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Work in Progress: Development of an AutoCAD Plugin to Increase Student's Spatial Visualization Skills

Omar Snosi
Dr. Kimberly Grau Talley, P.E., Texas State University

Dr. Kimberly G. Talley, P.E. is an associate professor in the Department of Engineering Technology, Bobcat Made Makerspace Director at Texas State University, and a licensed Professional Engineer. She received her Ph.D. and M.S.E. from the University of Texas at Austin in Structural Engineering. Her undergraduate degrees in History and in Construction Engineering and Management are from North Carolina State University. Dr. Talley teaches courses in the Construction Science and Management and Civil Engineering Technology Programs, and her research focus is in student engagement and retention in engineering and engineering technology education. Contact: talley@txstate.edu

Mr. Krishna Prasad Kisi, Texas State University

Krishna P. Kisi, holds a Ph.D. in Engineering from University of Nebraska-Lincoln, MS in Construction Management from University of Nevada, Las Vegas, and a Bachelor in Civil Engineering from Tribhuvan University. He has several years of teaching experie

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Abstract

Spatial visualization of three-dimensional (3D) objects based on two-dimensional (2D) drawings is a fundamental skill for engineers, contractors, and architects. A lack of spatial visualization skills frequently correlates with lower scores in math, science, and engineering courses and lower persistence to graduation. Moreover, after graduation, it may lead to costly mistakes in various engineering and construction disciplines. Although BIM (Building Information Modelling) technology has grown in adoption throughout the AEC (Architect, Engineering, and Construction) industry, 2D drawings are still a fundamental deliverable that requires correct interpretation for accurate construction. Most universities introduce AutoCAD in their lower-level classes to teach 2D drawings in their AEC curriculum and then include 3D visualization courses in their upper-level classes. However, students still need help interpreting 2D lines in AutoCAD, especially when they have poor spatial visualization skills. In addition, students often need to learn why they are taught to use different line types when drafting, such as what the difference between a solid and dashed line from a 2D drawing represents in the physical structure. This study aims to address the challenges in teaching 3D visualization skills in universities by developing a plugin called Spatial Visualization for AutoCAD (SVA). This work-in-progress project is testing the SVA plugin in AutoCAD to help undergraduates improve their spatial visualization ability by facilitating the connection between 2D sketches and 3D objects. This custom AutoCAD plugin has been developed that allows students to self-verify their 2D drawings by checking the 3D versions of what they have drafted. Students could then engage in what-if scenarios to visualize the interpretation of 2D objects in a 3D space by changing their drawings and the properties of the assigned line types. As a pilot test of this plugin, this study will collect feedback on the usability and training tutorial for the plugin from students who are enrolled in AutoCAD classes in the Construction Science and Management program in a large Hispanic Serving Institution in the South-Central United States. This pilot study guides the plugin tutorial's refinement so that the full test of the plugin's efficacy on students' spatial visualization skills can run smoothly. This paper shares the status of the SVA plugin development and assessment.

Introduction and Background

Despite advancements in BIM technology, 2D drawings continue to play a crucial role in construction. Misinterpreting these drawings can cause miscommunication between the design and construction teams, leading to delays, increased expenses, and potentially even structural issues (Côté et al., 2013).

In engineering and construction, 3D visualization is crucial in helping students comprehend and analyze complex systems and designs. It enables the creation of accurate testing and optimization models and facilitates effective communication of design concepts (Nasir et al., 2014; Gao, 2023). The challenge engineering and construction students face in interpreting 3D visualization is due to difficulties in spatial visualization. Some students arrive in engineering and construction courses with varying abilities in drawing and visualization, and difficulties in visualizing objects in 3D can lead to issues in interpreting and creating engineering and construction drawings and components, as well as problems visualizing forces, effects, and other concepts relating to the physical world (Besançon et al., 2021; Milne et al., 2014). To address these challenges, software such as AutoCAD might be able aid in enhancing the teaching of 3D visualization. AutoCAD, a widely utilized computer-aided design tool in engineering, construction, and architecture, is well known for producing 2D drawings, but also allows designing and visualizing objects in 3D (Zakaria et al., 2012).

