLO1xxx) and lot no. 1 on the same column (Fig. 4-a). The tags must be always available in the site's office. As this is a passive RFId tag, an RFId reader, equipped with a TX system, will be used by the crew leader to read the tag and transfer such reading together with its time and location to a local workstation (e.g. in the site office). Thus, the workstation will infer that one of the tasks of the "column erection" activity type has started in the position communicated by the RFId reader (e.g. position corresponding to lot no. 1 or sub-phase 1). Hence it will update the actual 4D visualization through the display of few columns in that lot and will store the related data in its database (for next reporting). At the end of the same task relative to the first lot (Fig. 4-b), the same crew leader or foreman will read that tag for the second time, meaning that such a task has been accomplished. Hence the server will integrate the actual 4D visualization by displaying all the columns connected to that lot, which are easily retrieved from the BIM model, through their codes. As a consequence, both the visualization and server's database are updated in real-time, just given the simple actions in charge of the foreman or crew leader, who are not asked to fill in paper documents and can save time in this way. Similarly, when the crew starts to put some columns in place in the second lot, another RFId tag of type 2 (e.g. LE1COLO2xxx) will be fixed and read (Fig. 4-c) and then read again at the end of the same sub-phase (Fig. 4-d).

Updating of the actual 4D visualization and server's database will be performed as in the previous case. Figs. 4-e and 4-f are representative of the same process repeated in phase/lot no. 3 of the activity. To be noticed that the localization capability of the monitoring system is essential to infer where the RFId reading has taken place and which lot is under construction.

While this process is ongoing, the same system used for RFId localization may perform resources monitoring, in terms of number of hours of presence on site and their positions. In a next iteration of this research, an algorithm to associate resource presence with the corresponding activity, given both their positions and work progress, will be studied. The technology used for resources monitoring and communications (which was applied in the experiments described in paragraph 4) is a wireless communication and localization sensor network, which is property of the Italian company Smart Space Solutions srl [12].

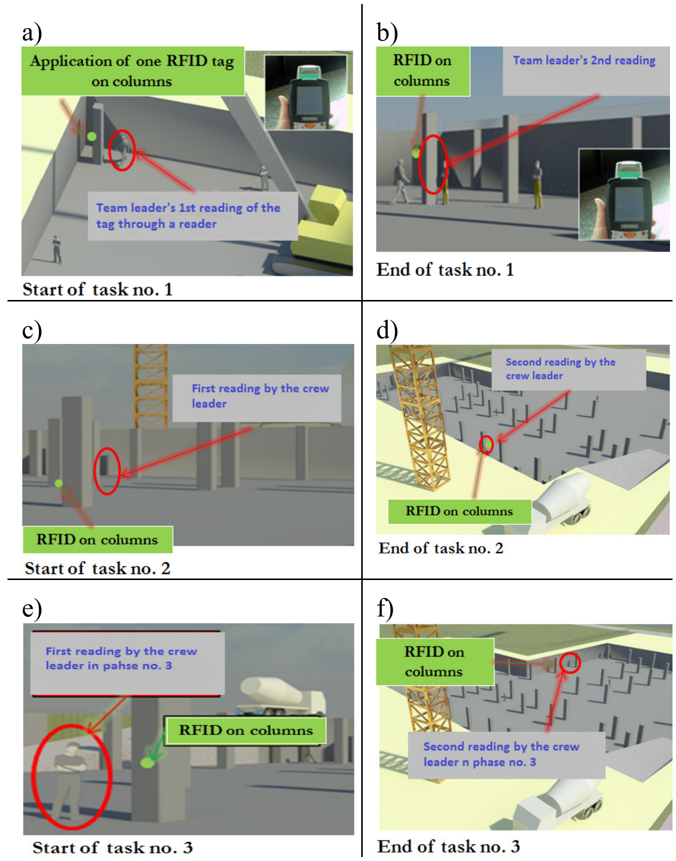


Fig. 4 Work progress monitoring over the column erection phase.

It is based on the IEEE 802.15.4 standard medium access and Zigbee stack communication protocol. It owns the advantages of working in ISM band, being reliable, self healing and easy to deploy, having low cost and low power consumption. It is made up of one or more coordinators used to initiate network formation, fixed devices with routing capabilities installed at known locations of the area under monitoring, and end devices (or tags) used as mobile nodes with associated IDs (Fig. 5). Localization is performed through the application of the "Weighted Centroid Localization" approach. Low power features of the network are assured thanks to a reduced routers' duty cycle in asynchronous mode. Each router remains in sleep mode for reducing power consumption until it has to route a message or reply to a request. In these cases an asynchronous signal wakes it up from sleep and allow it to work without wait for a sync. The localization hardware engine and the low power communication capabilities, combined with its self-healing property, make this wireless sensor network extremely suitable in dynamic environments, as compared to other tracking technologies.

