Application of BIM Revit Dynamo to improve precision in the quantification and cost of formwork in residential projects

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***Abstract*—** The study addresses the inefficiency in calculating estimates of quantities and costs of formwork using the traditional method in the construction industry. These methods are prone to human error, and this causes significant increases or losses in the project budget. Likewise, 80% of residential projects use the traditional method for estimating quantities and costs. On the other hand, according to the survey carried out, it shows that 80% of the most common errors in formwork items occur in metering. Therefore, the importance of implementing the BIM methodology in estimating quantities and costs. The proposed solution to this problem is through the application of the BIM methodology with Revit Dynamo. The combination of these 2 tools allows the creation of a prototype system capable of automating processes in the calculation of formwork quantities from three-dimensional models. The solution proposal has been implemented in 2 residential projects of medium-sized companies, the first is the project Rome (case study 1) and the second the Republic of Chile project (case study 2). Once the BIM methodology has been implemented in the case studies, a comparison is made between the traditional methodology and the solution proposal (Revit Dynamo), where it is shown that the BIM methodology is more efficient, since this methodology achieves an accuracy of 92.40%. in estimating quantities and costs. With this result, it is concluded that Dynamo visual programming together with Revit are tools that allow automating processes in estimating quantities.

Keywords—BIM, Dynamo, Formwork, quantification and Costs residential projects

I. INTRODUCTION

The construction industry is considered one of the most essential and complex industries worldwide. Its importance lies in the fact that it encompasses numerous complicated tasks that must be executed with extreme care to achieve high efficiency, Wahab, et al. [1]. Most activities in any construction project involve high costs, so a small error can cause significant increases in budgets, Reyes, C. [2]. Therefore, it is important to properly manage each activity and for all parties involved in the project to remain coordinated throughout its life cycle to avoid high costs or problems with the progress of the project.

Cost estimation in construction is without a doubt the most important aspect of the pre-construction process, since an accurate cost estimate influences the planning, coordination and bidding of the project, Wahab, et al. [1]. On the other hand, an early and accurate cost estimate in construction allows the contractor to organize the available resources to finance the project.

An important part of cost estimation in construction is the estimation of quantities, Liu, et al [3], therefore, efficiency in the calculations of quantities is essential so that they are as accurate as possible. Also, the method used for the estimation of quantities is important, since based on it the results can vary and affect the cost. Therefore, a survey has been conducted among engineers working on different residential projects to find out the method they use in the calculation of quantities. Fig. 1 shows that currently more than 80% of residential projects, from medium-sized companies in Metropolitan Lima, carry out the estimation of quantities in a traditional way, that is, they use printed plans or 2D software such as Autocad. Due to the use of the traditional method, inconveniences are generated in the estimation of quantities, that is, there is less precision due to manual calculation, lack of details in certain areas and there is little collaboration with other interested parties in the project, Barboza, et al. [4].

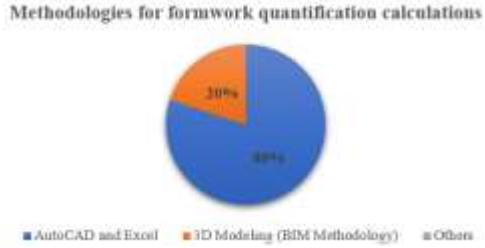

Fig. 1. Methods for calculating square footage in residential projects

On the other hand, this research focuses on the estimation of formwork quantities, since these materials represent 30% of the total cost of the project, Moses, et al. [5]. In addition, the Pareto chart has been developed based on the surveys, and as a result it is found that the estimation of quantities is within the 80% of the most common errors that occur in the formwork item, Fig. 2.

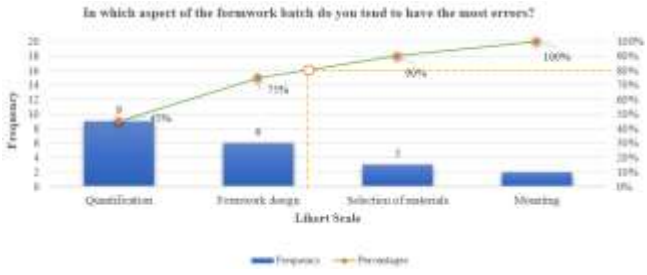

Fig. 2. Most common errors in the formwork process.

To date, various studies have explored ways to address the problem generated by the traditional method in the estimation of quantities of formwork and how this influences the budget. Therefore, the solutions proposed by other authors to address the problem will be mentioned.

Castro, et al. [6] mention that, to solve the inaccuracies and the time it takes to estimate quantities, the use of the BIM 5D methodology is proposed. In addition, Khosakitchalert, et al. [7] analyzes the advantages and importance of implementing the BIM methodology with

VDC, also mentioning that through this, productivity is improved, since the uncertainty in the estimation of quantities and the cost of the project is reduced. On the other hand, Liu, et al. [8], states that the BIM methodology with Revit improves the efficiency in the estimation of quantities, however, even using the program, errors occur when modeling, therefore, Revit Dynamo is implemented for the automatic modification of the modeling of a project when there are interferences. Also, the authors K Lee, et al. [9] investigate of programming software together with the Revit program to improve productivity and automate processes. Therefore, in their article they mention that, to improve efficiency in the estimation of quantities with the Revit software, Python and PyEnchant are implemented for the creation of algorithms and measurement rules, thereby improving accuracy by 3% with respect to the base metering. Finally, Yorozu, et al. [10] create the Unity 3D software, which has an automated design, and its main functions are quantity estimates, area calculations and types of formworks.