Most engineering and construction programs teach AutoCAD for 2D drawings in introductory courses and offer courses in 3D visualization in upper-level classes (Hao et al., 2016; Otey et al., 2019; Oyebode et al., 2015; Anneberg et al., 1997). However, the students enrolled in engineering and construction programs often possess mixed entry skills in engineering and construction drawing. Some students may be experts in the subject due to their exposure to it during their secondary school education, while others may find it entirely new for them. This disparity in knowledge and experience creates a significant gap in the students' spatial visualization skills. The students who are experts in the subject may find it easier to interpret and create engineering and construction drawings and components. Still, for others, this ability can be a significant barrier to their progress. This gap in spatial visualization between students creates a challenge for educators. It highlights the need for tailored support and instruction to help all students reach their full potential in this important engineering and construction aspect (Akasah et al., 2010).

Numerous studies have been conducted to enhance the spatial visualization skills of engineering students (Sorby and Baartmans, 2000; Rodriguez and Luis, 2018; Hartman et al., 2006; Friess, W.A. et al., 2016). Sorby and Baartmans (2000) presented a course that employs paper folding, freehand sketching, and CAD software to improve students' mental ability to manipulate 3D objects. Similarly, Delson and Van Den Einde (2015) developed an iPad application for spatial visualization training and freehand sketching, which recorded all student sketch attempts and performance on multiple-choice questions. Rodriguez and Luis (2018) utilized data analytics to identify predictive factors contributing to spatial visualization ability, their research indicated that scores on the Revised Purdue Spatial Visualization Tests with Rotations (Revised PSVT: R) and demographic data could aid in predicting performance and informing interventions. These studies and numerous others underscore the significance of creating effective interventions to improve spatial visualization skills among engineering students and the potential benefit of implementing data analytics and technology-based approaches to enhance learning outcomes.

Objective and Research Questions

This study aims to develop a Spatial Visualization plugin for AutoCAD (SVA). It will provide students with various tools and features for a smooth transition from 2D to 3D interpretation and vice versa. In addition, the plugin will make it easier for engineering and construction students to engage in scenario simulations, where they can visualize the interpretation of 2D objects in a 3D space by changing the drawings and properties of assigned line types, ultimately improving their understanding and application of both 2D and 3D visualization in their work.

The following research questions guide this project:

1. To what extent can a Spatial Visualization plugin for AutoCAD (SVA) contribute in

improving the spatial visualization skills of architecture, engineering, and construction students?

2. How do engineering and construction students perceive the usability and user-friendliness of the SVA plugin for 2D to 3D conversion in AutoCAD?

Methodology

The study consists of two major parts: 1) developing the SVA plugin and then, 2) assessing the effectiveness of SVA in improving 3D visualization skills for engineering and construction students and measuring the correlation between spatial visualization skills and plan interpretation. The following paragraphs explain the current state of this work-in-progress.

Part 1: Development of SVA

SVA architecture

The architecture of SVA consists of the AutoCAD API, WPF for creating graphical user interfaces, a custom C# framework for creating custom, a data model representing the underlying data used by the plugin, and the business logic defining the behavior and functionality of the plugin as shown in Figure 1. This architecture provides a flexible and scalable framework for creating powerful and feature-rich features to meet the specific needs of engineering and construction students.

