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TECHNOLOGIES CURRENTLY AVAILABLE TO OBTAIN THE OCCUPANCY RATE OF RESOURCES ON A CONSTRUCTION SITE

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Abstract: The construction industry is utilizing new emerging technologies that have the potential to help managers and contractors to track the work progress on construction sites. Combined with scheduling methods based on space planning, these technologies could aid in the stabilization of workflows, ensure better use of available space, provide a smooth flow of traffic and reduce conflicts on construction sites. The purpose is to optimize the construction operations and to improve the stagnant productivity in this industry. Technologies such as 360-degree pictures and videos, laser scans, photogrammetry, LiDAR, bar codes, RFID, and augmented reality could have a significant impact in achieving these goals. The purpose of this paper is to study and evaluate the existing technologies and their usefulness for optimizing the occupancy rate on construction sites. Following analysis based on case studies, the following evaluation criteria were retained: mobility and portability of the systems, the impact of the interventions on the works, the speed of the measurements, the quality of the results obtained, the ease of extracting information from the data collected, and the level of maturity of these technologies. Finally, an analysis and ranking are presented in this paper in order to measure the suitability and the adequacy of these technologies facing the predefined evaluation criteria.

INTRODUCTION

Progress in the monitoring of works on construction sites is considered an activity that is key to project success. For building projects, this monitoring usually occurs by directly observing the work that is being done on site. However, the shortcoming of the manual monitoring process is that such records tend to be long and incomplete. In addition, the surveys will be more complex if the manager requires monitoring to be performed by occupation and zone in order to ensure optimal site progress and good coordination between working teams. On the other hand, it is well known that the frequency of the follow-up is inversely proportional to the required efforts. In these circumstances, analysis of the latest technological advances, which can help to automate on-site work reports, could aid in identifying the most appropriate solutions for the construction industry. This paper presents and analyzes the existing technologies in three (3) categories: 1) taking and processing pictures and videos, 2) obtaining a point cloud, and 3) installing sensors on resources to identify their location. Thus, considering the objective of the actual research project that is mentioned above, the strengths and weaknesses of each of these technologies is presented and evaluated. The study also proposes a list of criteria and priorities to classify technologies according to construction site need and also to aid with identifying the requirements of a research project that seeks to model artifacts for construction operations.

1 RESEARCH OBJECTIVES

Therefore, the aim of this paper is to present, analyze, and classify technologies according to construction site needs and also to aid with identifying the requirements of a research project that seeks to model artifacts for construction operations to develop a process that will dynamically calculate the occupancy rate of a construction site (Morin Pépin and Francis 2018). The research project will use these technologies to estimate the occupancy of teams and their resources when they are present at the site.

This paper identifies and evaluates the current available technologies that could monitor the work progress by position, occupancy, and movement. The evaluation will be conducted to help achieve two sub objectives of the research project: 1) collect the necessary data for the development of the research procedure, and 2) assist contractors with tracking and updating their schedules by using a semi-automated process.

2 AVAILABLE TECHNOLOGIES

2.1 Pictures and videos processing

Modern cameras are compact, easy to carry, and can take good pictures. Photos can easily be kept, shared, and viewed later to provide additional information. However, a comprehensive survey requires many pictures to be taken, which can make the process long and increase the risk of missing many details. The use of spherical pictures reduces the number of images that are required to perform good follow-up by covering a larger area and reducing the risk of missing details (Figure 1). As a result, a specialized system has been developed to process pictures and videos. It offers contractors the potential to monitor a large quantity of resources using few cameras (Park and Brilakis 2012) to capture images that cover a large portion of the site (Brilakis, Park, and Jog 2011).

