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VISUAL PROGRAMMING ALGORITHMS AS AN EDUCATIONAL RESOURCE FOR CIVIL ENGINEERING

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Abstract. Visual programming offers a robust framework for bridging the gap between theoretical concepts and practical applications in engineering education. Providing accurate virtual representations of physical systems enhances students' understanding of complex phenomena. This article studies this potential in structural analysis by applying visual programming as an educational tool. A parametric workflow in Dynamo is employed to replicate the structural behavior of a beam within a Building Information Model (BIM). This approach allows students to visualize and analyze structural performance, fostering a deeper connection between classroom theory and practical experimentation. The educational impact of this tool was evaluated through a survey conducted in a structural analysis course at the University of La Serena (Chile), demonstrating its effectiveness in improving students' understanding and engagement with modern engineering practices.

1 INTRODUCTION

Civil Engineering education currently requires the incorporation of technological tools to:

(1) digitize data [1], (2) improve project modeling [2], (3) support decision-making [3], and (4) improve the visualization of specialties [4], all to prepare future professionals for the current challenges of developing modern and sustainable infrastructure [5].

Of the above objectives, information visualization is key to understanding engineering concepts. Tools such as 3D models and simulations allow for improved analysis and communication between specialties, especially in activities that require accurate interpretation of designs [6]. Using these visual tools improves students' competency in project design and execution processes, as they strengthen their technical skills.

However, the use of visual tools in the training of AEC professionals is not new. Its use in Civil Engineering encompasses the following four milestones: (1) manual development of plans, (2) generation of CAD drawings (computer-aided design), (3) generation of information models (BIM), and (4) development of digital twins.

BIM and digital twins require programming in text code to develop software and external applications. However, this type of language requires advanced programming knowledge. To fill this gap, visual programming currently appears to be a more user-friendly alternative for engineering professionals since, instead of using lines of text, it uses visual process diagrams, facilitating the understanding of the algorithms [7].

Each Visual Programming (VP) algorithm has four components [8]: inputs (initial data), nodes (elements that process the inputs), outputs (which represent the results), and connectors (which establish the algorithm sequence).

The integration of Visual Programming tools in education improves learning in structural analysis topics since it allows forces and displacements to be simulated in BIM models. These simulations offer more accurate predictions, identify problems early, and improve safety, design, and execution strategies.

The VP+BIM environment is revolutionizing education by offering immersive experiences that connect theory and practice, improving the understanding of complex processes and reducing dependence on physical resources [9].

This platform allows students to interact with virtual infrastructure models, simulating structural performance under different conditions. This deepens their understanding and develops practical skills to solve real-world challenges [10].

VP+BIM tools prepare civil engineering students for the sector's current demands, fostering the technical competencies needed to address the adoption of advanced technologies in the construction industry [11].

Many students in AEC programs are unaware of the existence and applications of these technologies due to their lack of inclusion in academic programs, especially in structural analysis courses where prior information is required [12].

2 BIBLIOGRAPHIC REVIEW

Several authors have studied the application of VP-BIM models in educational contexts. The following authors are highlighted:

(1) Guzmán et al. [13]: They reviewed publications on using visual programming in teaching computational thinking at the elementary level. They point out the need for frameworks and assessment standards, cautioning against relying exclusively on computers. However, they did not analyze its application in engineering education.

(2) Sanchez et al. [14]: They studied the impact of BIM-based educational strategies on architecture courses at Yale, Columbia, Stanford, and Hong Kong. BIM improved teamwork and model visualization, although the studio only covered architectural specialties.

(3) Ahn et al. [15]: They proposed a BIM course combining theory and practice in construction planning, successfully applied at a university in the USA. Although it strengthened knowledge, it did not address the development of educational modules in structural virtual models.

This gap exists because the studies focused on Architecture and Construction, not Civil Engineering. In addition, modeling structures with visual programming requires more time than with BIM software [16]. Traditional tools are used in structural engineering courses to illustrate theoretical concepts.

The literature shows a limited use of VP-BIM tools in education. This occurs because digital information is mainly used by architecture and construction, limiting collaboration on structural issues. This lack of integration affects teamwork and visual comprehension, evidencing the need to include these technologies in AEC programs.

To fill these gaps, this paper proposes a platform that integrates a VP algorithm and BIM model to simulate a structure and study its behavior under external loads. In the selected case study, the structural performance of a simply supported beam is analyzed and be applied on structural analysis courses. In general terms, this platform represents deformations and the distribution of shear and bending loads. Then, visual algorithms send specific data to the BIM software for further structural analysis.

