Abstract

An education-oriented computer application to draw sketches of polyhedrons that are automatically recognized to reconstructs the suitable three-dimensional models is presented. The users can modify the sketches and see the reaction their modifications have on the models. Earliest classroom tests show that the capacity for spatial vision is improved.

Keywords

Teaching methodology.

Innovative teaching-experiences.

Educational software.

Engineering graphics.

Computer-aided sketching.

1. Introduction

One important objective of basic courses in Engineering Graphics is the acquisition of *spatial vision*. This capability can be described as the ability to picture three-dimensional shapes in the mind's eye. Acquiring this skill is important for the future engineer [1], but the process becomes very complex when three-dimensional shapes are manipulated through two-dimensional drawings, which have the added drawback of being static. It is far better to deal with models, even though they are "virtual" or computerized models and are displayed just by means of two-dimensional representations. Indeed, such representations have two great advantages. First, they can achieve a greater degree of realism (by using shadows, textures, and so on) with a lower execution cost. They can also be varied dynamically, that is to say, the object can be rotated "as if we were holding it in our hand".

In spite of these advantages and although design-by-virtual-prototypes is being introduced in advanced courses, design-by-drawings is still used in basic courses (but with the introduction of the new computer-aided drafting tools). The consequence of this is that these courses attempt to combine learning the essentials of representation systems with the acquisition and/or consolidation of spatial vision. CAD modeling applications are not used for this purpose because their interfaces are not very user-friendly.

The interfaces of CAD modeling applications, in addition to not being user-friendly for those who have not acquired spatial vision, are of no use in the conceptual design phase, where incomplete and ambiguous ideas are being handled. Sketches have traditionally allowed designers to deal with this process in an efficient way. Yet, the "straightjacketed" commands and work schedules of present-day CAD modeling systems are aimed at enabling complete and consistent models to be created, and at preventing the generation of ambiguous models. The ideal situation is very different and has been described in very prominent studies [2]. Consequently, at present rough drafts and sketches are used to handle ambiguous or inconsistent designs. Here it is understood that rough drafts allow geometrical shapes to be expressed without being confined to the strict criteria of geometry (since they are drawings that are imperfect or inconsistent from a geometrical point of view), and sketches allow partial or unfinished ideas to be expressed (incomplete drawings). It is for this reason that rough drafts and sketches are often said to constitute the "natural" language that engineers and designers use to synthesize new designs. This shortcoming of CAD systems results in teaching students to sketch with "classical" instruments (pencil and paper) to become an even more important objective in Engineering Graphics courses. One undesirable consequence is that the current situation prepares the designer to generate the design by means of rough drafts and sketches and later to construct the model on a CAD system, once the process of drawing the rough draft has finished. In short, the designer must read the final draft and guide the CAD system in order to construct the corresponding model, which obviously creates a sensation of "repeating the same work" and gives rise to the mistaken idea that sketching is pointless.

In this paper we present computer software that attempts to put an end to the situation we have described above. The application provides the user with a *virtual pencil* with which to draw freehand on a sheet of *virtual paper*. The sketch introduced by the user is a (pseudo-axonometric) pictorial representation of a polyhedral shape. The application includes an analyzer that automatically recognizes and reconstructs the three-dimensional model sketched by the user. If the sketch contains very important imperfections, a second module is activated which "repairs" the sketch before analyzing it in order to reconstruct the model. The Graphical User Interface (GUI) is obtained through a calligraphic interface that implements a very elementary set of gestures (draw segment and erase segment). The interface has vertex snap-tolerance, segment snap-tolerance (so that very short segments are rejected) and parallelism snap-tolerance (which places the segments that form an angle below the tolerance level parallel to one another). Three-dimensional visualization is accomplished using OpenGL and consists of a window that displays the model as a wireframe representation or with solid faces. The visualization of the model can be freely rotated and scaled. Other complementary tasks are menu driven.

This application helps develop the capacity for spatial vision because the three-dimensional model can be seen and manipulated by the user at any time. For this reason any mistakes made while the axonometric representation is being sketched (such as the common errors that involve "forgetting" certain edges) are quickly shown up when the analyzer warns the user that no valid geometrical 3D model can be generated or when the analyzer generates a model that is perfectly coherent with the sketch, but differs from the mental image the user has of the object that he or she is attempting to sketch.

