Dynamo programming applied to the development of sustainable engineering projects via BIM methodology

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ABSTRACT

In the context of reinforced concrete, one of the main challenges faced by execution professionals is the correct interpretation and understanding of structural projects. The lack of proper understanding of these technical drawings can lead to a series of problems, such as: assembly errors, lack of compliance with current technical standards and even compromising the structural safety of the building. On the other hand, engineers and designers face their own challenges, especially about the time required to prepare the drawings. The pressure of tight deadlines often results in projects being drafted in a hurry, which can lead to significant design errors. In this context, the present work proposes an innovative solution: the development of a set of scripts using the Dynamo software aimed at structural engineering activities. These scripts are primarily intended to streamline the design process from conception to detailing. By automating repetitive and error-prone tasks, scripts not only reduce the time required to draw up drawings, but also significantly improve the final quality of formwork and reinforcement designs.

Keywords: BIM, Dynamo, Revit, Reinforced Concrete, Detailing.

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INTRODUCTION

The engineering industry has witnessed significant changes, driven by the implementation of new technologies in its processes. One of these landmark transformations was the introduction of Computer-Aided Design (CAD). Before its advent, engineering projects were prepared manually, requiring a considerable investment of time and effort. With the incorporation of CAD, engineers and architects have gained access to a diverse set of digital tools, enabling them to create, modify, and optimize designs faster and more accurately. [1]

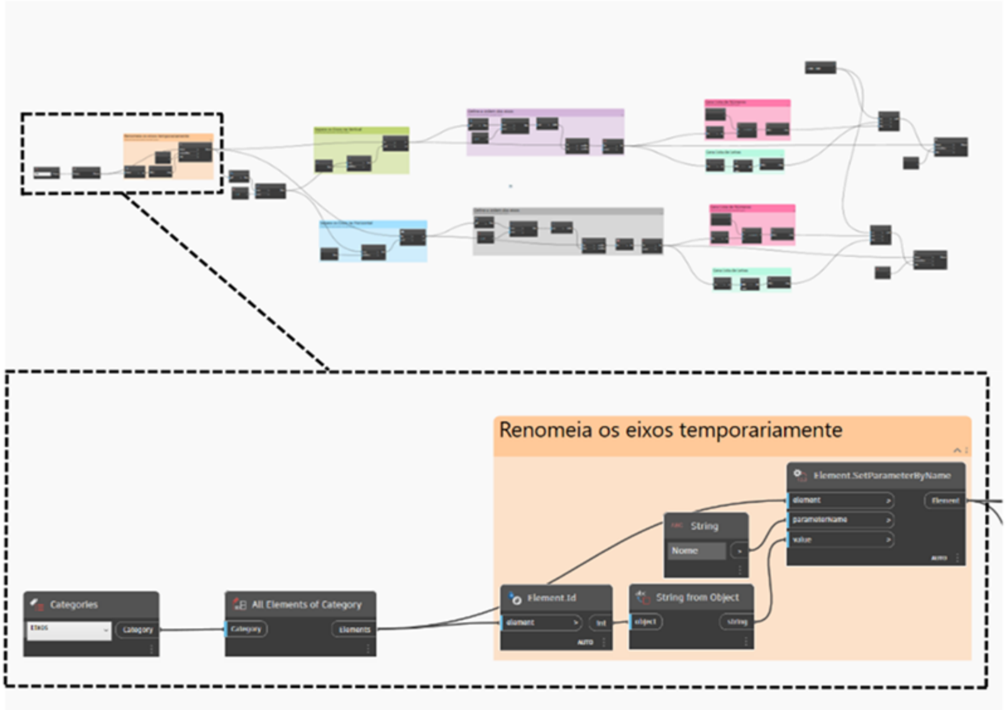
A new revolution in engineering has been taking place, led by Building Information Modeling (BIM). BIM, at its core, consists of creating an intelligent, multidisciplinary virtual model of a project throughout its entire life cycle (Eastman et al., 2014). One of the main advantages of BIM lies in its ability to facilitate collaboration and the exchange of information between the various stakeholders in the construction process. Unlike traditional approaches, in which different professionals worked in isolation with their 2D drawings or 3D models, BIM creates a shared platform on which architects, structural engineers, MEP (Mechanical, Electrical, Hydraulic) engineers, and other participants can contribute to a single comprehensive model.

