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IMPROVING REASONS FOR NON-COMPLIANCE DOCUMENTATION USING UAV ON CONSTRUCTION PROJECTS

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ABSTRACT

Most Last Planner System® (LPS) research focused on finding the Reasons for Non-Compliance (RNC) and their origins come from indirect means such as perception surveys, therefore, registered RNC are based on opinions and not facts. This situation causes an incorrect categorization of RNC, and consequently, these RNC remain unsolved and they would probably happen again.

The aim of this research is to create a formal registry of RNC on construction building projects during rough works for improving RNC documentation, using photos taken by an unmanned aerial vehicle (UAV). We performed 3 case studies: one using a traditional planning method, and two other projects using partial LPS implementation. We took aerial photos with the UAV to register unfulfilled Work Commitments (WC), their RNC and to propose a Corrective Action (CA) that would solve the RNC. This registry is supported by analyzing the RNC with an Ishikawa Diagram and using the 5 Why 2 How method (5W2H) to systematically propose a CA. We documented all this information in a “RNC Form” for each RNC detected. We took photos once a week for the project with a traditional planning method and twice a week for the projects with partial LPS implementation. We created 22 RNC Forms, which we shared with the project team professionals to receive feedback.

The results are a methodology that accounts for a standardized process on how to carry out the UAV flights, photo taking and subsequently, how to document the RNC creating a RNC Form. This shows a more objective and visual record of the RNC, from which a process of continuous improvement is encouraged, by proposing a CA that solves the identified problem. The methodology and the RNC Form were validated with surveys on a Likert scale, from 1 (strongly disagree) to 4 (strongly agree). We interviewed 7 construction field professionals from the three projects. The composition of the RNC Form and the future use of the proposed methodology reached a score of 4.0 and 3.9 respectively; therefore, they were highly valued by the field professionals.

KEYWORDS

Reasons for non-compliance, RNC, UAV, LPS, corrective action.

INTRODUCTION

Since its introduction by Glenn Ballard and Greg Howell at the end of the 20th century, the Last Planner System® (LPS) has proven to be an efficient tool in project management, evolving from short-term planning and problem solving to a unified, continuous process improvement system for planning and control of projects throughout their entire life cycle (Ballard & Tommelein, 2020).

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Despite the adoption of LPS, a large majority of construction projects implements only partial LPS, and they usually focus on short-term planning. The Percentage of Plan Completed (PPC) and Reasons for Non-Compliance (RNC) are the most used metrics on LPS projects (Daniel et al., 2015). However, RNC, which are recorded to generate a Corrective Action (CA) and thus prevent future recurrence, usually come from single case studies or indirect means such as perception surveys (Lagos & Alarcón, 2021). This indirect process may result in failure to identify the real source of the RNC, causing the proposed CA to be incorrect and not providing an adequate solution to the problem. Thus, our research question is: What should be the procedure to improve RNC documentation?

Therefore, this research proposes a methodology for documenting the RNC. We propose to use a type A3 document (Gupta et al., 2019; Koskela et al., 2020) called "RNC Form" to visually document site conditions related to detected RNC. The RNC Form provides background information about the Work Commitments (WC), it describes the RNC type and its impacts and once the problem is identified, it recommends a CA, which provides a solution to the problem. Site photos taken using an unmanned aerial vehicle (UAV) support this process. We also use the project schedule, and the construction methodologies to visually show the unfulfilled WC for short term planning. Our aim is to standardize the proposed methodology, indicating the relevant parameters for an adequate documentation and the required time to carry this out. We expect to replicate this procedure in future projects.

LITERATURE REVIEW

Reason for Non-Compliance (RNC) is defined in the Last Planner System® (LPS) literature as the reason why short term Work Commitments (WC) are not fulfilled (Ballard, 2000).