The application forces the user to acquire skill in sketching (since it is the only way to draw), and removes the feeling of repeating the same work that occurs when, after sketching on paper, modeling must be performed with a conventional modeling tool.

2. Background

Following classical models like Hohenberg's [3] course in constructive geometry, most Engineering Graphics courses do not emphasize learning descriptive geometry as a body of fundamental doctrine (knowledge) but rather they introduce its most practical aspects directly and then use them to solve problems in designing products (know how) [4, 5]. The traditional procedure in this approach has been to combine learning the foundations of systems of representation with the acquisition and/or consolidation of spatial vision.

Today, it is feasible to teach *design-by-virtual-prototypes* (based on three-dimensional geometry) instead of *design-by-drawings* (based on two-dimensional geometry), as there are 3D CAD modeling applications at reasonable academic prices and which work in a user-friendly manner that favors the learning process. Yet, although quite a number of ways of carrying out the transition have already been put forward (see for example [6]). For our purpose, we must simply state that it seems that most of the academic community understands that the transition must be slow, since in certain industrial sectors and in small and medium-sized industries design-by-drawings will survive for some time to come (a simple search on the Internet for courses on "Engineering Design Graphics" is enough to show that the objectives of most courses are aimed at teaching design-by-drawing [7, 8, 9, 10, 11]). This justifies the need to train future engineers in working in design-by-drawing environments. It is also the reason why design-by-virtual prototypes is usually introduced in advanced and specific courses, while basic teaching syllabuses (which are generic and included in the earlier courses) have opted to carry on with design-by-drawing but at the same time accepting the introduction of the latest computer-aided drafting tools.

With the introduction of drafting applications to replace the classical tools the acquisition of spatial vision has been put off until students attain elementary/intermediate skill in handling computerized drafting applications. To a certain extent this means that the future engineer will have less capacity to conceive new ideas from "mental images", i.e. what is seen in his or her mind's eye [1]. In other words, the emphasis that teaching projects place on computer-aided drafting tools leads to a poorer capacity to express the incomplete and/or badly organized ideas that are so common during the conceptual design phase, and which engineers have always put into a concrete form by means of sketches. Moreover, the capacity to sketch also tends to diminish because of the unavoidable cutbacks in teaching syllabuses.

The most frequently used solution to this dilemma consists in making students use a sketch to work out the answer to the problem and then asking them to reproduce a perfectly drafted version of that same piece of work. Although this strategy does indeed enable students to acquire skill in expressing themselves both through sketches and through technical drawings, it also produces a certain feeling that time is being wasted, since the student is aware that the same task is being performed twice.

A better solution consists in designing part of the problems (Figure 1) in such a way that they can be resolved by means of sketches (which shows the student that an accurate draft of the problem is really a waste of time, and at the same time it highlights the fact that sketches are powerful, efficient tools); other exercises, however, are conceived in such a way that the solution cannot be obtained (at least not with the required degree of accuracy) if computer-aided drafting applications are not employed (Figure 2).

Figure 1. Near here

Figure 2. Near here

However, it is a very encouraging task to prepare a syllabus taking care to get a balanced mixture of computer-aided drafting and hand sketching skills; especially if those skills have to be obtained in completely different environments.

3. Sketcher/modeler

In this paper we present our computer software called REFER that attempts to help partially resolve the dilemma described above. This application provides the user with a “virtual pencil” that is used to draw freehand on a sheet of “virtual paper”. In standard PC environments, the physical peripheral that is used to emulate the pencil is the mouse. In more modern environments that use tablets, or in tablet PCs (see *http://www.microsoft.com/windowsxp/tabletpc/*), it is the pointer or pen devices that act as a virtual pencil.

In the current version of our application (Figure 3), the sketch that the user introduces is a pictorial representation of a polyhedral shape, that is to say, a pseudo-axonometric representation. We chose to begin with a pictorial-type representation because the aim is to foster the student's capacity for spatial vision and it is commonly accepted that orthographic parallel projections are more suited to *measuring* than to *seeing*. The application has a second restraint that consists in the fact that the polyhedral models must be rectangular. In other words, they have to be models in which all the edges that converge at each vertex form a 90° angle between one another, as do all the faces that share an edge. We call "normalons" to such orthogonal polyhedrons. In fact the system is not so restricted because it is capable of reconstructing "quasi-normalon" models. In brief, they are those polyhedral shapes in which none of the vertices of the original model are lost after removing all the edges that are not orthogonal (see the edges marked with an arrow in Figure 3). Details on how the application was designed and implemented can be obtained from [12, 13].