The multidisciplinary nature of BIM makes it possible to detect and resolve conflicts during the design phase, reducing the likelihood of errors and conflicts during construction. In addition, BIM provides an amount of data that goes beyond geometric representation, including material specifications, cost estimates, and construction schedules. This information is invaluable for project management, helping teams make informed decisions and optimize resource allocation [2].

Inconsistencies, inaccuracies, and uncertainties in the design make it difficult to manufacture the materials outside the construction site [2]. It is often during the construction phase that such errors are detected, resulting in sudden changes in the design to fit the field and the consequent expenses arising from these errors. This need for sudden adjustments highlights the importance of improving accuracy from the design conception in order to reduce the occurrence of sudden modifications and save time and effort during execution. Therefore, the search for solutions that optimize the process of designing and drafting, such as the use of automation tools, becomes essential to ensure the effectiveness and quality of the work of engineers and designers.

The use of BIM can be greatly enhanced with the help of programming in Dynamo software, a visual programming tool present in Autodesk software. Dynamo has a visual interface, which means that users create scripts through a graphical representation, connecting blocks of functions into a flowchart logic. This makes programming more accessible for those who may not have experience with traditional coding. By using Dynamo programming, it is possible to speed up the modeling of elements and automate repetitive tasks that are susceptible to human error. This automation streamlines the design process, allowing professionals to focus on more complex and more value-added activities.

Figure 1: Example of a programming routine in Dynamo



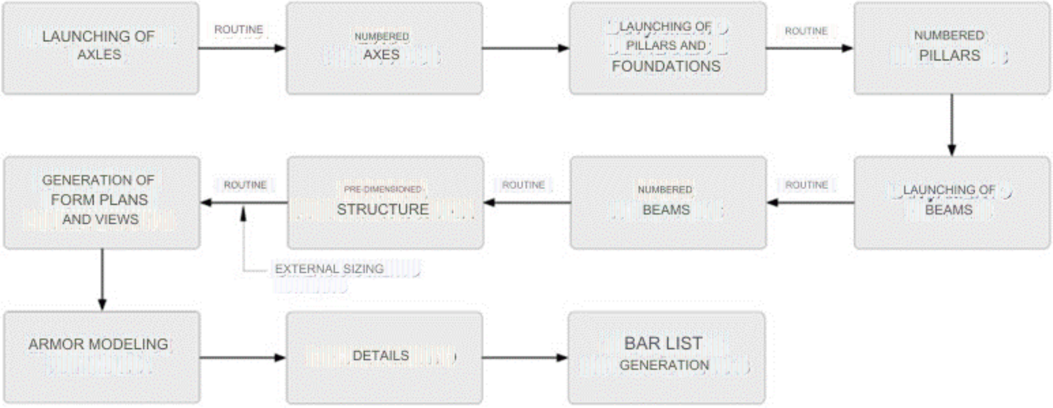
Source: the author.

Dynamo works by manipulating and handling the parameters (or information) of elements in Revit. Parameters in Revit play a key role in defining and controlling the properties of a model's elements. The correct definition of parameters in Revit is extremely important in ensuring the interoperability of the model. Interoperability refers to the ability to efficiently and accurately exchange information between different software and disciplines involved in a construction project. In the following items, the logics used in the routines will be explained. Thus, this article aims to automate structural projects using BIM technology. To this end, through the Dynamo software, routines were developed in order to streamline the design process from its conception to the detailing phase.

DEVELOPMENT OF ROUTINES

Dynamo scripts are designed with a project's workflow in mind, from defining structural axes to launching columns, followed by beams, slabs, and foundations. Subsequently, a script for the pre-dimensioning of the beams was developed. In addition, routines were developed to document the project, such as the numbering of the elements and the generation of plans and views. Figure 2 exemplifies the workflow developed.

Figure 2: Script production flowchart.



