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CONSTRUCTION PROGRESS MONITORING USING UNMANNED AERIAL SYSTEM AND 4D BIM

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ABSTRACT

Construction progress monitoring may help for an efficient management process as planned. Studies have proposed the use of visual data technologies; however, little has yet been done for the development and implementation of methods for integrating such technologies into construction management routine. This study aims to implement and evaluate the proposed method for systematic visual progress monitoring integrating into the production planning and control process, supported by 4D BIM, photogrammetric 3D mapping using Unmanned Arial System imagery, and performance indicators. The proposed method was implemented for 20 weeks in a case study on a construction project. The data collection included construction site 3D mapping generation, visual comparison of 4D BIM and 3D mapping status, measurement of performance indicators, and structured interviews. The evaluation focused on the following research constructs: compliance with the planned goals, impact on the construction progress deviations, transparency, and collaboration. The main findings indicate an improved integration of progress analysis and decision-making, improvement of progress deviations' identification, and allowed for better compliance with planned goals and increased transparency and collaboration. The main contribution of this work is a better understanding of the impact and added value of the new information flow provided by using the proposed method.

KEYWORDS

Construction progress monitoring, Visual management, 3D mapping, Unmanned Aerial System (UAS), 4D Building Information Modeling (BIM).

INTRODUCTION

Construction projects are characterized by the great dynamism, complexity, and diversity of activities and processes (Tuttas et al. 2017). This means that the execution of work packages as planned requires monitoring and control of their operations and progress.

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Del Pico (2013) defines the process of construction progress monitoring as steps and metrics that aim to evaluate the construction performance and compare it with the planned one, identifying deviations and implementing corrective actions. In order to meet the planned goals, such monitoring and control process must be systematically and continuously developed over different hierarchical levels of production planning and control system (Del Pico 2013).

However, according to Teizer (2015) and Yang et al. (2015), the most common practices for construction progress monitoring are based on frequent individual observations, depending on manual data collecting, and rely on textual documentation and subjective interpretations of data. Therefore, they are time-consuming, prone to errors and variability of data quality, and result in distance and delay in the exchange of information between the construction site and the management team (Teizer 2015).

Aiming to improve such aspects, studies propose the use of visual data technologies, such as photographs, videos, 3D and 4D models (Yang et al. 2015; Han and Golparvar-Fard 2017). For Tezel and Aziz (2017), the use of these technologies can contribute to the reduction of non-value adding, error-prone, and time-consuming activities associated with the construction progress monitoring process. Such benefits are related to the optimization of managerial tasks, the decrease of the number of mistakes made in routine tasks associated with the progress monitoring process, and the possibility of integrated visual management between schedule planning and production performance control, making the construction progress monitoring more efficient, transparent and collaborative (Tezel and Aziz 2017; Han et al. 2018; Álvares and Costa 2018).

Among these visual data technologies, recent studies highlight the great potential of: (a) 4D Building Information Modeling (BIM) for visual simulation of the as-planned construction progress, (b) construction site 3D mapping by digital photogrammetry, often as point cloud model, for visual representation of the as-built construction progress, and (c) Unmanned Aerial System (UAS) with an attached camera, as an effective tool to capture site images, since it can provide fast imagery, from different positioning, and with accurate control of the visual records' parameters (Han and Golparvar-Fard 2017; Lin and Golparvar-Fard 2017; Tuttas et al. 2017; Álvares et al. 2018; Han et al. 2018).

Despite the development of studies that address the use of visual data technologies for progress monitoring (Braun et al. 2015; Han and Golparvar-Fard, 2015; Tuttas et al. 2017; Han and Golparvar-Fard 2017; Son et al. 2017), most of them focus on the improvement of the technology itself, in terms of the development of automated computer systems with digital automation of data processes and integration of the visual tools' features.

Based on that, a gap regarding the effective systematic integration of these technologies into construction management systems was identified. Kopsida et al. (2015), Han et al. (2018) and Álvares and Costa (2018) note that there is a growing recognition among researchers that the use of visual data technologies can improve communication and evaluation of the construction progress. However, these authors also acknowledge that little has yet been done about the formalization, development, implementation, and validation of methods based on technologies such as BIM and 3D mapping with UAS, for optimization of the construction progress control.