Most of the RNC are caused by the general contractors (construction companies) and subcontractors in high-rise building projects (Lagos & Alarcon, 2021). The lack of workspace is a frequent problem that construction companies must constantly coordinate and review to avoid site congestion and interference among trades that affect the work performance for the rest of the team (Sabbatino et al., 2011). Subcontracts fail in what is generally the most frequent RNC in the construction industry: lack of labor (Sabbatino et al., 2011).

Registry of RNC usually comes through third parties (Lagos & Alarcón, 2021) or indirect means (Daniel et al., 2015), which can lead to erroneous registry and consequently to persistent unsolved construction problems. This deficiency of current LPS practice should be addressed. According to López (2013) the average PPC in construction projects does not exceed 70%, therefore this represent a big problem. The lack of an accurate RNC registry can be addressed using the Ishikawa Diagram analysis to visually identify the root causes of RNC in 6 generic categories of idea generation (Tague, 2005).

We identify the RNC to understand the causes of the problem and to generate a corrective action (CA). Thus, we create a continuous improvement process and we avoid the repetition of RNC for subsequent WC (Ballard, 2000). We used the 5W2H method for this purpose (Tague, 2005) and we asked 7 structured questions to briefly explain the proposed CA, to describe the procedure to follow and justify its cost. As input, we use all relevant information about the detected RNC (problem).

The use of a camera-equipped UAV provides an unprecedented opportunity for inexpensive, easy and fast documentation of the execution of on-site planning (Ham et al., 2016) and this information allow us to find of a large number of spatial interferences (Zapata & Sánchez, 2020). UAVs have been used in the construction industry for different purposes, such as: safety inspections (Irizarry et al., 2012), applications in construction management like land surveying, logistics, on-site construction, maintenance and demolition (Li & Liu, 2019). They have even been used for progress tracking (Álvares & Costa, 2018). However, commercial use of UAVs has experienced an exponential growth in recent years, which has consequently led to an increase of aerial incidents recorded in the last decade (Pérez & Ortiz, 2020). Therefore, we need an UAV flight strategy adequate to each project´s site conditions.

Bordin et al. (2018) noted the use of A3 reports as a Kaizen tool to provide context of a problem, describe the current situation, the improvement objective, provide an analysis, and an action plan that addressed the situation to be improved. According to Gupta et al. (2019), A3 documents have a great potential to improve the effectiveness and communication of information in the construction industry. Therefore, we standardized the format to describe the information gathered in the field and to present the analyses performed using an A3 document as a single page report.

METHODOLOGY

We followed the CIFE Horseshoe (Fischer, 2006) to guide our observation of a practical problem, to develop a plan to address it. In our literature review, we identified the lack of objectivity in the registration of RNC as a problem and we found that UAV use might facilitate visual information to perform such registration (Chica et al., 2019; Zapata & Sánchez, 2020). The most common RNC in Chilean construction projects during rough construction are: lack of labor, lack of workspace and missing prerequisites (Sabbatino et al., 2011), therefore that will be our initial research focus. Then, we will document non-compliance of work commitments (construction activities) using UAV pictures.

We carried out three case studies on Chilean building projects during the rough works stage. One of the projects used traditional planning, while the other two had a partial LPS implementation. We conducted on-site monitoring for a maximum of 6 weeks per project. We planned UAV flight strategies for each project to take high-resolution photos of workspaces and to avoid possible accidents both on the field and on its surroundings. Figure 1 shows the three case studies. Figure 1a shows a 2-story building in a low-density neighborhood. Figure 1b and 1c show cases 2 and 3, both midsize residential buildings on high density neighborhoods.

We analyzed the RNC using the visual information of unfulfilled work commitments (WC). We briefly explained the factors causing non-compliance using an Ishikawa Diagram. After analyzing the RNC, we proposed a Corrective Action (CA) using the 5W2H methodology, providing a brief explanation of the procedure. We created a RNC Form that documents the analysis and visualization of the detected RNC and we shared it with the field office to receive feedback.

Figure 1: Case Studies: (a) 2-story reinforced concrete and confined masonry building (384 m2); (b) 7-story reinforced concrete building (approx. 2,000 m2); (c) 7-story reinforced concrete building (approx. 900 m2).