This article proposes the application of BIM Revit Dynamo for the estimation of quantities of formwork in residential projects, to obtain calculations with greater precision and thus positively influence project costs, since being more precise avoids project overruns.

II. TOOLS AND MATERIALS

This section details the tools and materials required to implement and use Revit Dynamo in estimating formwork quantities in residential projects.

A. Tools

1) Autodesk Revit: Autodesk Revit is a building information modeling (BIM) software that allows to design, plan and manage buildings, Julcamoro, P. [11]. In this work, Revit 2024 is used due to its advanced modeling capabilities and its compatibility with Dynamo.

2) Dynamo: Dynamo is a visual programming platform that integrates with Revit, allowing you to automate tasks and create custom workflows, Chavez, et al. [12].

3) Plugins and script: To extend Dynamo's capabilities, additional libraries such as Clockwork and Data Shapes are used, and custom scripts for formwork estimation are developed that allow extracting and calculating the required quantities directly from the BIM model, Chavez, et al. [12].

B. Materials

1) Formwork: It is important to understand the process involved in measuring the formwork for a better design of the implementation proposal, Rajeshkumar, et al. [13].

2) Plans and specifications: A Access to detailed drawings is important, as it allows for the validation of the estimated quantities of formwork, Roldán, M. [14]. These drawings must accurately reflect the project design and serve as a reference for the calculations performed with Dynamo. It is also necessary to have technical specifications for the project that describe the requirements of the formwork, including types of material, construction methods and applicable standards.

3) Project Data

a) Detailed BIM models: It is important to have detailed BIM models of residential projects, that is, these models must be well organized and contain all the necessary parameters for formwork estimation, Villa, J. [15].

b) Revit parameters and families: Model elements should have specific parameters that facilitate data extraction, such as material type, dimensions, and locations. Revit families used should be configured to include these parameters, allowing for accurate and efficient estimation.

III. METHODOLOGY

To achieve the objective of this study, the methodology used is shown in Fig. 3. To analyze the effectiveness of BIM with Revit Dynamo in cost estimation, the estimation of quantities of the formwork is being compared between the traditional method and with Revit Dynamo.

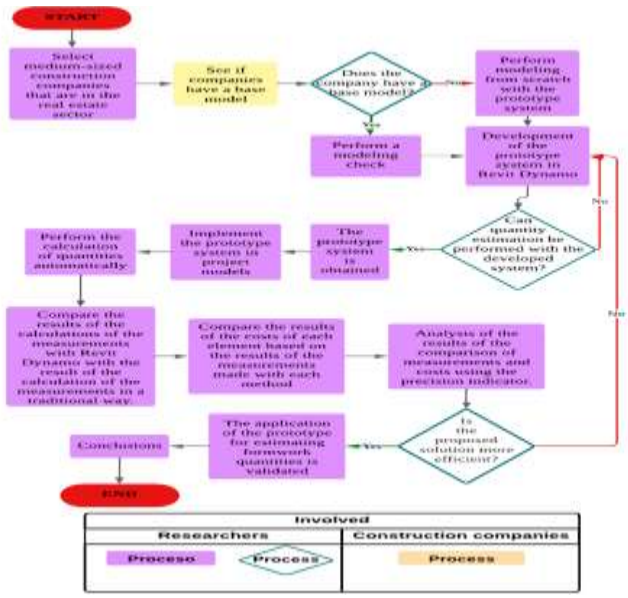

Fig. 3. Methodology flowchart tool.

A. Select Projects

The research is selecting two residential projects that are currently in the construction phase and are located in the city of Lima. The first case study is the Roma project (case study 1), which has 27 levels and 4 basements, and the second case study is the República de Chile project (case study 2), which has 17 levels and 2 basements. It is worth mentioning that the estimation of quantities in both projects has been carried out using the traditional method, that is, using plans and AutoCAD software. It is also very important that both projects are 100% modeled, otherwise, the modeling is done from scratch.

B. Prototype design

The prototype design focuses on creating scripts in Dynamo that automate the filling of information into Revit parameters, the extraction of the calculation of the quantities required in a residential project, the 3D modelling of formwork and the export of the information to an Excel file. To do this, the necessary parameters are first defined in

Revit, such as the element codes, levels, axes and the code of the formwork item, Fig. 4.

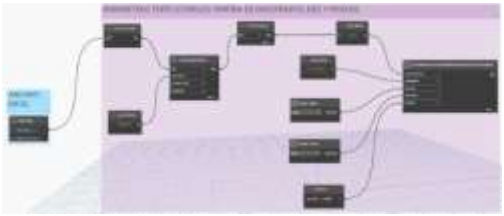

Fig. 4. Script to create parameters in Revit.

After having the parameters in Revit, scripts are created that allow filling in the information in these parameters. It is worth mentioning that 1 script is created for each element (footings, beams, columns, walls, slabs), but only 1 will be shown in the article, since the others are similar. This script is seen in Fig. 5.

Fig. 5. Script to fill information into Revit parameters..

After filling in all the information in the parameters, another script is created that allows estimating the quantities of the formwork and that can create the 3D model of the formwork, Fig. 6.

