GEOMETRY MAPPING TOOL: IMPROVEMENTS ON A DESCRIPTIVE GEOMETRY LEARNING TOOL

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Abstract. *Over the past decades, the technological presence has been increasing in education, producing new applications and digital platforms to assist with learning. This technological shift raises the achievement of students and promotes better school performance. This paper aims to explore the improvements made on Geometry Mapping Tool, a web application to support the teaching of Descriptive Geometry, specifically, the Monge method. The improvements were result of gathering criticism from students and professors in the field of study. The decisions made to improve the tool can provide useful insights to other educational tools. The web app was then re-evaluated to capture the feedback on the changes made and additional improvements.*

Key words: Descriptive geometry, technology education, web development.

INTRODUCTION

In the last decade, technology and the digital world have shown exponential growth and, consequently, technological solutions have emerged in various fields of study. The teaching of Descriptive Geometry (DG) is no exception and has undergone changes with the introduction of new technologies in the classroom, both on a physical level (e.g., computers and projectors) and digital level (e.g., PowerPoint presentations and virtual school platforms).

Stachel (2003) summarized DG as a method to study 3D geometry through 2D images providing insight into structure and metrical properties of spatial objects, processes and principles. The education in Descriptive Geometry provides a training of the students' intellectual capability of space perception.

"At present, the basic content of DG is taught in the last years of pre-university education and in practically all branches of Engineering; it is of vital importance in Design, Mechanical and Civil Engineering." (García et. al., 2007)

The purpose of this article is to discuss the improvements made on a DG learning tool specifically designed to assist the teaching of Gaspard Monge's method (Barbosa & Pereira, 2022).

Monge's method resorts to Orthographic Projection (OP) to describe the 3D geometry on a sheet of paper. The 3D geometry is projected to two perpendicular planes called: Vertical Plane (VP) [φ] and Horizontal Plane (HP) [υ] (Figure 1). The line of intersection of these two planes is called the Ground Line (GL) [x]. To represent the system in the 2D model, the HP is rotated around the GL until it coincides with the VP (Müller, 2022).

The developed learning tool is called Geometry Mapping Tool (GMT). While the traditional classroom studies of DG relies on paper sheets to faithfully represent a 2D plane, this tool comprises a web application that allows users to observe and interact with geometric representations on both 2D and 3D systems simultaneously. The tool was developed and

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implemented by the first author with guidance and supervision from the second author of the paper.

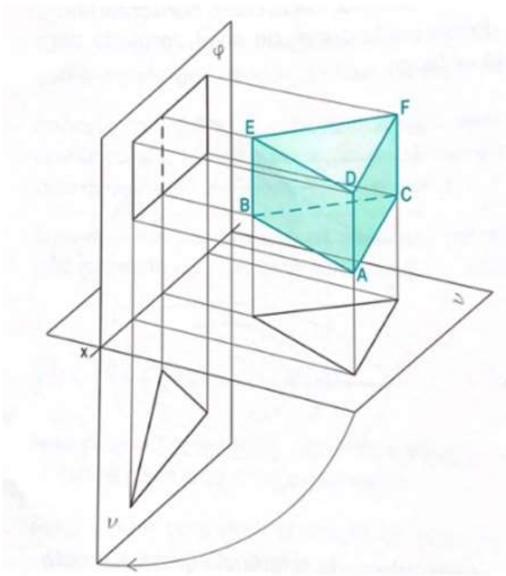

Figure 1: Monge's method (Müller, 2022).

The current paper is divided in six sections, being this one the first and introductory section. Following this, section 2 is reserved to discuss the related work and the technological decisions made to develop the application. Section 3 documents the engineering process followed in the development of the tool and its functionalities. Section 4 focuses on the implementation of the improvements and new functionalities and section 5 covers the results of a usability evaluation on the new features. The article ends with a small and concise conclusion about the work and prospects for the future development of the tool.