Therefore, the main motivation for this study is the improvement of the information flow for construction progress monitoring, by using a structured, formalized and effective implementation of visual data technologies. This approach results in an easier understanding and communication of progress information in a quicker way and with greater reliability. The aim of this study is to implement and evaluate the proposed method for systematic visual progress monitoring integrating into the production planning and control, supported by 4D BIM, photogrammetric 3D mappings using UAS, and performance indicators. This work contributes to a better understanding of the impact and added value of the adoption of these technologies for progress monitoring through a practical, structured and in-depth implementation in an empirical study.

This study is part of a research still under development. The scope of this paper focuses on the initial implementation of the proposed method from a case study, and the evaluation of this implementation.

METHODOLOGY

This research uses the Design Science Research (DSR) concepts (Van Aken and Romme 2009) as the research strategy. The proposed artifact of this research is a method for visual construction progress monitoring using 3D mapping by UAS imagery and 4D BIM, named *Integrated 3D-UAS 4D-BIM Visual Progress Method.*

Based on the research strategy adopted and in order to meet the objective of this study, the research methodology was structured according to the following steps: Awareness, Artifact suggestion, Artifact development, Evaluation, and Conclusion. However, this paper focuses only on part of the steps of the artifact (the proposed method) development and evaluation, according to the research design presented in Figure 1.

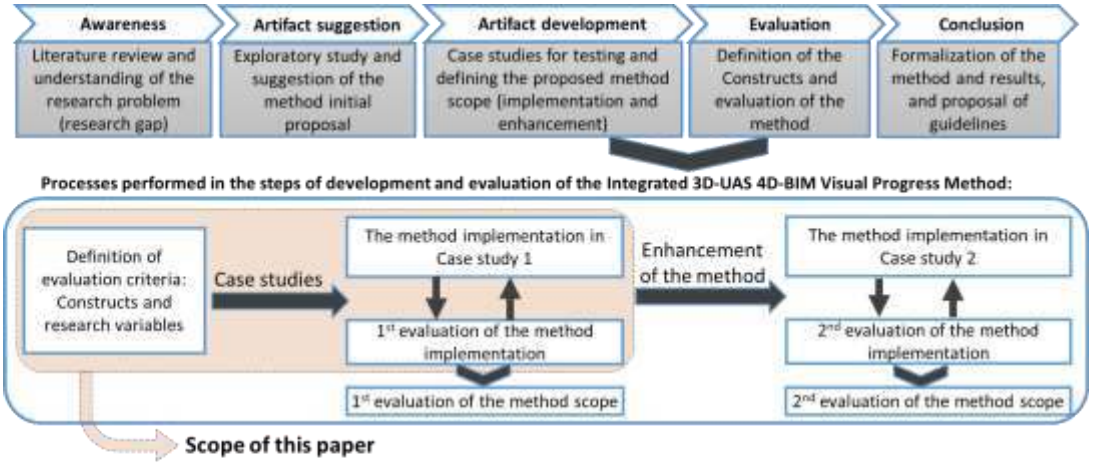

Figure 1: Research design with emphasis on artifact development and evaluation

IMPLEMENTATION OF THE INTEGRATED 3D-UAS 4D-BIM VISUAL PROGRESS METHOD IN CASE STUDY

The case study for the method's implementation was developed on a construction project in Brazil. The main features of this project are presented in Table 1.

Table 1: Features of the case study project

Features Description	Project picture (orthophoto)
- A residential low-income housing project - Land area: 22,800 m² - 20 buildings of five floors each, with a total of 400 units (four units per floor) - Construction time: 18 months (started in July 2017) - Main constructive method: Concrete wall structure	

The case study was developed for almost eight months, from February to September 2018. During the case study period, the following activities were conducted:

