Interactive Construction of Solids from Orthographic Multiviews for an Educational Software Tool

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ABSTRACT

Although the use of 3D digital product modeling is widespread, engineering drawings with orthographic multiviews still serve as legal documents for product development processes. Many engineering students are required to create and interpret the engineering drawings, but a significant number of students have problems in understanding the multiview drawings. An educational software tool for interpreting the engineering drawings has been developed to help students to improve the skills. Users will learn the concepts by sketching an isometric view of an object represented in multiview drawings via dynamic visual feedback, and a corresponding 3D solid model is constructed interactively. As the solution 3D models are interactively created, instructors do not need to provide the solutions with the problems.

Keywords: drawing interpretation, education software, interactive system.
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1. INTRODUCTION

Interpreting engineering drawings is an important skill that many engineering students must achieve. Students learn the concepts in their first engineering course in many engineering curricula, before learning solid-modeling skills, and their experiences of the course often affect their decisions to continue their pursuits of engineering careers. Students need to be familiar with spatial reasoning skills and the many strict rules defined by the engineering drawings standards. The engineering drawings are typically represented in orthographic multiviews as shown in Fig. 1. Although the mathematics of the mappings is sound and simple, interpreting the multiviews and visualizing them in a three-dimensional space presents a great challenge for students.

The interpretation of orthographic views is a vital skill that must be developed in early engineering courses. Sketching an isometric view of an object by interpreting its multiview drawing is an exercise often used in teaching and learning the concepts as shown in Fig. 2. Students often need individual attentions from instructors to resolve any problems they may face as they go through many different exercises. Instructors demonstrate the concepts using many examples, pointing out the matching entities in the multiviews. Unfortunately, freshmen class sizes are usually large, which limits the time and availability of such personal instructions. Solutions of many textbook problems are not immediately available, and students cannot check their solutions without instructors' help even if they finish the tasks. Therefore, not all students can perform enough exercises to fully grasp the idea and concepts.
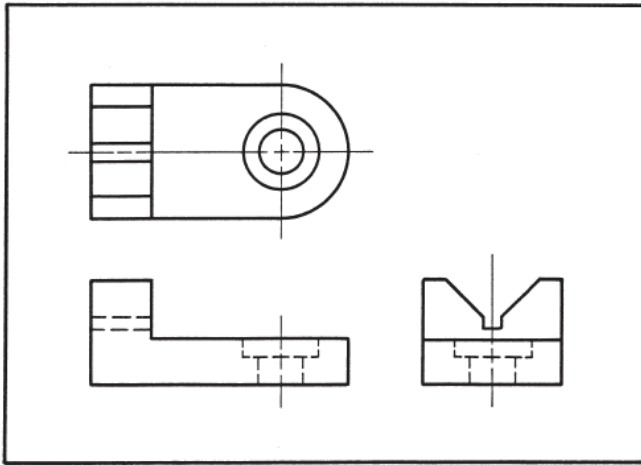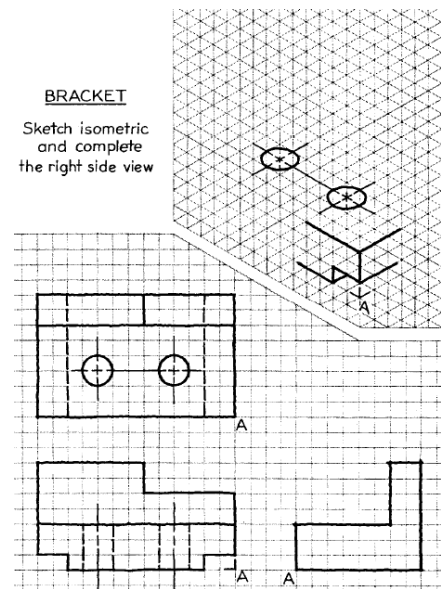
Fig. 1: Orthographic multiview drawing.

Fig. 2: An isometric sketch problem.

Due to heavy graphical nature of the contents, traditional textbooks will not serve the educational purpose sufficiently as well as using multimedia or software tools that can dynamically visualize the contents. A software tool called *EGWorks* has been developed so that 3D models can be interactively created by interpreting orthographic multiviews. The EGWorks gives interactive feedback for the students to understand and visualize the mapping problems. Once a student has mastered the basic tenets of interpreting engineering drawings, the learning curve is much less steep when the student begins formal CAD instruction. As students draw an isometric view while receiving visual and textual guidance, a 3D solid model of the object is automatically created so that the solution can be checked at the end of the process. Any users can input multiviews without knowing their solutions, and the users can reach the solution dynamically as they interactively solve the problems with the guidance provided by the software. This is one of the differences from other educational tools that require problem-solution pairs be provided by instructors upfront.

To achieve the goals, many existing techniques of automatic construction of 3D models from engineering drawings are adopted and modified. The mapping from 2D drawings to 3D models, however, is a mathematically under-defined problem, hence multiple solutions may exist and ambiguities arise. This will lead to complex algorithms that contribute to unstable software. These are typical obstacles to automatic solution approaches. The interactive nature of the educational software helps reduce such issues, and the design of the software is described in this paper.

2. RELATED WORK
Some techniques in automatic construction of 3D models from orthographic engineering drawings are adopted and modified for use in EGWorks. In this section, previous work on automatic conversion of orthographic drawings to 3D models is described. Also, a few educational software tools teaching concepts related to engineering graphics in the literatures are also briefly reviewed.