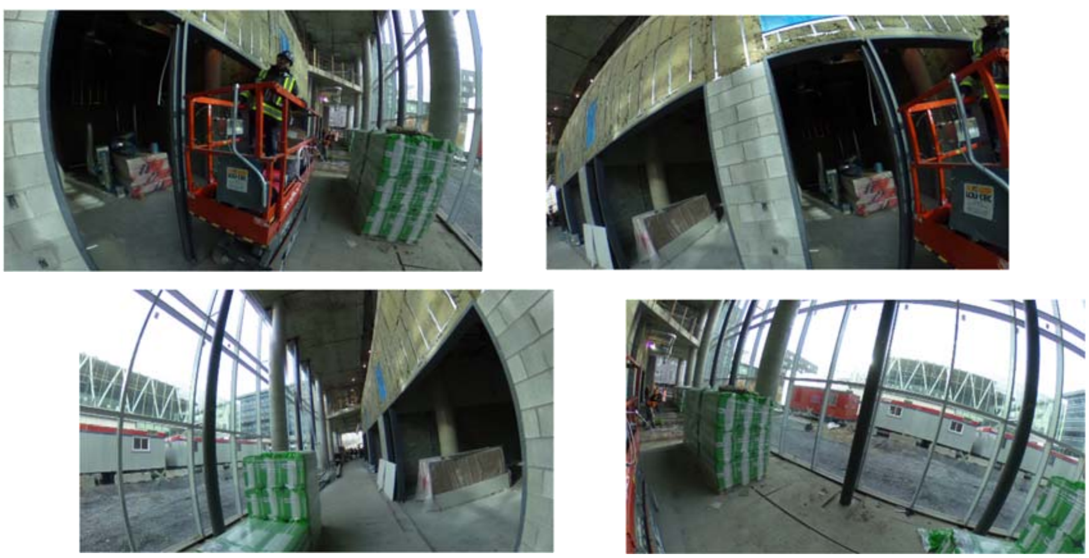

Figure 1: Four (4) viewpoints of the same spherical photo

Thus, the development of procedures and software that have the ability to extract information from pictures or videos taken on site is necessary. However, one of the main difficulties in processing pictures and videos by software is the variation of lighting and quality between pictures. Moreover, software cannot easily distinguish between two (2) similar elements, such as a pedestrian and a construction worker (Park and Brilakis 2012).

In order to analyze the movement of the workers, the system created by Weerasinghe and Ruwanpura (2009) integrated sound-processing amenities and infrared cameras to identify the different trades present on site. However, this requires the use and proper operation of several separate systems (images, sound and infrared), thus complicating the tracking process because each of these systems can be a source of errors. A similar problem occurs when using multiple cameras to determine the positioning of the items (Brilakis, Park, and Jog 2011; Shahi et al. 2012) because each camera needs to be calibrated according to the environment in which they are installed.

The use of computer learning and artificial intelligence in these systems proposes more robust algorithms to variations in lighting, quality, and the partial occlusion of items (Golparvar-Fard, Heydarian, and Niebles 2013; Gong, Caldas, and Gordon 2011). However, the use of these methods requires advanced computer knowledge, which effectively limits the accessibility of this technology in the construction industry.

However, the ability to identify the inside of the building represents a major challenge due to the constant change of viewpoint, divided spaces, frequent occlusion, and variable lighting conditions (Hamledari and McCabe 2016; Kopsida, Brilakis, and Vela 2015). Hamledari, McCabe, and Davari (2017) developed a system that is able to detect pictures to depict the state and rate of advancement in the interior walls. However, as is common in most systems based on project pictures and videos, the quality of their system's survey significantly depends on the quality of the pictures that are taken.

2.2 3D reconstruction

The procedures and systems have been developed to allow the use and analysis of 3D renderings of a building under construction to determine work progress (El-Omari and Moselhi 2008; Gao et al. 2015; Turkan et al. 2012) and to detect the as-built dimensions of the structure (Bosché 2010). In order to obtain the point cloud, three technologies are analyzed in this paper: computer vision, laser scans, and LiDAR.

2.2.1 Computer vision

Software is also available on the market that allows an object to be reconstructed in 3D from pictures. However, a preliminary test conducted during this research project revealed that this reconstruction required 99 pictures and several hours to process in order to produce the model shown in Figure 2.