We believe that the element that differentiates our application from other similar applications is that a second window exists in which the three-dimensional model of the sketched object is displayed (Figure 3).

Figure 3. Near here

That is to say, the user/designer can see the 3D model while he or she is sketching an axonometric representation of it. The model is displayed with solid faces or by means of a wireframe representation (as chosen by the user) and can be rotated and scaled dynamically by the user. The sketch can also be modified and the interactive modification of the sketch is automatically reflected in the model (Figure 4).

Figure 4. Near here

The easiness to erase is an extra help in the sketching process, since auxiliary lines are freely introduced as needed and are easily deleted after use (Figure 5).

Figure 5. Near here

The user can choose from a series of pre-programmed views of the model: the main orthographic views (front, top and side views) and the two standard axonometric representations (isometric and dimetric). The hidden edges that correspond to the views selected in each moment can also be obtained whenever the user so wishes (Figure 6).

Figure 6. Near here

This aid has been introduced to simplify the learning of orthographic views system. It is intended to drive the student in the process of establishing correlations among orthographic views (automatically generated by the application) and the sketched axonometric representation of the part that he or she has drawn. Moreover, the possibility to change from first to third angle projections, and the possibility to activate or deactivate the visualization of the reference system both help in increasing the spatial vision capability and encourage the relation between axonometric and orthographic views.

The intrinsic ambiguity of wireframe representations, which are known to be compatible with two "inverse" solid models, is considered too. The user can change from one model to its "Necker reversal" at any moment (figure 7).

Figure 7. Near here

Another capabilities the application has can be used to query the student about relevant information related to the part. How many symmetry planes does the part sketched in the left side of figure 8 have? The question is easy to answer with the help of the application that automatically calculates all symmetry planes and displays them (as seen in the right side of figure 8). This kind of questions do have a great learning value for students that, precisely because of their lacks in spatial vision, haven't got yet the required ability to clearly perceive this kind of properties. For instance, it is not common for the students to perceive all four symmetry planes displayed in figure 8. What is usual is that a large majority of students *unconsciously* discard two of those plans (σ_3 y σ_4), because they do not accomplish metrical perceptions (resemblance in both length and angular proportions of the two halves resulting from the candidate symmetry plane). In other words, students are not able to discriminate the topological features from the metrical ones. This kind of exercises helps them to become conscious about such sort of decisions, and gain control to make them only when desired.

Moreover, frequently they are not able to identify σ_2 as a symmetry plane. Probably, the reason for that omission is that this is a symmetry plane that gives any significant information on the shape of the part (because they have previously perceived it as an "extruded" shape, and hence, this symmetry plane is seen as a consequence of that feature). In other words, the freshman students are not able to analyze the object to extract all it topological information. They just extract the part of topological information that is relevant for them.

Figure 8. Near here

4. Discussion

The first thing to be highlighted is that the sketcher allows the user to generate axonometric representations in a more user-friendly manner than can be done with current computer-aided drafting software (2D CAD applications).

Employing an axonometric sketcher instead of the virtual instruments that aid the drafting of axonometric projections included in commercial computer-aided drafting applications fosters creativity; this is because these tools are focused on enabling the user to draft rigorously geometric axonometric representations (that is to say, representations with longitudinal and angular measurements that satisfy the laws of projective geometry that correspond to axonometric projections). The isometric grid in AutoCAD (Figure 9) and the isometric locks in Microstation (Figure 10) are typical examples of these instruments. Indeed AutoCAD has a tool that makes it easier to draft a particular type of axonometric projections: isometric SNAP. The tool combines with a switch that activates one of the three main work planes (upper, left and right). This "isometric parallax" makes it easier to construct isometric representations but has some serious drawbacks, such as not allowing the user to vary the angles in order to obtain other axonometric projections. Another serious shortcoming is that it does not modify the behavior of some transformations that could help construct the isometric figures. This is the case of parallelism, which builds lines parallel to the original one but measures the separation in a direction that is orthogonal to the original line instead of measuring in the isometric direction (see Figure 10). Something similar happens with Microstation's isometric grid block and its three isometric planes.