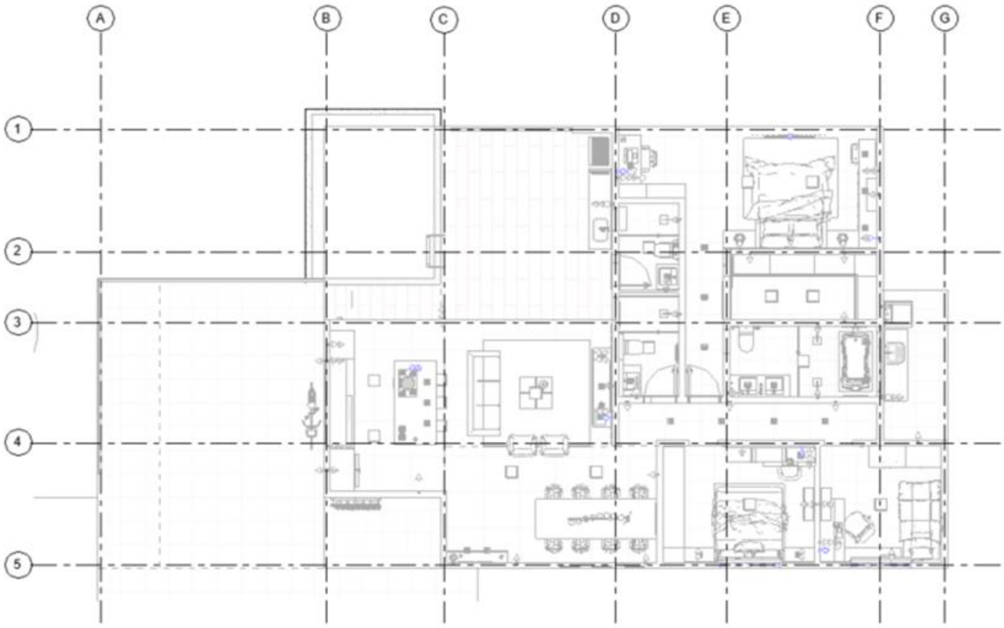
Source: the author.

AXLE NUMBERING

First, the routine examines the number of axes in the project and divides them into two groups: vertical and horizontal axes. This is done by creating vectors parallel to each axis and comparing them with the Cartesian axes X and Y. Once separated, the user can specify whether he prefers one of the groups to be identified by numbers and the other by letters. For example, vertical axes can be numbered sequentially, while horizontal axes can be labeled alphabetically.

Finally, the routine determines the order of the axes from top to bottom and left to right. It calculates a center point for each axis and compares its coordinates to order them. The routine then counts how many axes there are in each group and enumerates them according to the sequence defined for each group. Figure 3 shows the result of the routine.

Figure 3: Numbered axes



Source: the author.

NUMBERING OF PILLARS AND FOUNDATIONS

The principle of operation of the routine is based on an organization of the pillars and foundations by their Y and X coordinates in the global system. First, the routine orders them according to their Y coordinates, that is, in their vertical position. Then, it performs a second organization, now based on the X coordinates, that is, in its horizontal position. In this way, a logical sequence of the pillars and foundations is obtained, aligned with their position in the project.

Once the ordered sequence is established, the routine generates a list containing the total number of columns and foundations. With this list in hand, the numbering is assigned automatically and consecutively, ensuring that each one receives the number corresponding to their position in the sequence.

BEAM NUMBERING

The beam numbering routine presents a complex process for obtaining and arranging the beams of the project. Initially, all beams are collected and sorted into horizontal and vertical beams. From there, a comparison procedure is carried out with all the other beams in the project to check if there are intersections between them. When identifying intersections, beams that share segments are grouped into sublists, representing continuous beams.

After the formation of the sublists, the routine identifies if each sublist has more than one element, indicating the presence of connected spans in the beam. If so, sequential letters ("a", "b", "c", etc.) are generated for each span, providing the appropriate distinction between the segments. An additional challenge faced during programming was the need to start numbering the vertical beams from the number of the last horizontal beam. This detail was solved in the development of the routine, ensuring the correct numbering. In addition, a prefix option has been added, which allows the user to define the default they want for the nomenclature (e.g. V101a)

STRUCTURE PRE-DESIGN

Pre-dimensioning is a crucial step in structural design, which takes place in the initial phase of the project. This stage aims to carry out a preliminary analysis of the structure, determining the approximate dimensions of the structural elements based on predetermined estimates and criteria.