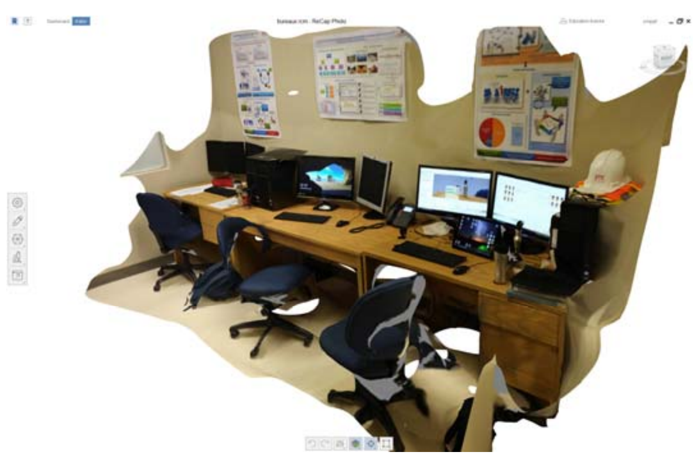

Figure 2: 3D reproduction using pictures and a specialized application

In the same vein, Golparvar-Fard (2010) proposed a procedure in conjunction with the D4AR system: The use of pictures taken during the construction process to rebuild a point cloud in presentation of the construction progress. Thus, at various times during construction, adding pictures as the project advances adds information to the point cloud. The latter is then compared to the 3D BIM model of the building in order to produce a 4D "as-built" simulation. However, as with other systems that use pictures, the D4AR is limited when the time comes to apply it to the inside of a building, as creating a 3D reconstruction of the interior of a building is complex. Several factors, such as low-textured surfaces, limited visibility between the different parts, and the dominance of thin structures such as doors and tables, complicate the process (Furukawa et al. 2010).

Stereo cameras offer better capabilities than a single picture to detect depth for 3D reconstruction. This type of camera is already available on the market and is generally more affordable and more compact than laser scanners. However, the modeling solutions proposed by the manufacturers of these cameras are aimed at developers of technologies and industrial solutions. Therefore, their uses require advanced knowledge in computer programming. Preliminary tests also show that they are sensitive to lighting conditions, thus requiring the camera to be constantly recalibrated according to new lighting conditions.

2.2.2 Laser scanners

Laser scanners have been available for some time and have proven themselves in the quality and accuracy of the point cloud they generate. However, a scan on a large surface or for several connected rooms requires repositioning the scanner at regular intervals. During a test on a reconstruction project, an area of 3200 m2 required 6 scans, which took 3 hours, to cover the entire area (Figure 3). This makes the process long and even impossible at times (El-Omari and Moselhi 2008). These constant movements are an obstacle to materials and worker productivity.

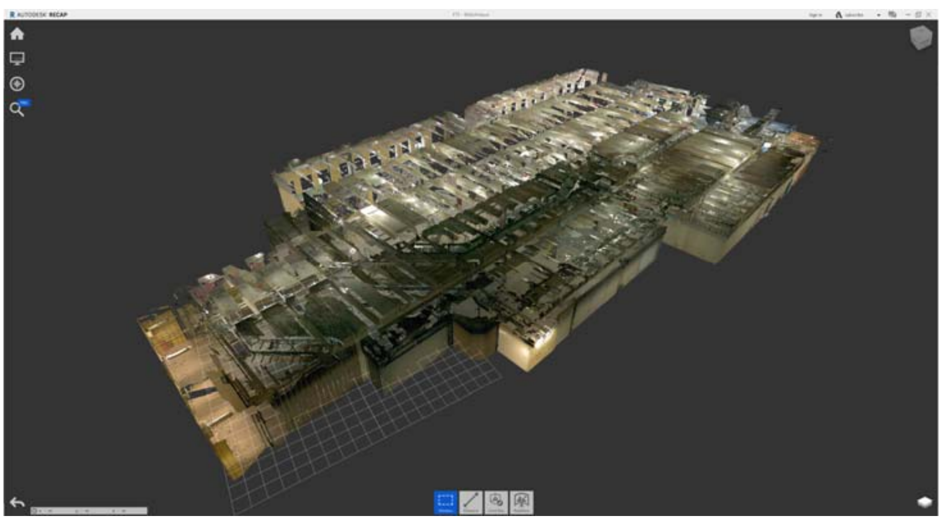

Figure 3: 3D points and clouds by laser scan

2.2.3 LiDAR

The LiDAR method was designed specifically for making 3D scans while moving and is relatively compact and mobile (Lee et al. 2006; Wang et al. 2015). In the field of construction, LiDAR are mainly used to perform aerial reconnaissance of terrain and building (Bangaru et al. 2018; Lee et al. 2006; Verma, Kumar, and Hsu 2006; Yan et al. 2015). However, Wang et al. (2015) has developed a system for monitoring the progress and checking the quality by comparing a survey carried out with LiDAR (as-built) to the BIM model (as-planned). Xia and Wang (2019) have sought to use the ability of LiDAR to obtain the footprint of buildings from a scan of facades.