BACKGROUND

Throughout the years, there have been many attempts to introduce software in the teaching of DG and each approach has advantages and disadvantages. Currently, DG is lectured in a specific subject integrated in the Science and Technology Course and Visual Arts Course for the high school education. Since the main target for this tool was pre-university students and teachers, the criteria used to evaluate the effectiveness of the tools was based on three principles (Barbosa & Pereira, 2022):

- **Accessibility:** Accessible and compatible with most devices regularly used by DG students and teachers.
- **Dynamism:** Dynamic in the visualization of 3D space so that the user can have the best spatial perception of the exposed geometric elements.
- **Functionality:** Describes as many features as possible to demonstrate the content of the DG field of study.

We can group the technological learning solutions into two types: web platforms and executable applications.

Web platforms such as GeoGebra (cf. Hohenwarter & Jones, 2007) offer easy access and compatibility since they are mostly free web platforms requiring only a browser to access. Most platforms address the complete GD curriculum, thus demonstrating a strong functional aspect. However, these web platforms perform poorly according to the dynamism principle and the best that they can offer is a step-by-step view of DG exercises and their respective 3D view.

Executable applications are more diversified in terms of functionalities and capabilities and most of them offer a good dynamic presentation of the 3D geometry. AutoCAD has been a choice in many university classes and has gathered interest from students to learn DG. However, for a pre-university class, the software is costly, and the level of complexity brought to the user can become a big obstacle to the learning experience (Bokan et al., 2009).

Another candidate is the application "AEIOU – Geometria Descritiva" that focuses on teaching the Monge method (cf. Alves, 2008). Developed in 2001, the executable is not compatible with the modern Operating Systems (OS) and the Graphical User Interface (GUI) looks outdated. Nonetheless, the tool is simple and clear for teaching DG and more specifically the Monge method.

The Geometry Mapping Tool (GMT) seeks the combination of these three approaches, taking advantage of the strengths identified and reducing the problems pointed out in each of them. Therefore, the tool was designed and developed to become a highly accessible web platform with the functionalities and dynamic visualization from the executable applications.

To display 3D graphics in a web environment, the tool was developed with a JavaScript framework named ThreeJS. This framework is built around the Web Graphics Language (WebGL) library and provides a level of abstraction that facilitates the development of the tool without compromising it. To support this framework the tool was implemented with a simple web stack: Hypertext Markup Language (HTML), Cascading Style Sheet (CSS) and JavaScript (JS)/ TypeScript (TS). These technologies allow the development of web platforms where HTML establishes the structure of the page, CSS describes the style of the page and JS/TS defines the logic and functionality of the page (ThreeJS, n.d.).

As of now, the platform migrated to a modern web framework called SvelteKit. This decision was made due to the increasing work in development and the need to be up to date with the current web technologies. SvelteKit is a full-stack meta-framework (a framework built on top of another framework) that ties the frontend and backend together to deliver the best developer and user experience. This framework allows the developer to build high-performance web apps with ease due to the Hot Module Replacement (HMR), where changes to the code are reflected in the browser instantly. SvelteKit provides features like preloading pages and offline support to facilitate the accessibility from low-performance devices. With this framework, the project can be implemented at a higher pace and deliver new functionalities without compromising the user experience. Being a full-stack framework, SvelteKit opens the possibility of implementing a backend that integrates with a database to persist data within the two representational domains thus, expanding the use cases of the tool (Joy of Code, 2022).

GEOMTERY MAPPING TOOL

The development of the tool followed every step of the software engineering process with the gathering of the functional and non-functional requirements, modeling the system at different levels of abstraction and describing the solution components. To understand the core concepts and relationships between the components of the application, Figure 2 exposes a simplified version of the domain model of the system.