Finally, we applied validation surveys to the project team members for each case study to quantify the impact of this research. 7 construction professionals (civil engineers and construction managers with 5-10 years of construction experience), answered our survey after a 30-min presentation of our methodology. Their familiarity with the project, with our work and the weekly feedback received during the on-site monitoring brought valuable feedback to our proposal. The validation survey had 11 question and we used a Likert scale, from 1 (strongly disagree) to 4 (strongly agree) to receive feedback about the proposed methodology, the structure of the RNC Form and the future use of the proposed methodology.

RESULTS

We created 22 RNC Forms that we shared with project team members for each case study to validate our hypothesis about the need of an objective RNC registry. At the end of the 6-week construction project monitoring, we showed our RNC Forms and methodology to each field office team and asked them for feedback with a validation survey. The purpose of this survey was to demonstrate the usefulness of the proposed methodology, the adequate visualization and understanding of the RNC Form structure and to test the potential adoption of this process in future projects.

PROPOSED METHODOLOGY

Figure 2 summarizes the main three components of the methodology: (i) Creation of a flight strategy in a simulated environment (steps in light blue); (ii) Weekly site visits (steps in gray); and (iii) Creation of the RNC Form (steps in orange). The time required for the execution of the proposed methodology is divided into two categories:

1. One time processes: They establish the flight strategy for each case study. They have a total duration of 4:30 hours and we show them in light blue in Figure 2.

2. Periodically executed processes: Steps that are executed every week. Total execution time depends on the number of weekly site visits and the number of RNC Forms made. The site visit includes the request of the weekly planning, thus, we know the weekly work commitments and workspaces beforehand and we plan the UAV flight strategy and capture pictures accordingly. The RNC Forms register the unfulfilled WC and their RNC, according to the weekly planning. Figure 2 shows that each site visit takes 45 minutes (grey steps), and that the estimated time to create a RNC Form is 1 hour (orange steps).