- *Adaptations of the proposed method to the management context of the construction project, and BIM models' generation:* conducted from February to March 2018, this activity included the selection of the set of performance indicators to be used, adjustments of protocols for data collection and data sharing, and the development of the 3D BIM model and the initial 4D BIM model of the project (respectively using Revit and Navisworks software).
- *Implementation of the proposed method:* it was conducted from April to August 2018, according to the steps, processes, and products presented in Figure 2 (in the following section). Five cycles associated with the look-ahead planning and control were monthly conducted. A 4D BIM model, using Navisworks software, was updated based on the look-ahead planning data for supporting the monthly visual progress analysis and the preparation of the short-term planning. Twenty cycles associated with short-term planning were weekly also conducted. To support this, automatic UAS flights were performed on a weekly basis, using Pix4D app, following a standard grid path defined to cover the construction area. Protocols for safety flights were adopted based on Álvares et al. (2018). The images collected were processed using PhotoScan software, generating photogrammetric point clouds and orthophotos. For the visual progress monitoring of the outside work packages in the monthly cycles, these point clouds (visual representation of as-built progress) were overlapped with the project 3D BIM model and integrated into the 4D BIM (visual representation of as-planned progress) in the Navisworks platform. The progress deviations for outside work were identified from the visual comparison of the models (point cloud and 4D BIM), and the indoor work packages status were identified from direct field measurements by the project team. The progress deviations of all project work packages were also coded with visual color indicators in the 4D simulation to highlight work behind schedule, ahead of schedule, and on schedule.
- *Structured interviews with the project management team:* For the evaluation of the method implementation, structured interviews were conducted in September 2018. The interviewees were the members of the project management team that were directly involved in the method implementation (Table 2). The interview's protocol includes objective questions, using a three-level impact scale (low, intermediate and high), and complementary open-ended questions.

Table 2: Characteristic of the construction management team interviewed

Function	Years of experience in the construction industry	Management level of the function	Interview results classification code
Construction Coordinator	18 years	Top management	CC
Contract Manager	10 years	Construction general management	CM
Production Analyst	4 years and 10 months		PdA
Planning Analyst	2 years and 3 months		PA
Control Analyst	8 years		CA
Engineering Trainee	1 year and 9 months	Production coordination	ET
Engineering Assistant	6 years		EA

EVALUATION OF THE PROPOSED METHOD AND THE PROCESS OF IMPLEMENTATION

This step aims to evaluate the contribution of the proposed method to the progress monitoring improvement. For this, constructs and research variables (evaluation criteria) were defined, as shown in Table 3. These constructs and variables were mainly defined from the literature review, based on what previous studies highlight as management aspects which were improved through the application of systematic and continuous progress control, and the adoption of visual data technologies for progress monitoring. Those previous studies include, for example, the work from Han and Golparvar-Fard (2017), Tezel and Aziz (2017), Tuttas et al. (2017), Son et al. (2017) and Han et al. (2018).

Table 3: Research evaluation criteria - Constructs, Variables and Sources of evidence

Construct	Variables	Sources of evidence
Compliance with the planned goals	- Compliance with the planned progress - Activities started in the estimated period - Activities finished in the estimated duration - Minimization of progress deviations	- Performance indicators' results - Visual models of progress (4D BIM + point cloud) - Project team feedback
Impact on the construction progress deviations	- Improved analysis of progress deviations - Improved identification of the causes of negative progress deviations - Planning and application of actions to correct negative progress deviations	- Structured interviews - Project team feedback - Visual models of progress (4D BIM + point cloud)
Transparency	- Improved communication and identification of progress status - Simple and fast understanding of progress information - Viewing and obtaining new production information	- Structured interviews - Project team feedback - Visual models of progress (4D BIM + point cloud)
Collaboration	- Improved exchange and sharing of progress information - Improved integration and communication among the management team members - Shared analysis of progress status and joint decision-making	- Structured interviews - Project team feedback

INTEGRATED 3D-UAS 4D-BIM VISUAL PROGRESS METHOD

Figure 2 presents the framework of the *Integrated 3D-UAS 4D-BIM Visual Progress Method*, including its three steps, the flow of processes and products. These steps are based on the long-term, look-ahead and short-term planning and control levels. The proposed method framework includes managerial procedures for collection, processing, and analysis of data, and also decision-making procedures, mainly regarding the work progress status.

