ON THE BENEFITS OF VISUAL PROGRAMMING IN GEOTECHNICAL PLANNING PRACTICE

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Visual Programming, Automation, Geotechnics, VPL, BIM

ABSTRACT

Currently, the adoption of the method of Building Information Modelling (BIM) in geotechnical planning practice is rising. Most of the BIM-authoring tools offer the possibility to use visual programming environments, which also allow for text-based scripting within them. These can exemplarily be used to extend software capabilities and to automate workflows. Whilst practitioners occasionally utilize these tools, there is no comprehensive analysis on the use cases of them in geotechnical planning processes. In this contribution these use cases are analyzed, categorized and evaluated considering all common major steps in the planning phase. Identified applications are (I) parametric and computational geometry, (II) visualization and documentation, (III) integration and automatization, (IV) model management and coordination and (V) design analysis and simulation.

1. INTRODUCTION

The adoption rate of Building Information Modelling (BIM) is increasing across all disciplines involved in the construction process. A relevant part of its promised efficiency gains results from automation routines that run on top of the information model. BIM authoring tools provide various built-in routines for common tasks. However, in construction projects specific problems may arise that cannot be adequately supported by these built-in routines. These scenarios more frequently occur with increasing project complexity and as the use differs from the authoring tool's intended scope. To overcome this hurdle in workflow automation, many authoring tools enable users to write custom routines. Visual programming environments (VPE) are a common option for doing so.

Research question

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Geotechnical projects utilize the BIM methodology are often complex and use authoring tools, that are not specifically designed for geotechnical engineering problems. Therefore, various custom routines can be expected throughout the planning process to enable efficient workflows. The aim of this contribution is to explore the application and benefits of visual programming in geotechnical planning processes.

Methodology and structure

The following section of this contribution presents the main terms and concepts in visual programming. It then conducts a literature study on their use in the AEC sector with focus on geotechnical engineering. The identified applications are clustered and the underlying benefits are discussed. An illustrative example of a pile foundation is created to demonstrate the applicability to a common geotechnical problem. The present study concludes by highlighting the potential of visual programming in geotechnical engineering.

2. LITERATURE STUDY

Visual Programming Languages (VPLs)

A programming language is considered a VPL, if it includes visual expressions in its syntax [1]. VPLs typically follow the dataflow paradigm, hence they are also known as *flow-based* [1], [2]. This means that they illustrate the flow of information from input to output within an information processing system. Figure 1 displays a script written in Autodesk Dynamo, that generates a cylinder. A VPL script is created by placing nodes from a node collection on a canvas and connecting the node outputs to node inputs with wires. The dataflow can be read from left to right by following the wires from node to node. If an input parameter, such as the number slider defining the circle's and therefore the pile's radius is changed, all subsequent nodes are updated when the script is recomputed. Geometric-centric VPLs, commonly used in AEC, allow for rapid iteration over potential design solutions based on user interactions.

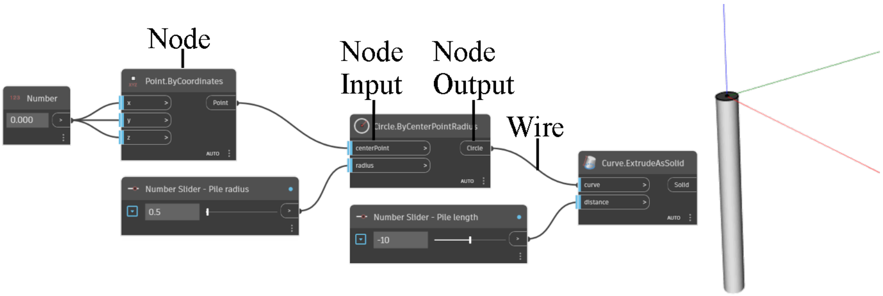

Figure 1 Dynamo-Script for creating a cylinder / pile and its resulting geometry

The advantages and disadvantages of VPL compared to traditional textual programming are well-discussed. VPLs are easier to learn, as investigated in regard to query languages in [3] and [4] and exemplified by Scratch, a VPL designed for teaching programming fundamentals. The visualization of the data flow may benefit visually-orientated people and VPLs are well-suited for rapid prototyping. On the downside, the execution time tends to be slower, and functionality is limited. Additionally, larger scripts or projects can be harder to organize and maintain.

VPLs in architecture, engineering and construction (AEC)

Many BIM authoring tools and CAD packages come with their own VP plugins or provide an interface to interact with such tools, although there are also standalone VP environments. Examples include GenerativeComponents in various Bentley programs, Grasshopper in Robert McNeel and Associates' Rhinoceros3D, Dynamo in various Autodesk programs, Geometry Nodes / Sverchok in Blender and Marionette in Vectorworks. This means that no additional installations or setups are necessary, making them more accessible.

In VPLs, scripting nodes are often available, allowing for textual programming within the VPL. This provides greater flexibility and enables the creation of more complex and advanced programs. Therefore, the use of custom scripts is actually addressed when discussing the benefits of VPLs.

Ritter et al. [5] discuss the use of VPLs in the AEC sector. They identify six use cases, which can be grouped into two categories: (1) generation of geometric and semantic information and (2) querying and analysis of existing models [2]. The first group includes geometric modelling, knowledge-based design, and system modelling, while the latter group includes query languages, design decision support, and code checking.

Collao et al. [6] reviewed the applications of VPLs in infrastructure projects. They found, that most papers using VP in this domain address the design phase and within that, parametric design being the dominating use case. The authors also noted a rising popularity of these tools, as evidenced by the increasing number of publications in recent years. They conclude, that future efforts are expected in improving the interoperability with web applications expanding the use of VPLs in monitoring.