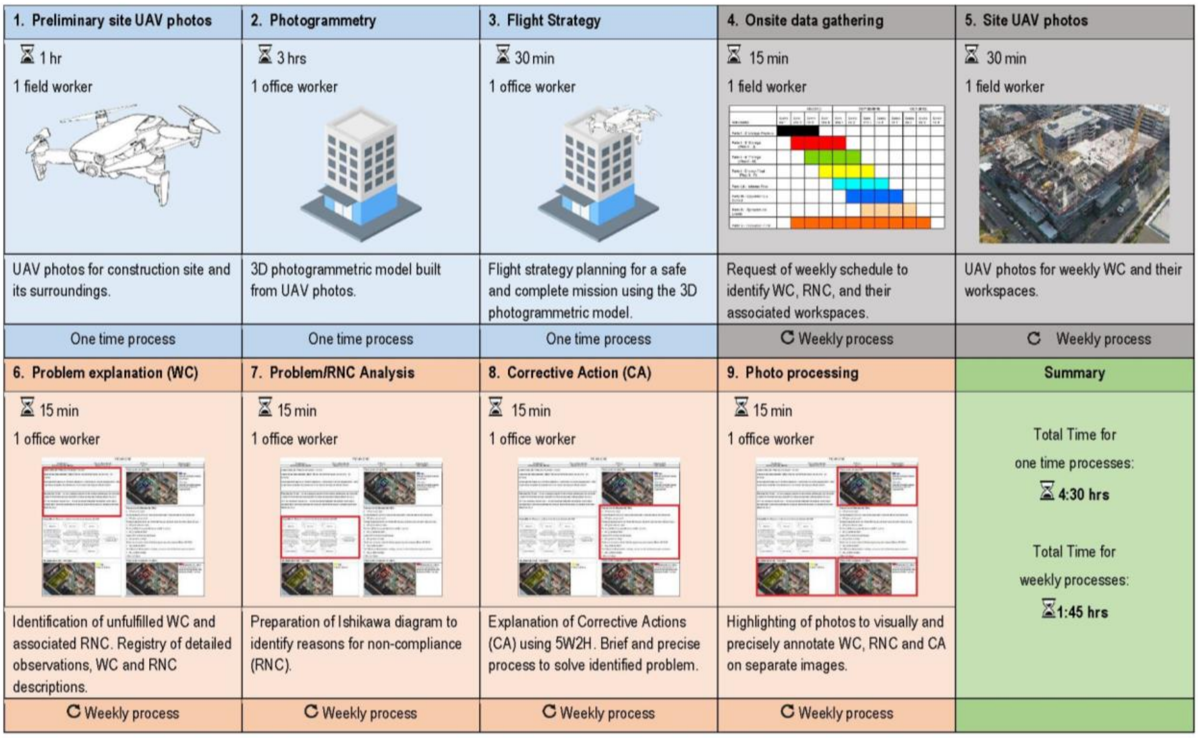

Figure 2: Proposed methodology and execution time summary.

Flight Strategy

We created photogrammetric 3D models to develop a flight strategy for each project. These models, shown in Figure 3, allowed us to explore the construction site and its surroundings for each case study, in order to plan the weekly UAV photo shooting and avoid obstacles. We built the photogrammetric model from a single grid flight mission around each project site. Each model is approx. 100 m by 100 m. These parameters allowed us to generate photogrammetric models with a GSD of less than 2 cm/pixel. On these 3D photogrammetric models, we planned/tested the flight strategies. In most cases, we chose circular flights around fixed points on site, with a target flight height of 40 m and a radius of 30 m (as shown in Figure 3).

Case study 1: The project size is approximately 12 m by 32 m, so our flight strategy captured the entire project with a single circular UAV flight, as shown in Figure 3a.

Case study 2: The largest project required 3 circular UAV flights to cover the entire project site, as shown in Figure 3b. Unlike the other case studies, this project was near completion of the rough works during our research, thus we only spent 4 weeks on-site and consequently we built fewer RNC Forms.

Case study 3: The buildings surroundings and the presence of a tower crane in this project, forced us to reduce the flight strategy to a semicircle (as shown in Figure 3c) and to elevate the flight height from 40 m to 60 m to avoid collision with the crane.

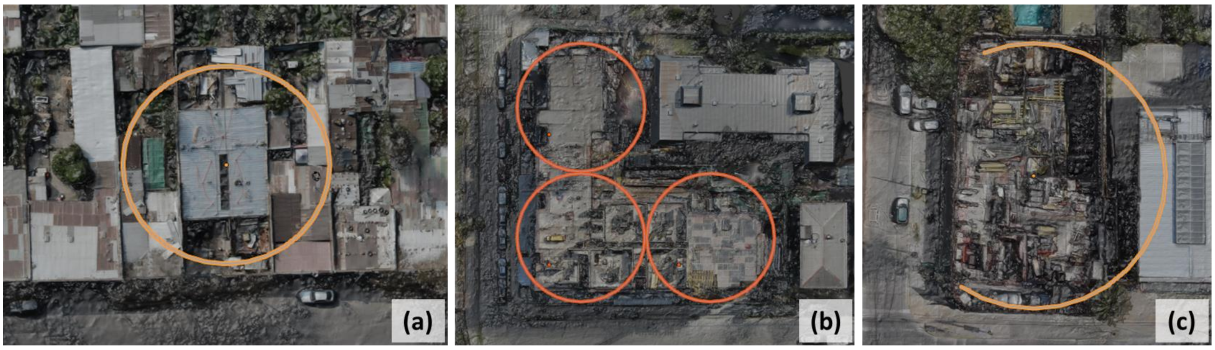

Figure 3: Flight Strategies: (a) Case study 1: single circular flight; (b) Case study 2: large project footprint demands 3 circular flights; (c) Case study 3: obstacles and tower crane presence force a semicircle flight.