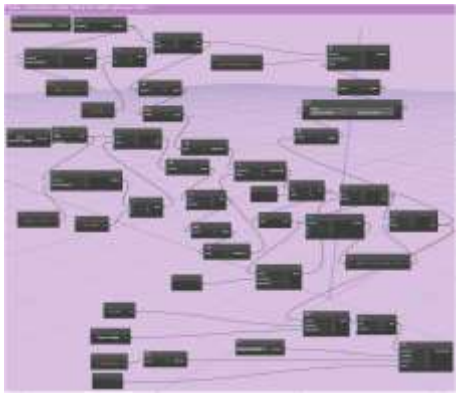

Fig. 6. Script for quantity estimation and 3D formwork modeling.

Finally, a script is created that allows all this information to be exported to an Excel file, Fig. 7.

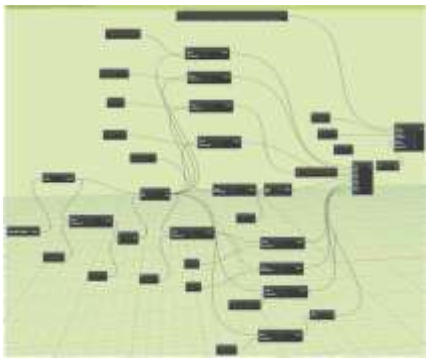

Fig. 7. Script to export quantity estimation information to an Excel file.

C. Implementation of the prototype system in case study 1

Once the prototype system has been designed and tested in Dynamo, it is implemented in case study 1. To do this, all the information in the scripts is first modified according to the project. After that, the scripts mentioned above are executed. These results of the quantity estimation and the modelling of the footings' formwork are shown in Fig. 8. It is worth mentioning that this procedure has been carried out for each element.

Fig. 8. Calculation of the quantities of formwork per m2 and 3D modeling of the foundations.

Based on these calculation results and all the necessary information required for estimating the quantities of formwork, the export is carried out in an Excel file using the script mentioned in Fig. 7. This export result can be observed in Fig. 9.

PLANILLA DE METRADO ESTRUCTURAS							
				ENCOFRADO Y DESENCOFRADO		ID DE TIPO	TOTAL
CODIGO	TIPO	EJES	NIVEL	ALTURA	PARCIAL (m2)		
OE.2	ESTRUCTURAS						
OE.2.2	OBRAS DE CONCRETO ARMADO						
OE.2.2.1	ZAPATAS						728.23
OE.2.2.1.1	ENCOFRADO Y DESENCOFRADO				Área (m2)		
OE.2.2.1.1	Zapata - h=1.00	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	1	10.60	3025216.00	
OE.2.2.1.1	Zapata - h=1.50	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	1.5	27.70	3379245.00	
OE.2.2.1.1	Zapata - h=1.50	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	1.5	26.70	3379245.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-6	Sotano 06 (NPT -18.50)	1.8	32.84	3379501.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-5	Cisterna (NPT -21.50)	1.8	32.76	3379501.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-4	Cisterna (NPT -21.50)	1.8	36.45	3379501.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	1.8	36.76	3379501.00	
OE.2.2.1.1	Zapata - h=1.50	Ubicado en el Eje: B-2	Cisterna (NPT -21.50)	1.5	27.78	3379245.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-2	Cisterna (NPT -21.50)	1.8	32.40	3379501.00	
OE.2.2.1.1	Zapata - h=1.80	Ubicado en el Eje: B-2	Cisterna (NPT -21.50)	1.8	32.76	3379501.00	
OE.2.2.1.1	Zapata - h=2.35	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	2.35	136.35	3380257.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-5	Cisterna (NPT -21.50)	0.6	8.38	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-5	Cisterna (NPT -21.50)	0.6	2.29	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-4	Cisterna (NPT -21.50)	0.6	1.12	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-4	Cisterna (NPT -21.50)	0.6	3.55	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	0.6	3.20	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	0.6	3.02	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	0.6	4.84	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-3	Cisterna (NPT -21.50)	0.6	2.18	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-2	Cisterna (NPT -21.50)	0.6	1.44	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-2	Cisterna (NPT -21.50)	0.6	1.74	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-5	Sotano 06 (NPT -18.50)	0.60	5.88	3025382.00	
OE.2.2.1.1	Zapata - h=0.60	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	0.60	1.76	3025382.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	0.80	5.91	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	0.80	7.93	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-7	Sotano 06 (NPT -18.50)	0.80	20.52	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-6	Sotano 06 (NPT -18.50)	0.80	25.84	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-4	Sotano 06 (NPT -18.50)	0.80	16.73	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-3	Sotano 06 (NPT -17.60)	0.80	9.10	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-1	Sotano 06 (NPT -17.60)	0.80	21.79	3026318.00	
OE.2.2.1.1	Zapata - h=0.80	Ubicado en el Eje: B-1	Sotano 06 (NPT -17.60)	0.80	38.38	3026318.00	
OE.2.2.1.1	Zapata - h=1.20	Ubicado en el Eje: B-1	Sotano 06 (NPT -17.60)	1.20	32.79	3385997.00	
OE.2.2.1.1	Zapata - h=1.20	Ubicado en el Eje: B-3	Sotano 06 (NPT -17.60)	1.20	15.93	3385997.00	
OE.2.2.1.1	Zapata - h=1.20	Ubicado en el Eje: B-4	Sotano 06 (NPT -17.60)	1.20	9.05	3385997.00	
OE.2.2.1.1	Zapata - h=1.20	Ubicado en el Eje: B-5	Sotano 06 (NPT -18.50)	1.20	11.20	3385997.00	
OE.2.2.1.1	Zapata - h=1.20	Ubicado en el Eje: B-6	Sotano 06 (NPT -18.50)	1.20	29.96	3385997.00	
OE.2.2.1.1	Zapata - h=2.10	Ubicado en el Eje: B-5	Sotano 06 (NPT -18.50)	2.10	6.51	3386720.00	
OE.2.2.1.1	Zapata - h=1.70	Ubicado en el Eje: B-4	Sotano 06 (NPT -18.50)	1.70	4.08	3386835.00	

Fig. 9. R Result of the estimation of quantities of formwork for the footings per m^2.