A common approach to beam pre-design is to adopt the L/10 ratio, where "L" represents the clear span between the beam supports. This ratio suggests that the height of the beam should be approximately equal to 1/10 of the span. [3]

This routine will be able to identify the span of the beams and, based on the L/10 criterion, will perform the pre-dimensioning, ensuring an adequate initial height for each beam. In addition, the values obtained will be rounded to multiples of 5 centimeters, following the usual practice.

Another important feature of the routine will be the identification and treatment of continuous beams. The user will have the flexibility to choose between two approaches: pre-design the continuous beams according to the largest span found, thus standardizing the section of the entire beam, or pre-design by section, considering individual spans.

After these steps, the job will generate a report in .xls format, containing all the relevant information used in the pre-sizing process. This report will provide an overview of the data, including beam spans, estimated heights according to the L/10 criterion, and the resulting cross-sections after rounding. Figure 4 shows an example of a spreadsheet generated by Dynamo, and Figure 5 shows the model already pre-sized.

Figure 4: Dynamo-generated spreadsheet

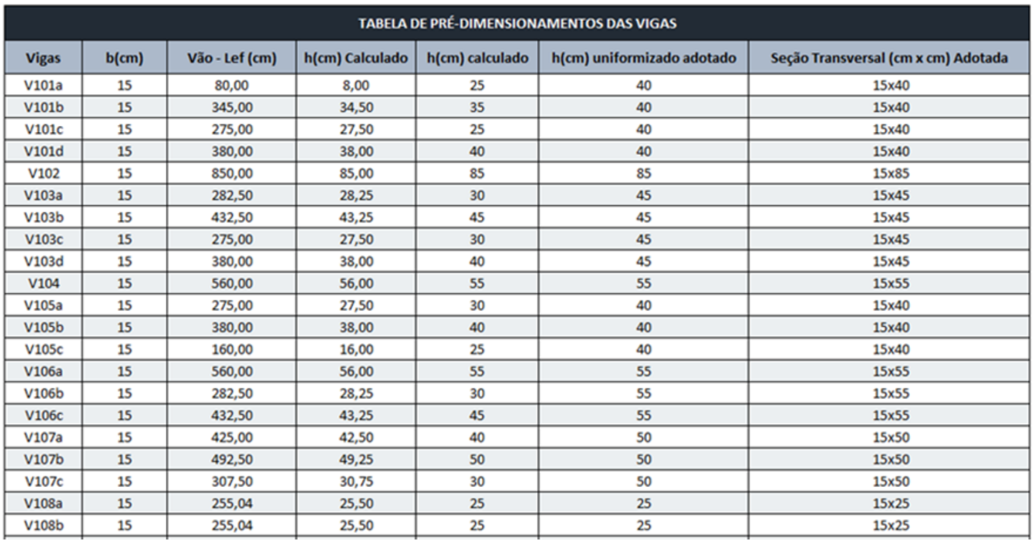
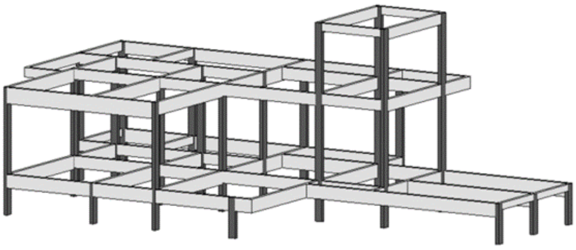


TABELA DE PRÉ-DIMENSIONAMENTOS DAS VIGAS

Vigas	b(cm)	Vão - Lef (cm)	h(cm) Calculado	h(cm) calculado	h(cm) uniformizado adotado	Seção Transversal (cm x cm) Adotada
V101a	15	80,00	8,00	25	40	15x40
V101b	15	345,00	34,50	35	40	15x40
V101c	15	275,00	27,50	25	40	15x40
V101d	15	380,00	38,00	40	40	15x40
V102	15	850,00	85,00	85	85	15x85
V103a	15	282,50	28,25	30	45	15x45
V103b	15	432,50	43,25	45	45	15x45
V103c	15	275,00	27,50	30	45	15x45
V103d	15	380,00	38,00	40	45	15x45
V104	15	560,00	56,00	55	55	15x55
V105a	15	275,00	27,50	30	40	15x40
V105b	15	380,00	38,00	40	40	15x40
V105c	15	160,00	16,00	25	40	15x40
V106a	15	560,00	56,00	55	55	15x55
V106b	15	282,50	28,25	30	55	15x55
V106c	15	432,50	43,25	45	55	15x55
V107a	15	425,00	42,50	40	50	15x50
V107b	15	492,50	49,25	50	50	15x50
V107c	15	307,50	30,75	30	50	15x50
V108a	15	255,04	25,50	25	25	15x25
V108b	15	255,04	25,50	25	25	15x25

