Automation of schedule of values process for subcontractors using technological tools in residential buildings projects

R Chavez, Bachelor of School of Civil Engineering[1], S Vilchez, Bachelor of School of Civil Engineering[1],
S Rodriguez, Master of School of Civil Engineering[1], and A Hinostroza, Master of School of Civil Engineering[1]
[1]Universidad Peruana de Ciencias Aplicadas, Perú, u201612546@upc.edu.pe, u201615789@upc.edu.pe,
sandra.rodriguez@upc.edu.pe, pcipahin@upc.edu.pe

***Abstract–* A common and well-established practice in residential building projects is for main contractors to resort to subcontracting, that is outsourcing the execution of specific project activities to another party, generally more specialized. The purpose is to achieve the quality standards of assigned activities and reduce costs of work execution by transferring the risk. However, it increases supervision workload for main contractor, which reflects in control and coordination issues, since monitoring and controlling project work as well as schedule of values are processes performed manually. This becomes more relevant during the finishing phase, where there are at least ten subcontractors working simultaneously and since there is not an efficient progress tracking method, it results in a time consuming and error-prone task for project team.**

For this reason, this paper proposes to automate part of the schedule of values process for subcontractors by implementing BIM methodology, using modeling software and programming tools. Thus, repetitive tasks are optimized in order to reduce the time associated with this process. The proposal does not intend to be disruptive, allowing it to adapt to the current workflow. By implementing the proposal, a reduction in time average spent by the project members involved in the schedule of values process is achieved.

Keywords— BIM, Schedule of Values, Subcontract, Dynamo, Automation

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2021.1.1.550
ISBN: 978-958-52071-8-9 ISSN: 2414-6390

Automation of schedule of values process for subcontractors using technological tools in residential buildings projects

R Chavez, Bachelor of School of Civil Engineering[1], S Vilchez, Bachelor of School of Civil Engineering[1],
S Rodriguez, Master of School of Civil Engineering[1], and A Hinostroza, Master of School of Civil Engineering[1]
[1]Universidad Peruana de Ciencias Aplicadas, Perú, u201612546@upc.edu.pe, u201615789@upc.edu.pe,
sandra.rodriguez@upc.edu.pe, pcipahin@upc.edu.pe

***Abstract*– A common and well-established practice in residential building projects is for main contractors to resort to subcontracting, that is outsourcing the execution of specific project activities to another party, generally more specialized. The purpose is to achieve the quality standards of assigned activities and reduce costs of work execution by transferring the risk. However, it increases supervision workload for main contractor, which reflects in control and coordination issues, since monitoring and controlling project work as well as schedule of values are processes performed manually. This becomes more relevant during the finishing phase, where there are at least ten subcontractors working simultaneously and since there is not an efficient progress tracking method, it results in a time consuming and error-prone task for project team.**

For this reason, this paper proposes to automate part of the schedule of values process for subcontractors by implementing BIM methodology, using modeling software and programming tools. Thus, repetitive tasks are optimized in order to reduce the time associated with this process. The proposal does not intend to be disruptive, allowing it to adapt to the current workflow. By implementing the proposal, a reduction in time average spent by the project members involved in the schedule of values process is achieved.

Keywords— BIM, Schedule of Values, Subcontract, Dynamo, Automation

I. INTRODUCTION

In residential building projects there is a high level of demand in quality, guarantee and safety. That is why main contractors resort to personnel with greater specialization in tasks such as architectural finishes and equipment, seeking to guarantee correct work, as well as reduce execution costs and transfer risks. However, this results in an increase in the number of responsible in the project, as well as their interdependence [1], since a large percentage of these works are performed in parallel. From the projects analyzed in this research, it is estimated that there are around ten subcontractors working simultaneously during finishing phase. This increase makes main contractor's supervision and control tasks tedious when issuing the corresponding Schedule of Values or SOV, which is a start-to-finish list of work items on a project and their associated cost, because this process is usually effectuated manually where precision, difficulty, the time required and the level of skill could not exist in the personnel in charge of this task [2]; This may cause delays and errors in the payment-request of the subcontractors SOV, usually weekly, intensifying conflicts between the project stakeholders putting project's overall progress at risk [3]. Consequently, due to the lack of time and control, main contractor neglects other activities that helps create value for project.