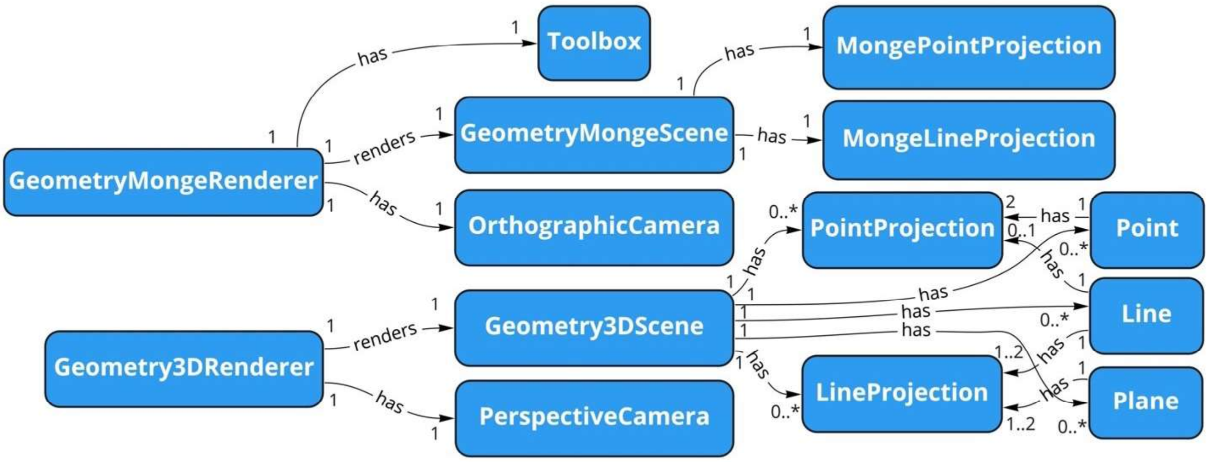

Figure 2: Simplified domain model of the application (Barbosa & Pereira, 2022).

The application is divided into two domains: the 3D domain and the Monge domain. These two domains characterize, respectively, the real-world 3D view and the 2D representation with the help of the Monge method. Consequently, the Graphical User Interface (GUI) is split between two windows representing the respective domain. In Figure 3, we can observe these two domains highlighted with a color (highlighted in yellow for the 3D domain and in blue for the Monge domain). To help with the creation of the geometry in the Monge view, the application provides a set of tools in a toolbox component (highlighted in red).

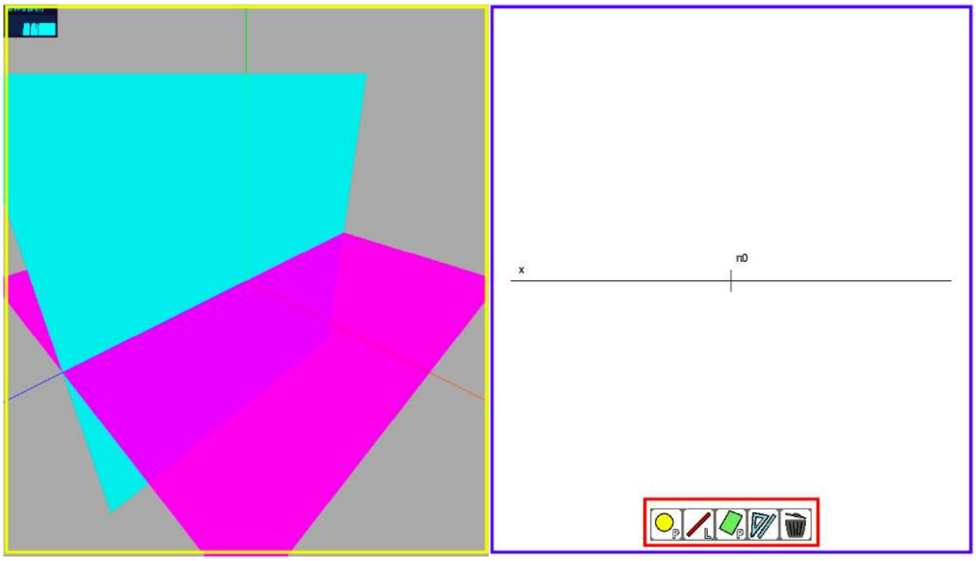

Figure 3: GMT's GUI (Barbosa & Pereira, 2022).

This way, the application supports the creation of geometric elements in the Monge view, simulating the experience of the user solving exercises in the DG class and simultaneously providing the real-world representation in one single screen.

GMT'S IMROVEMENTS IMPLEMENTION

The major criticisms to the previous version of the tool targeted the use of the point tool. The problem users had when dealing with this tool was that it provided poor accuracy since it allowed the creation of a point projection where the cursor was positioned. An improvement to fix this low accuracy problem was to fix the selection of the y coordinate along the x-axis and when chosen, fix the x coordinate and wait for the selection of the y coordinate. By splitting the selection process of the coordinates, it allowed the user an easier control and more accuracy when creating the point projections.