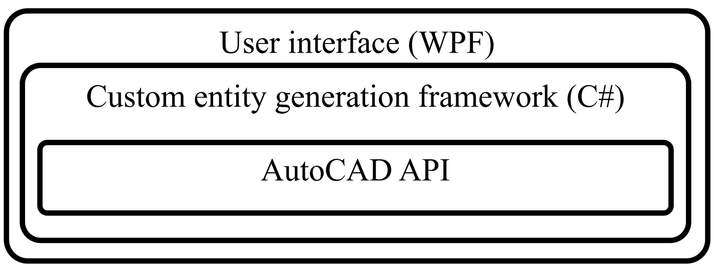

Figure 1: An architecture of the SVA

SVA user's interface

The SVA plugin is intended to be easy to use, even for those with limited experience with AutoCAD. As shown in Figure 2, the plugin features a tab with two ribbons, the activation ribbon and the creation ribbon, which provide direct access to all the available features. The activation ribbon includes buttons to turn the plugin on and off, while the creation ribbon has buttons for creating 2D beams, columns, walls, slabs, and footings.

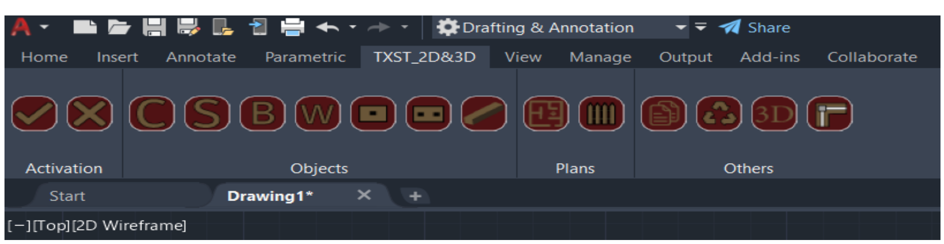

Figure 2: SVA plugin tools

The SVA plugin features a second ribbon tab dedicated to object creation, which includes buttons for creating 2D beams, columns, walls, slabs, and footings. The user interface form attached to each object allows the user to adjust properties.

SVA key features

1. Customized object's form:

A key objective of the SVA plugin is to facilitate the creation of 2D objects such as beams, columns, walls, slabs, and footings in a user-friendly manner. This objective is achieved by enabling the user to access a personalized form (as illustrated in Figure 3) by double-clicking on any of these objects, which allows for the seamless modification of object properties and immediate visualization of changes in the drawing.

Figure 3: Customized objects' form

2. 2D to 3D conversion:

The 3D conversion button (Figure 4 (c)) is a key feature of the SVA plugin. This button turns 2D drawings into 3D models allow users to interact with their objects by rotating and viewing them from various angles. The research team hypothesized that by quickly seeing the 3D representation of their 2D drawings, students will gain a deeper understanding of the interconnections between different design components. and that understanding can improve spatial visualization skills.

To illustrate the 2D to 3D conversion, consider the 2D structural plans in Figures 4 (a) and (b). These plans provide essential information about the design and structure of a building, but they can be challenging to visualize in 3D for students. By clicking the 3D conversion button (Figure 4 (c)), the SVA will generate a 3D plan as shown in Figure 4 (d).

SVA Debugging

To ensure the quality and reliability of the plugin, rigorous debugging and testing processes were implemented during its development to carefully examine the code and test the plugin to identify and resolve any issues. The testing process was designed to validate the functional and performance requirements of the plugin, ensuring that it met the needs of its target users. The debugging process involved using various tools, such as Visual Studio Debugger and Debug Diagnostics Tool, to identify and resolve issues related to code logic and performance. Regression testing will be performed, which involves retesting the plugin after code changes were made to verify that the changes did not introduce new problems or affect the existing functionality.

Part 2: Investigate the effectiveness of SVA.

The study's primary purpose is to investigate the effectiveness of the SVA plugin on students' spatial visualization skill development and any correlation between their spatial visualization skills and their plan interpretation skills. The details of the research plan, as shown in Figure 5, will be presented in the following sections.