Figure 9. Near here

Figure 10. Near here

Unlike commercial CAD applications, the sketcher focuses on controlling the topology of the object that has been designed and ignores its final dimensions.

Secondly, and this is perhaps the most important advantage, the feeling that sketching is a waste of time disappears when using this application since the student sees that, after sketching the object he or she has conceived, both a 3D model and different two-dimensional representations of the same object are automatically displayed. In other words, after using a sketch to conceive the object, it is automatically generated and there is no need to construct it a second time.

The capacity for spatial vision is obviously also reinforced because the student can see and manipulate the 3D model. Furthermore, any mistakes made while sketching (such as the common errors that involve "forgetting" certain edges) are quickly shown up when the analyzer warns the user that no valid geometrical 3D model can be generated or when the analyzer generates a model that is perfectly coherent with the sketch, but differs from the mental image the user has of the object that he or she is attempting to sketch.

The sketcher is very simple and intuitive to use when the objects being represented are low or medium complexity polyhedrons. However, a lot of skill in drafting and a great capacity for spatial vision are required when it comes to generating complex shapes. Examples such as the one in Figures 11 and 12 show that only an expert can accomplish such sophisticated representations, which amounts to saying that the tool is of no practical use to an expert designer who conceives sophisticated shapes. In Figure 11 only the faces and edges that are completely visible are represented. The rest of the polyhedral model has not been represented. For this reason the model is successful, but what is constructed is a "bent sheet" or "origami" type model.

Figure 11. Near here

Figure 12 shows the complete model and its reconstruction. It can clearly be seen how difficult it is to achieve parallel, collinear and convergent edges because the model generated is quite distorted. Figure 13 shows the result that is obtained if an analyzer module is run to "repair" the original drawing by "parallelizing" the edges that are badly drawn. The result obtained after applying this parallelization function is shown on the left, but it is has an unacceptable computational cost for an interactive system (several minutes). The image on the right shows the result after touching up the drawing a little by hand (i.e. redrawing the edges that are obviously not parallel) and then also running the analyzer before reconstructing. In both cases, the model that is finally generated still contains some distortions.

Figure 12. Near here

Figure 13. Near here

Although, as described above, the system is still not easy to use when it comes to sketching complex shapes, the initial aims of this work have been more than fulfilled. The experimental results show that the percentage of success obtained from introducing this application into a classroom full of students who are beginning their training in axonometric representations and who are also expected to acquire a certain degree of mastery of spatial vision is very high. Students quickly got used to using the sketcher. Furthermore, when they learn to export axonometric views in DXF, they prefer to do the sketch in REFER and export the axonometric view rather than draw directly with the isometric tools provided by commercial 2D CAD applications.

5. Conclusions and future research

The sketcher is a simple tool and it is easy to incorporate into a design-by-drawing syllabus. Its main value lies in its being able to reinforce the capacity for spatial vision at the beginning of the course. It is especially appealing because in that moment the student still does not have enough skill in handling commercial 2D CAD applications, and also because the tools for drafting axonometric projections included in these applications are very limited and force the user to work in a way that is not particularly natural and not at all user-friendly.

Secondly, the sketcher makes learning the absolutely necessary skill of sketching more attractive to the student because, since the final model is generated automatically, the feeling that sketching is "pointless work" disappears.

The system has been tested in the classroom and very promising results were obtained. The application will become more powerful and user-friendly if some of the more usual operations are added to the already-existing draw edges and erase edges. Operations such as extrusion, revolution and symmetry will help to generate complex drawings (such as the one in Figures 11, 12 and 13) with less effort and greater precision. This will therefore extend the number of shapes that can be constructed directly from the sketch. Introducing more natural "virtual pencils" (such as, for example, the pointing instruments used with tablet PCs) into the classroom is also bound to make this work environment even more user-friendly.

Finally, introducing tablet PCs that can be connected to multimedia projectors by infrared connections will mean that tools such as those described in this paper will become fundamental elements of the "teachware" used in the Engineering Graphics classroom.