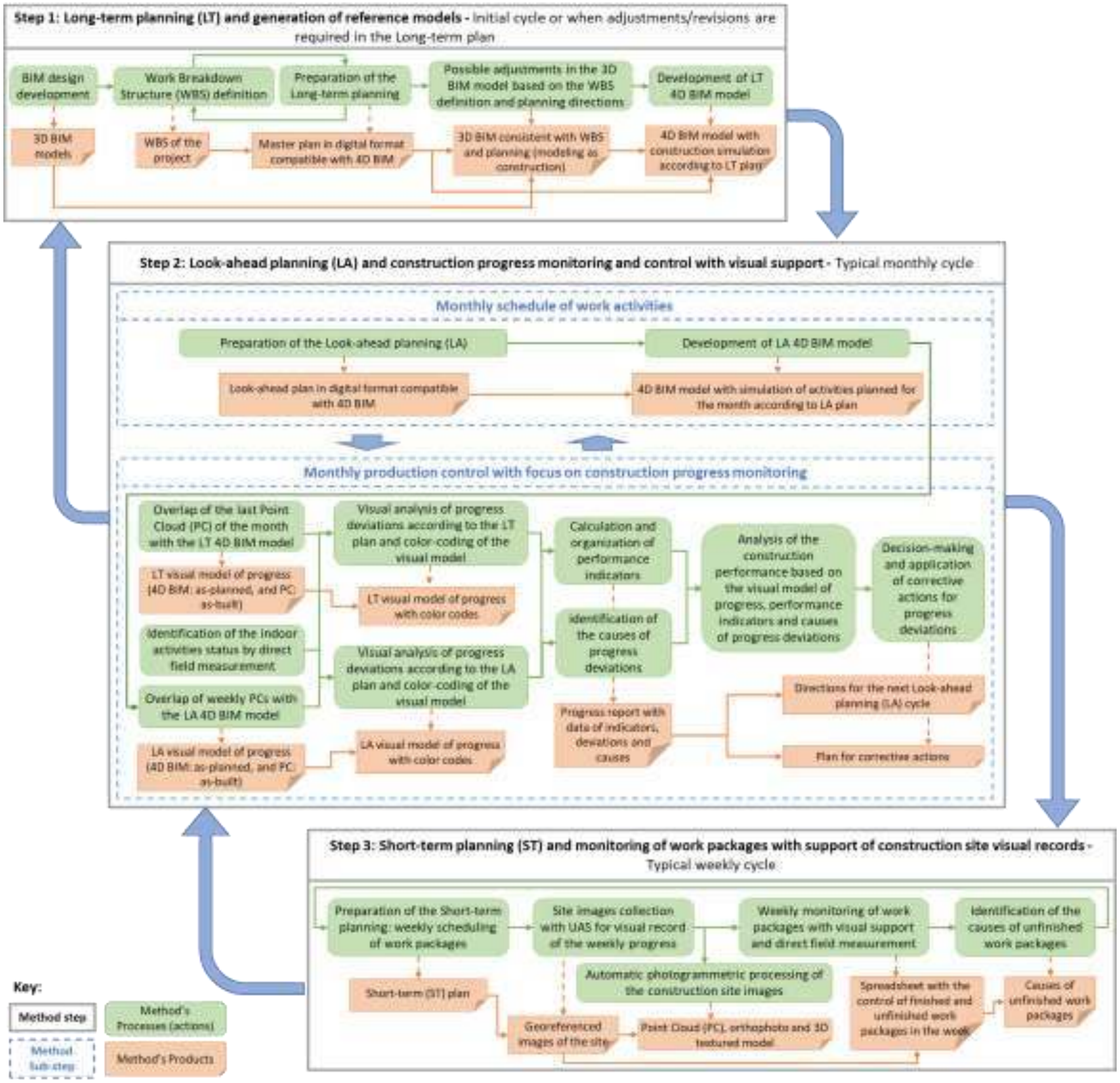

Figure 2: Framework of the **Integrated 3D-UAS 4D-BIM Visual Progress Method**

RESULTS AND DISCUSSIONS

IMPACT ON THE CONSTRUCTION PROJECT DEVELOPMENT

In this section, the data and discussions related to the constructs of "Compliance with the planned goals" and "Impact on the construction progress deviations" are presented.

Table 4 presents performance indicators measured monthly over the implementation period. These data show the construction project improvement in terms of compliance with the planned progress. During the implementation time, the construction eliminated the delays identified in the first three months (negative WPDs) and obtained even higher percentages of work progress than planned over the last two months (positive WPDs).