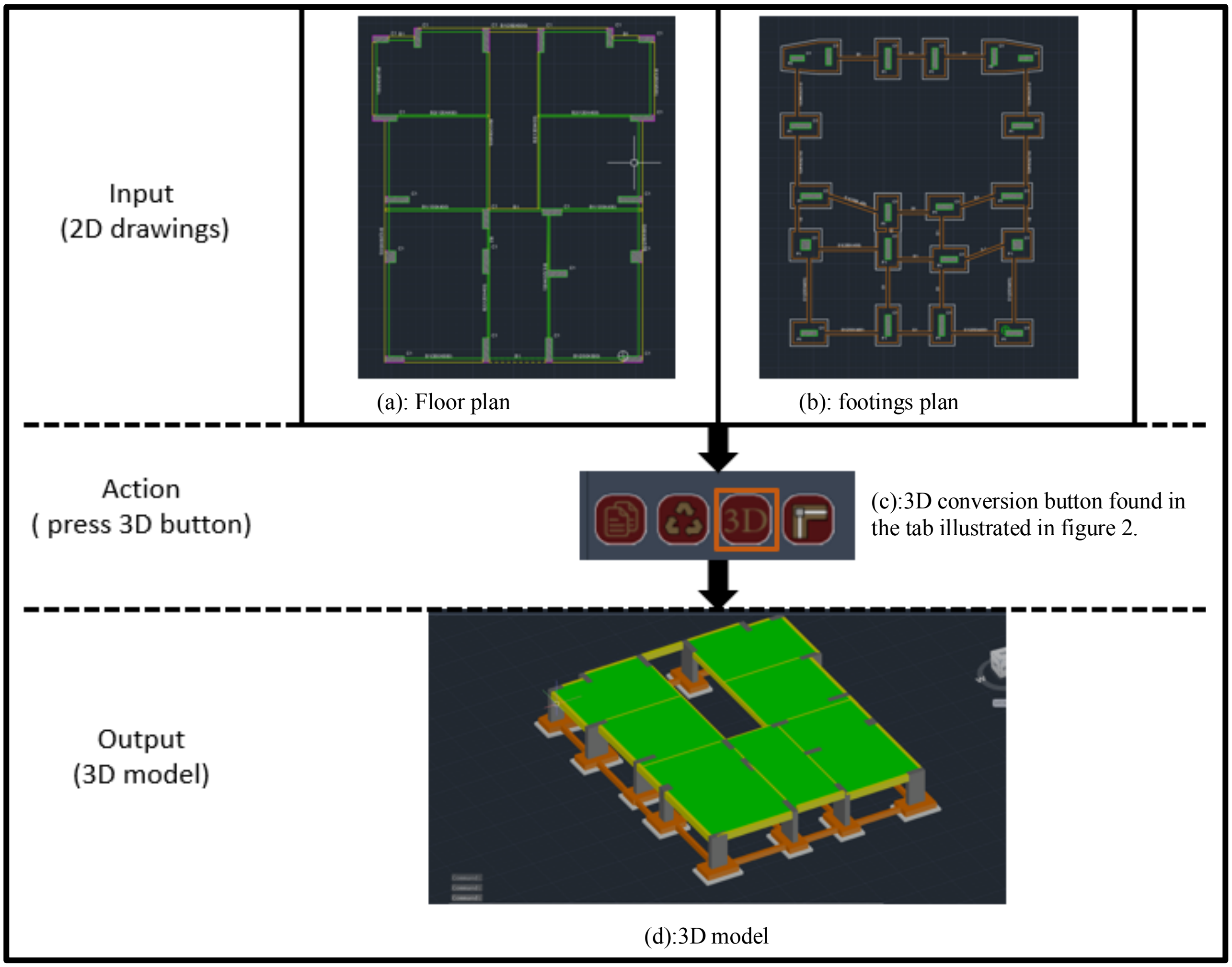

Figure 4: 2D drawings to 3D model using 3D conversion feature in SVA

Research Plan

It should be noted that the SVA plugin is a recently developed tool. The process of further study aims to assess the effectiveness of the SVA plugin through a series of ongoing steps, including defining evaluation criteria, gathering and analyzing data in both a pilot study and semester-long study, and making continuous improvements. The implementation of these steps is described in detail in the research plan section and is represented visually in Figure 5.