2.1 Automatic Construction of 3D Models from Engineering Drawings
Constructing 3D solid models from orthographic drawings has been studied for decades. [9],[12-15],[27-29] There are basically two different approaches; bottom-up and top-down approaches. The bottom-up approach (also called Brep approach) is more widely used, and the advocates of the approach claim that it can handle a wider range of geometries than the top-down approach. The algorithm is briefly described by the following steps [7], [10], [11], [18]:

1. Constructing 3D points from the junction points in the three-view drawings.
2. Constructing a wireframe by connecting the 3D points.
3. Finding all faces from the wireframe model.
4. Removing any false lines and faces.
5. Constructing a solid from the faces.

The algorithms can handle planar, conic, and toroidal surfaces, [8] and they tend to be complex and slow as the drawings become more complicated. Recently, research has been focusing on accelerating the reconstruction process and identifying and removing the false lines and faces. The top-down approach, on the other hand, constructs a 3D object by a combination of volumes of elementary objects. [1],[19],[21] Interested readers may read survey papers on this topic [4], [6], [23-25].

Hubbard and Kim [9] describe operators for building 3D solid models from 2D orthographic views. From two orthographic views, various modeling operators are defined and implemented to help construct a 3D solid model from the orthographic views.

2.2 Educational Software for Engineering Drawings

Company et al. [3] and Contero et al. [5] present an educational software tool. They have been working on constructing 3D models from a single isometric view for many years. They applied the algorithms they have developed to the educational software with which students can construct 3D models by drawing isometric views. The constructed 3D models then are projected to create three-view drawings.

There are an infinite number of solutions (3D models) from a single isometric sketch and is a mathematically ill-defined problem. It is very difficult, if possible, to make a robust and practical program. Hence, the software must impose a lot of limitations on the geometry of the models. Company et al. can handle some specific polyhedral models called *quasi-normalons* [2] in which most of the faces must be aligned with the coordinate axes. Authors have presented the progress report on EGWorks in [22].
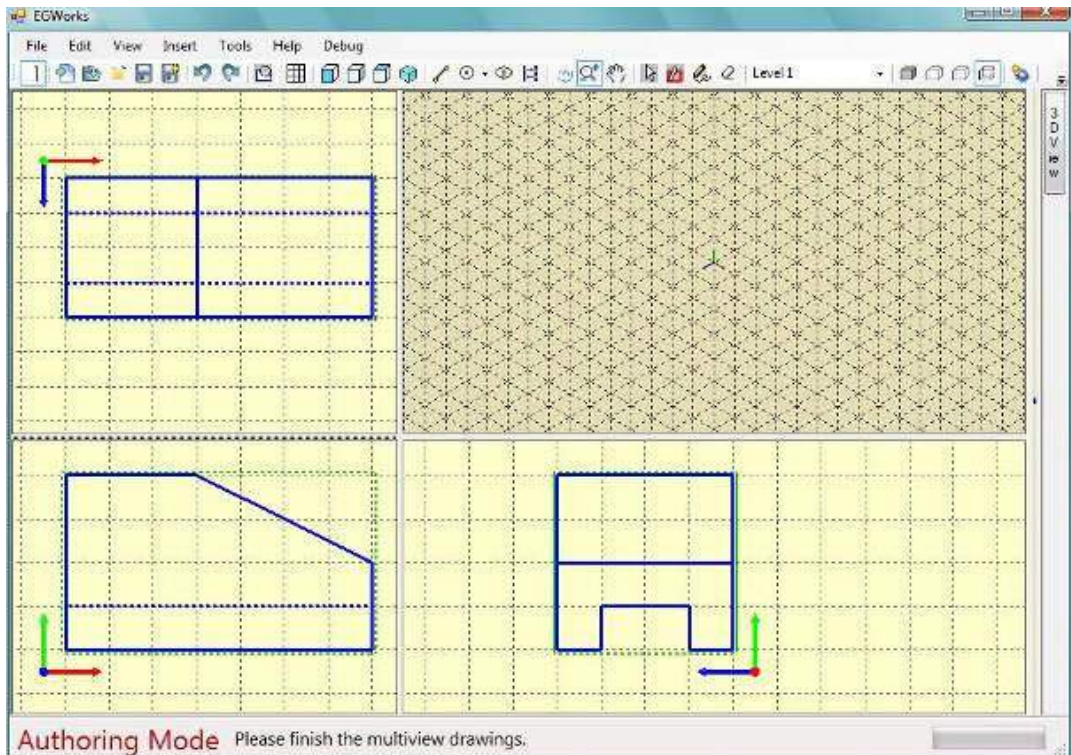

Fig. 3: User interface in the learning mode.

3. SOFTWARE OVERVIEW

3.1 User Interface Design
The user interface of EGWorks is based on typical windows menus and icons using Windows Forms with OpenGL graphics library, as shown in Fig. 3. It runs on a Windows operating system. The screen is divided into four windows in which three multiviews and isometric views are displayed. Each view takes independent mouse and cursor inputs and graphical processing. The screen sizes can be easily adjusted by dragging the sashes of the windows, but the alignment of the three multiviews is always maintained. This means that the panning and zooming of the graphics must be synchronized to maintain the vertical and horizontal alignments between the front and top views and the front and right views. The isometric graphics can be independently zoomed and panned.

For adding sketch entities, four drawing tools are currently available: line, circle, ellipse, and pencil. The pencil tool supports drawing freehand sketching, although it's not yet currently used. Except for the pencil tool, all drawing tools are automatically snapped to the grids by default. The size and resolution of the grids can be adjusted. Any sketch entities can represent hidden lines by turning them to dotted lines from solid lines, or vice versa.