Table 4: The results of performance indicators over the method's implementation period

Month	**Planned Progress (PP)**	**Work Progress (WP)**	**Work Progress Deviation (WPD)**	**% of the Work Progress Visually Measured (WPVM)**	**% of Activities Started in the Estimated Period (ASEP)**	**% of Activities Finished in the Estimated Duration (AFED)**
April	9.59%	8.75%	**-8.75%**	**66.75%**	69.57%	30.43%
May	10.91%	10.75%	**-1.43%**	**60.18%**	77.27%	31.82%
June	12.70%	9.97%	**-21.50%**	**59.51%**	82.22%	35.56%
July	8.04%	8.51%	**5.81%**	**44.09%**	91.67%	64.58%
August	7.11%	7.66%	**7.72%**	**33.93%**	95.92%	63.27%

Figure 3 shows the results of the visual analyses of progress according to the look-ahead planning on visual models of as-planned and as-built progress (4D BIM + point cloud). In the visual models' view depicted in Figure 3, the 4D simulation paused on the date of the last point cloud of each month is presented with color-coded progress.

Figure 3: Visual models of progress (4D BIM + point cloud) with color codes

Note: Color-code for the work packages: behind schedule in red, ahead of schedule in green, being executed according to the schedule in purple, and already completed in real appearance.

The models in Figure 3 also visually express the improvement of compliance with planned progress. Over the past two months, a decrease in the number of outside work packages behind schedule (in red) can be observed. However, it is important to highlight that the impact of the 3D mapping (point cloud) for visual assessment of as-built progress decreased over the observed months. As long as the proportion of indoor activities grows, such an impact decreased. This can be confirmed by the decrease in "percentage of the work progress visually measured" (Table 4). However, the project team highlighted that the use of the 3D mapping in July and August was still important for the progress monitoring of the activities of facade painting, roof installation, landscaping, and pavement.

Regarding the ASEP and AFED indicators, the values presented in Table 4 also indicate improvements throughout the time in which the method was implemented. The increase of the ASEP represents improvements in compatibility between the activities planned in look-ahead and the monthly activities effectively running at the construction site. The increase of the AFED represents improvements in compatibility between the planned volume of the activities and the total monthly production capacity of the construction site.

The authors believe that the general improvements in terms of compliance with the planned goals and reduction of negative progress deviations could be related to observed changes, including: better structuring in the planning routine at the short-term level; more systematic production control; greater participation of the direct production coordination team in planning and control, providing more realistic production estimates and greater commitment to its compliance; and the positive response of the management team regarding the use of the new information provided by the method implementation.

To further evaluate the impact of the method on the construction progress deviations, three aspects were assessed by the project's team using a three-level impact scale (Table 5) and complemented with questions about the main reasons for the impact levels assigned.

Table 5: Interviewees' evaluation of the "Impact on the construction progress deviations"

Construct	**Evaluated aspect (variable)**	**Evaluation per interviewee of the method's impact**		
		Low	**Intermediate**	**High**
Impact on the construction progress deviations	1) Analysis of progress deviations		CC	CM, PdA, PA, CA, ET, EA
	2) Identification of the causes of negative progress deviations	CC	CA	CM, PdA, PA, ET, EA
	3) Mitigation of negative progress deviations with corrective actions		CC, EA	CM, PdA, PA, CA, ET

Note: The label for the interviewees' classification codes used in this table is presented in Table 2.

The majority of respondents considered the impact of the products and processes of the proposed method high in terms of the "Analysis of progress deviations", "Identification of the causes of negative progress deviations", and "Mitigation of negative progress deviations with corrective actions" (Table 5). According to them, the highest evaluated aspect, "Analysis of progress deviations", was mainly improved by the systematic and integrated use of visual models of progress with color codes and performance indicators.

However, the Construction Coordinator rated as low the impact on "Identification of the causes of negative progress deviations", and as intermediate the impact on the other two evaluated aspects (Table 5). Although he recognized the method's impact on the decision-making about progress negative deviations, he still believes that it is necessary to further incorporate the method's products and processes into the company's management procedures. This would, in his opinion, meaningfully impact all the three evaluated aspects.