The use of digital tools to optimize the monitoring of progress in residential works it is becoming more common. Research proposes the use of a mobile app named Finalcad, resulting in a 30%-time reduction for preparing the project's daily progress report [4]. Likewise, the lack of digitization in the monitoring and control of projects is a frequent problem in construction projects, due to the use of Finalcad is proposed to reduce the time of observation management process. As a result, the duration of the process is reduced by 44%, demonstrating the usefulness of digital tools [5]. The implementation of BIM during project development encourages a collaborative work environment where coordination of stakeholders is substantially improved, which generates a more reliable information flow and synthesize a large part of conventional processes [6]. A methodology has been developed that integrates BIM and Ontology to establish an ontological model that expresses the payment-request information of the work item and its relationship with the BIM elements in a model, according to the LOD (Level of Development) specified. Then, the required quantities are obtained directly from the attributes of the BIM elements through custom algorithms required by the work items and are exported to a database to speed up the processing of payment according to the subcontractor's SOV report. The research proposes the use of visual programming in Dynamo, which automates workflows within Revit. Authors conclude that the use of BIM makes it easier for the project manager to generate and control subcontractors SOV [7]. In addition, Dynamo is used to facilitate data transfer from a BIM model to external software such as Microsoft Excel. This proposal seeks to automate repetitive tasks using macros, API and parametric design tools, which allows manipulating, classifying and assigning information to the BIM element on the model. The result obtained is the cost and time reduction invested to maintain a BIM model throughout the life of a project [8]. In 2020, the concept of "BIM contracts" was introduced by linking digital information models (BIM) with "Smart Contracts", using the "Blockchain" technological system. This approach provides an integrated automated billing model, where all the quantities involved (materials and labor) in the execution of outsourced activities are extracted from BIM elements on the model, the same that define the bases of the process's verification of the contract. If the progress made has been reviewed and accepted, the payment-request is generated automatically. The authors conclude that the proposal makes the management of payments to subcontractors in construction projects simpler, more transparent and automated [9]. On the other hand, an investigation focuses on BIM solutions by integrating the cost component to a BIM model, turning it into a 5D BIM model from which a budget can be instantly generated by taking advantage of the Quantity Takeoff function (data quantification) that significantly reduces the time to extract data from the BIM model, improves the accuracy of calculations, minimizes conflicts caused by ambiguity in CAD data, and enables main contractors to spend their time creating value for the project [10].

The contributions of the previous authors are aimed at optimizing, through digital tools, various functions of the work staff such as the control and monitoring tasks of progress, as well as the subcontractors SOV report payments. However, previous research is still limited. Therefore, this research proposes to automate the process of valuation of subcontractors using a visual programming language tool in a collaborative BIM environment that allows reducing the average time required to issue a SOV report.

II. METHODOLOGY

In order to achieve the objectives of the research, buildings projects for residential use with similar characteristics are evaluated. These projects are executed by small and medium sized construction companies. This scenario is chosen, due to the substantial increase in demand for these projects in the real estate sector. The sample that has been evaluated, is shown in Table 1.

TABLE 1.
SUMMARY OF THE PROJECTS

	Evaluated Projects			
Characteristics	Project 1	Project 2	Project 3	Project 4
N° of Floors	07	07	07	07
N° of subcontractors	09	12	11	10
Company size	Small	Medium	Medium	Medium
Finishing stage time	8 months	9 months	8 months	7 months
Use	Residential			

The information extracted from projects 1, 2 and 3 is considered to define the scope of the problem and outline the traditional schedule of values process for subcontractors. While project 4 serves as the scenario for the implementation of the proposal process.

This research conducts interviews to identify the deficiencies present during the schedule of values process, in addition to pie charts that determine the critical specialty of the project, that has the largest number of outsourced items. Likewise, flowcharts are used to describe the traditional process and the proposal, and comparative tables are used to perform the analysis of results between both processes by comparing time indicator. As part of the implementation, Revit; BIM modeling software, and Dynamo are used. The last one is a visual programming application that allows developing custom algorithm that follow a logical sequence of processes with inputs and outputs of information extracted from the 3D model.