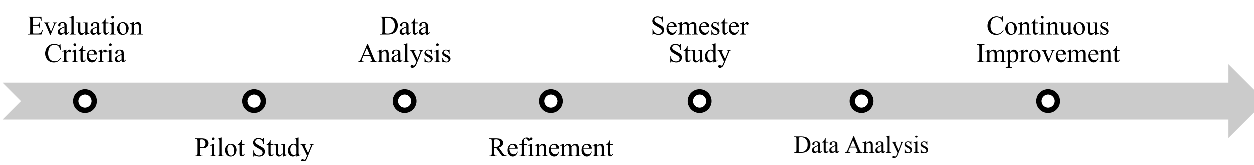

Figure 5: Plugin assessment research plan

Define evaluation criteria.

To answer the two research questions, two unique instruments are needed. The first is to use a validated instrument of students' spatial visualization skills, the Revised Purdue Spatial Visualization Test (Revised PSVT:R) (Yoon, 2011). The second is an assessment of students' construction plan interpretation. It is built upon the concepts of the Revised PSVT:R, but instead of rotating blocks or elevations of blocks, it presents the students with construction drawings and asks for them to identify the correlating 3D image of the structure, or vice versa. An example of a plan interpretation questions is shown in Figure 6.

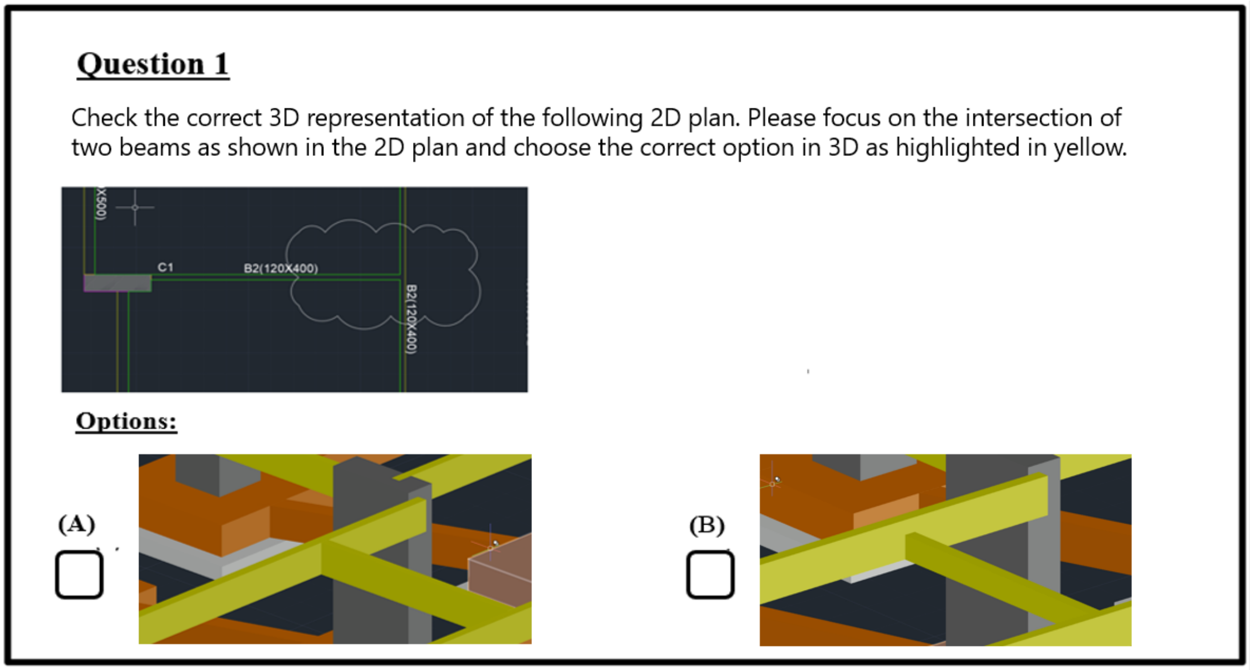

Figure 6: Sample of pre- and post-workshop questions

For the pilot study, the plan interpretation assessment will be administered pre- and post- the one day workshop and the Revised PSVT:R will be administered only during the pre-workshop survey. This point in time measurement of spatial visualization and plan interpretation will provide preliminary data for RQ2 and the pre- to post-survey comparison will look at short term impacts of the SVA plugin. For the semester-long study, both assessments will be administered pre- and post-semester.

Pilot Study

A workshop will be held for undergraduate students in the CSM 2313- Architectural Design I – Construction Drawings course at Texas State University. The workshop will provide an overview of the study and the steps involved. The students will receive a brief introduction to the study, collect informed consent, and then watch a five-minute video introducing the SVA plugin and its features to kick off the session. The video will give students an understanding of using the plugin and its benefits for improving 3D visualization skills.

After the video, students will have twenty-five minutes of hands-on experience with the plugin, allowing them to apply their knowledge and improve their 3D visualization skills. A multifaceted approach to data collection will be implemented to evaluate the influence of the

SVA plugin, including and pre- and post-workshop surveys. The IRB (#8671) has been approved to collect the data, and the study will follow the IRB protocol during data collection. User surveys will provide quantitative data on users' perceptions of the plugin's effectiveness. At the same time, pre- and post-workshop tests will better understand users' experiences. The pre-workshop instrument will be a homework assignment that is due before the workshop. The post-workshop survey will be administered towards the end of the workshop.

Data Analysis