Source: the author.

Figure 5: Pre-sized Model



Source: the author.

DETAILING

After the design of the structural elements, the next step would be to detail their reinforcement. To drill down to each element, you would need to create a plan view and sections individually for each one. Thus, a routine will be developed that will create the views for all the structural elements of the project.

FOUNDATIONS

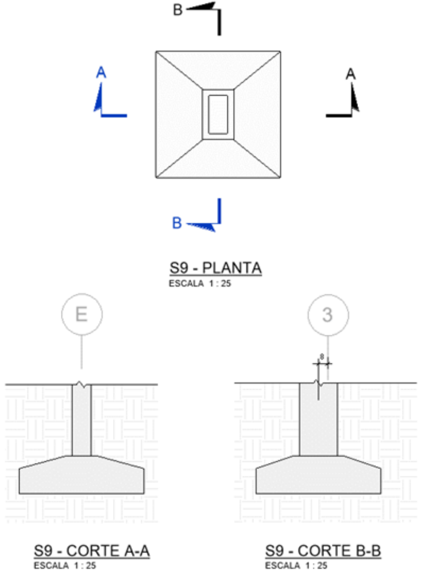
The routine is divided into two main blocks, which are:

1. Create the plan: In this case, Dynamo has the function of selecting the geometry of the footing/block and delimiting a region around it, where the plan will be created, then creates a unique view for the foundation, names the view with its name and applies the view model. E.g.: S10 or B10.

2. Create the sections: Based on the geometry of the foundation, create two sections, one horizontal and one vertical, and apply the correct view model.

The result of the routine can be seen in Figure 6.

Figure 6: Result of the routine of creating foundation views



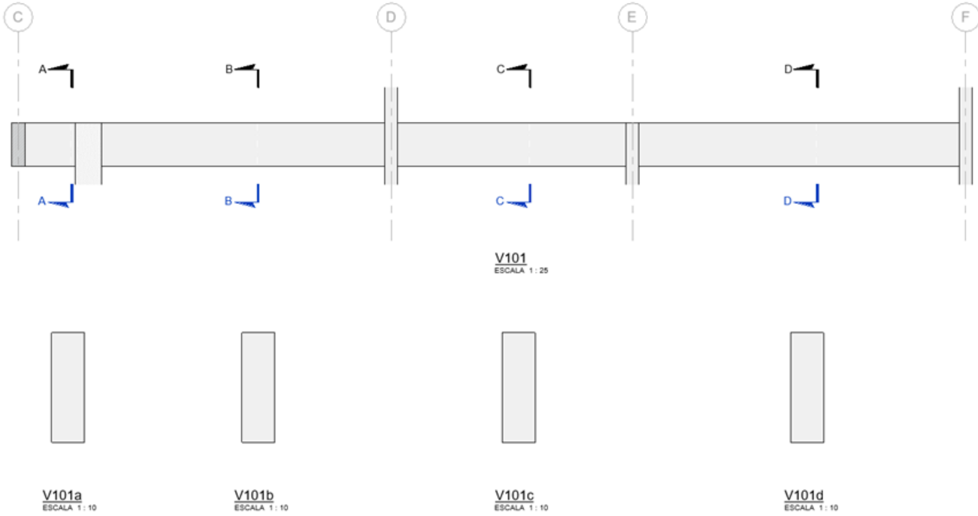
Source: the author.

BEAMS

The routine has two stages, in the first, the routine will initially select the beams and create an imaginary line on the axis of each one, recognizing continuous beams and grouping their lines. Then create the cut line and set the boundaries of the view crop. Finally, you create the section view and apply the correct view template. The routine also has a Python script that has the function of removing the alphanumeric index from beams, if they have one. For example a continuous beam that has several spans (V102a, V102b, etc.), the letter at the end will be removed to create a single view with the name V102.