Weekly Project Visit

We visited each project twice a week during the construction project monitoring. We executed our UAV flight strategies to take site photos. We asked about the construction processes and WC for each case study, and we gathered information about the weekly planning. We also showed the RNC Forms from past weeks to the field professionals. The visits were at least 1 day apart, to be able to notice significant changes between one visit and another. Case study 1 was the smallest project and it used a traditional planning method. It did not show much weekly progress, thus we reduced the site visits to once per week.

RNC FORM

The RNC Form is divided into 2 main parts: left and right. The left part seeks to describe and provide context to the unfulfilled WC, the identification of the associated RNC and its analysis using the Ishikawa Diagram, and an illustration of the WC and its location in the field. The right part seeks to illustrate the RNC, how to achieve the CA using the 5W2H method and a picture showing the CA location. Figure 4 shows a RNC Form that has 7 major sections: (1) General Information about the construction company, date and time of photos for the CNC Form, and the UAV operator's name; (2) Background about the name, description, and explanation of the WC and RNC; (3) Ishikawa Diagram that explains the factors causing unfulfilled WC; (4) WC

Visualization that shows an annotated (yellow) photo of the WC location, and a brief text description; (5) RNC Visualization that shows an annotated photo (blue) of the RNC location and type; (6) Corrective Action (CA) that describes the solution to the RNC according to the 5W2H method; and (7) Visualization of the CA that shows an annotated photo (red) of the CA location, accompanied by a brief explanation.

