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CONTRIBUTION OF UAS MONITORING TO SAFETY PLANNING AND CONTROL

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ABSTRACT

Among the technologies used for safety management at construction sites, Unmanned Aerial System (UAS) stands out due to its ability to capture images and videos of large areas, reduce data collection and processing times, and improve risk identification at the jobsite. Despite the advances in safety monitoring using UAS, there is still a gap regarding the effective use of information provided by this technology for assisting Safety Planning and Control (SPC). This study proposes a set of practices to incorporate the information collected from a UAS safety monitoring system into SPC routines. The research strategy used was the Design Science Research (DSR), and preliminary implementation of the artifact occurred during 14 weeks in a residential construction project. The evaluation involved establishing a set of constructs and variables such as transparency, collaboration, and utility to analyze the contributions of the practices proposed. As preliminary contributions, results show that the visual display implementation significantly impacted the sharing of safety information, the awareness of safety conditions, and the promotion of new learnings for workers. Moreover, the practices implemented provided foreman participation in decision-making related to safety and construction site organization and housekeeping.

KEYWORDS

Safety management, safety inspection, unmanned aerial systems (UAS), construction site, digital technologies.

INTRODUCTION

The dynamism of workflows at construction sites makes safety management challenging through the conventional methods, which are time-consuming and prone to errors (Guo et al., 2017). Some of the challenges encountered are related to large construction sites (Irizarry et al., 2012), the sharing of large amounts of information, and the lack of practice in transforming the information gathered into performance indicators (Zhang et al., 2016). In addition to those limitations, the lack of adequate technological support hampers effective decision-making at construction sites.

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The literature shows that digital technologies improve performance and make processes more straightforward and productive (Guo et al., 2017). However, Simpson et al. (2019) noted the need to implement the technologies with management practices. Their contribution is not limited to digitalize processes but to solve real problems in the construction industry.

Among the digital technologies used for safety management on construction sites, Unmanned Aerial Systems (UAS) have attracted attention. The main positive characteristics of UAS are their ability to capture images and videos of large areas, reducing data collection and processing time, and facilitating the identification of risk situations (Irizarry et al., 2012; Melo and Costa, 2019).

According to Melo and Costa (2019), UAS monitoring supports activities workflow, enables the identification of safety and production trade-offs, and anticipates risk situations faced by workers, as well as interferences between processes. For these authors, the information provided by UAS could enhance SPC; however, an effective response is related to the team's skills to make it promptly. Martinez et al. (2020) proposed a method for safety planning and monitoring using UAS in which visual information (photos and 3D models) generated by UAS were used to identify and assess hazards. According to these authors, the pictures and 3D models allowed identifying more hazards than in the traditional method, besides improving managers' perceptions concerning risk assessment. Both studies performed weekly safety monitoring; however, none of them proposed learning mechanisms or practices to support the continuous improvement of safety planning, such as tools for follow-up action plans regarding the nonconformities identified on-field. Based on that, there is a gap regarding the effective use of information provided by UAS for safety management.

Despite the advances in safety monitoring using UAS, few studies, such as Melo and Costa (2019) and Martinez et al. (2020), have explored UAS monitoring to assist Safety Planning and Control (SPC). Therefore, this paper suggests a set of managerial practices and indicators to incorporate the information provided by UAS monitoring into SPC. A computerized safety inspection system, called Smart Inspecs System, is used for data processing, analysis, and storage.

BACKGROUND

According to Saurin and Formoso (2008), an effective risk assessment consists of four stages. First, the risks to which workers are exposed must be identified and evaluated. In response, the management teams must define measures to control the hazards and monitor their implementation. During the monitoring, performance measurement must be carried out, and actions must be implemented, providing feedback to the previous stages of the management cycle.

Regarding practices to enhance SPC, Coble and Elliot (2000) say that the identification and evaluation of risks must be performed by the production and safety teams, taking into account the work packages scheduled, the workforce's capabilities, and the participation of frontline workers. Jiang et al. (2014) highlighted that the communication between managers and workers about safety issues is essential to improve safety awareness and knowledge. The adoption of visual tools improves communication efficiency, ensures transparency, and increases employee motivation and self-management (Galsworth, 2017). The compliance with mandatory regulations and internal procedures must be evaluated through safety inspections (Kjellén and Albrechtsen, 2017), generating safety indicators. Thus, to achieve continuous improvement in safety performance measurement, there is a need to assess whether planned objectives are getting reached, identify target areas for improvement, propose proactive measures, and evaluate their effectiveness (Lingard et al., 2019).