In order to achieve the objective of the study, the following research process is developed:

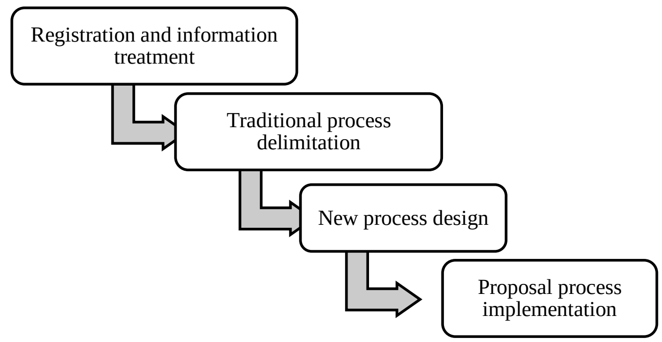

Fig. 1: Research methodology

First, the information collected from the evaluated sample is recorded to determine the specialty of the project with the highest incidence of subcontracting. The evaluated specialties are structures, architecture, sanitary facilities, electrical facilities and mechanical facilities. After this, the deficiencies of the selected specialty, during the schedule of value process, are detailed.

Then, the current schedule of value process, those responsible and the tasks that conform that process are defined through a flow chart. From the schematization, the average time it takes for the personnel in charge to issue the SOV report for each subcontractor is obtained.

Subsequently, it proceeds with the design of the new process. This improvement proposal also considers a preliminary phase to the new process mentioned. The proposal establishes the technical considerations and the necessary requirements for the tools used to automate the schedule of value process for subcontractors.

Finally, the proposal is implemented in a project whose results are compared with the traditional process. For this analysis, a sample work item is evaluated. In this manner, the benefit of the proposal is measured through a time analysis.

III. RESULTS

A. *Registration and information treatment*

The information register of the work items that conform the budget of projects 1, 2 and 3 is prepared. It is determined the specialty that presents the highest incidence in subcontracting. The specialty of architecture is then one with more incidence with 59%. It is because the execution of the activities requires a high level of detail, so is resorted to hiring specialized labor. The results are shown in Fig. 2

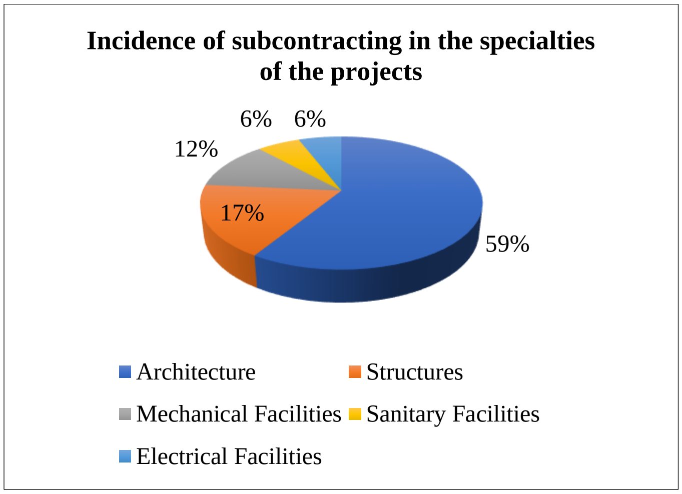

Fig. 2: Incidence of subcontracting by specialty

From the results of Fig. 2, the architectures specialty is analyzed as it has the highest incidence. A second level analysis is carried out, in which the main causes of the delays in the issuance of the SOV of the subcontractors are established. The main causes of delays in the schedule of values process are defined below:

- Discrepancy with subcontractors: when there are disagreements between the subcontractor and the main contractor. The disagreements are due to the required scope is no completed, is behind time or does not meet quality standards. Therefore, the payments are withheld. However, this creates huge problems for the subcontractor, since he need this payment to continue the job.

- Inefficiency in tracking progress: when mistakes are made when the information from printed plan is transferred to a digital format; an important part of the information is lost. In addition, the process is inadequate since there are not predetermined formats.

- Lack of control of the accumulated progress: when there is duplication in the quantification of work, due to not having a correct control of the progress that has already been valued. Namely, a double payment is made, or the full payment is not made for some activities that have been performed.

- Approval without quality verification: when a SOV report whose progress has not been exhaustively verified is approved. This causes problems of incompatibilities in successor activities. This happens most often in activities like doors and windows installation.

The frequency of the main causes of delays in the 3 projects analyzed is registered. The results are shown in Fig. 3.