3.2 Authoring and Learning Modes
The EGWorks operates in two modes; *Authoring* mode and *Learning* mode. In the authoring mode, users (instructors) can add the three orthographic views. Students work in the learning mode in which the isometric view can be added while the three views are locked and cannot be modified. Students can also create new multiviews in the authoring mode to add their own problems. The problem sets created can be saved as files with or without the solutions. Since anyone can create multiview problems even without knowing the solutions and share them with others, the problem set is expected to grow quickly so that a large problem database is available to be shared.

3.3 Multiple Learning Levels
EGWorks supports multiple learning levels, and the level is set by a drop-down menu as shown in Fig.4. In the learning mode, users receive different visual and textual feedback based on the levels. Currently there are three levels (Level 1, 2, and 3) with higher levels offering less feedback. At level 3, users can work in any order. At level 1, however, students may have to follow a certain specific order in order to proceed. An example is the face-by-face method that will be described in detail in Section 5.3.

3.4 Automatic Generation of Solutions
As a user draws an isometric view of the object, a corresponding 3D model is constructed in the background. Users can check the model at any time. Fig. 5 shows an example of a constructed solid model displayed overlapped with the isometric sketch. Until the isometric view is completed, the 3D model is represented as a non-manifold model with sheets, cells, and wires. Any false faces (ghost faces) and edges (ghost edges) can be handled with the non-manifold model. Because the 3D model is generated and the multiviews and the solid model will be visualized by highlighting matching points, the users can easily check if the isometric sketch is correct or not. Therefore, instructors do not need to provide the solution when making the problem. The solid model must be synchronized with the isometric sketch as the user can modify the isometric sketch at any time. Currently, the solid model is reconstructed each time from the bottom up whenever the sketch is modified.

3.5 Tools and Limitations
The software is implemented in C# language with OpenGL graphics library [20] running on a Windows operating system. For constructing solid models, Parasolid solid modeling kernel [16] is used.
At present, the geometry of the model is limited to polyhedral models with no holes. All three views must be provided.
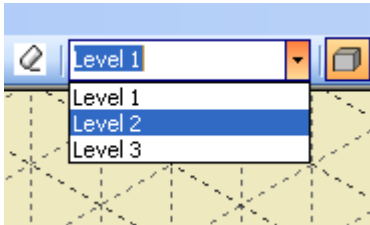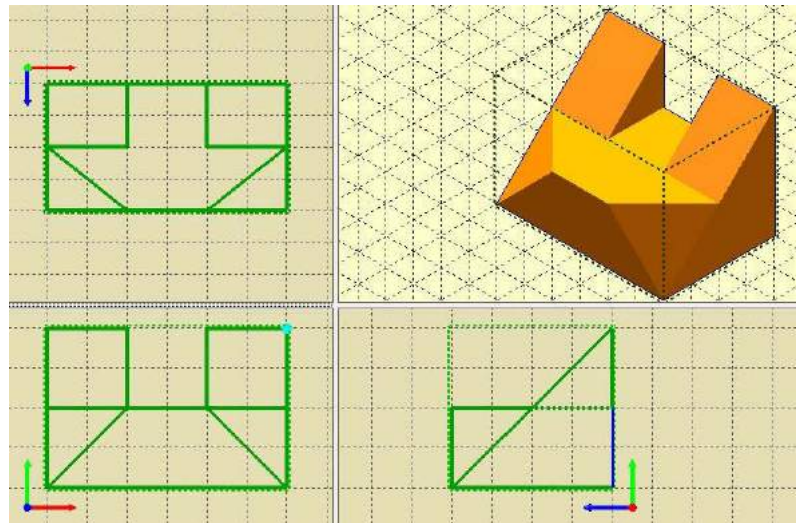
Fig. 4: Setting the levels.

Fig. 5: Solid model generation.

4. ADDING MULTIVIEWS IN AUTHORING MODE

Instructors add three orthographic views in the authoring mode. Currently, all three views must be drawn, following the third-angle projection rules, although two-views may be sufficient for some objects. This limitation can be later easily removed. Note that students can also create their own problems by adding multiviews using the same process discussed in this section.

4.1 Input Bounding Box

An instructor must first enter the size of the bounding box of the object to be added. The bounding box is aligned along the XYZ axes. Although the bounding box can be automatically calculated after the views are created without the input, it displays the layout and alignments of the three views clearly, and users can draw views more easily using the bounding boxes as guidelines.

4.2 Sketching Multiviews with Sketch Tools

After the bounding box is set, the instructor will start drawing the three views using the drawing tools such as line, circle, and ellipse. An eraser tool can delete the sketched entities, and undo is also supported. All sketch entities are snapped to the grids, which can be overridden by pressing the control key. Users can also modify the added sketch entities by dragging the segments or end junction points. All the hidden lines must also be drawn with a dotted-line font. Users can draw the sketch entities in any order, and it is not required to draw in any particular order of front, right, and top views. There is an internal rule that all sketch entities must meet with other sketch entities only by their end junction points. The sketch entities are automatically split at all intersection points, and any overlapping entities are also merged. Therefore, the users should not worry about the rule.

Instead of sketching multiviews by hand, it is possible for an instructor to create a three-dimensional model in a CAD system, and import it to the system to obtain the multiviews. Currently, the system can import solid bodies saved in Parasolid native file format [16]. It is worth noting, however, that one of the design goals of the software is to let students create their own problems, and many early engineering students do not yet have access to solid-modeling software and lack CAD experiences.