RESEARCH METHOD

This study adopted the Design Science Research (DSR) approach (Vaishnavi and Kuechler, 2015). The practical problem is how to effectively use the information provided by UAS monitoring to improve the safety planning and control processes. The research was conducted according to the following steps: awareness, suggestion, implementation and evaluation, and conclusion. This paper focuses on the first cycle of the implementation and evaluation steps (see Figure 1).

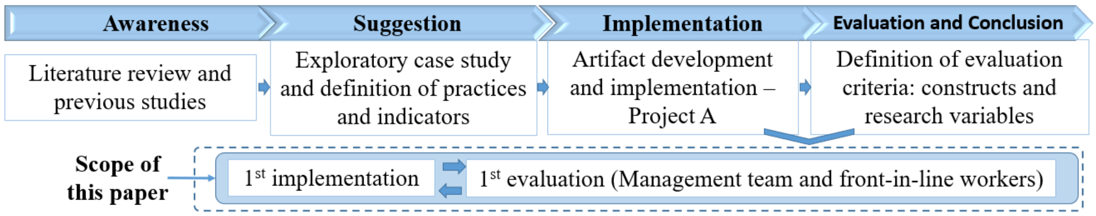


Figure 1: Research design

IMPLEMENTATION OF PRACTICES AND INDICATORS PROPOSED

The **implementation stage** initially occurred during 14 weeks in Project A, a residential condominium consisting of three 20-story buildings and a garage building (5 floors). During the study, the construction phases were the residential towers' foundation and the garage building's precast concrete structure.

Based on the awareness and suggestion stages, the artifact proposed and implemented consists of a **set of practices and indicators to incorporate the UAS safety monitoring using the Smart Inspecs System into the SPC process** at two levels (weekly and monthly), as shown in Figure 2.

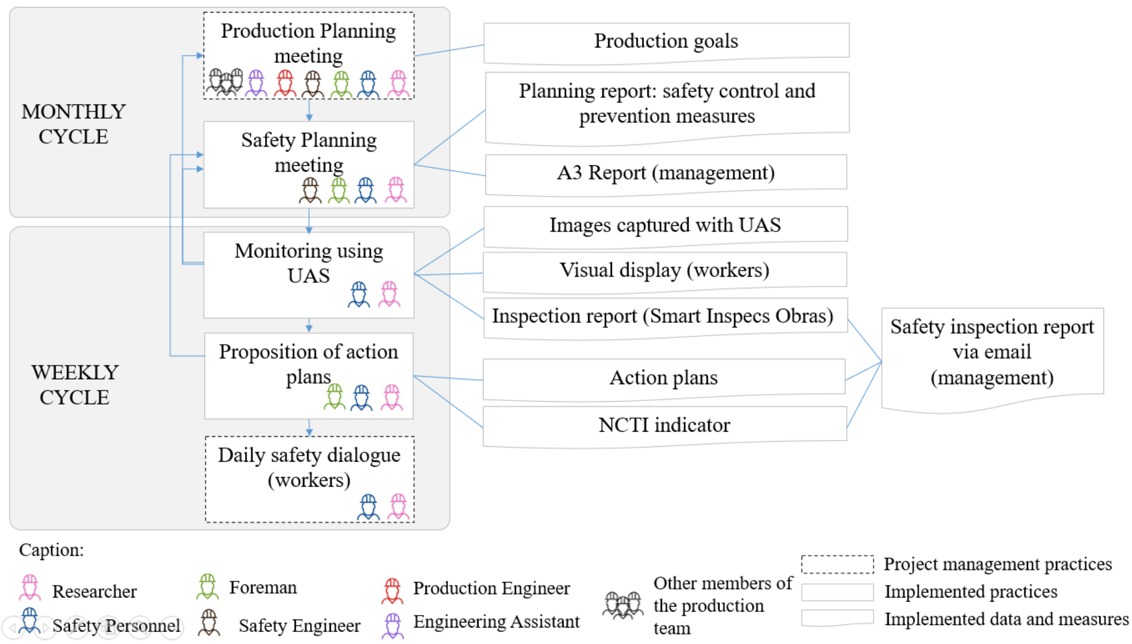


Figure 2: Workflow to use the information provided by UAS monitoring into SPC.