In the second step of the routine, the goal is to create sections for each section of the beam. Then, the center point of each span is selected and the cut created transversely to the beam, like this in Figure 7.

Figure 7: Result of the Beam View Creation Routine



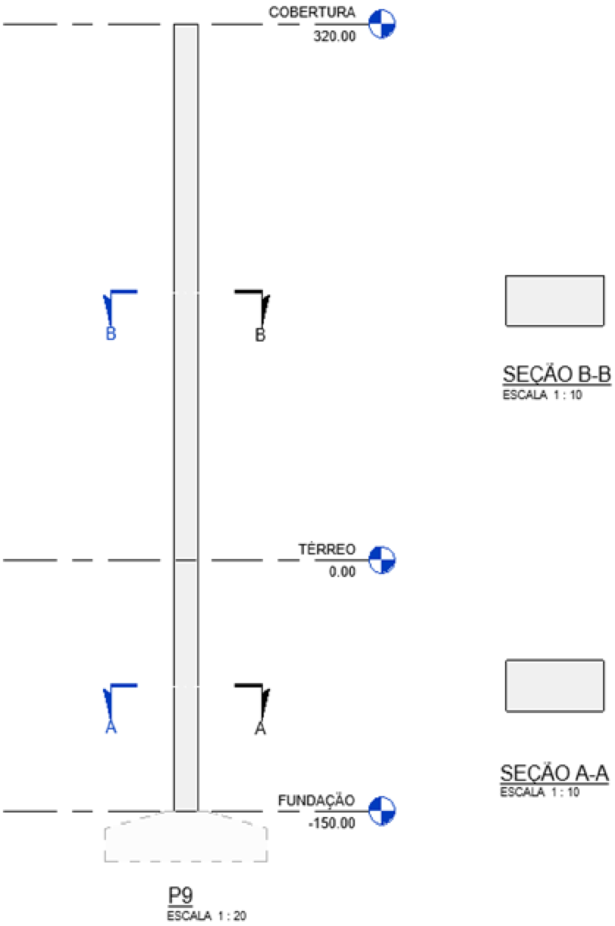
Source: the author.

PILLARS

To create the detailing, a routine similar to the foundation routine will be developed, where the column will be selected and in the middle of each floor that it passes, a cross-section will be generated. In addition, a front view of the column will be generated. The result can be seen in Figure 8.

The results illustrated by the figures represent only one structural element and each type, but the routine when executed does not generate the views only for one element, but for all those contained in the project. And with the views ready, you only need to model and detail the reinforcements.

Figure 8: Result of the routine of creating column views



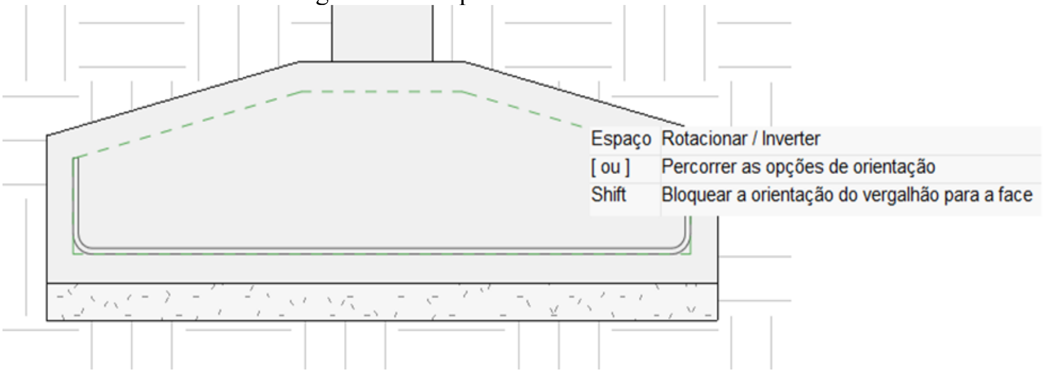
Source: the author.