4.3 Missing Sketch Segments

As a user finishes drawing the multiviews, instructors change the mode to the Learning mode before saving the file. The system has its own file format with an extension name of *.eg. As the document is switched from the authoring mode to the learning mode, the multiviews are briefly checked for any inconsistencies including missing lines and points. Extensive checking involves a full reconstruction of

solid, and it is not a trivial problem. [17],[26] At present, only quick-and-dirty checks are performed including checking if all matching points exist in all views and if all entities are properly aligned. If any errors such as missing lines are detected, a warning message is displayed as shown in Fig. 6 highlighting the problematic area.
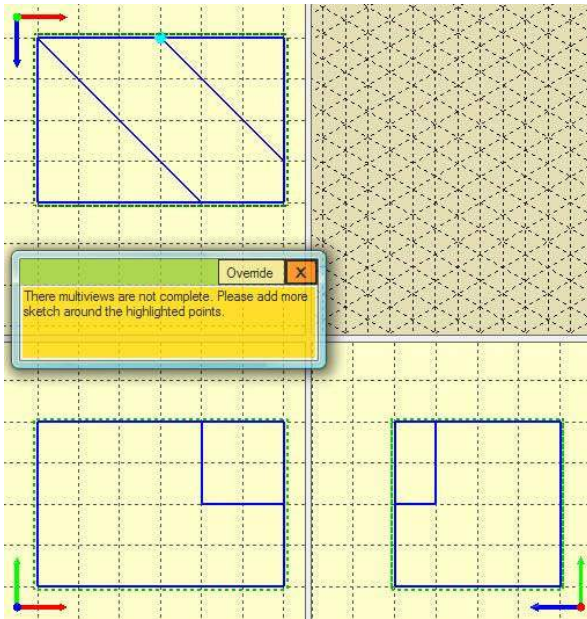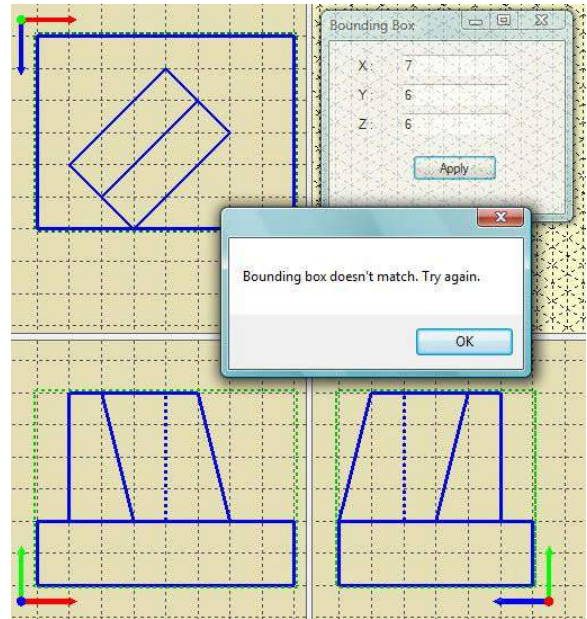

Fig.6: Checking missing lines.   Fig. 7: Checking bounding box.

5. CONSTRUCTING AN ISOMETRIC VIEW IN LEARNING MODE
In the Learning mode, students sketch the isometric view of an object represented in the three multiviews. The multiviews are displayed in a darker color, and students cannot modify the mltiview drawings. Depending on the levels set by the instructor (or the student), students receive different types of dynamic feedback while constructing the isometric view.

5.1 Bounding Box
As the first step, students are required to enter the size of the bounding box from the given three views. The size of the bounding box must match in order to proceed further; otherwise an error message is displayed as illustrated in Fig. 7. Students must understand the coordinate systems of the three views to enter the correct size of the bounding box by counting the grids. Once entered correctly, the bounding box is displayed in the isometric view window.

5.2 Displaying Matching Points
As a user moves the cursor over the window of the isometric view in the learning mode, any matching junction points in the three views under the cursor position are highlighted as shown in Fig 8. In the isometric view orientation, the cursor point constructs a 3D ray in the view direction of an eye, or *eye_vector* = (-1, -1, -1) in a vector representation. The view ray is also displayed in each viewport at Level 1 as shown in pink lines shown in Fig. 8. As locating a cursor point on an isometric view is like shooting the rays onto the model, any junction points intersecting with the ray are highlighted as shown in Fig. 8. When multiple points are intersecting with the ray, a list of the selected points is displayed to the user, and the user selects one of them by double-clicking on the matching color from the list of color panels as shown in the figure. In Fig. 8, three junction points intersect with the ray, and the points are highlighted in yellow, cyan, and green colors. In this particular example, the point with green color must be chosen as it belongs to the top plane that the student is currently sketching.
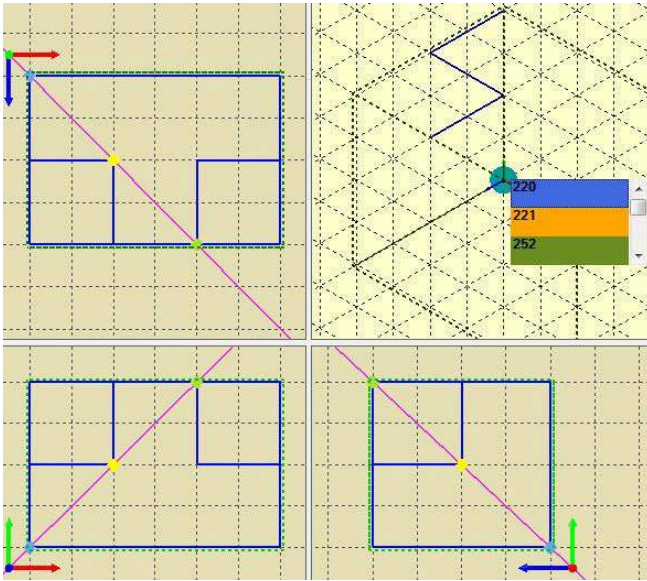
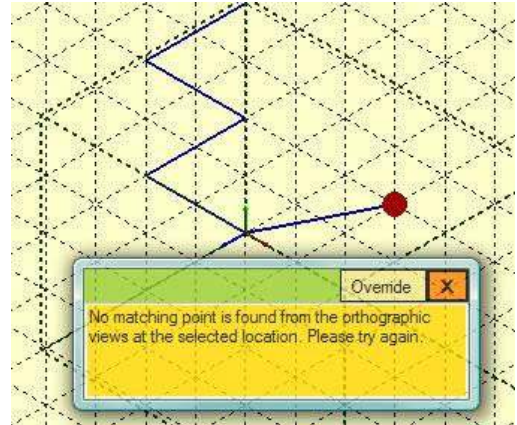Fig. 8: Multiple matching points under cursor point.   Fig. 9: Message for incorrect position input.