D. Implementation of the prototype system in case study 2

In case study 2, the same procedure is followed as in the previous case, where all the information in the scripts is first modified according to the project. After that, the scripts mentioned above are executed. These results of the quantity estimation and the modelling of the footings' formwork are

shown in Fig. 10. It is worth mentioning that this procedure has been carried out for each element.

Fig. 10. Calculation of the quantities of formwork per m^2 and 3D modeling of the foundations.

Based on these calculation results and all the necessary information required for estimating the quantities of formwork, the data is exported to an Excel file. This export result can be seen in Fig. 11.

PLANILLA DE METRADO ESTRUCTURAS							
				ENCOFRADO Y DESENCOFRADO			
CODIGO	TIPO	EJES	NIVEL	ALTURA	PARCIAL (m2)	ID DE TIPO	TOTAL
OE.2	ESTRUCTURAS						
OE.2.4	OBRAS DE CONCRETO ARMADO						
OE.2.2.4	ZAPATAS						741.55
OE.2.4.4.2	ENCOFRADO Y DESENCOFRADO				Área (m2)		
OE.2.4.4.2	ZAPATA H=1.30	Ubicado en el Eje: 6-1	Cisterna	1.3	52.95	1205200.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 6-3	Cisterna	1	41.14	1205481.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 15-1	Cisterna	1	31.44	1205481.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 6-1	Cisterna	1.1	18.48	1206500.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 6-2	Cisterna	1.2	18.24	1206618.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 6-3	Cisterna	1	12.00	1205481.00	
OE.2.4.4.2	ZAPATA H=0.65	Ubicado en el Eje: 6-3	Cisterna	0.65	4.16	1206748.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 6-1	Cisterna	1.2	18.24	1206618.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 6-2	Cisterna	1.2	30.36	1206618.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 4-1	Cisterna	1.2	20.69	1206618.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 4-1	Cisterna	1.2	18.24	1206618.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 4-1	Cisterna	1.2	19.20	1206618.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 4-1	Cisterna	1	12.51	1205481.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 4-1	Cisterna	1	12.20	1205481.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 4-1	Cisterna	1.1	15.66	1206500.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 7-1	Cisterna	1	17.00	1205481.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 10-1	Cisterna	1.2	16.88	1206618.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 13-1	Cisterna	1	13.60	1205481.00	
OE.2.4.4.2	ZAPATA H=1.40	Ubicado en el Eje: 16-1	Cisterna	1.4	24.64	1207774.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 16-3	Cisterna	1	15.70	1205481.00	
OE.2.4.4.2	ZAPATA H=0.65	Ubicado en el Eje: 16-3	Cisterna	0.65	4.16	1206748.00	
OE.2.4.4.2	ZAPATA H=0.65	Ubicado en el Eje: 16-3	Cisterna	0.65	4.16	1206748.00	
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OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 8-3	Cisterna	1.00	17.70	1205481.00	
OE.2.4.4.2	ZAPATA H=0.90	Ubicado en el Eje: 6-3	Cisterna	0.90	10.26	1208292.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 11-3	Cisterna	1.00	12.20	1205481.00	
OE.2.4.4.2	ZAPATA H=0.65	Ubicado en el Eje: 6-3	Cisterna	0.65	4.16	1206748.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 6-3	Cisterna	1.10	13.45	1206500.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 6-3	Cisterna	1.10	13.45	1206500.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 5-1	Cisterna	1.00	35.67	1205481.00	
OE.2.4.4.2	ZAPATA H=0.60	Ubicado en el Eje: 6-3	Cisterna	0.60	5.48	1209093.00	
OE.2.4.4.2	ZAPATA H=0.80	Ubicado en el Eje: 6-3	Cisterna	0.80	7.67	1209164.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 8-3	Cisterna	1.00	13.10	1205481.00	
OE.2.4.4.2	ZAPATA H=0.80	Ubicado en el Eje: 7-3	Cisterna	0.80	7.55	1209164.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 9-3	Cisterna	1.00	12.60	1205481.00	
OE.2.4.4.2	ZAPATA H=0.90	Ubicado en el Eje: 7-1	Cisterna	0.90	12.55	1208292.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 7-1	Cisterna	1.10	15.68	1206500.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 10-3	Cisterna	1.00	21.60	1205481.00	
OE.2.4.4.2	ZAPATA H=1.20	Ubicado en el Eje: 10-1	Cisterna	1.20	23.86	1206618.00	
OE.2.4.4.2	ZAPATA H=0.90	Ubicado en el Eje: 16-3	Cisterna	0.90	10.31	1208292.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 16-3	Cisterna	1.10	14.69	1206500.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 6-3	Cisterna	1.10	14.30	1206500.00	
OE.2.4.4.2	ZAPATA H=1.00	Ubicado en el Eje: 8-3	Cisterna	1.00	13.40	1205481.00	
OE.2.4.4.2	ZAPATA H=1.10	Ubicado en el Eje: 11-3	Cisterna	1.10	15.84	1206500.00	
OE.2.4.4.2	ZAPATA H=1.18	Ubicado en el Eje: 10-1	Cisterna	1.18	1.44	1394831.00	

Fig. 11. Result of the estimation of quantities of formwork for the footings per m2.