This article is organized as follows: Section 3 describes the tools and processes of the platform; Section 4 presents the case study applied to Construction Engineering students at the University of La Serena; Section 5 shows the results of the survey; Section 6 presents conclusions and future lines of research.

3 TECHNOLOGICAL PLATFOM PROPOSAL

This section describes the concepts and tools requires to develop this proposal which connects VP algorithms and BIM models. Section 3.1 presents the developed VP algorithms and section 3.2 the developed case study.

3.1 Development of Visual programming algorithms

The platform simulates forces, deformations and rotations under different scenarios, representing them in a didactic and understandable way. This proposal is defined as follows:

1. Define the Educational Objectives: Before developing a script in Dynamo, it is important to define the learning outcomes. In civil engineering, these typically include visualizing deformations and stresses, automating reinforcement details, simulating external factors such as wind and temperature, and connecting sensor data to BIM models.

1. Setup and Integration with Revit: First, make sure that Dynamo is installed and wellintegrated into Revit. Then, open a suitable BIM model such as a structural framework or bridge, launch Dynamo within Revit, and create a new script to begin the automation or analysis workflow.

2. Create the Dynamo Workflow: A workflow in Dynamo has three parts: data input (material properties, loads, dimensions, sensors), data processing (using nodes, Python, or DesignScript), and data output that updates the model in Revit or generates visual feedback.

3. Validating and Testing the Workflow: To validate the flow, simulations must be run with test data and compared with theoretical values. Visual representation should also be verified in Revit and user interface optimized to improve student interaction and educational effectiveness.

4. Deploying the Educational Tool: The Dynamo script should be integrated into a Revit template for ease of use. In addition, manuals or tutorials should be provided to help students

and collect feedback to improve the tool's usability and effectiveness.

Figure 1 represents the proposed methodology in this study, highlighting each objective and its key processes.

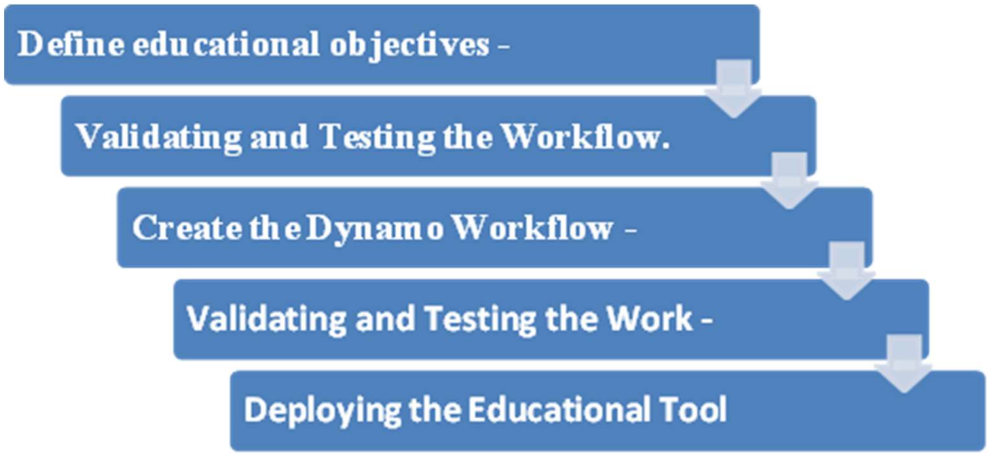

Figure 1: Represents the workflow of this study's proposed methodology, highlighting each objective and its key processes.

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Integrating Visual Programming tools in education improves learning in structural analysis topics since it allows forces and displacements to be simulated in BIM models. These simulations offer more accurate predictions, identify problems early, and improve safety, design, and execution strategies.

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3.2 Case Study:

This section describes how the proposed educational tool was applied to teach fundamental concepts of structural analysis to Construction Engineering students at the University of La Serena (Chile).

A case study was conducted to apply a Dynamo script connected to BIM to improve the visualization and understanding of structural concepts in civil engineering students. This proposal automatically generates deformations, reactions, shear force, and bending moment diagrams within the BIM software. Dynamo has extracted geometric and material properties from Revit, applied predefined loads, and calculated internal stresses. Then, the results were visualized using the BIM model, allowing real-time structural analysis and reinforcing the theoretical concepts by integrating them with the simulated structure. This proposal requires the development of the following visual programming nodes in Dynamo.