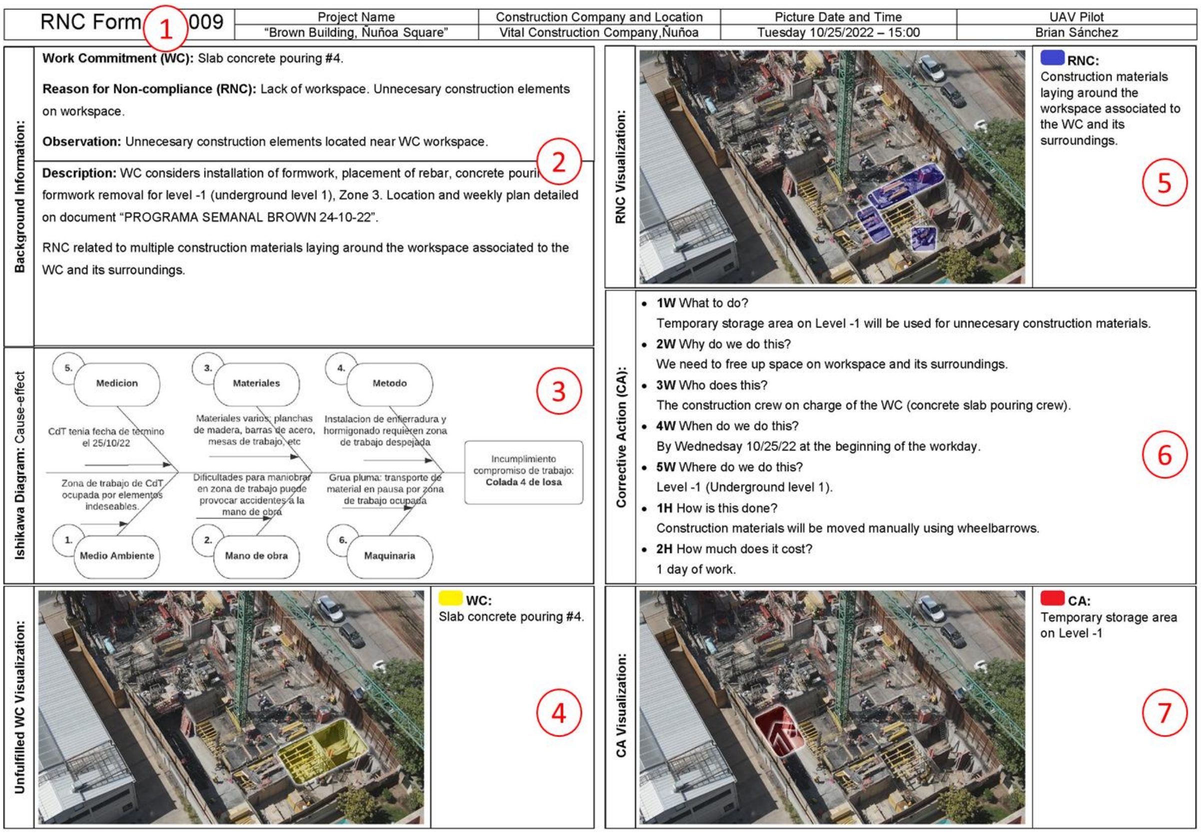

Figure 4: RNC Form 009, Case Study 3 – Brown Building, Ñuñoa Square.

We analyzed the photos taken during the week to identify and describe the unfulfilled WC and to identify and classify the observed RNC.

RNC are different in nature, thus for each type of RNC studied, we built a detailed definition of the 6 categories of the Ishikawa Diagram: Measurement, Materials, Method, Environment, Labor and Equipment. For instance, *RNC lack of workspace* refers to any undesirable element that prevents the realization of the WC. This can be dirt, debris and/or disorganized storage of materials. In this case, *Environment* is the most relevant aspect for the RNC (what can I find in the workspace? and why it hinders WC?). We list each category according to its importance for each case: 1 is the most important factor in the diagram and 6 the least important. This ranking varies for each RNC type. However, for the same RNC type, the main category is always the same. *Labor* is the most important factor for *RNC lack of labor* and *Measurement* is the most important factor for *RNC missing prerequisites.*

For each recorded RNC, we proposed a corrective action (CA) to solve the problem using the 5W2H method (Tague, 2005). After defining the CA, we searched among the UAV photos to find the one that best visually depicts the site conditions. We use yellow, blue and red annotations in the picture to highlight the location of the WC, RNC and CA respectively. We highlight them in separated pictures to avoid annotation overlapping, as shown in Figure 4.

We prepared at least 1 RNC Forms for each site visit and we showed them to the field professionals for each project the following week. We shared the RNC Forms in A3 format as shown in Figure 4 in both electronic (PDF) and printed form.

We prepared and shared 22 RNC Forms for the 3 case studies with the field professionals and we periodically received their feedback and validation regarding the RNC, its depiction, and the associated CA. Several of our suggested CA were actually implemented. We did not find *RNC lack of labor*. We found 9 instances of *RNC missing prerequisites*, 8 instances of *RNC lack of workspace* and we had to define a new type we called *RNC lack of materials* (5 instances). We created 6 RNC Forms for Case Study 1 (our guinea-pig project), 6 RNC Forms for Case Study 2 and 10 RNC Forms for Case Study 3.

VALIDATION

We applied a validation survey to 7 field professionals from the 3 case studies. The survey has three major groups of questions. First, we asked whether the proposed methodology is adequate as a tool for creating an objective RNC registry for short term planning. We asked about the suggested procedure and the time required for its execution. Second, we asked whether the RNC Form structure is clear. We asked if the RNC Form adequately explains, analyzes and visualizes the WC; and if it adequately describes and visualizes the RNC; and if it adequately explains the proposed CA and its visualization. Third, we asked about the future use of the proposed methodology for construction projects during rough works. We used a Likert scale for the validation survey with multiple-choice answers ranging from 1 to 4, where: strongly disagree (1), disagree (2), agree (3) and strongly agree (4). The validation results are shown in Figure 5.