When a user selects a grid point at the isometric view where no matching point in the three views is found, a warning message is displayed as illustrated in Fig. 9 at levels 1 and 2. At level 1 and 2, as the user draws a sketch segment in the isometric view, the matching segments in the three views are highlighted as a line is drawn on the isometric view as shown in Fig. 10. These give proper feedback to the students if they are doing correctly.
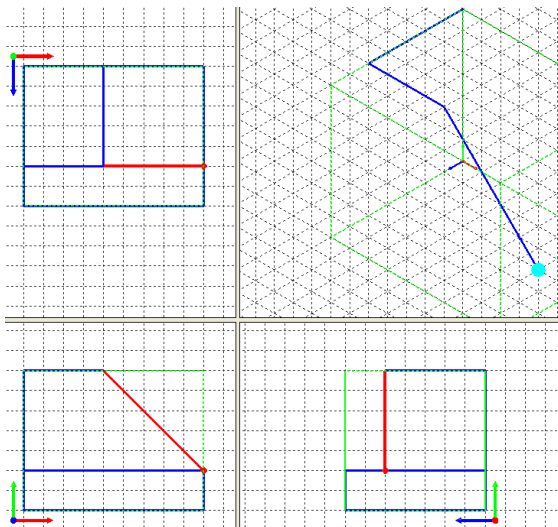

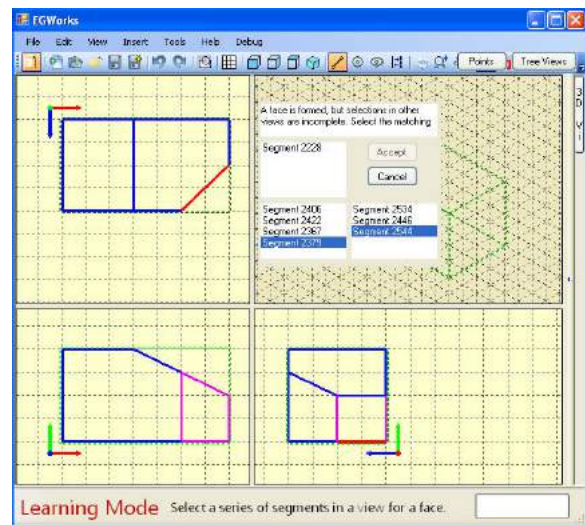Fig. 10: Highlighting matching sketch segments.   Fig. 11: Face-by-face method.

5.3 Constructing Models in Face-by-Face Method
At level 1, students may choose to draw isometric views in a face-by-face approach. After entering the bounding box, students are first required to select a face by selecting all the sketch lines around it

from all three views. Fig. 11 shows that an inclined face is being selected from the three views, while a dialog box is displayed with lists of selected segments and a message board. Users must select all the matching segments of a face from all three views. If any one or more segments in any view are missing, the dialog is not closed and the student cannot proceed. Fig. 12 shows various feedback messages displayed progressively as the students selects the lines of a face. Once a face is successfully selected, the dialog box disappears, and only the lines and points belong to the face must be drawn in the isometric view. Students cannot add any other lines or points that are not part of the face (such points are not highlighted nor snapped). Once the face is completely sketched in the isometric view, the same (but empty) dialog box is displayed again for the next face (if any), and the user must repeat the process until all the faces are selected and drawn. At any time, students can cancel this process and use a normal sketching process by pressing the Cancel button.
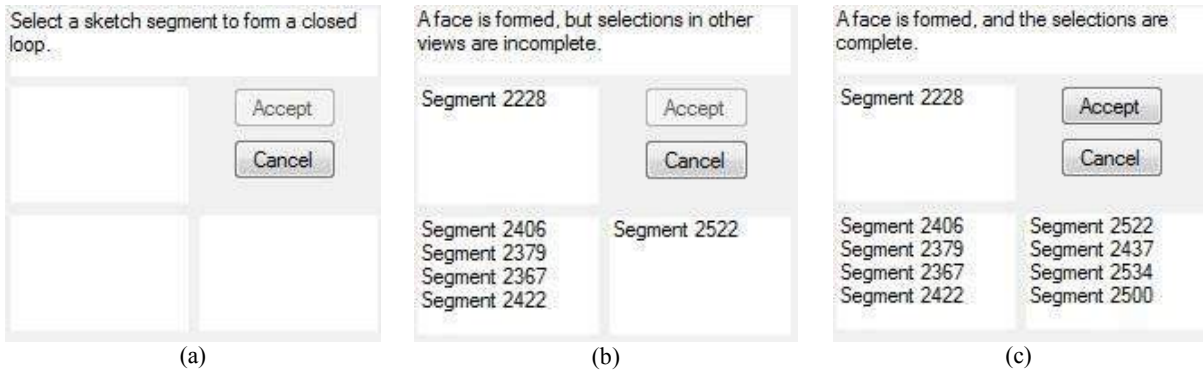

Fig. 12: Messages as sketches of a face are selected progressively (a)-(c).