IV. RESULTS

A. *Accuracy in estimating measurements*

The precision indicator evaluates the accuracy of the measurement of each element in comparison with the proposed solution. To do this, a specific element of any floor will be selected to perform the measurement with the proposed solution (Revit Dynamo). Likewise, the measurement of the same element will be performed manually (with Excel) to compare the accuracy of the calculation of the measurements of the formworks.

1) Case study 1: In case study 1, the slab of floor 17 will be taken as an example, which is seen in Fig. 12.

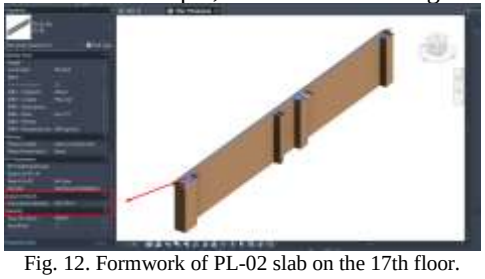

Fig. 12. Formwork of PL-02 slab on the 17th floor.

The selected plate has been executed by the script for the calculation of the measurements and the modeling of this element. The result can be seen in Fig. 12, where the formwork of this element is shown. In addition, in the lower left part (part that is selected in red) the result of the measurement of the plate is observed, having a value of 69.11 m2.

On the other hand, the calculation of the measurements of the formwork is carried out manually, for this, the information of the project is taken, such as the height, width and length of the plate. With these considerations, the calculation of the area of the plate is carried out, as shown in Fig. 13.

PLATE PL-02			
Perimeter (m)		Upper Height	46.15
Side1	14.90	Lower Height	44.03
Side2	0.55	Height (m)	2.12
Side3	0.80		
Side4	0.30		
Side5	5.97	Height	Perimeter	Area (m2)
Side6	0.30	2.12	32.622	69.159
Side7	0.25			
Side8	0.30			
Side9	1.20	Manual quantification		69.159
Side10	0.30	Quantification with Dynamo		69.110
Side11	0.50	Variation (Δ)		0.049
Side12	0.30			
Side13	5.60			
Side14	0.30			
Side15	0.50			
Side16	0.55			
Total	32.622			

Fig. 13. Result of traditional measurement (with Excel)

The information on the plate is used to calculate the measurement of this element using Excel. The calculation process can be seen in Fig. 13. The value obtained from the measurement of the plate is 69.159 m2.

In the end, both results will be compared, in this way, the precision will be measured. Once the comparison has been made, the following results are obtained: the variation in the measurements of the formwork of the PL.02 plate is 0.05 m2, that is, for every 100 m2 of area of an element, it will have a variation margin of 0.03 to 0.08 m2 of area.

2) Case study 2: In case study 2, the slabs and beams of floor 16 will be taken as an example, which is shown in Fig. 14.

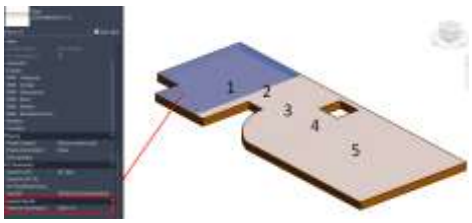

Fig. 14. Formwork of solid slabs and beams.

The selected beams and slabs have been subjected to the script for calculating the measurements and modelling the formwork. The result of the area can be seen in Fig. 14, where it is shown that the measurement of element 1 is 4.861 m2. Similarly, the measurements of the other solid slabs and beams are obtained; these results for the areas are 0.722 m2 (element 2), 3.731 m2 (element 3), 0.637 m2 (element 4) and 7.835 m2 (element 5). Adding the areas of the 5 elements gives a total value of 17.786 m2 of formwork.

On the other hand, the calculation of formwork measurements is done manually, for this, the information of the project is taken, such as the width, length, and height of

the elements. With these considerations, the calculation is done based on the areas.

Solid slabs and beams			
Base area (m2)		Perimeter	21.437
Total area (+)	14.80	Height (m)	0.15
Minor area (-)	0.27	Perimeter area	3.21561
Total	14.530		
		Total area	
Perimeter 1	19.37	Area 1	14.530
Perimeter 2	2.07	Area 2	3.216
Total	21.437	Total	17.746

Manual quantification	17.746
Quantification with Dynamo	17.786
Variation (Δ)	-0.040

Fig. 15. Result of traditional measurement (with Excel)

With the information from the slabs and beams, the measurements of these elements are calculated with Excel. The calculation process can be seen in Fig. 15. The value obtained from the measurements of the solid slabs and beams is 17.746 m2.

In the end, both results will be compared, in this way, the precision will be measured. Once the comparison is made, the following results are obtained: the variation in the measurements of the formwork of the slabs and beams is 0.04 m2, as mentioned above, the variation in this case is also minimal.

B. Cost accuracy

This indicator will be measured based on the results of the total measurements of each element, and the unit price (PU) will be multiplied by these values. It is worth mentioning that there will be 2 tables in each case study, one table will be of the costs based on the results of the measurement with the traditional method and the other table will be of the costs based on the results of the measurement with the proposed solution (Revit Dynamo).