Inputs: beam length (L), section width (w), modulus of elasticity (E), inertia (I), load (P), momentum, and spacing between points. These variables allow the structure to be digitally modeled.

Operations: Three structural parameters were calculated: forces, deformations, and rotations.

Outputs: From the inputs and operations, the following are calculated: (1) reactions in supports, (2) deformations, (3) shear forces, and (4) bending moment diagrams.

The operations and results are calculated for different load cases, generating parametric equations for each. Three cases were considered: (1) point load, (2) evenly distributed load, and (3) point moments on supports.

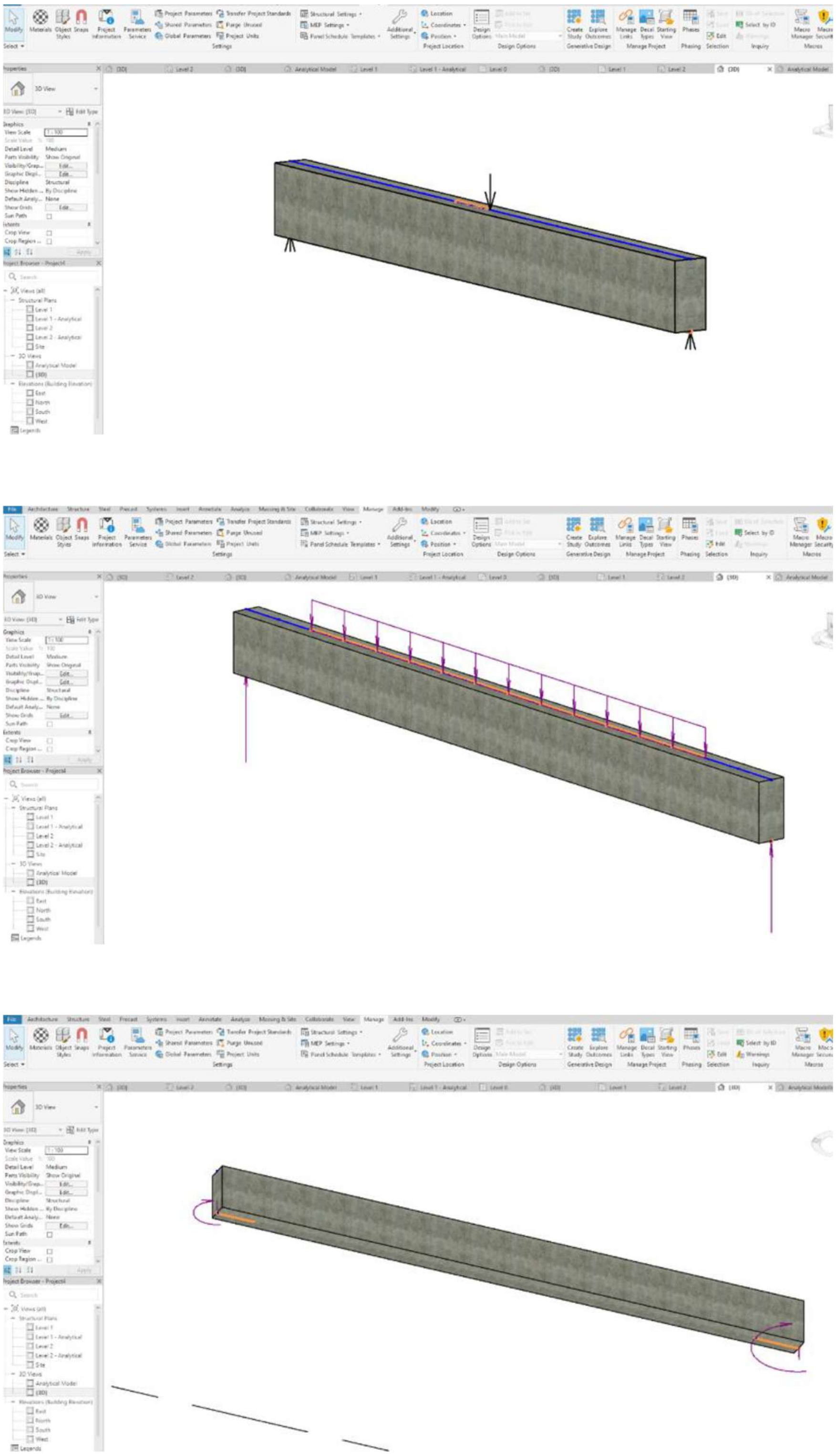
The class was taught on January 24 at the Faculty of Engineering of the University of La Serena, with 25 students. This group is relevant for its basic training in structures and impartial perception. All the teachers indicated that it was their first contact with this technology. The class lasted 90 minutes and was divided into 4 sections, described in Table 1.