The face-by-face approach is a useful educational tool as the students must be able to identify matching faces from the multiviews. Also, this step-by-step approach is particularly helpful if an object is complex. Fig. 13 shows an example with an object with relatively many features. Students will have difficulties in sketching the isometric view that has many confusing overlapping lines and hidden features. Instead of randomly drawing the sketches, the face-by-face approach will help finish the sketch in an orderly way.
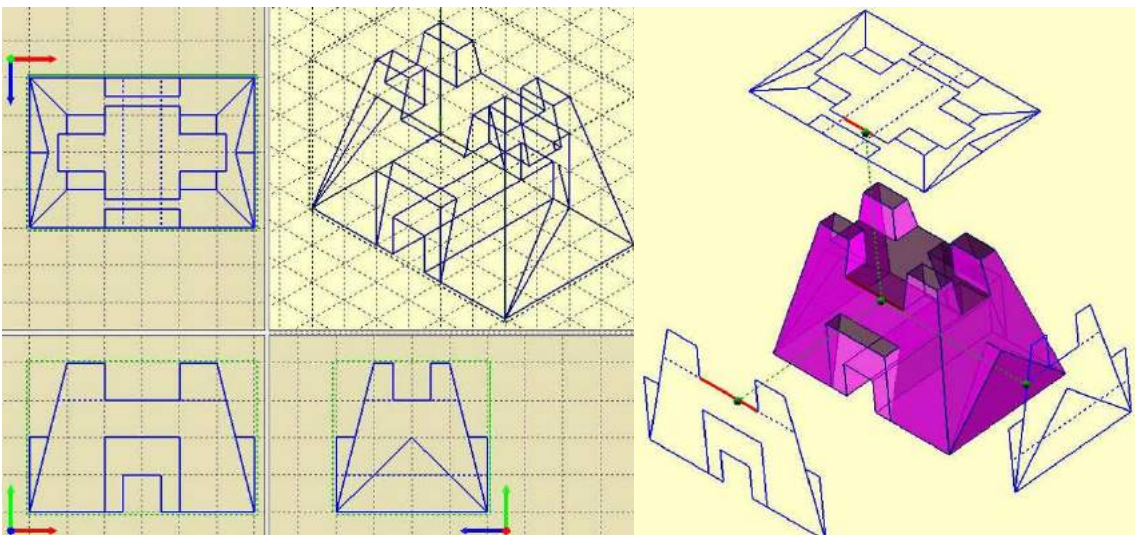

Fig. 13: Angle block example.

5.3 Constructing Solid models

While a user is sketching an isometric view, a corresponding 3D model is constructed in the background. Users can view the 3D model at any time while it is being constructed. The 3D models can be viewed in the isometric viewport by turning the shade view option on, or switching to a separate 3D viewer window. The 3D model is constructed incrementally and interactively. The face does not need to be drawn in a particular order. If one or more faces are formed as the student draws sketch segments in the isometric view, the faces are automatically found. A sheet body is constructed for each face found. Multiple sheets are then sewn together as more faces are identified. Fig. 14 (a) shows an object being built in progress with a couple of sheets. Once all faces are found, a complete solid is constructed if the union of the sheet bodies forms a two-manifold volume successfully. If a face contains holes, the hole-loops must be trimmed from the sheet, but it is not yet implemented.

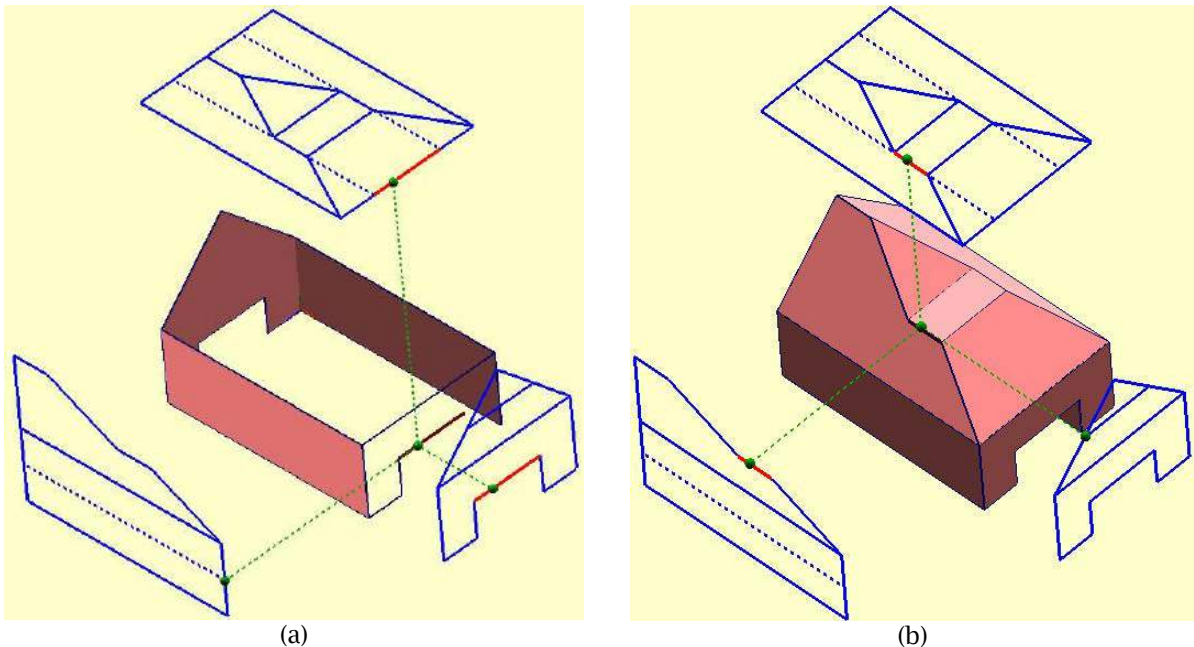|	
(a)	(b)

Fig. 14: Construction of an intermediate model from sheets (a) to form a solid (b).