1) Case study 1: In this project, the cost of each element will be measured based on the measurements and the PU in soles. Fig. 16 shows the result of the cost of each element using the traditional method.

COSTS WITH THE TRADITIONAL METHOD			
Elements	Quantification	PU (S/.)	Partial
Zapatas	705.753	34.114	S/ 24,076.19
Viga de cimentación	48.547	36.975	S/ 1,795.81
Columnas	4219.420	43.700	S/ 184,388.65
Placas	10759.850	42.600	S/ 458,369.61
Muros estructurales	4871.347	42.029	S/ 204,735.76
Vigas	9547.770	55.800	S/ 532,765.57
Preloza aligerada	12163.828	28.550	S/ 347,277.06
Preloza maciza	1575.560	31.467	S/ 49,577.62
Losas macizas	222.210	40.800	S/ 9,066.17
Pavimento	168.360	34.800	S/ 5,858.93

Fig. 16. Cost result using the traditional method.

Likewise, the result of the costs of each element is obtained with Revit Dynamo, Fig. 17.

COSTS WITH REVIT DYNAMO			
Elements	Quantification	PU (S/.)	Partial
Zapatas	728.230	34.114	S/ 24,842.97
Viga de cimentación	47.239	36.975	S/ 1,746.67
Columnas	4175.804	43.700	S/ 182,482.63
Placas	10733.767	42.600	S/ 457,258.68
Muros estructurales	4916.060	42.029	S/ 206,615.00
Vigas	9601.509	55.800	S/ 535,764.19
Preloza aligerada	11814.905	28.550	S/ 337,315.55
Preloza maciza	1569.229	31.467	S/ 49,378.40
Losas macizas	231.766	40.800	S/ 9,456.04
Pavimento	155.500	34.800	S/ 5,411.68

Fig. 17. Cost result with Revit Dynamo..

2) Case study 2: In this project, the cost of each element will also be measured based on the measurements and the PU in soles, as in case study 1. Fig. 18 shows the result of the cost of each element with the traditional method.

COSTS WITH THE TRADITIONAL METHOD			
Elements	Quantification	PU (S/.)	Partial
Cimiento Corrido	373.725	37.040	S/ 13,842.77
Zapatas	634.498	37.040	S/ 23,501.81
Losa Contra Terreno	266.510	13.350	S/ 3,557.91
Columnas	6206.660	43.520	S/ 270,113.86
Placas	9353.794	39.040	S/ 380,788.10
Muros de Sótano	1480.964	41.180	S/ 60,986.11
Muros Anclados	2202.977	49.040	S/ 108,034.00
Muros de Jardinería	1211.213	40.220	S/ 48,714.97
Vigas	9500.497	58.240	S/ 553,308.94
Vigas de Cimentación	77.102	37.040	S/ 2,855.86
Preloza Aligerada	16763.459	26.467	S/ 443,672.88
Losa Maciza	2283.426	43.020	S/ 98,232.97
Preloza Maciza	2316.810	28.133	S/ 65,179.59

Fig. 18. Cost result using the traditional method.

Likewise, the result of the costs of each element is obtained with Revit Dynamo, Fig. 19.

COSTS WITH REVIT DYNAMO			
Elements	Quantification	PU (S/.)	Partial
Cimiento Corrido	345.450	37.040	S/ 12,795.47
Zapatas	641.550	37.040	S/ 23,763.01
Losa Contra Terreno	273.180	13.350	S/ 3,646.95
Columnas	6187.454	43.520	S/ 269,277.99
Placas	9840.332	39.040	S/ 384,166.34
Muros de Sótano	1479.369	41.180	S/ 60,920.42
Muros Anclados	2141.888	49.040	S/ 105,038.18
Muros de Jardinería	1213.889	40.220	S/ 48,822.63
Vigas	9393.991	58.240	S/ 547,100.06
Vigas de Cimentación	81.254	37.040	S/ 3,009.64
Preloza Aligerada	16592.061	26.467	S/ 439,136.55
Losa Maciza	2279.308	43.020	S/ 98,055.82
Preloza Maciza	2336.325	28.133	S/ 65,738.61

Fig. 19. Cost result with Revit Dynamo

V. RESULTS ANALYSIS

In the results analysis, a comparison will be made of the results obtained with the traditional method and with the proposed solution (Revit Dynamo), both in terms of measurements and costs.

A. Precision in measurements

Next, a comparison will be made between the accuracy indicator of the measurements with the traditional method using Revit Dynamo. It should be noted that the comparison will show the variation that exists between both methods. On the other hand, it should be noted that the measurements with the traditional method were provided by the construction company that is executing the aforementioned projects.

1) Case study 1: Fig. 20 shows the comparison that has been made with the results of the measurements in case study 1, and also shows the variation that was obtained between both methods.

QUANTIFICATION COMPARISON			
Elements	Traditional quantification	Revit Dynamo	Variation
Zapatas	705.753	728.230	3.185%
Viga de cimentación	48.547	47.239	-2.693%
Columnas	4219.420	4175.804	-1.034%
Placas	10759.850	10733.767	-0.242%
Muros estructurales	4871.347	4916.060	0.918%
Vigas	9547.770	9601.509	0.563%
Preloza aligerada	12163.820	11814.905	-2.868%
Preloza maciza	1575.560	1569.229	-0.402%
Losas macizas	222.210	231.766	4.300%
Pavimento	168.360	155.500	-7.634%

Fig. 20. Comparison of the measurement with the traditional method and the proposed solution in case study 1.