6. Acknowledgement

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7. References

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Figure captions

Figure 1. Example of an exercise “to be sketched”

Figure 2. Example of an exercise “to be drafted”

Figure 3. Sketching a quasi-normalon model in REFER

Figure 4. Interactive modification of the sketch and automatic update of the model

Figure 5. Interactive creation of the sketch with auxiliary lines that are latter removed.

Figure 6. A sketched part and their six main orthographic views in the first angle projection method.

Figure 7. A wireframe of a part and the orthographic main views of their two “Necker reversal” models.

Figure 8. A wireframe of a part and their four topollogically valid symmetry planes.

Figure 9. Drawing with Isometric locks and Accudraw compass in Microstation.

Figure 10. “Unnatural” functioning of parallelism.

Figure 11. Origami model

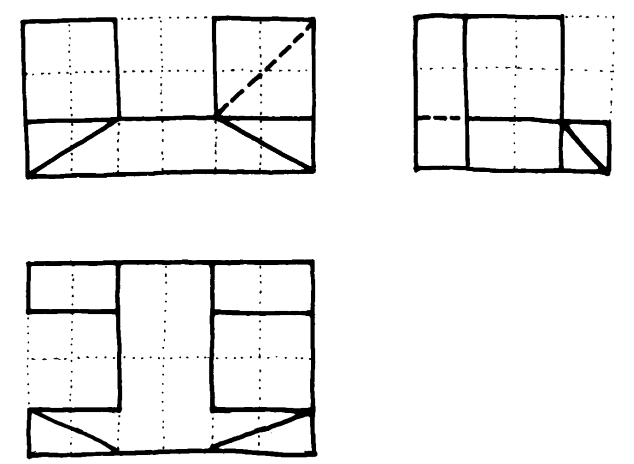
Figure 12. Complex polyhedral shape with apparent distorsions in the output model

Figure 13. Output model obained after beautification of input drawing and refinement of output model

Figures

A polyhedral shape is sketched in the figure below through its front, side and upper views (first angle projection method). Both visible and hidden edges are drawn. The dimensions follow a 10 mm modulation (dotted lines).

Obtain a pseudo-axonometric view of the part.



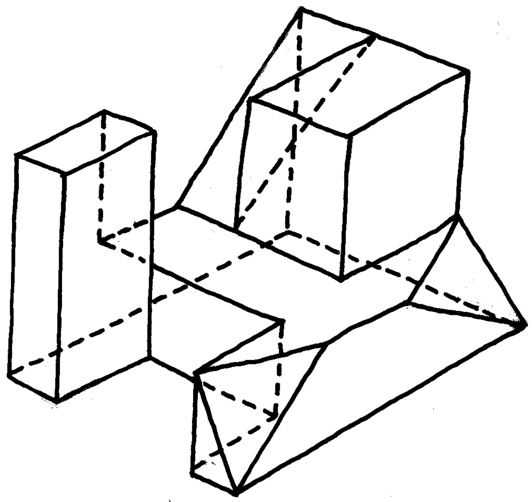
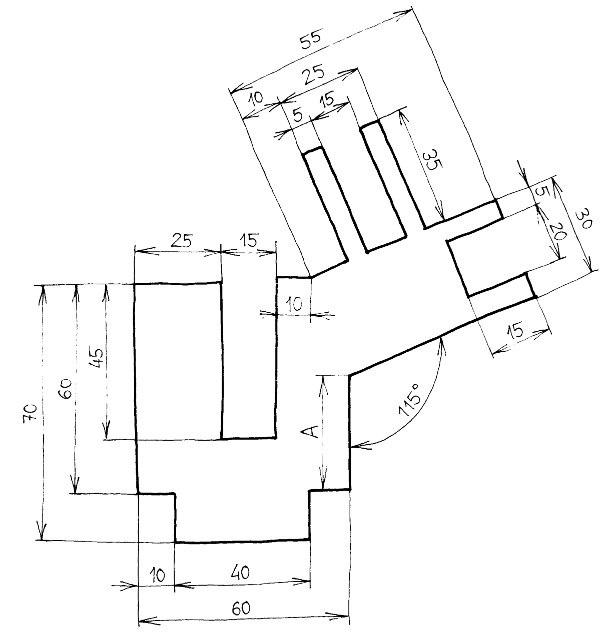


Figure 1.