The Construction Coordinator is one of the main agents for the implementation's success, so his opinion is essential. In fact, more structural integration of the method into the company's planning and control system is necessary for effective exploring of its potential. Different levels of managerial acting need to be involved in the implementation, adjusting the information and the processes of the method associated with each level.

INCREASED TRANSPARENCY AND COLLABORATION

In this section, the evaluation of the constructs of "Transparency" and "Collaboration" is presented. Table 6 presents the results of the method's impact on the main aspects of these constructs, based on the project team perception using a three-level impact scale.

Table 6: Interviewees' evaluation of the "Transparency" and "Collaboration"

Construct	**Evaluated aspect (variable)**	**Evaluation per interviewee of the method's impact**		
		Low	**Intermediate**	**High**
Transparency	1) Communication and identification of progress status			CC, CM, PdA, PA, CA, ET, EA
	2) Understanding of progress information			CC, CM, PdA, PA, CA, ET, EA
Collaboration	1) Exchange and sharing of progress information		CC, CM, PdA	PA, CA, ET, EA
	2) Integration and communication of the management team		PdA	CC, CM, PA, CA, ET, EA
	3) Shared analysis of progress status and joint decision-making	CC	CM, PdA, CA	PA, ET, EA

Note: The label for the interviewees' classification codes used in this table is presented in Table 2.

According to the data presented in Table 6, a high impact of the implemented tools and processes for increasing transparency was identified. From the use of the visual data technologies and performance indicators, the management team highlighted that the information flow about the construction progress became more visible and understandable.

The project team also highlighted new information obtained about the production as increased transparency indicative. This new information was associated with the identification, analysis and documentation of progress using the visual models (4D BIM + point cloud); the monitoring of the planning effectiveness and the production performance from the data of performance indicators; and the accurate external view of the construction site status (as-built progress) from the aerial photographs and photogrammetric products.

Regarding "Collaboration", the high impact evaluated on the second aspect presented in Table 6 shows a greater integration and communication of the management team in the progress monitoring, especially between the teams of production coordination and general management in commitment meetings for planning and control.

However, a considerable part of respondents evaluated the impact of the method as intermediate and even low on two of the three aspects evaluated for "Collaboration" (Table 6). Although they consider that a shared analysis of the visual models of progress can contribute to better decision-making; the Construction Coordinator and Production Analyst commented that this will only happen effectively when the management team becomes more familiar and has more autonomy over this new way of progress monitoring.

Such evaluation is indeed relevant since the learning curve is very important when it comes to the adoption of new technologies and new working process. When the user gains more familiarity and autonomy over this new way of progress monitoring, the value perceived and the potential explored of the method's products and process are increased.

Because of this, investment in training, development of pilot study for initial experiences, and incorporation of skilled professionals are important aspects that must be considered.

MAIN BENEFITS AND LIMITATIONS OF THE PROPOSED METHOD

To complement the results presented, Table 7 presents a summary of the main benefits and limitations of the proposed method and the implementation process. These benefits and limitations were highlighted by the project management team, based on the interviews.

Table 7: Proposed method benefits and limitations highlighted by the interviewees

Main benefits	Main limitations
• Better visualization and clearer analysis of the construction progress status through the use of the visual models of progress with color codes; • Improvement of compliance with the planned goals; • Better identification of negative deviations of progress and search for solutions; • Increased transparency and collaboration; • Improved short-term planning and control through the systematic information flow and visual data; • A more complete and accurate view of the construction site status from the aerial photographs and photogrammetric products.	• Requires greater incorporation of the proposed method into the company's management procedures; • The short period of the implementation limited the use of the visual models of progress; • The low familiarity of the project team with the used technologies hampered a better use of the visual models of progress; • Lack of visual analysis of the indoor activities.

CONCLUSION

This paper presents the initial implementation and evaluation of the proposed method for systematic visual construction progress monitoring integrating into production planning and control, supported by 4D BIM, 3D mappings using UAS, and performance indicators. The implementation took place in a case study on a Brazilian construction project. The main contribution of this work is a better understanding of the impact and the added value of the information flow provided by the proposed method, in terms of compliance with planned goals, impact on the progress deviations, transparency and collaboration.