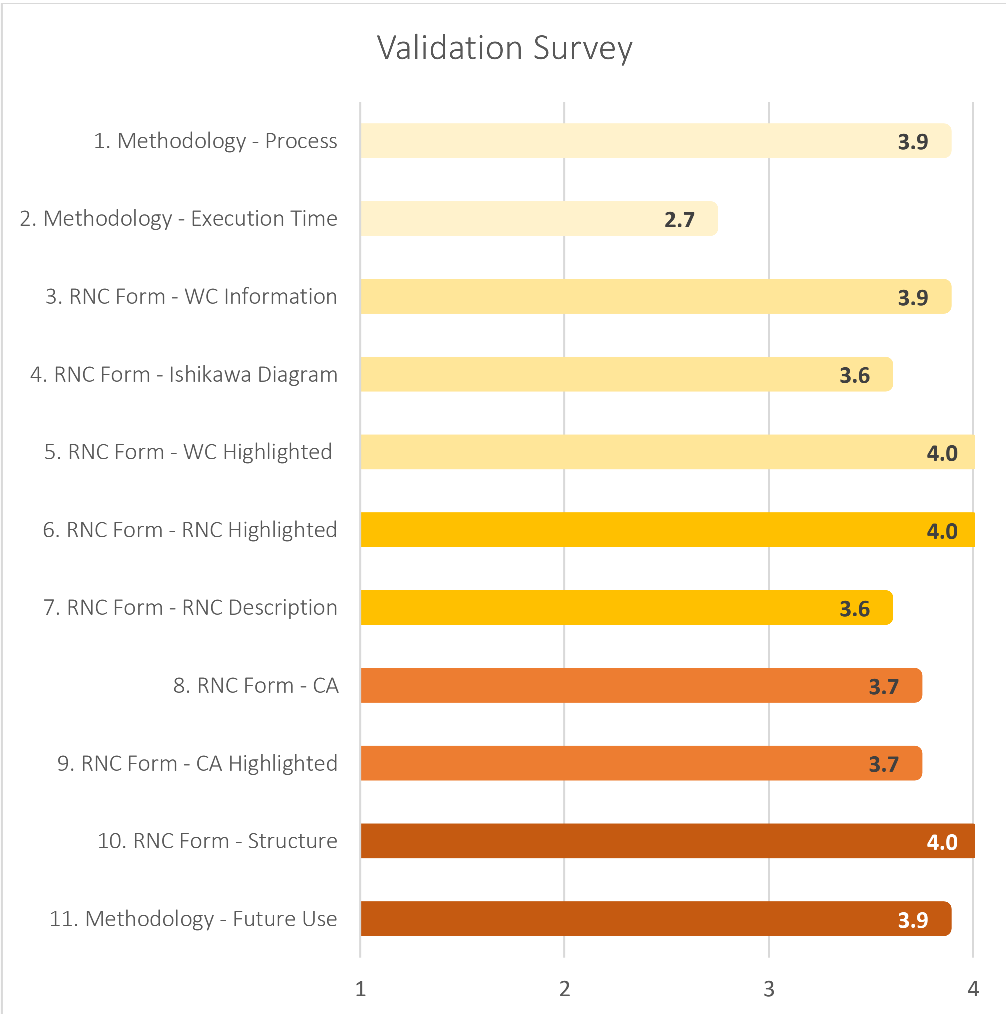

Figure 5: Validation Survey Summary Results.

In the first group of questions, we asked about the proposed methodology and it was well received with an average score of 3.3 (Q1 & Q2). For the second group of questions we asked about the RNC Form and its structure as a registry for RNC. We received a high level of approval with an average score of 3.8 (Q3 to Q10). In the third group of questions, we asked about future use of our methodology and we obtained the best results with an average score of 3.9 (Q11). Thus, as a whole we obtained an overall score of 3.7 in the survey, which means that our methodology was highly valued by the field professionals.

Respondents liked the proposed research with an average score of 3.9, but they pointed out that was a lengthy process with a score of 2.7, as shown in Figure 5. Regarding the RNC Form, respondents valued the WC section, and they rated the WC background context, the explanatory Ishikawa diagram and the WC visual annotation with scores of 3.9, 3.6 and 4.0 respectively. They also valued the RNC visualization and the explanation for each annotated picture, with scores of 4.0 and 3.6 respectively. Respondents also valued the CA proposed using the 5W2H method and its annotated picture, where both received a score of 3.7. Finally, the respondents had a positive feedback about the structure/organization of the RNC Form and they were willing to use the methodology in future projects, with scores of 4.0 and 3.9 respectively.