ARMOR MODELING

A first step before starting the reinforcement modeling is the correct configuration of the commercial diameters and their characteristics according to ABNT NBR 6118:2023. For example, for each type of steel (CA-25, CA-50, CA-60) the software must be informed of the gauges, diameters of the bending pin, straight end of hooks, among other properties inherent to the bar. It is worth mentioning that all these configurations only need to be done once and can be reused in other projects.

By clicking on the structural element, the "rebar" function will be enabled in the "reinforcement" tab. You must select the desired gauge in the properties, rebar shape, and spacing tab. The reinforcement will automatically adapt to the structural element, already with the correct coverings, as seen in Figure 9. The same reinforcement modeling logic applies to any structural element.

Figure 9: Example of reinforcement insertion

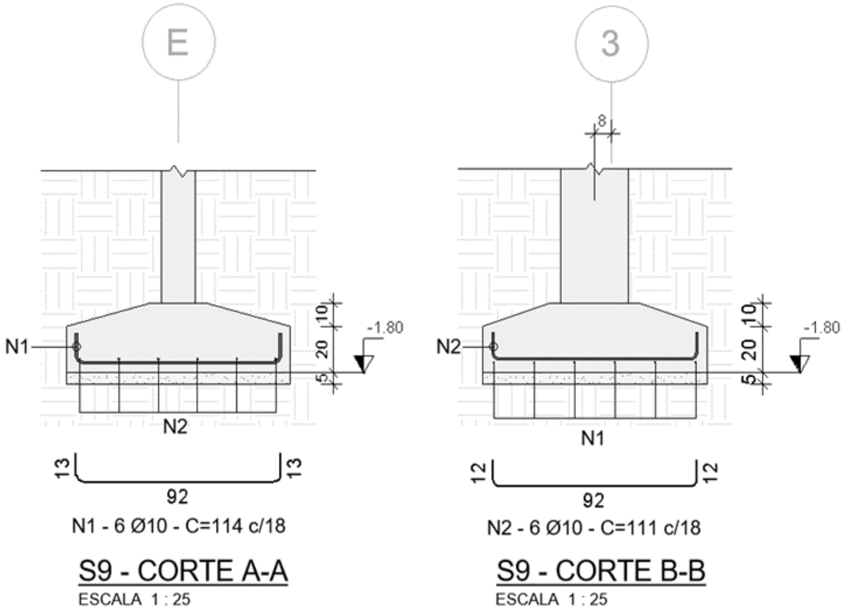


Source: the author.

Each bar modeled in a project carries with it a series of essential information for its correct characterization and detailing. This information includes its position, its gauge, its length, curvature details, among other relevant parameters. All this information will be represented automatically, using the identifier tool, as seen in Figure 10. Identifiers work by extracting information from the model. Thus, any modification made to the model members, whether in gauge, length or quantity, is automatically reflected in the corresponding identifiers.

By clicking on the structural element, the "rebar" function will be enabled in the "reinforcement" tab. You must select the desired gauge in the properties, rebar shape, and spacing tab. The reinforcement will automatically adapt to the structural element, already with the correct coverings, as seen in Figure 9. The same reinforcement modeling logic applies to any structural element.

Figure 10: Example of reinforcement detailing



Source: the author.

Bar lists are also automatically generated from the model data, as illustrated in the **Erro! Fonte de referência não encontrada.**. This avoids possible human errors that could arise during the manual process of summing the bar positions in the design.

One of the significant advantages of this methodology is the flexibility in generating the bar lists. The template parameters can be used to configure the lists in a variety of ways, allowing for a variety of representation options. For example, you can generate German-style lists, where each bar is represented in an exploded way in the drawing, or adopt the American system, in which the folding details are displayed directly in the bar list. [4] This customizability gives designers greater freedom in choosing the most suitable format for their specific needs.

Figure 11 Example of a steel abstract. List in German system on the left and American format on the right.