Another criticism focused on the GUI for being outdated and hard to grasp. After taking these insights into account, the toolbox was updated to a much simpler GUI creating space for new tools. Since the appearance of the toolbox was also a target of criticism the icons were updated to give a modern style. Figure 4 represents the previous version of the toolbox's GUI on the left and the recent design on the right. For a better comparison both tools have all their buttons hovered to demonstrate all changes made. The older version of the toolbox was composed of five major tools: point tool (a) allowing the creation of point projections, line tool (b) allowing the creation of line projections, plane tool (c) allowing the creation of plane projections, auxiliary line tool (d) allowing the creation of line or plane projections perpendicular or parallel to an existing one and the delete tool (e) allowing the removal of any projection. Point, line and plane tools had options to change between projection types ("F" for frontal projections and "H" for horizontal projections).

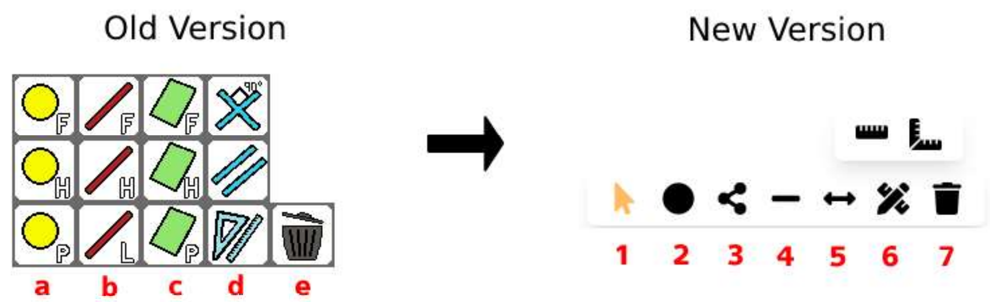

Figure 4: Previous and current version of the toolbox's GUI.

In the Monge method the type of projection is defined by the number after the name of the projection (e.g., "a1" represents the horizontal projection of the line "a"). It was concluded that there was no reason to have separate buttons for the creation of each projection type and instead move that decision to the prompt after the selection. Furthermore, in the Monge method a point projection can represent part of a line (Figure 5) and a line projection can also represent plane projections. Therefore, the line tool and plane tool become redundant, and the point tool can be modified to be compatible with the line projection creation leaving these decisions to the prompts after selection. The current toolbox's GUI kept the four tools: point tool (2), line tool (4), auxiliary line tool (6), delete tool (7) and displayed three new tools that we are going to cover in this section: view tool (1), point association tool (3) and segment tool (5).

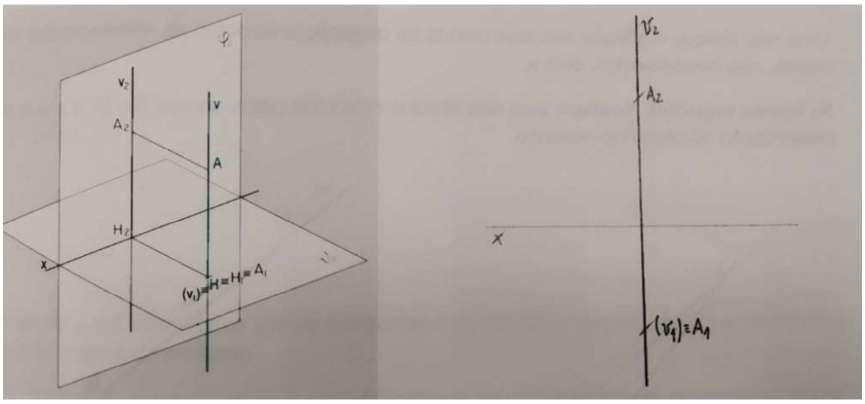

Figure 5: Vertical line composed of a point projection (v1) and a line projection (v2) (Müller, 2022).

User experience (UX) is a key factor when designing the tool and the purpose of the Monge view is to simulate the work environment of a DG's student/professor. The point association tool allows the user to select a line within the Monge view and create a point projection of that line along the x-axis. This feature facilitates the user when creating point projections where a line projection intersects another.