In Project A, monthly Production Planning meetings are held to present and discuss production goals. The study proposed the implementation of Safety Planning meetings to establish preventive and control measures for the planned work packages. These meetings involve Safety personnel, Safety Engineering, and Foreman. A **Safety Planning report** containing the decisions and planned actions established at the meeting is shared with managers via email. The **safety monitoring using UAS** was carried out weekly using the DJI Phantom 4 and the Smart Inspecs System.

The Smart Inspecs System is a computerized safety inspection system that uses UAS to monitor safety conditions on-site and a web system to automate the inspection process [9]. The UAS safety checklist has 241 items divided into 21 categories, such as organization and housekeeping, storage of materials, construction site signaling, stairs and ramps, collective protective equipment, and earthwork and foundation. The pilot (principal author) performed the inspections, supported by an observer (assistant researcher) and the project safety personnel who participated in eight from 14 assessments. Figure 3 presents the safety inspection protocol used and Table 1 shows the Flight log data collected during the 14 inspections performed in Project A.

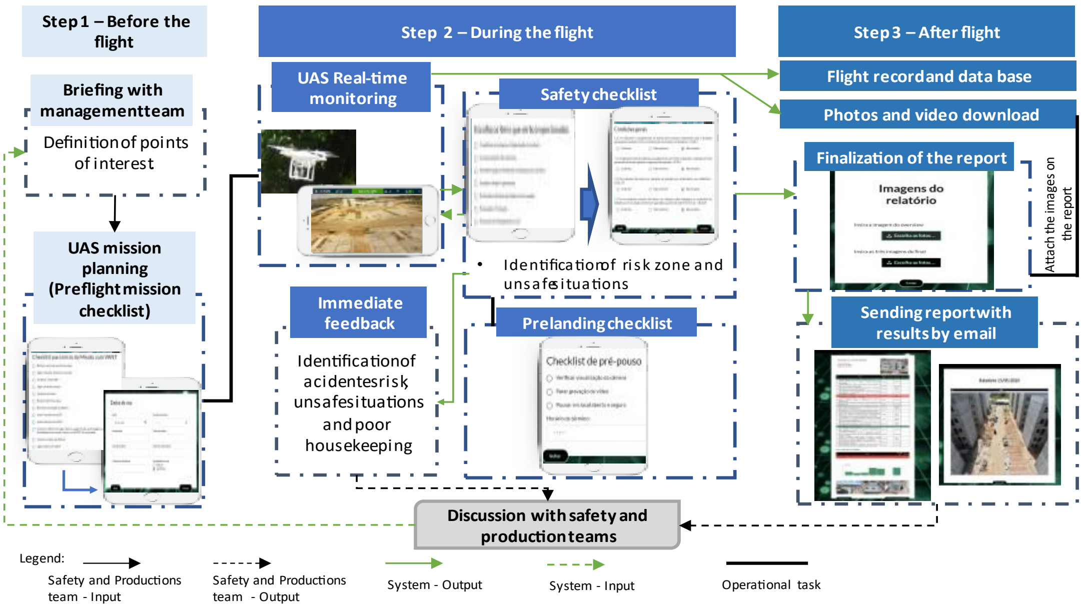


Figure 3: Safety inspection protocol using Smart Inspecs Systems (adapted from Melo, 2020)

Table 1: Visual assets data collected in Project A

Number of Inspections	Number of Images	The average flight distance (m)	Maximum height (m)	Total Flight time (h)	Average Flight time (h)
14	477	867	75	03:59:34	00:17:06

The output of the inspections using the Smart Inspecs System is composed of an **inspection report** which contains a safety checklist assessment, images collected with UAS, and the safety compliance indicator (i.e., the ratio of the sum of compliant items and the sum of items checked). At the end of the inspection, a feedback meeting is performed involving safety personnel and Foreman to propose an **action plan** for each nonconformity identified on the assessments.