The front elevation of a 2mm thick guide plate has been sketched in the figure below.

Draw the guide plate in order to determine the "A" dimension, indicated in the drawing below, as accurate as possible.



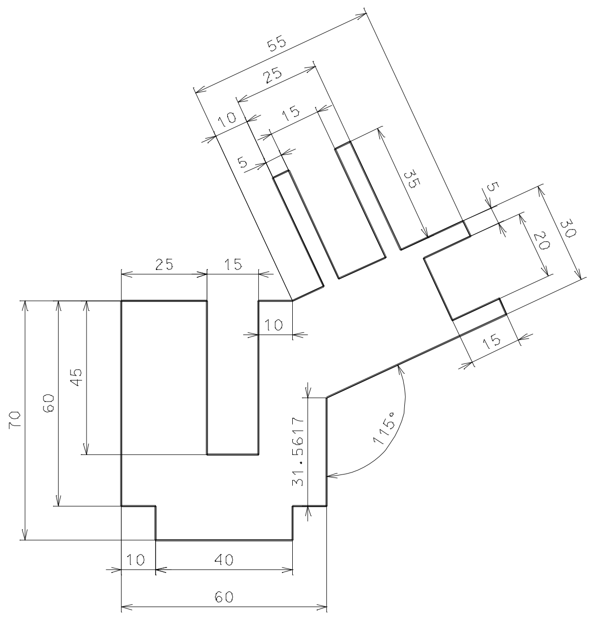


Figure 2.