From the comparison, it can be observed that there are positive and negative values. Positive results indicate that the measurements made with Revit Dynamo are above the traditional measurements. On the other hand, negative values indicate that the measurements made with Revit Dynamo are below the measurements made with the traditional method. Finally, from the comparison, it can be observed that the greatest variation in the result is -7.634%, which means that the proposed solution is 92.37% accurate.

2) Case study 2: Fig. 21 shows the comparison that has been made with the results of the measurements in case

study 2, and also shows the variation that was obtained between both methods.

QUANTIFICATION COMPARISON			
Elements	Traditional quantification	Revit Dynamo	Variation
Cimiento Corrido	373.725	345.450	-7.566%
Zapatas	634.498	641.550	1.111%
Losa Centro Terreno	266.516	273.100	2.503%
Columnas	6206.669	6187.454	-0.309%
Placas	9753.794	9840.332	0.887%
Muros de Sótano	1480.964	1479.269	-0.108%
Muros Anclados	2202.977	2141.888	-2.773%
Muros de Jardinería	1211.213	1213.889	0.221%
Vigas	9500.497	9393.991	-1.121%
Vigas de Cimentación	77.103	81.254	5.385%
Prelosa Aligerada	16763.459	16592.061	-1.022%
Losa Maciza	2283.426	2279.308	-0.180%
Prelosa Maciza	2316.814	2336.325	0.842%

Fig. 21. Comparison of the measurement with the traditional method and the proposed solution in case study 2.

From the comparison made, positive and negative results were obtained, in the same way as in case study 1, the positive results indicate that the measurement made with Revit Dynamo is above the measurement made with the traditional method, in the case of the contract with negative values, it means that they are below the traditional measurement. Finally, from the comparison made, it is observed that the greatest variation of the result is -7.566%, this means that the proposed solution is 92.43% accurate.

B. Cost accuracy

The cost accuracy indicator will be measured based on the case study estimates and the PU. Then, a comparison will be made between both methods to determine the variation that exists in the budget with the traditional method and with Revit Dynamo..

1) Case study 1: In this project, the cost of each element will be compared based on its PU. Fig. 22 shows the comparison between both methods and the variation that exists, where the item with the greatest variation occurs in the pavement.

COST COMPARISON			
Elements	Traditional quantification	Revit Dynamo	Variation
Zapatas	S/ 24,076.19	S/ 24,047.97	-3.185%
Vigas de cimentación	S/ 1,795.01	S/ 1,746.67	2.693%
Columnas	S/ 184,388.65	S/ 182,482.63	1.034%
Placas	S/ 458,369.61	S/ 457,258.48	0.242%
Muros estructurales	S/ 204,735.76	S/ 206,615.00	-0.918%
Vigas	S/ 532,765.57	S/ 535,764.19	-0.563%
Prelosas aligeradas	S/ 347,277.46	S/ 337,313.55	2.868%
Prelosas macizas	S/ 49,577.62	S/ 49,378.40	0.402%
Losas macizas	S/ 9,866.17	S/ 9,456.04	4.300%
Pavimento	S/ 5,858.93	S/ 5,411.68	7.634%
Total	**S/ 1,817,910.57**	**S/ 1,810,271.62**	**0.420%**

Fig. 22. Cost comparison with the traditional method and the proposed solution in case study 1.

From the comparison made, it can be observed that in Fig. 22 there are positive and negative results, as well as the comparison in the measurements, these results mean that the cost values obtained with Revit Dynamo are below or above the values obtained with the traditional method. Likewise, the greatest variation that exists in the comparison occurs in the pavement, with a value of -7.634%, in other words, applying Revit Dynamo for the calculation of automatic measurements achieves a precision of 92.37% of the cost.

2) Case study 2: In this case study, the same thing will be compared as in the previous case, therefore, in Fig. 23 the comparison between both methods and the variation that exists can be observed, where the item with the greatest variation occurs in the continuous foundation.

COST COMPARISON			
Elements	Traditional quantification	Revit Dynamo	Variation
Cimiento Corrido	S/ 13,042.27	S/ 12,795.47	7.566%
Zapatas	S/ 23,501.81	S/ 23,763.01	-1.111%
Losa Centro Terreno	S/ 3,557.91	S/ 3,646.91	-2.503%
Columnas	S/ 176,113.86	S/ 269,237.09	0.309%
Placas	S/ 384,788.10	S/ 384,166.54	0.887%
Muros de Sótano	S/ 60,988.11	S/ 60,920.42	0.108%
Muros Anclados	S/ 108,874.00	S/ 105,838.28	2.773%
Muros de Jardinería	S/ 48,714.97	S/ 48,822.68	-0.221%
Vigas	S/ 503,388.94	S/ 547,106.06	1.121%
Vigas de Cimentación	S/ 2,893.86	S/ 3,089.44	-5.385%
Prelosa Aligerada	S/ 443,672.88	S/ 439,136.33	1.022%
Losa Maciza	S/ 90,232.97	S/ 90,055.82	0.100%
Prelosa Maciza	S/ 65,179.59	S/ 65,726.61	-0.842%
Total	**S/ 2,072,709.75**	**S/ 2,063,467.86**	**0.586%**

Fig. 23. Cost comparison with the traditional method and the proposed solution in case study 2.

From the comparison made, it can be observed that in Fig. 23 there are positive and negative values, these mean the same as case study 1. Likewise, the greatest variation that exists in the comparison occurs in the continuous foundations, with a value of -7.566%, in other words, applying Revit Dynamo for the calculation of automatic measurements achieves an accuracy of 92.43% of the cost.