Table 1: Topics and time periods developed in the expository talk.

Block	Name	Description	Time [min]
1	Introduction	The concepts and main elements of visual programming in BIM projects are presented.	20
2	Virtual Model application	Explanation of the virtual model proposed in section 2: inputs, operations and outputs are presented and explained.	35
3	Case analysis	Load cases are developed and analyzed.	25
4	Conclusions	The main ideas of the experience are delivered and the public answers the perception survey.	10

A beam simply supported was chosen as a base structure for practical application, since it is one of the most used elements in Structural Engineering exercises and classes.

Figure 2 represents a beam modeled during the experience (rectangular section) considering the following load scenarios: (1) point load, (2) distributed uniform load and (3) moments applied at the supports.



(a)

(b)

(c)

Figure 2: Loading scenarios modeled during the educational experience: (a) point load, (b) distributed uniform load, and (3) moments applied at the supports.

A survey was carried out to evaluate the effectiveness of the proposed methodology, aimed at teachers and students who attended the class. It was created in Google Forms and distributed via link by mail or a QR code displayed in class.

The instrument consists of seven questions designed to assess the following educational aspects: (1) Visualization and Simulation, (2) Understanding of Fundamental Concepts, (3) Solving problems capacity, (4) Development of technical skills, (5) Confidence in Structural Verification, (6) Potential as an Educational Resource, (7) General Satisfaction of the Experience. Questions from 1 to 9 had the following answers: (1) no improvement, (2) slight improvement, (3) moderate improvement, (4) significant improvement, or (5) excellent improvement. On the other hand, a satisfaction scale was proposed, numbered from 1 to 10, with 1 being the worst and 10 being the best score.

4 RESULTS AND ANALYSIS

This section breaks down the results of the survey, considering each of the available alternatives per question.

The results of applied survey shows that 60% perceive a good or excellent improvement in structural analysis concepts, highlighting that BIM VP algorithms facilitate intuitive learning. 20% report moderate improvement, possibly due to differences in previous knowledge, and another 20% perceive little or no improvement, reflecting resistance to methodological change. The last question shows that the 2 ratings with the most votes are 7 and 8 (72%). Therefore, the proposed educational application is validated with a high rating of general perception. 16% of respondents have evaluated the experience with a score of 5 and 6, which means a partial evaluation of the experience. This group can be associated with those who found limitations in time, resources, or adaptation. Finally, the 2 categories with the lowest rating were 3 and 4, representing 12% of the responses. This percentage represents the group that prefers traditional learning methods or presents some resistance to adopting digital tools in educational contexts.

5 CONCLUSIONS

- This paper presents a virtual BIM model as an educational tool in structural analysis courses. It integrates visual programming algorithms to simulate structures under different loads and supports. The model was applied to students and professors of Construction Engineering at a Chilean university, and its impact was evaluated through a survey.
- The study integrates a Dynamo algorithm with a BIM model in Autodesk Revit, visualizing deformations, shear diagrams, and bending moments. This demonstrates structural behaviors and the potential of BIM as an educational resource.
- The model was presented to 19 students and 6 professors from the University of La Serena as a case study. It was evaluated through a survey on concepts, simulation, problem solving, technical skills, and educational usefulness, with more than 50% strongly supporting the proposal.
- The results indicate that BIM and visual programming improve the teaching of structural analysis. However, resistance to digital technologies must be addressed to maximize their educational effectiveness.

6 LIMITATIONS AND FUTURE RESEARCH

The main limitation was not modeling more complex structures. Therefore, the research will seek to integrate visual programming with specialized BIM software such as Tekla Structures and Autodesk Robot, which require languages such as Python and C++.

Another limitation was not implementing digital twins in the educational experience. To solve this, low-cost sensors, databases, and visual programming algorithms will be integrated, creating a technological platform for engineering projects.

This experience was only applied in Structural Analysis courses. To expand the scope of the project for subjects such as (1) Solid Mechanics, (2) Structural Dynamics, and (3) Seismology.

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