However, performing a scan of the inside of a building means doing so while moving. However, performing a 3D scan while moving creates distortions in the point clouds (Zhang and Singh 2015). This process requires several fixed scans or several LiDARs to be installed to cover all of the locations to be scanned (Yoshisada et al. 2018). In addition, unlike the laser scanner, LiDAR alone does not allow the color of the individual elements to be recorded, which can make their identifications difficult. To accomplish such a task, they need to be combined with other technologies, such as cameras, to allow the capture of the color of the elements.

2.3 Sensors

The main purpose of the sensors is to install a transmitter or label on the item you wish to follow. Then, with the help of a specialized reader, the positioning of the element in question is collected. The best example is the use of GPS to track the movement of vehicles and machinery (Pradhananga and Teizer 2013). Autonomous, easy to use and accessible, it is simple to install a sensor to obtain the positioning of an element. However, the accuracy of standard GPS varies a lot—up to a few meters—and it depends on the capacity of the sensor to receive the GPS signals (Pradhananga and Teizer 2013), thereby affecting the reliability of the system. Although there is high-precision GPS, the latter suffers from the same signal reception problem.

In the case of UWB, fixed stations must be installed at regular intervals on the site in order to get the positioning of an installed transmitter. The accuracy of the positioning is affected by the number of stations able to detect the transmitters at a specific time and by the number of transmitters that are simultaneously detected (Maalek and Sadeghpour 2013). In order to make a survey on the whole site, it is, therefore, necessary to install and maintain several stations distributed on the site to ensure optimum coverage and precision.

RFID tags can be read by a handheld detector. Affordable and easy to print, passive RFID tags are small and have a considerable lifespan, considering that they do not require batteries to be detected (Costin et al. 2010). However, RFID tags are not designed to allow to detect their positioning, so it is necessary to combine them with another technology, such as GPS, in order to be able to locate the tags on a site (Razavi and Haas 2011).

Although the sensors have an advantage in the speed of the readings and the portability of the system, they only collect the information of the identified elements. In addition, questions must be asked regarding the ethics about installing sensors on workers in order in order to track their movements at the work site. Therefore, their use should be limited to materials and machinery.

3 EVALUATION CRITERIA AND PRIORITIZATION

In order to determine which of these technologies will be adapted, an assessment of their capabilities will be necessary. Thus, based on previous research and comparisons, the criteria presented below seek to bring out and prioritize (Table 1) the technological needs according to the user, whether for the purposes of the research project or to be used by contractors:

1. **Measurements speed:** The survey will be carried out on a large portion of the site, so it must be done within a reasonable time, as a quick statement will limit the changes associated with the relocation of resources during the survey.
2. **Portability**: Due to the magnitude of the survey, which causes a lot of displacement, the system must to be easy to install and transport.
3. **Quality**: In order to enable efficient processing and to ensure the accuracy of information, the technology must allow for the identification of the resources present, their positioning, their movements, and the space they occupy on the site.
4. **Minimize the impact on the work progress**: Given the importance of the coordination and the work flow, the surveys must be able to be done without interruption and without interfering with the work and with minimized interaction with the workers.
5. **Information processing**: Regardless of the technology used, the information collected must be processed after a survey. Thus, the speed with which this information can be processed must be considered.
6. **Accessibility of information**: It is important that the generated information is accessible throughout the project, even after its completion. In addition, some technologies require the use of specialized software to process and view information. It will be necessary to ensure the availability of the software, as well as their compatibility throughout the years.

7. **Maturity**: The objective of the research project is not to develop these survey technologies. The technology will have to be available and applicable, thus requiring minimal development while being reliable and accessible.

Table 1: 3D points and clouds by laser scan

For the research project	By contractors
1- Quality	1- Measurements time
2- Accessibility	2- Information processing
3- Minimized impact	3- Maturity
4- Measurements time	4- Impact
5- Portability	5- Accessibility
6- Maturity	6- Quality
7- Information processing	7- Portability

In the research project context, the quality of the survey and access to information are particularly important because, if necessary, they must be able to access and extract information throughout the research process and take the time needed to do it. However, if the survey is carried out by the contractors for the monitoring of the work, the time required for processing the information is important, as a contractor will have to assign an employee to do the survey and the treatment. Thus, the priorities of the evaluation criteria presented above are different, depending on whether it is used for the research project or by the contractors.