Another tool that enhances the UX is the view tool. This tool allows the user, to a certain degree, zoom and pan the Monge window. By having this available, the user can guarantee a more rigorous use of the tool and, consequently, have more accuracy when using the other tools. Along with this feature, it was implemented an auxiliary button to set the zoom and position of the camera back to their default values.

Currently the application is in a work in progress state, so it doesn't cover the complete DG's curriculum. To help accomplish that, the segment tool was implemented. This tool allows the user to connect point projections hence creating segment projections and 3D segments. This feature contributes for the completion of the DG's curriculum by enabling the construction of 3D figures and solids (Figure 6).

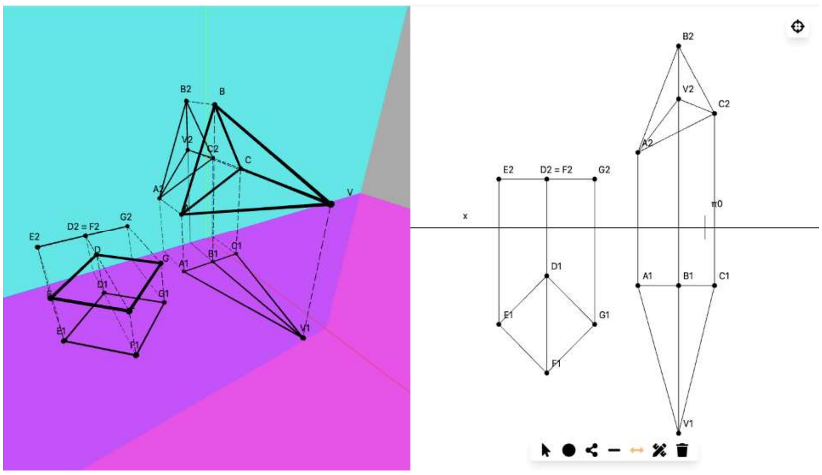

Figure 6: Square and a pyramid built with the segment tool.

EVALUATION

To properly assess the implementation of the new improvements an evaluation session was conducted. In this evaluation, the participants solved a DG exercise, adjusted to the tool's capability. Upon conclusion, the participants gave an informal opinion about the tool, on a practical level, by addressing three topics: criticisms of the system and aspects for improvement; benefits of having the 3D representation view; suggestions for additional functionalities. The session occurred on the 7th of December 2022 and there was a total of four participants: three students and one tutor of DG from the tutoring center "Grupo Peculiar". Participants had no previous experience with the tool at any stage of development.

At the start of the activity, participants pointed out that the selection of point projections from the use of the point association tool was sometimes difficult to make. However, with the help of the zoom and pan from the view tool this difficulty nearly disappeared. One participant noted that a substantial amount of time was wasted switching tools and so, suggested the use of the view tool simultaneously with the other tools via keyboard shortcuts.

When asked about the 3D representation view, all participants agreed that the tool contributes greatly to the understanding of the Monge method and improve the intellectual capability of space perception. Furthermore, the 3D view provided additional information about the exercise and gave the ability to check for mistakes and rectify them.

Participants made a lot of suggestions regarding new functionalities for the tool. Most suggestions were minor improvements to the existing tools such as: highlighting point projections that have the same x coordinate; have the point association tool work for segment projections; facilitating the creation of point projections in line projection intersections. Another great suggestion that resonates with the tool's objectives was the ability to save and load exercises developed with the tool.

CONCLUSION

Following the opinions from the evaluation session, the tool seems to be at a very optimistic state and the improvements implemented have been proven helpful and positive. The 3D view continues to serve an important role in developing the user's space perception and it was identified a desire for UX improvements in this view. As stated in section 2 and reported in section 5, the meta-framework SvelteKit improves the development rate of future improvements for the tool and opens the possibility of implementing complex use cases.

Continuously capturing feedback from the academic world is a vital step in the software engineering process of the tool. To become successful in the education environment, it's recommended for the tool to be put into practice on a larger population with an extended timeframe.

A reminder that GMT's purpose is to assist students and professors in the teaching and learning of the Monge method and not substitute the traditional approaches used in DG. Manual practice is of great importance for success in DG and the rigor required in it is part of the criteria used to assess students. In this way, the desire remains for the tool to be further developed and applied in classrooms, thus fulfilling its purpose.

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