DISCUSSION

In our literature review, we identified the "lack of labor" as a relevant RNC during rough works projects; however, we could not capture this type of RNC in our UAV flights for the three case studies. We took photos during our site visits centered on the workspace for each WC, but the crews of construction trades were constantly moving throughout the construction site and we could not document missing workers. Therefore, we were not certain that unfulfilled WC were due to lack of labor.

Depending on the project scheduling sophistication, the project team valued differently our proposed methodology. Team members from Case Study 1 (traditional planning) valued the suggested CA for unfulfilled WC. For instance, in our 1st RNC Form we suggested the implementation of a temporary staircase that would provide safe access to the 2nd floor. Our RNC Form documented the problem and CA proposed and the project team built such staircase (on a different location though). For Case Studies 2 and 3 (partial LPS planning), the project team particularly valued the usefulness of the RNC analysis shown in the Ishikawa Diagram of the RNC Form. As no formal RNC registry existed, they valued the RNC analysis, which complemented the weekly planning and project PPC metric (Percentage of Plan Completed).

Our RNC Form arose from the need to summarize the analyses of the proposed methodology in a compact format and using weekly visual information from the UAV pictures. The RNC Form final version corresponds to the 7th iteration of this process. We modified preliminary versions of the RNC Forms, both by incorporating the feedback obtained in each project from the field professionals and by continuous improvement.

CONCLUSIONS

The purpose of this research was to create an objective RNC registry, based on actual weekly site conditions. We proposed a methodology that standardized the analyses for the WC, the RNC and its associated CA, and that is visually supported by photos taken using an UAV. We called it the RNC Form. We built 22 RNC Forms for the 3 case studies. We received feedback and validated the RNC Form and our methodology with field professionals.

Our methodology has an estimated execution time of 1 hour per week per RNC Form and can be summarized in three parts:

(1) Flight strategy in a simulated environment: We use a 3D photogrammetric model to create a safe and efficient UAV flight strategy for each project. This process is done only once per project and has an estimated duration of 4:30 hours.
(2) Weekly site visits: We gather site information to build a RNC Form. We asked for the project weekly planning and used the flight strategy for taking UAV photos of the workspace associated to weekly work commitments (WC). This weekly process lasts approximately 45 minutes.
(3) RNC Form: Given the weekly schedule, the unfulfilled WC and the RNC, we built visual RNC Forms that proposed a CA. This weekly process lasts approximately 1 hour per RNC Form.

Our validation survey shows that field professional valued our visual RNC Form (The overall score of 3.7). They considered adequate the explanation and description of the WC, the RNC analyses, and the suggested CA (with an average score of 3.8). They are willing to use the RNC Form in future projects (average score of 3.9).

FURTHER RESEARCH

Our methodology aims to work in support of field professionals, i.e., we do not want to interfere in the construction processes or planning used in building projects. We want to enhance the scheduling process, using an LPS-based tool to document RNC that interrupt the workflow and propose a solution (CA) that eliminates waste.

We see opportunities for future research implementing RNC Forms on different types of construction projects as well as exploring other types of RNC. We applied the methodology on 3 case studies during the rough works, but we see potential for use during other construction phases such as excavation. We worked on an urban environment, but we could also explore the application of our RNC Forms on other building types on rural or/and remote environments.

Finally, if we are able to systematically create RNC Forms for ongoing projects, which seems plausible given the acceptance and willingness to use them by field professionals, we could perform a better categorization of RNC Forms, beyond the three types we found with our UAV-pictures (*RNC missing prerequisites*, *RNC lack of workspace* and *RNC lack of materials*). Once we have a large number of RNC Forms, we could perform statistical analyses of RNC or explore the effectiveness of CA to avoid recurrence of RNC.

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