VPLs in geotechnical engineering

In the following, examples of the VPL usage in geotechnical engineering are listed.

In Khan et al. [7] Grasshopper is utilized for earthworks modelling through a voxelization algorithm. Kahlström and Hansen [8] employ Grasshopper to create as-built-models of dry deep mixing ground improvements based on machine data. VPLs are used for geometry creation, data analysis and visualization. In Alaei [9] Dynamo is utilized for geometry processing and generation, including structures like piles and tunnels as well as the subsoil model. Ninić et al. [10] present an integrated workflow for BIM and numerical simulations using Dynamo and Python for geometry creation, data processing and post-processing. Huang et al. [11] use Dynamo with Python scripting nodes in a similar workflow for geometry creation (subsoil and underground metro station), preparation of executable scripts for numerical simulations and visualization of calculation results. In [12–14] meta models are additionally run in Dynamo using Python components enabling a real-time design assessment. Khan et al. [15] use Grasshopper for excavation safety modeling. In detail, geometry and semantic information is queried, analyzed and new geometry is created based on knowledge. Quantity take-offs for the new geometry are then conducted. El Sibaii et al. [16] employ Dynamo to process data from geotechnical investigations and create an information model from them. Zhu et al. [17] leverage Dynamo for manipulating BIM elements, data processing, constraint handling and design optimization in a segmented tunnel design. Wang et al. [18] use Dynamo geometric modelling, automating parameter assignment and create cross-passages within a tunneling project. Xun et al. [19] use the same VPL for visualization, data import and export in a tunneling project. They establish a connection to a MySQL database, reading sensor data periodically. Several other authors have addressed the parametric modelling of tunnels, e.g. [20–25].

Dynamo is used for modelling a subway station, extracting parameters and creating files for running a numerical simulation in Xie et al. [26]. In Jiao et al. [27] Dynamo is utilized to identify and resolve collisions of outside corner anchor rods in excavation pits. Additionally, data export and real-time visualization is achieved using the VPL. Filardo et al. [28] leverage Dynamo and its Python environment to create an automated and optimized construction schedule for a pile foundation. Peansupap et al. [29] use Dynamo for creating an automated system for clash detection and resolving in strut arrangements of deep excavations. Chuang et al. [30] leverage the same VPL for modeling a deep foundation pit. Barbieri et al. [31] highlight, that VPLs can be used for creating specific modeling and parametrization tools ad hoc and use automating rock bolts placement along lines with constant spacing as an example. Grasshopper has also been used to optimize slab and pile design layouts [32,33].

In previous research of the authors, VPLs have been applied to various problems related to the calculation of geotechnical structures such as pile foundations and sheet pile walls. Use cases include integration of heterogenous data sources, models and software applications, analysis and visualization and reporting [34–36]. For this paper, an educational example has been developed. It demonstrates fundamentals of VPLs using a pile foundation. Features include automatic adaption of pile length based on minimal depth within the load-bearing soil layer and automated report creation. The script and additional contents can be accessed in [37].

To conclude, the literature on VPLs in geotechnical engineering is compared with findings in [6], which focuses on infrastructure projects. In both domains, VPLs are mostly used in the design stage. Another mutuality is, that Dynamo is by far the most common VPL, followed by Grasshopper. The papers listed above mainly use Dynamo in conjunction with Autodesk Revit. Within this setup, a common approach is to create reusable parametric elements within Revit, named families, then use Dynamo to place them inside the project and control their parameters. The tendency in [6], that VPLs are becoming more popular in recent years reflects also in the found literature on VPLs in geotechnical engineering. Tunnels are the type of geotechnical construction, where until now most uses of VPLs can be found in literature.

It is evident, that many of the previous works utilize tabular data formats as starting point or for storing the results. Therefore, tools such as Microsoft Excel play an important role in current automation practices in the field of geotechnics.

Regarding the use of VPLs, five major groups can be identified: (I) parametric and computational geometry, (II) visualization and documentation, (III) integration and automation, (IV) model management and coordination and (V) design analysis and simulation. As mentioned, the first application is the most common. As for visualization, the most frequently seen technique is coloring objects within the 3D / BIM model. Reporting and drawing generation are rarely addressed in literature. Automation and integration of various data sources and applications are carried out on both small and large scales, with the aim of achieving efficiency, particularly when designs are altered. There are only a few publications that indicate the use of VPLs in model management and coordination. This may be because these tasks are likely not within the scope of geotechnical engineers in larger project. Yet, they are used for quality assurance of geotechnical models. Finally, three options for using VPLs in design analysis and simulation are identified: (I) performing the calculations within the VPL, (II) use the VPL to create input files for another application and (III) load external models for calculation within the VPL.

3. CONCLUSION

The conducted literature review indicates that the trends of VPLs in geotechnical engineering align with those in the infrastructure sector. The benefits of VPLs in geotechnical engineering include: (I) Automation of repetitive tasks leads to efficiency gains, (II) the expansion of software capabilities enables the use of generic BIM tools in the field of geotechnics, (III) improved interoperability is achieved through importing, processing and exporting capabilities in

VPLs, (IV) design quality is improved through by knowledge-based design, simple design iterations, and automated issue detection and resolving.

VPLs provide a relatively easy way to access and modify the data in BIM projects. As these projects are increasingly demanded and a trend towards a more data centric way of working can be observed, further increases in VPL adaption in geotechnical engineering can be expected.

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