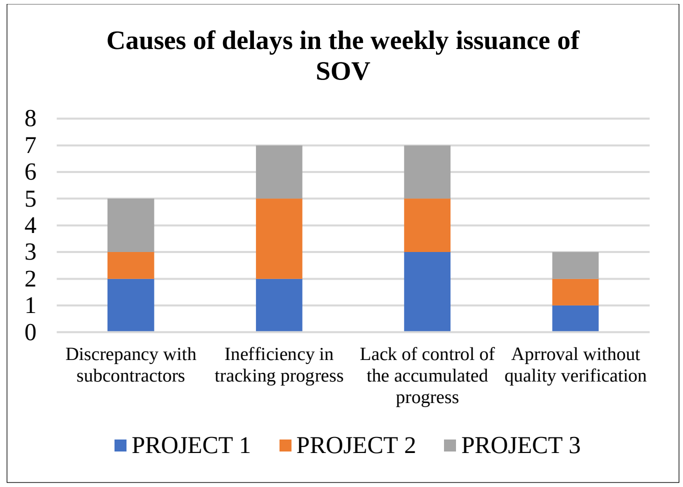

Fig. 3: Causes of delays in the weekly issuance SOV

With these results, it is considered that the inefficiency in the tracking progress and the lack of control of the accumulated progress are the main causes of delays in the issuance of SOV report. Therefore, both causes are the focus to be solved in this research.

B. *Traditional process delimitation*

Through data collection in the field and interviews with those in charge of the first three projects, information is obtained about the functions of each person in charge in the SOV process. The personnel involved is composed by the Resident Engineer (RE), the Quality Engineer (QE), the Subcontractor (SC), the Assistant of Resident Engineer (AR) and the Administrator (AD). This process has a weekly frequency and begins when the subcontractor sends the SOV document. The responsible of carrying out the field verifications is the Quality Engineer, who confirms the work carried out. If there are no observations, his approval is referred to the Resident Engineer; the latter is in charge of quantifying the work item in an Excel spreadsheet and requests the AR to integrate the information into a SOV format. Finally, this format is signed by the RE and it is sent to the AD, who coordinates with the SC and issues the invoice for General Management to proceed with the payment of the SOV. The flowchart shown in Fig. 4 describes the traditional process.

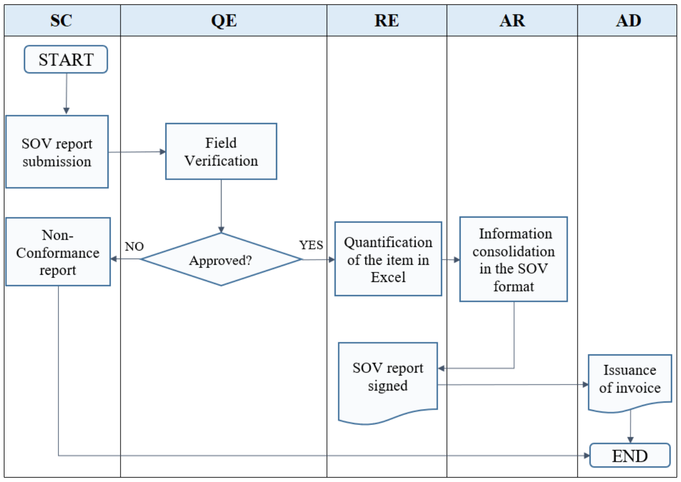

Fig. 4: Flowchart of the traditional process

Based on the previous scheme, the average time required for the personal responsible for creating the SOV report for a work item belonging to architecture specialty is determined. The time registered correspond to the Wall Painting work item for each project. It is necessary to clarify that the performance of each activity in this process does not happen immediately after the completion of the previous one but is done in isolated times during the workday. These time frames between one task and the next are not included in the record.

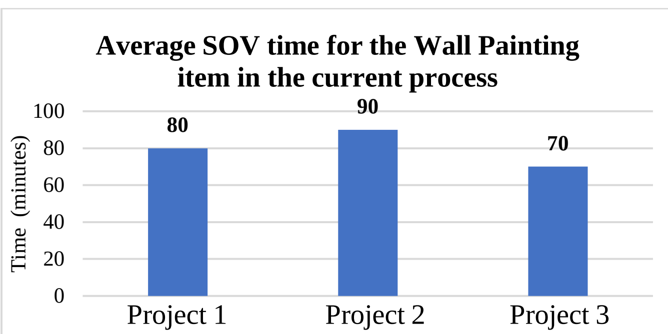

Fig. 5: Average SOV time for the Wall Painting work item in the current process

Fig. 5 shows the approximate time in the three projects. There is an average time of 80 minutes to elaborate a SOV report.