The findings show that the adopted visual data technologies and performance indicators have brought about more effective and transparent information flow. It was apparent that the information provided by the method contributed to the improvement of production monitoring and identification of planning failures and progress deviations. This allowed for better compliance with the planned goals over the implementation months. In addition, the project team highlighted the method's impact on the improved analysis of progress and decision-making about planning redirects and corrective actions to negative deviations.

However, limitations were also identified, including the need for a greater integration of the method's processes and products with the company's management procedures; low familiarity and autonomy of the project team with the use of the visual data technologies; and non-visual measurement of the indoor activities' status, still needing of direct field measurements. For the next step in this research, the authors will try to address the identified limitations and a new case study will be developed, including another implementation and evaluation of the proposed method in an enhanced version.

REFERENCES

Álvares, J. S., and Costa, D. B. (2018). "Literature review on visual construction progress monitoring using Unmanned Aerial Vehicles." *Proc. of the 26th Annual Conference of the International Group for Lean Construction*, Chennai, 669-680.

Álvares, J. S., Costa, D. B., Melo, R. R. S. (2018). "Exploratory study of using unmanned aerial system imagery for construction site 3D mapping." *Construction Innovation*, 18(3), 301-320.

Ballard, G., and Tommelein, I. (2016). *Current Process Benchmark for the Last Planner System*. <p2sl.berkeley.edu> (May 17, 2018).

Ballard, H. G. (2000). *The Last Planner System of Production Control*. Ph.D. Dissertation, Faculty of Engineering, The University of Birmingham.

Braun, A., Tuttas, S., Borrmann, A., Stilla, U. (2015). "A concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds." *Journal of Information Technology in Construction (ITcon)*, 20, 68-79.

Del Pico, W. J. (2013). Project Control: Integrating Cost and Schedule in Construction. Hoboken: John Wiley & Sons, Inc.

Han, K. K., and Golparvar-Fard, M. (2015). "Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs." *Automation in Construction*, 53, 44-57.

Han, K. K., and Golparvar-Fard, M. (2017). "Potential of big visual data and building information modeling for construction performance analytics: An exploratory study." *Automation in Construction*, 73, 184-198.

Han, K. K., Degol, J., Golparvar-Fard, M. (2018). "Geometry- and Appearance-Based Reasoning of Construction Progress Monitoring." *Journal of Construction Engineering and Management*, 10.1061/(ASCE)CO.1943-7862.0001428, 144(2): 04017110.

Kopsida, M., Brilakis, I., Vela, P. A. (2015). "A Review of Automated Construction Progress Monitoring and Inspection Methods." *Proc. of the 32nd CIB W78 Conference 2015*, Eindhoven, 421-431.

Lin, J. J., and Golparvar-Fard, M. (2017). "Proactive Construction Project Controls via Predictive Visual Data Analytics." *Proc., Computing in Civil Engineering*, Seattle, 147-154.

Son, H., Kim, C. Cho, Y. K. (2017). "Automated Schedule Updates Using As-Built Data and a 4D Building Information Model." *Journal of Management Engineering*, 10.1061/(ASCE)ME.1943-5479.0000528, 33(4): 04017012.

Teizer, J. (2015). "Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites." *Advanced Engineering Informatics,* 29, 225-238.

Tezel, A., and Aziz, Z. (2017). "From Conventional to IT Based Visual Management: A Conceptual Discussion for Lean Construction." *Journal of Information Technology in Construction (ITcon)*, 22, 220-246.

Tuttas, S., Braun, A., Borrmann, A., Stilla, U. (2017). "Acquisition and Consecutive Registration of Photogrammetric Point Clouds for Construction Progress Monitoring Using a 4D BIM." *Photogrammetrie, Fernerkundung, Geoinformation*, 85, 3-15.

Van Aken, J. E., and Romme, G. (2009). "Reinventing the future: adding design Science to the repertoire of organization and management studies." *Organization Management Journal*, 6, 5-12.

Yang, J., Park, M.-W., Vela, P. A., Golparvar-Fard, M. (2015). "Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future." *Advanced Engineering Informatics*, 29, 211-224.