The action plans analysis is carried out through the **Nonconformity Treatment Indicator (NCTI)**, calculated as the ratio between the sum of planned corrective actions and the sum of the executed corrective actions. The **safety inspection report**, the NCTI, and the action plans are delivered via email to the management team. The inspection results are communicated to workers via **visual display** and during the **daily safety dialogue**. The visual display is updated on a weekly and monthly basis, as presented in Figure 4.

Figure 4: Visual display

The information collected during the weekly cycle is used to support the SPC for the following month. The communication of monthly results to the management team is done using an A3 report containing (a) the graph of the evolution of the Safety Compliance Indicator, (b) the Nonconformity Treatment Indicator per week, (c) the classification of the nonconformities per categories, and (d) the recurrences of non-conformities. An example of the A3 report is presented in Figure 5 (Result Section). Finally, the information is used to support monthly Safety Planning meetings.

Evaluation of the Practices and Indicators Implemented

The **evaluation phase** involved analyzing the contribution of the practices and indicators implemented into the SPC routines through a set of constructs and variables (Table 2). Those constructs and variables were defined based on the literature review and previous studies carried out by the research group. The primary sources of evidence used for this evaluation were: (a) participant observations during the 14 weeks, (b) document analysis (safety planning report, A3 report, production planning spreadsheet, safety inspection report, emails, action plans spreadsheet), (c) images collected with UAS, and (d) semi-structured interviews, as detailed as follows.

The first round of interviews to collect the managers' perception of the implementation of the artifact proposed in Project A was carried out with five members of the management team composed by Production Engineer, Assistant Engineer, Foreman, Safety Engineer, and Safety Personnel (n=5). The questionnaire used in the interviews had eight closed-ended questions with subheadings using a Likert Scale with five-level impact and four complementary open-ended questions. Additional data collection involved the use of a questionnaire to collect the workers' perception. A total of 22 workers were interviewed (n=22 workers) about the understanding of safety conditions information (transparency) and use of the information provided by UAS to improve safety conditions (utility). This questionnaire had two closed-ended questions with subheadings using the same Likert Scale described above and four complementary open-ended questions.

Table 2: Constructs and Variables (Research evaluation criteria)

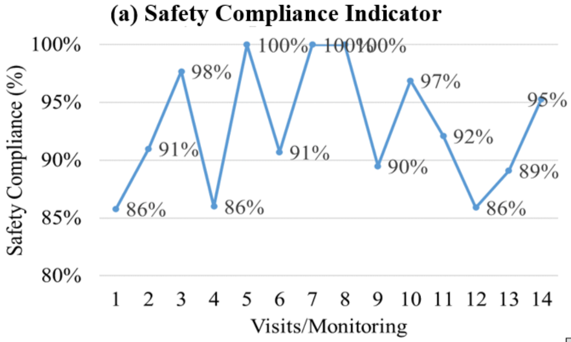
Constructs	Variables
Collaboration	Sharing information related to SPC between safety and production teams.
	Interaction between the production and safety teams to improve decision-making.
Transparency	Contribution for a better understanding of safety conditions information.
	Identification of risks and conditions not previously considered in the SPC.
Utility	Use of the information provided by UAS to plan preventive and corrective measures.
	Use of the information provided by UAS for planning the acquisition of resources.
	Use of the information provided by UAS to anticipate and eliminate safety constraints.
	Use of the information provided by UAS to improve safety conditions.
	Identification of factors that influence safety performance.

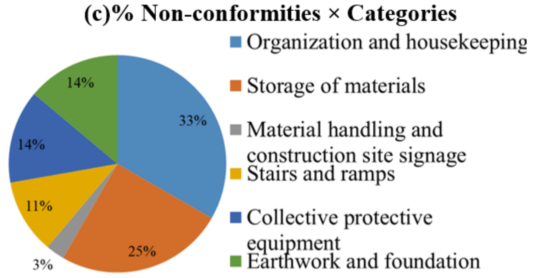
RESULTS AND DISCUSSION

This section presents the results obtained during the implementation and evaluation stages.

Safety Performance Based on the Practices Implemented

Figure 5 shows the A3 report with the results of the 14 weeks of implementation in Project A.