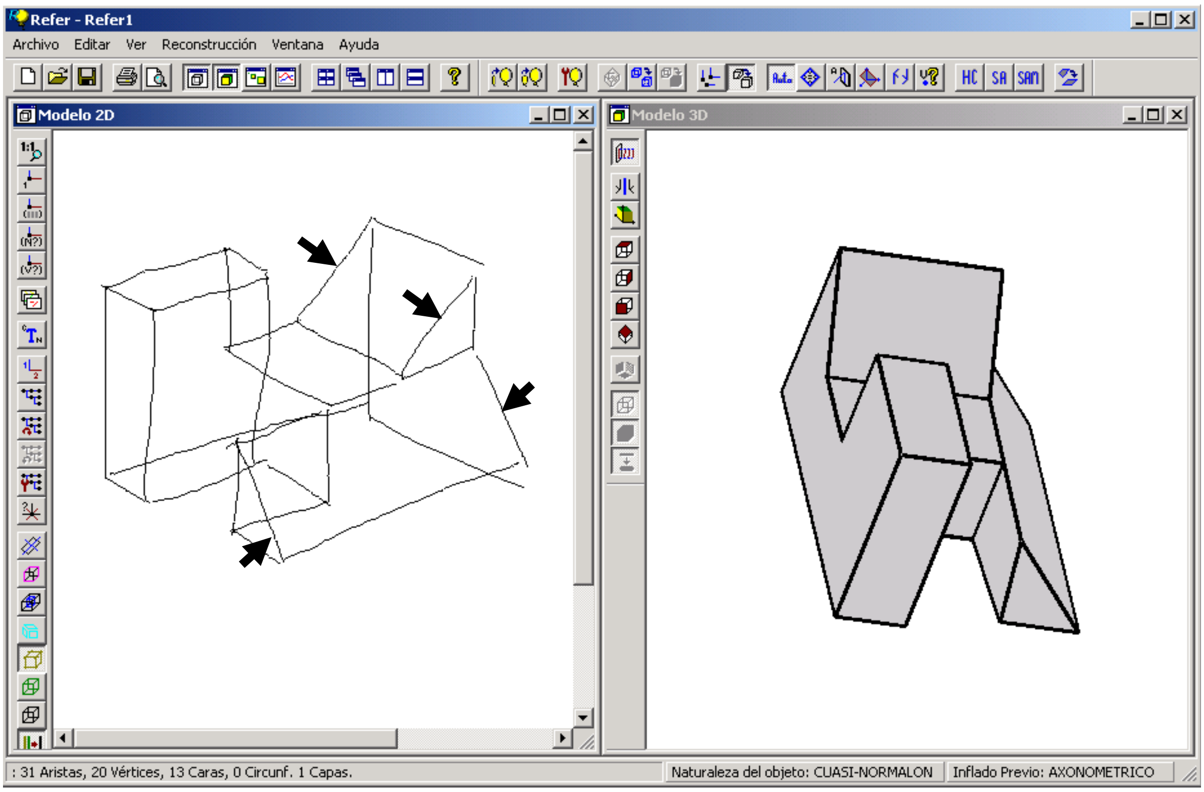

Refer - Refer1
Archivo Editar Ver Reconstrucción Ventana Ayuda
Modelo 2D
Modelo 3D
: 31 Aristas, 20 Vértices, 13 Caras, 0 Circunf. 1 Capas.
Naturaleza del objeto: CUASI-NORMALON
Inflado Previo: AXONOMETRICO

Figure 3.

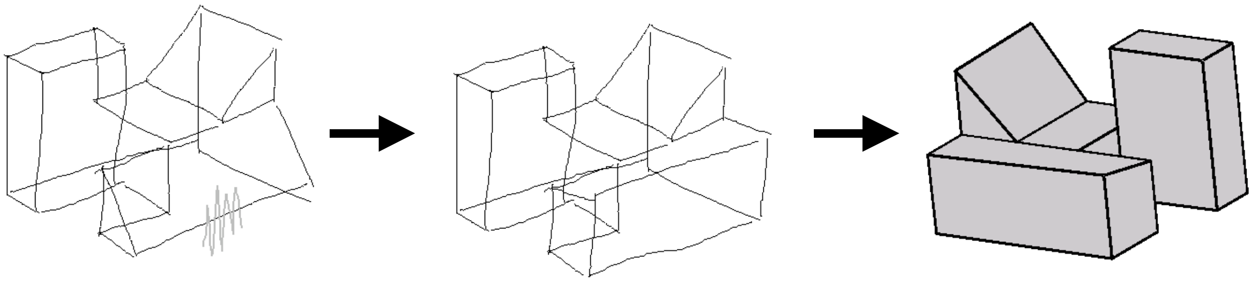


Figure 4.

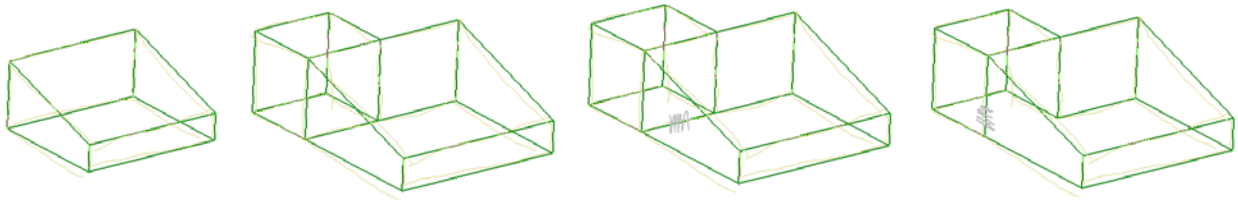


Figure 5.