4 TECHNOLOGY ASSESSMENT

All of the technologies evaluated are divided into 3 categories: i) pictures and videos, ii) the point clouds, and iii) the sensors. Subsequently, based on previous research and our preliminary tests, each of these technologies is evaluated against the evaluation criteria presented in the previous chapter and is assigned a good, acceptable, or low performance rating, such as illustrated in Table 2. The results and comments of this evaluation are presented in Table 3.

Table 2: Technology performance evaluation chart

Good performance	Acceptable Performance	Low Performance

5 CONCLUSION AND FUTURE RESEARCH

The purpose of this paper is to assess the technologies applicable to the construction industry that are currently available and/or in development that could help to collect the space occupied by the resources present on a site. As part of a research project that aims to develop a procedure for the dynamic spatiotemporal calculation of the occupancy rate of a site, the technologies presented were evaluated for 2 types of uses: The first for the research project in order to collect the necessary data for the elaboration of the procedure, and the second for use by contractors to track a schedule made using the procedure developed by the research project.

A list of evaluation criteria has therefore been established and prioritized according to the type of use. Thus, after evaluating these technologies, the quality and the accessibility of information to the standard and spherical pictures and videos means that these technologies will be used when collecting the initial data for the research project. For the contractors, the measurements' speed of reading and the information processing makes LiDAR and stereo cameras the best fit. However, although solutions are currently available on the market, these two technologies still lack some maturity for efficient use by entrepreneurs.

Table 3: Technology Performance Compared to the Evaluation Criteria

	Measurements time	Portability	Quality	Impact	Treatment	Information access	Maturity
Manual takeoff	Record information by hand	Paper, pencil, phone, tablet	Complete survey difficult to do on a large construction site	No interaction with the workers required	Limited to information collected	Depends on where the Information is stored	Mature
Standard pictures and videos	Quick if set up in automatic mode	Compact cameras available	Good, but depends on the pictures	No interaction with the workers required	Manual processing of each picture	Direct access to pictures, easy sharing	Mature
Spherical pictures and videos	Quick if set up in automatic mode	Compact spherical cameras available	Very good (spherical picture)	No interaction with the workers required	Manual processing of each picture	Direct access to pictures, easy sharing	Specialized software required to view pictures
Pictures and software	A few hours to get the point cloud	Camera + Computer	Depends on the pictures and the reconstruction software	No interaction with the workers required	Measurements on the point cloud	Point cloud processing software required	Difficult to apply on an entire site
Scan laser	+/- 5 min. per scan.	Moving the scanner between each scan	Very good	May interfere with the movement of workers	Measurements on the point cloud	Point cloud processing software required	Laser scanner available on the market
Stereo camera	Continuous takeoff possible	Hand-portable	Depends on the lighting conditions and the calibration	No interaction with the workers required	Measurements on the point cloud	Point cloud processing software require	Development to be done *
LiDAR	Continuous takeoff possible	Backpack (+/- 10 kg)	Good **	No interaction with the workers required	Measurements on the point cloud	Point cloud processing software require	Development to be done, but systems are available **
GPS	Fast	Large GPS receivers for small objects	Depends on the satellite reception	Installing the receivers	Fast	Easy with manufacturer software	Mature
UWB	Fast	Requires installation of stations	Depends on the stations	Requires the installation of the stations	Fast	Easy with manufacturer software	Mature
RFID	Fast	Hand readers available	Development to be done ***	Very small passive labels	Fast	Specialized equipment required	Development to be done ***

* The tools that allow the development of custom solutions are usually offered by the manufacturers of the stereo cameras.
** LiDAR alone does not capture the color of the elements. LiDAR-based technologies for capturing colors cost about $300,000.
*** RFIDs are not designed for positioning. They must be combined with other technology and specialized systems.

In future research, LiDAR and stereo cameras will need to be studied in more detail to determine how they can be used by contractors. Also, a study should be conducted to determine the possible solutions that could increase the automation to collect the occupancy rate from a 3D reproduction point cloud following a survey.

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