C. New process design

The design of the new SOV process is based on the adoption of the current workflow to a collaborative environment such as BIM using Revit software and Dynamo. The incorporation of these technological tools in the new process allows the creation of a parametric model, which facilitates the access and manipulation of data extracted from the Revit model, which improves the efficiency of the process. However, the use of these tools does not fully replace the tasks that correspond to the work staff, since some activities regardless of the process must be carried out by the personnel in charge, one of them is the field verification that is still present and is performed in the same way.

The application of this new process requires a preliminary phase focused on the generation of the SOV template and the creation of the Dynamo scripts. The standardization of the SOV formats offers the main contractor an adequate control of the information extracted from the parametric model and allows him to measure the weekly subcontractor progress in a more accurate form. The design of the new workflow is structured in the flowchart shown in Fig. 6.

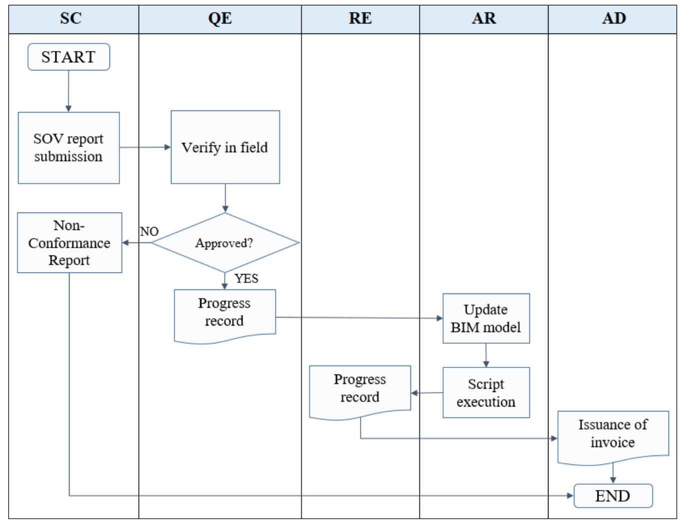

Fig. 6: Flowchart of the new subcontractor SOV process

This process begins with the verification in the field by the QE, who grants the agreement and records the approval of the subcontractor's work. This validation serves as an input for the AR, who updates progress information to the BIM model by creating two project parameters: "Project Week" and "Approval Status".

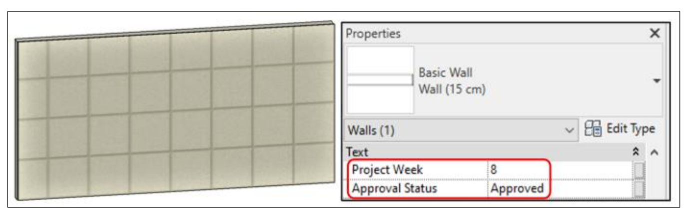

Fig. 7: Update information of project parameters

After this, the Dynamo script that has been developed in the preliminary phase is executed, and it automatically emits two outputs: the visualization of the 3D model according to the approval status of the executed work and the SOV report of the analyzed work item. This document is approved by the RE and is referred to the AD, who is responsible for issuing the corresponding invoice.

D. Proposal process implementation

The proposal is implemented in project 4, taking the Wall Painting work item as a sample. Prior to the application of the new process and as part of the preliminary phase, the Dynamo script is developed. The main purpose is to filter the walls in the Revit model according to the Project Week and the Approval Status parameters. These parameters are used for automatic quantification of the work item and is exported to the .xls format. In Fig. 8, is shown part of the script corresponding to the Approval Status parameter of the Wall Painting work item.

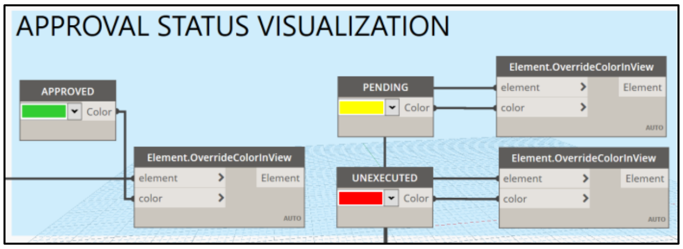

Fig. 8: Dynamo script creation

Similarly, Fig. 9 shows the part of the script that export the processed information to an Excel spreadsheet.