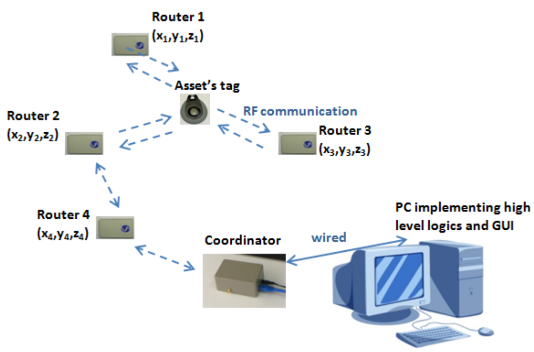


Fig. 5 Low-invasive monitoring system architecture.

3.3 Automated information structuring

The most relevant information coming from such a monitoring is relative to activity progress and resources usage. In the case tested in this paper, the second type of information have been filtered and restructured into a pattern of daily site reports.

4. ON-SITE PRELIMINARY TESTS

Although the whole procedure has not been fully tested, yet some preliminary experiments have been executed in order to evaluate how data regarding resource allocation may be retrieved and filtered to obtain structured information and automated Daily Site Reports (DSR). The wireless system described in sub-paragraph 3.2 was installed on a 1200 m^2 portion of the site depicted in Fig. 6-a, as shown in part b of the same figure, relative to the erection of a building targeted to parking areas and commercial activities. Then three tags were deployed: tag no.1 was give to one worker, tag no. 2 was fixed inside a dumper and tag no. 3 inside an excavator. As a first trial it was tested that positions were correctly estimated, like in Fig. 7-a, obtaining successful results.

A software application at the server level was set up, for automatic production of daily site reports. The data retrieved from the site are stored and associated to the resources positions over time. Then they are filtered and elaborated to provide a first version of daily site reports in an automatic way. In particular, it is expected that at the end of any working day, every crew leader will input the list of tag codes associated with the workers of their crew. The system will automatically set a daily site report as shown in Fig. 7-b (both in its digital and paper version), where the time of permanence of the resource on site is reported, together with the site's data and the list of pieces of equipment concurrently present on site. The paper version of the report has been predisposed to give users the opportunity to make corrections or integrate it with further information, if needed.

a) b)

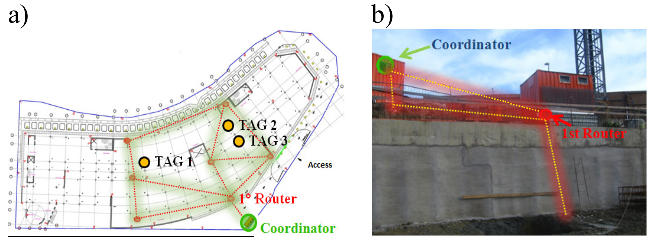


Fig. 6 On-site system installation.

At this stage the part of the reports regarding the list of activities where each worker has been involved in, has been left blank, because it will be filled in when a further research step in the monitoring procedure described in sub-paragraph 3.2 will be accomplished.

Similarly, other sensing technologies will be developed to automatically associate the actual usage period of equipment and the corresponding operators. As a first idea, vibration sensors will be integrated in the tags installed on the machines in order to record their actual working time.

a)

b)

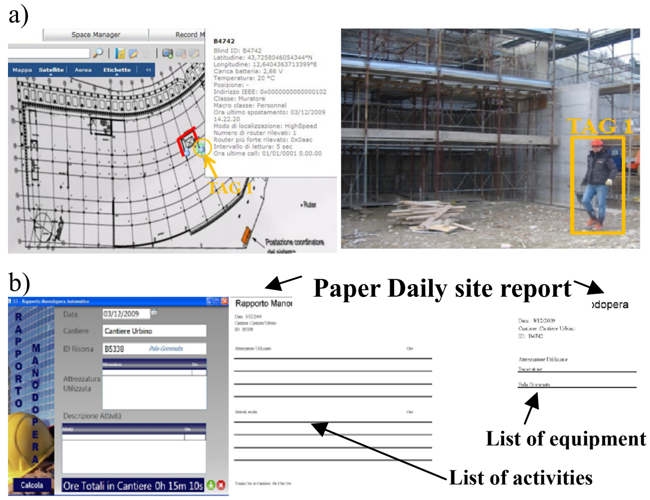


Fig. 7 Localization accuracy estimation and daily site reports production.

When they are turned on, proximity queries will be sent by the tags in the machine, in order to select those operators who are inside and forward such information to the local server. In this way, the daily site report's lines regarding equipment usage by workers will need no more to be filled in by operators, but will be automatically managed.

5. CONCLUSIONS

The approach for monitoring of construction progress presented in this paper is based on two main pillars: semi-automated monitoring of activity progress and automated estimation of resources allocation through non-invasive technologies. This paper has assessed a procedure based on BIM modeling useful at the design phase to organize information, so that it facilitates the next monitoring phase. Then it has been tested how resources can be monitored and the corresponding information automatically re-organized in support of construction managers and inspectors.

6. ACKNOWLEDGEMENTS

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