The data from the pilot study will be analyzed to provide preliminary results about the correlation of students' spatial visualization skills to their plan interpretation skills. Comparison of the pre- to post-workshop plan interpretation assessment will provide evidence of short-term impacts of a one-time exposure to the experimental plugin. Further, the feedback from the post-workshop survey will be used to guide any improvements in the SVA plugin.

Refinement

The development team will also conduct user acceptance testing (UAT) with a group of professors at Texas State University to ensure the quality and reliability of the SVA plugin. The feedback received from UAT will be utilized alongside the student feedback from the pilot study to enhance the plugin's functionality and user experience. The results of the evaluation process are essential in ensuring the effectiveness of the newly developed SVA plugin. Based on the findings, the research team will make necessary improvements to the plugin to address any shortcomings or limitations identified. This may include modifying the design, improving the functionality, or addressing user comments.

Semester Study

To better answer research question 1, the experimental plugin will be deployed in a section of CSM 2313 while an additional section of the course, taught by the same instructor, will serve as the control group. Both sections will take the pre- and post-semester surveys that include the Revised PSVT:R and the plan interpretation assessment. The only difference between the sections will be the availability of the SVA plugin to the experimental section and instruction on how to use this plug in, which will be provided the lesson after students draft their first structural members so that they will have some context for its use.

Data Analysis

The longer scale intervention of the semester study will be able to look at whether student improvement in Revised PSVT:R can come from instruction in AutoCAD alone, or to what extent it is enhanced by the use of the SVA plug in. The pre- and post-semester surveys also offer two additional point in time surveys of spatial visualization and plan interpretation skills to allow the investigation of any correlation between them to address research question 2.

Continuous Improvement

Continuous improvement through regular re-evaluation of the plugin is crucial to assess its ongoing effectiveness and identify areas for further improvement. The research team will re-evaluate to ensure that the plugin remains relevant and meets the changing needs of the users. Regularly re-evaluating the plugin will help identify areas for improvement, address any limitations, and ensure that the plugin remains effective in supporting users' work processes and productivity.

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