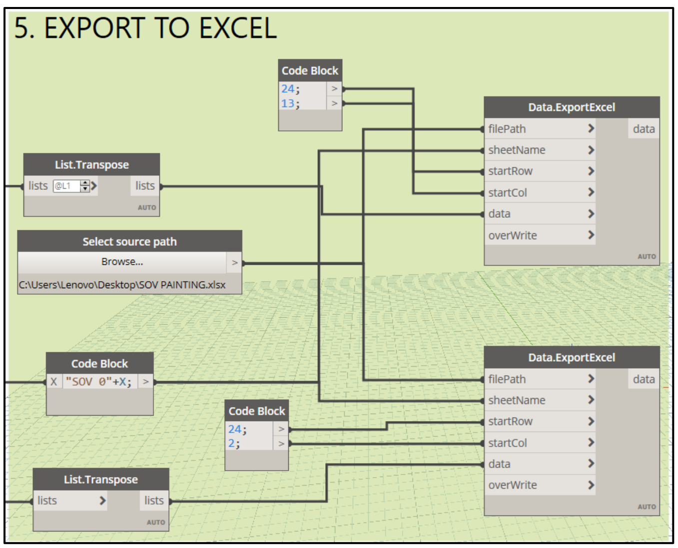

Fig. 9: Quantity Take-Off information exported to Excel spreadsheet

Once the previous steps are completed, the proposed process begins. It starts with the tracking progress of subcontractor. This information serves as an input for updating the project parameters created on Revit model. With the updated parametric model, the script previously created is executed and the 3D model is visualized with the shaded walls according to their Approval Status. Fig. 10, shows only the green walls that will be considered on the SOV report.

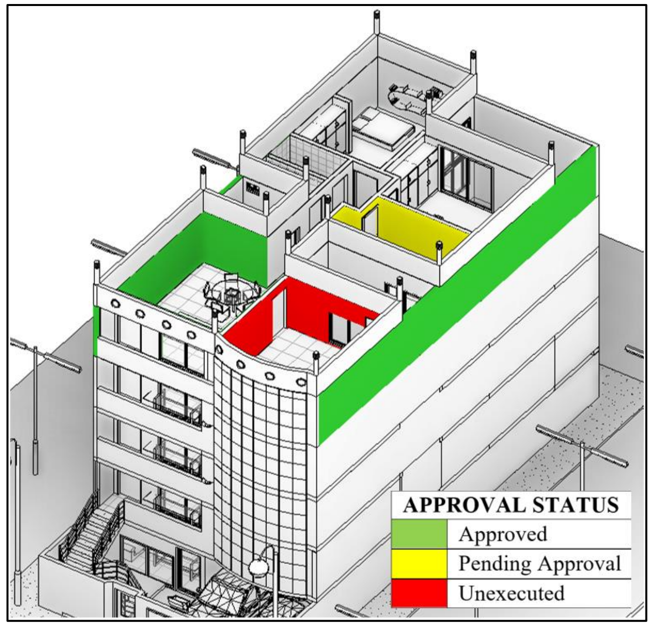

Fig. 10: Visualization of BIM elements according to the approval status

In addition, the SOV report of the work item is automatically obtained, which is constructed from the information collected and processed by the script.

			CONTRACTUAL BUDGET		
Item	Description	Unit	Quantity	Cost (S/.)	Total (S/.)
					S/ 7,074.50
1	WALL PAINTING				
1.01	PAINTING IN BATHROOMS	sq^2	30.56	18.00	550.08
1.02	LATEX PAINT ON INTERIOR WALLS	sq^2	280.86	17.00	4,774.62
1.03	LATEX PAINT ON EXTERIOR WALLS	sq^2	87.49	20.00	1,749.80
	Subtotal 1 (S/.)				7,074.50
	Prepayment amortization (0%)				0.00
	Subtotal 2 (S/.)				7,074.50
	IGV (18%)				1,273.41
	Total to Bill S/. (Soles)				8,347.91
	Guarantee Fund Retention (5%)				-353.73
	Net to Pay S/. (Soles)				7,994.19

Fig. 11: SOV report (.xls format)

Finally, a comparative analysis of the SOV process average time between both processes is carried out for the Wall Painting work item. Fig. 12 shows the results obtained from the analysis.