In the solid model view, three multiview drawings are also displayed at the proper projected orientations aligned with the solid model, as shown in Fig. 14 and Fig. 15(b), so that the solid and the orthographic views can be compared. As a user moves a cursor on the solid, the corresponding point and entities under the cursor is highlighted in the three views as shown in Fig 14 and Fig. 15. If some ghost faces exist in the model, the 3D model will be represented as a non-manifold model similar to [10]. Any redundant topological entities have to be removed manually by the students.

6. CONCLUSIONS

A new educational software tool for interpreting orthographic multiviews drawings is described. Using the software, students will sketch an isometric view of an object represented in three orthographic views. Students will receive graphical and textual feedback as the isometric view is sketched, and the corresponding 3D solid model is automatically constructed. By comparing the 3D model and the orthographic views, students will be able to understand the relationships between the views. As the solution (isometric view and matching 3D model) is dynamically created, the instructor does not need to provide solutions to the problem. The interactive construction procedure of the 3D model can be a practical solution to the problem of reconstructing 3D models from engineering drawings. Although many automatic reconstruction algorithms have been proposed for decades, few can automatically construct 3D models from working drawings reliably and robustly even for error-free and clean

drawings without annotations. Due to ambiguities with possible multiple interpretations and incorrectness of some drawings, it may be very difficult, if possible, to achieve the goal using an automatic approach. Instead, further development of the interactive approach as described in this paper will be able to handle real industrial working drawings with many annotations as well as inaccurate drawings with missing or redundant lines.
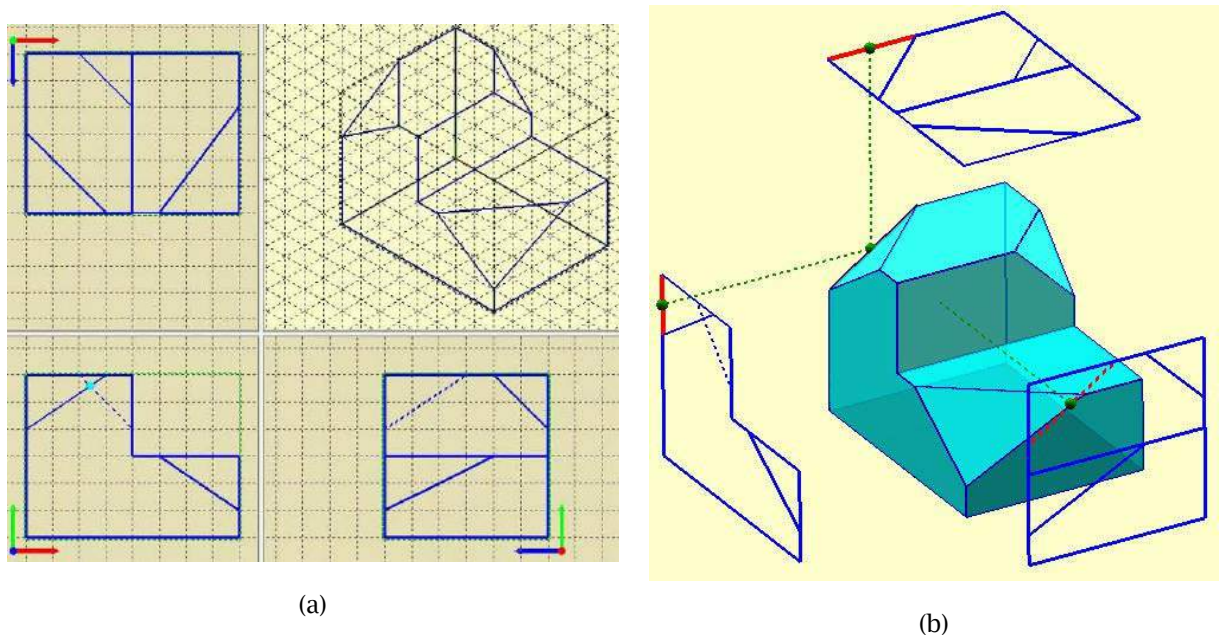

(a)

(b)

Fig. 15: Construction of isometric view (a) and the solid model view with aligned orthographic views (b).