VI. VALIDATION

A. Precision in quantification

Next, the accuracy of the measurements of the proposed solution will be validated with Revit Dynamo for both case studies. It is worth mentioning that a target range of 80 to 100% accuracy is being set, based on what is indicated in the study carried out by Wahab, et al. [1]. Likewise, this study mentions that with the BIM Revit methodology, the calculation of measurements can be obtained 90% more accurately compared to the traditional method.

1) Case study 1: From the analysis of the results carried out, it was found that the solution proposal with Revit Dynamo is 92.37% accurate, so it is within the target range. In addition, this result means that the solution proposal is a viable option for calculating the formwork measurements, since the accuracy is more than 80%. Likewise, in Fig. 24 the validation based on the target range can be observed.

Indicator	Unit of measurement	Range	Goal	Case Study 1 Results
Level of efficiency in precision for the quantification of formworks	%	0-100%	80-100% The BIM methodology in the calculation of quantification is 90% more accurate compared to the traditional method (Wahab, A. & Wang, J., 2023)	92.37% The results obtained in the measurement accuracy indicator in case study 1 is 92.37%, this percentage is within the stated objective.

Fig. 24. Comparison of the cost with the traditional method and the proposed solution.

2) Case study 2: From the analysis of the results it was obtained that in study 2 the proposal with Revit Dynamo is 92.43% accurate for the calculation of the measurements, which is why it is mentioned that it is within the target range. Likewise, it is validated that the solution proposal is a viable option for the calculation of the measurements of the formwork, since the precision is more than 80%. Below, in Fig. 25, the validation of the proposal based on the target range is observed.

Indicator	Unit of measurement	Range	Goal	Case Study 2 Results
Level of efficiency in precision for the quantification of formworks	%	0-100%	80-100% The BIM methodology in the calculation of quantification is 90% more accurate compared to the traditional method (Wahab, A. & Wang, J., 2023)	92.43% The results obtained in the measurement accuracy indicator in case study 2 is 92.43%, this percentage is within the stated objective.

Fig. 25. Comparison of the cost with the traditional method and the proposed solution.

B. *Cost accuracy*

In the same way as the validation of the measurements, the validation of the precision of the costs of the solution proposal will be carried out with Revit Dynamo for both case studies. It is worth mentioning that a target range of 60 to 100% precision is being set, this based on what is indicated in the study carried out by Wahab, et al. [1]. In addition, this research mentions that with the BIM methodology, the calculation of costs based on the measurements can be obtained in a 78% more precise way compared to the traditional method.

1) Case study 1: From the analysis carried out above, it is concluded that with the BIM methodology with Revit Dynamo, it is possible to obtain a precision of 92.37% of the project cost of the selected elements based on the calculation of the measurements. In addition, the result obtained is within the target range proposed, according to the author mentioned above, since the result obtained is greater than 60%. In addition, in Fig. 26 you can see the validation based on the target range.

Indicator	Unit of Measurement	Range	Goal	Results of case study 1
Efficiency level of accuracy in estimating costs based on quantification	%	0 - 100%	80 – 100% BIM methodology in cost calculation is 78% more accurate than the traditional method (Wahab & Wang, 2023).	92.37% The results obtained for the cost accuracy indicator in case study 1 is 92.37%, which is within the target percentage.

Fig. 26. Comparison of the cost with the traditional method and the proposed solution.

2) Case study 2: From the analysis carried out above, it can be seen that with the BIM methodology with Revit Dynamo, a precision of 92.43% of the project cost of the selected elements is achieved. In addition, the result obtained is within the target range proposed. Therefore, the implementation of Revit Dynamo in residential projects is viable, since it allows reducing costs and improving the precision of the measurements. Likewise, in Fig. 27 you can see the validation based on the target range.

Indicator	Unit of Measurement	Range	Goal	Results of case study 2
Efficiency level of accuracy in estimating costs based on quantification	%	0 - 100%	80 – 100% BIM methodology in cost calculation is 78% more accurate than the traditional method (Wahab & Wang, 2023).	92.43% The results obtained for the cost accuracy indicator in case study 2 is 92.43%, which is within the target percentage.

Fig. 27. Comparison of the cost with the traditional method and the proposed solution.

VII. CONCLUSIONS

It is concluded that the use of Revit Dynamo to obtain formwork measurements reduces uncertainty and increases the accuracy of the values obtained, since it allows the visual and systematic review of the three-dimensional models.

The implementation of the BIM methodology for the estimation of formwork quantities in residential projects is only 20%, while 80% of the respondents mention that they use the traditional method for these calculations.

From the results obtained, it is concluded that the accuracy in the calculation of formwork measurements is 92.37% using Revit Dynamo, in case study 1. Likewise, in case study 2, an accuracy in the calculation of formwork measurements of 92.43% is obtained.

In conclusion, the most frequent problems that occur in the formwork item are the measurements, since they are within 80% according to the Pareto chart.

From the results obtained, it is concluded that the cost accuracy using Revit Dynamo has a precision of 92.40% in case study 1, while in case study 2 it has a precision of 92.43%.

The combination of the Dynamo visual programming language with Autodesk Revit allows the automation of the calculation of formwork measurements from three-dimensional models. Likewise, the application of automated scripts generates measurement calculations more efficiently and with greater precision compared to traditional methods.

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