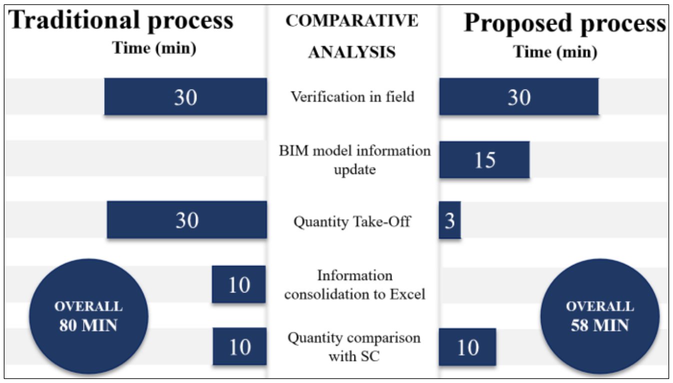

Fig. 12: Comparative analysis between both processes for wall painting work item

The implementation of the new process allows to register a lower average SOV process time per subcontractor, which is 58 minutes compared to the 80 minutes required by the traditional process. It is observed that the main differences between these two lies in the Quantity Take-Off feature and the information consolidation to Excel, activities whose time is considerably reduced due to the incorporation of digital tools used in the new process. However, there is a new time associated to the BIM model information update.

IV. Conclusions

The proposal process focuses on reducing the time of the SOV issuance process, by automating processes through visual programming in Dynamo. In this research, a 22-minute reduction in the emission of the SOV for Wall Painting work item is achieved. Taking into consideration that up to 10 weekly SOV report must be issued, with the proposal are saved: 3.7 hours a week, 14.8 hours per month and approximately 103.6 hours during the entire finishing phase. This allows the staff to efficiently use their resources in other activities that create value to the project. For future research, it is suggested to continue with the optimization of other staff functions, in order to reduce the number of people that comprise it.

References

[1] J. Shimizu, and F. Cardoso, "Subcontracting and cooperation network in building construction: A literature review," in 10th Conference of the International Group for Lean Construction, 2002, pp. 6-8.

[2] H. Alzraiee, "Integrating BIM and Earned Value Management System to Measure Construction Progress," in Construction Research Congress, 2018, pp. 684-693.

[3] H. Luo, M. Das, J. Wang, and J.C.P. Cheng, "Construction Payment Automation through Smart Contract-based Blockchain Framework," in 36th International Symposium on Automation and Robotics in Construction, 2019, pp. 1254-1260.

[4] M. Aronés, and A. Mendoza, "Use of Data Acquisition Technologies to Optimize Construction Progress Monitoring Times in Residential Buildings," in Proceeding of the 5th Brazilian Technology Symposium, 2020, pp. 605-615.

[5] A. Mesías, and R. Vásquez, "Implementación de una herramienta digital móvil en el área de calidad para optimizar el proceso de la gestión de observaciones en edificios residenciales," in 18th LACCEI International Multi-Conference for Engineering, Education and Technology, 2020.

[6] Y. Lui, Y. Lui, M. Lin, J. Zhang, C. Yang, G. Huang, Y. Zhang and Q. Zhao, "Research on Application of BIM 5D in Communication of Project Multi-participants – A Case Study of Nagpur Metro Project," *IOP Conference Series: Earth and Environmental Science*, vol. 568, pp. 012051, September 2020.

[7] C. Feng, Y. Chen, and H. Yu, "Employing Ontology and BIM to Facilitate the Information for Subcontractor's Payment Requests and Ledger Generation," in 34th International Symposium on Automation and Robotics in Construction, 2017, pp. 783-792.

[8] X. Ye, and M. Konig, "Framework for Automated Billing in the Construction Industry Using BIM and Smart Contracts," in 18th International Conference on Computing in Civil and Building Engineering, 2020, pp. 824-838.

[9] A. Khaja, J. Seo and J. McArthur, "Optimizing BIM metadata manipulation using parametric tools," *Procedia Engineering*, vol. 145, pp. 259-266, December 2016.

[10] I. Kamardeen, "8D BIM modelling tool for accident prevention through design," in Proceedings 26th Annual ARCOM Conference, 2010, pp. 281-289.