7. ACKNOWLEDGEMENTS

8. REFERENCES

[1] Çiçek, A.; Gülesın, M.: Reconstruction of 3D models from 2D Orthographic Views using Solid Extrusion and Revolution, Journal of Materials Processing Technology, 152, 2004, 291-298.
[2] Company, P.; Conesa, P. J.; Aleixos, N.: Axonometric Inflation in Line Drawings Reconstruction, Regeo Techical Report, www.regeo.uji.es/regeo, January, 2001.
[3] Company, P.; Contero C.; Piquer, A.; Aleixos, N.; Consesa, J.; Naya, F.: Educational software for teaching drawing-based conceptual design skills, Computer Applications in Engineering Education, 12(4), 2004, 257-268.
[4] Company, P.; Piquer, A.; Contero, M.; Naya, F.: A Survey on Geometrical Reconstruction as a Core Technology to Sketch-Based Modeling, Computers & Graphics, 29(6), 2005, 892-904.
[5] Contero, M.; Company, P.; Saorin, J.L.; Consea, J.: Improving Visualization Skills in Engineering Education, IEEE Computer Graphics and Applications, 25(5), 2005, 24-31.
[6] Fahiem, M. A.; Haq, S. A.; Saleemi, F.; A Review of 3D Reconstruction Techniques from 2D Orthographic Line Drawings, Geometric Modeling and Imaging (GMAI'07), 2007, 60-66.
[7] Giesecke, F. E.; Mitchell, A.; Spencer H. C.; Hill, I. L.; Dygdon, J. T.; Novak, J. E.; Loving R. O.: Engineering Graphics, 8th Edition, Prentice Hall, 2003.
[8] Gong J. H.; Zhang H.; Zhang G. F.; Sun J. G.: Solid Reconstruction Using Recognition of Quadric Surfaces from Orthographic Views, Computer-Aided Design, 38(8), 2006, 821-835.
[9] Gu, K.; Tang, Z.; Sun, J.: Reconstruction of 3D Objects from Orthographic Projections, Computer Graphics Forum, 5(4), 2007, 317-323.

[10] Hiroshi, M.; Masayuki, N.: A Cell-based Approach for Generating Solid Objects from Orthographic Projections, Computer-Aided Design, 29(3), 1997, 177-187.
[11] Hubbard, C.; Kim, Y. S.: Geometric Assistance for Visual Reasoning and Construction of Solids with Curved Surfaces from 2D Orthographic Views, Advances in Engineering Software, 32(1), 2001, 21-35.
[12] Idesawa, M.: A System to Generate a Solid Figure from Three View, Bulletin of the JSME, 16(92), 1973, 621-652.
[13] Kuo, M. H.: Reconstruction of Quadric Surface Solids from Three-View Engineering Drawings, Computer-Aided Design, 30(7), 1998, 517-527.
[14] Liu, S. X.; Hu, S. M.; Sun, J. G.; Tai, C. L.: A Matrix-Based Approach to Reconstruction of 3D Objects from Three Orthographic Views, The 8th Pacific Conference on Computer Graphics and Applications, 2000, 254-259.
[15] Markowsky, G.; Wesley, M. A.: Fleshing Out Wire Frames, IBM Journal of Research and Development, 24(5), 1980, 582-587.
[16] Parasolid, http://www.plm.automation.siemens.com/en_us/products/open/parasolid, Siemens
[17] Poliakoff, J. F.; Thomas, P. D.: Error Correction in Scanned Engineering Drawings Using 3-D Knowledge-Based Reconstruction, Graphics Recognition Algorithms and Systems, Springer Berlin/Heidelberg, 1389/1989, 1998, 280-290.
[18] Shin, B. S.; Shin, Y. G.: Fast 3D Solid Model Reconstruction from Orthographic Views, Computer-Aided Design, 30(1), 1998, 63-76.
[19] Shum, S. S. P.; Lau, W. S.; Yuen, M. M. F.; Yu, K. M.: Solid Reconstruction from Orthographic Opaque Views Using 2-Stage Extrusion, Computer-Aided Design, 33(1), 2001, 91-102.
[20] Shreiner, D.; Woo, M.; Neider, J.; Davis, T.: OpenGL Programming Guide: The Official Guide to Learning OpenGL, Version 2.1 (6th Edition), Addison-Wesley Professional, 2007.
[21] Soni, S.; Gurumoorthy, B.: Handling Solids of Revolution in Volume-Based Construction of Solid Models from Orthographic Views, Journal of Computing and Information Science in Engineering, 3(3), 2003, 177-271.
[22] Suh, Y.: Development of Educational Software Tool for Interpretations of Multiview Engineering Drawings, ASEE 63rd Annual Mid-Year Conference, Berkeley, CA, January 4-7, 2009.
[23] Varley, P.; Martin, R.: Sketch input of 3D Models, Current Direction, International Conference on Computer Vision Theory and Applications VISAPP07, Proceedings of the Second International Conference on Computer Vision Theory and Applications, Barcelona, Spain, March 2007.
[24] Vesselov, N. A.; Golovin, S. I.: A Review of Methods for Computer-Aided Reconstruction of Solid Models by their Orthographic Views, Moscow University Computational Mathematics and Cybernetics, 31(3), 2007, 128-132.
[25] Wang, W.; Grinstein, G. G.: A Survey of 3D Solid Reconstruction from 2D Projection Line Drawings, Computer Graphics Forum, 12(2), 1993, 137-158.
[26] Watanabe, T.: Revision of Inconsistent Orthographic Views, Journal for Geometry and Graphics, 2(1), 1998, 45-53.
[27] Weiss-Cohn, M.: 3D Reconstruction of Solid Models from Engineering Orthographic Views Using Variational Geometry and Composite Graphs, Computer-Aided Design & Applications, 4(1-4), 2007, 159-167.
[28] Wesley, M.A.; Markowsky, G.: Fleshing Out Projections, IBM Journal of Research and Development, 25(6), 1981, 934-954.
[29] Zhang, A.; Xue, Y.; Sun, X.; Hu, Y.; Luo, Y.; Wang, Y.; Zhong, S.; Wang, J.; Tang, J.; Cai, G.: Reconstruction of 3D Curvilinear Wireframe Model from 2D Orthographic Views, Lecture Notes in Computer Science, ISSU 3037, Springer-Verlag, 2004, 404-411.