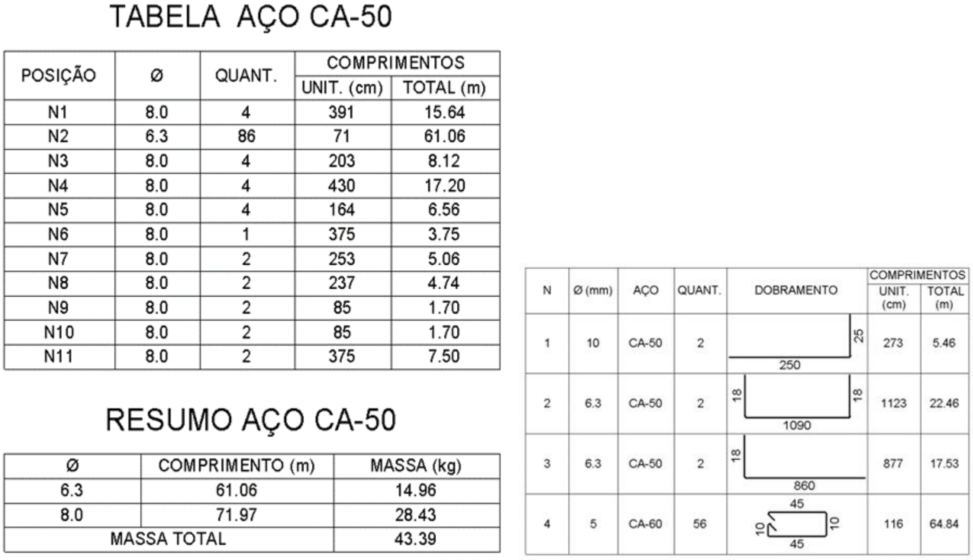


TABELA AÇO CA-50

POSIÇÃO	Ø	QUANT.	COMPRIMENTOS	
			UNIT. (cm)	TOTAL (m)
N1	8.0	4	391	15.64
N2	6.3	86	71	61.06
N3	8.0	4	203	8.12
N4	8.0	4	430	17.20
N5	8.0	4	164	6.56
N6	8.0	1	375	3.75
N7	8.0	2	253	5.06
N8	8.0	2	237	4.74
N9	8.0	2	85	1.70
N10	8.0	2	85	1.70
N11	8.0	2	375	7.50

RESUMO AÇO CA-50

Ø	COMPRIMENTO (m)	MASSA (kg)
6.3	61.06	14.96
8.0	71.97	28.43
MASSA TOTAL		43.39

N	Ø (mm)	AÇO	QUANT.	DOBRAMENTO	COMPRIMENTOS	
					UNIT. (cm)	TOTAL (m)
1	10	CA-50	2	25 250	273	5.46
2	6.3	CA-50	2	18 18 1090	1123	22.46
3	6.3	CA-50	2	18 860	877	17.53
4	5	CA-60	56	45 10 10 45	116	64.84

Source: the author.

CONCLUSIONS

The history of social and technological evolution converges on the time factor as one of its most valuable assets. In this sense, the work showed that the integration of the accurate and comprehensive representation of BIM, together with the developed routines, proved to be a highly effective strategy, both in improving the manufacturing time (mitigating rework due to eventual errors and/or design modifications) and in the understanding of technical drawings in reinforced concrete projects. Not only did the scripts make it possible to automate repetitive tasks, such as element numbering, speeding up the design process, but they also provided a flexible and parametric solution for creating drawings, allowing them to quickly adapt to design changes without having to redraw again.

The success of this approach is not just limited to saving time, but extends in technical terms. It was noted that with all families properly configured, they will already behave in accordance with current standards, for example with regard to bending diameters. In addition to the benefits mentioned, the implementation of BIM provided the ability to extract accurate quantities from all materials involved in the project, contributing to efficiency in cost control. Thus, it is concluded that the integration between BIM and Dynamo schedules not only solved specific challenges in the context of reinforced concrete, but established an innovative approach to the improvement of the project life cycle.

All the applications created can be easily adapted to any design need, once the operating logic of the nodes is understood. As a suggestion for future work, the following routines can be developed:

- Pre-sizing footings based on column load and soil resistance;
- Pre-dimensioning of slabs;
- Automatic modeling of lean concrete layer under the footings;
- Automatic insertion of reinforcement in structural elements;
- Design of steel area in structural elements.

Additionally, the creation of routines aimed at the prestressed concrete area can be extended, such as:

- Laying of prestressing cable;
- Calculation of friction loss based on cable geometry;
- Calculation of shrinkage loss and creep of concrete.

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