(b) Nonconformities Treatment Indicator

Visits	1	2	3	4	5	6	7
NCTI	50%	75%	100%	100%	-	100%	-

Visits	8	9	10	11	12	13	14
NCTI	-	100%	0%	67%	67%	100%	100%

$$NCTI\ (\%) = \left(\frac{sum\ of\ the\ correction\ action\ planned}{sum\ of\ correction\ action\ executed}\right)$$

(d) Recurrence of nonconformities

Inspection	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Rubble and any leftover materials must be regularly collected and removed															5
The materials are stacked directly on a stable, dry and level floor.															5
The construction site is organized, clean and unimpeded, especially in the traffic routes, passages															3

Figure 5: A3 Report - Safety performance Project A

In Project A, during the 14 inspections carried out, there were 36 nonconformities associated with 18 safety requirements, which corresponds to two notifications per assessment. These 36 nonconformities are distributed into six categories (see Figure 5), such as organization and housekeeping (33%), material storage (25%), and collective protective equipment (14%).

Results show that five action plans had performance (NCTI) below the average (78%), and the time taken to carry out the corrective actions was 1 to 3 weeks. The main difficulties faced on the implementation of correction actions were the layout planning failure, equipment unavailability, lack of technical experience with the construction process adopted and, the lack of prioritization to correct situations with low accident risk.

Additionally, during the implementation, the management team made efforts to improve site organization and housekeeping. However, regarding the production pressure, the safety team argues that the production goals are overly aggressive, making it difficult to propose any action.

EVALUATION OF THE ARTIFACT

Table 3 describes the management team's perception, including the Production Engineer, Assistant Engineer, Foreman, Safety Engineer, and Safety Personnel regarding the evaluation of collaboration and transparency constructs.

Table 2: Management team's perception about collaboration and transparency (n=5)

CONSTRUCTS	**COLLABORATION**					**TRANSPARENCY**				
Variables	Sharing information related to SPC between safety and production teams					Understanding information about safety conditions				
Data and measures	**Very low**	**Low**	**Indifferent**	**High**	**Very High**	**Very low**	**Low**	**Indifferent**	**High**	**Very High**
Safety inspection report				100%					40%	60%
Images collected with UAS				60%	40%				40%	60%
NTCI				80%	20%				40%	60%
Visual display			20%	40%	40%				40%	60%
A3 report			20%	60%	20%				80%	20%
Variables	Interaction of the production and safety teams for improving decision-making					Identification of risks and conditions not previously considered in the SPC				
Practices	**Very low**	**Low**	**Indifferent**	**High**	**Very High**	**Very low**	**Low**	**Indifferent**	**High**	**Very High**
Safety planning meetings			40%	40%	20%		20%		40%	40%
Action plan meeting			20%	80%					60%	40%

Regarding the collaboration, most interviewees considered that the data and measures adopted have a high to a very high level of efficiency in sharing safety information. They highlighted the relevance of the images collected with UAS and the visual display to improve communication, as Galsworth (2017) indicated. The participants indicated that the data and measures delivered are objective and easy to understand, in addition to providing better visualization of the project's failures.

The interaction between the production and Safety teams was mainly promoted by the safety meetings and action plans. According to the interviewees, the research contributed to the collaboration between the teams and increase the Foreman's participation on the decision-making process. The Foreman reported that "before the safety meetings, I only received the plans of how things need to be performed. Along the study I began to participate in the discussions and my opinion was considered". However, for the Production Engineer, Foreman, and Safety Engineer, the practices impact in improving the interaction between teams was "indifferent" or "low" because the participation of the production team was centralized in the Foreman. They consider that it is necessary to involve the entire production team. Thus, there is a need for better alignment between the production and safety meetings, so everyone involved can participate.

About the **transparency,** the five members of the management team highlighted a better understanding of the safety conditions due to the aerial images captured by UAS. Respondents noted that the aerial images allow them to view the site as a whole and identify situations that are not perceived on a daily basis. According to the respondents, the data and measures had a high to very high contribution to the understanding of safety conditions.

Regarding the variable understanding information about safety conditions, most of the workers interviewed, a total of 22 workers, reported a high level of understanding about the information presented on the visual display. However, 18% of the interviewees faced difficulties in the understanding of the graph about safety compliance indicators, and 9% had problems understanding the good practices.

Table 4 presents the management team's perception of the utility of data and measures and practices to improve the SPC process. The results show that the main contribution concerning the utility of the practices proposed was in their ability to anticipate and eliminate safety constraints. According to the interviewees, the safety planning meetings and the definition of action plans allowed identifying challenges in resource acquisition and the elaboration of effective planning with a focus on safety. The images collected with UAS contributed to planning resources acquisition, including production supplies, such as concrete blocks. These results are similar to those achieved by Melo and Costa et al. (2019), which identified the potential use of the products generated by the monitoring with UAS to determine the trade-off between safety and production and support safety planning. The safety inspection report and the images collected with UAS had a high impact on the planning of corrective and preventive measures, supporting the immediate decision-making.

Table 3: Management team's perception regarding utility (n=5)

CONSTRUCT	**UTILITY**									
Variable	Use of the information provided by UAS for planning preventive and corrective measures					Use of the information provided by UAS for planning resources acquisition				
Data and Measures	**Very low**	**Low**	**Indifferent**	**High**	**Very High**	**Very low**	**Low**	**Indifferent**	**High**	**Very High**
Safety inspection report		20%	20%	20%	40%				60%	40%
Images collected with UAV			20%	20%	60%				60%	40%
NCTI			20%	60%	20%		20%	20%	40%	20%
Visual display			40%	40%	20%		20%	20%	60%	
A3 report			40%	60%			20%	20%	40%	20%
Variables	Use of the information provided by UAS to anticipate and eliminate safety constraints					Identification of influencing factors for safety performance				
Practices	**Very low**	**Low**	**Indifferent**	**High**	**Very High**	**Very low**	**Low**	**Indifferent**	**High**	**Very High**
Safety planning meetings		20%			80%			60%		40%
Action plan meeting		20%			80%			20%	40%	40%

For the management team, the main benefits of the implementation were (a) the increased productivity of the safety team, (b) the better analysis of site conditions through the images collected with UAS, and (c) the improvement of the response time due to the speed of inspection and feedback.

Regarding the **use of information provided by UAS to improve safety conditions**, 77% of the workers' interviewed (n=22) noted a very high impact on the safety conditions. They highlighted improvements in the organization and housekeeping aspects, adequate waste disposal, and construction site signalling. According to 86% of the workers, the construction management team has promoted discussions about the nonconformities identified in the inspections with UAS, especially in the daily safety dialogues.

The main difficulty is related to the incorporation of the practices into safety routines due to the overwork and prioritization of production goals by managers. As further opportunities, the respondents noted the need for an indicator that emphasizes the recurrence of nonconformities and more engagement of the production team in discussions and UAS inspections.

On the following implementation, the recurring nonconformities will be included in the email sent with the safety inspection report (weekly) and in the A3 report (monthly). Moreover, the A3 report and the safety planning report will be printed and exhibited in the engineering and foreman rooms. To enhance the indicators' use, the production engineer can use the ITNC indicator to evaluate the team commitment to put the planned actions in practice, understand the difficulties they face, and contribute to taking the activities on time. Production and safety planning must be integrated and developed in a way that involves all stakeholders, achieving a greater interaction between teams in the data analysis and SPC decision-making. Besides the researcher's efforts to incorporate the monitoring using UAS into SPC, it is essential the management commitment to align the safety and production plans and use the information provided by UAS monitoring to make the SPC process more efficient.

CONCLUSION

This paper presents the proposition and implementation of practices and indicators to incorporate the information generated by UAS monitoring into SPC. The results obtained in Project A show that the Smart Inspecs System and the practices implemented have the potential to contribute to the development of safety skills since they improve visual management through the visual display, images collected with UAS, and A3 report. These data and measures proved to be helpful to enhance safety training and workers' risk awareness, as evidenced by the management team and workers' perception.

Additionally, the proposed practices supported a better discussion between safety and production teams, promoting more consistent safety planning meetings and anticipating and eliminating safety constraints, such as resource acquisition. Despite the advances, the management team argues that the interaction between safety and production teams in the SPC processes remains inefficient with minor production teams' involvement. As a suggestion, there is a need to encourage the discussion of safety results with the entire production and safety teams.

As the main limitation, it should be highlighted the impossibility to inspect safety requirements within buildings. In addition, the practices and indicators were implemented only in Project A, which stands out the need to apply them in others types of construction sites with more structured safety management systems. As future research, this paper indicates the need to investigate how to use the information provided by UAS to improve SPC in the medium and long term, as well as use the information to increase the engagement and participation of workers in safety practices.

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