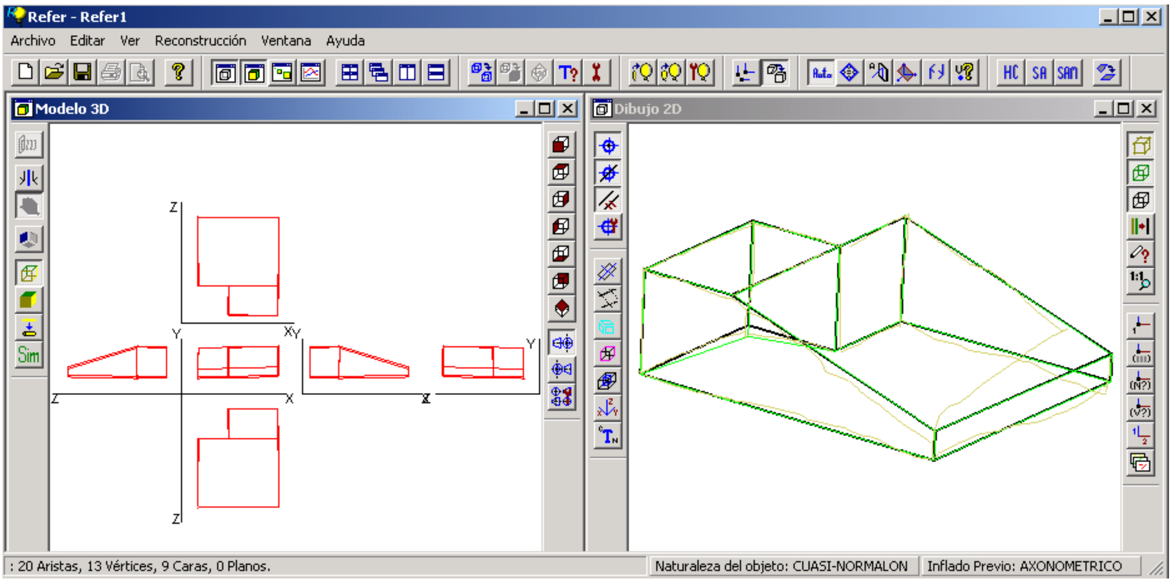

Refer - Refer1
Archivo
Editar
Ver
Reconstrucción
Ventana
Ayuda
Modelo 3D
Dibujo 2D
: 20 Aristas, 13 Vértices, 9 Caras, 0 Planos.
Naturaleza del objeto: CUASI-NORMALON
Inflado Previo: AXONOMETRICO

Figure 6.

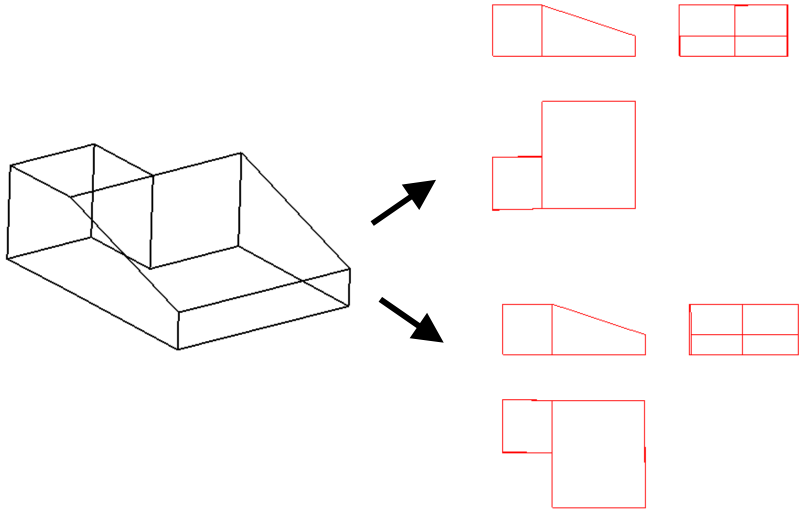


Figure 7.

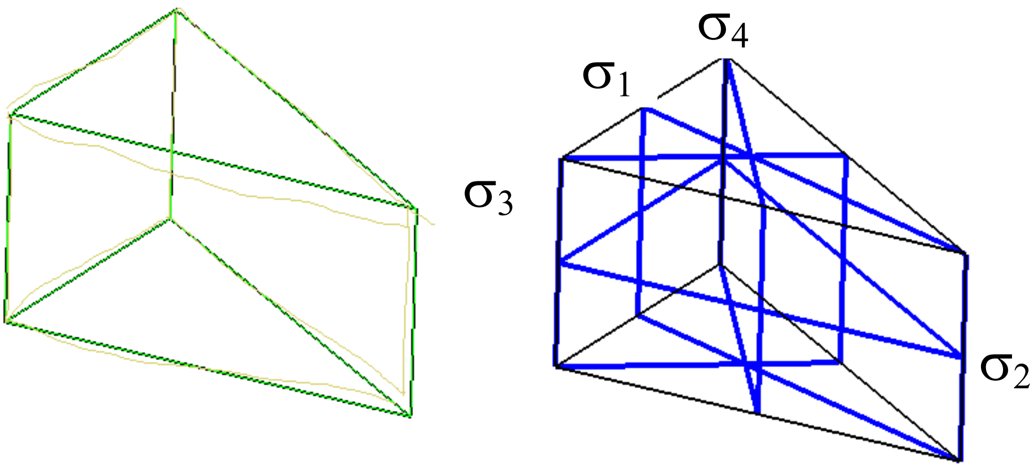
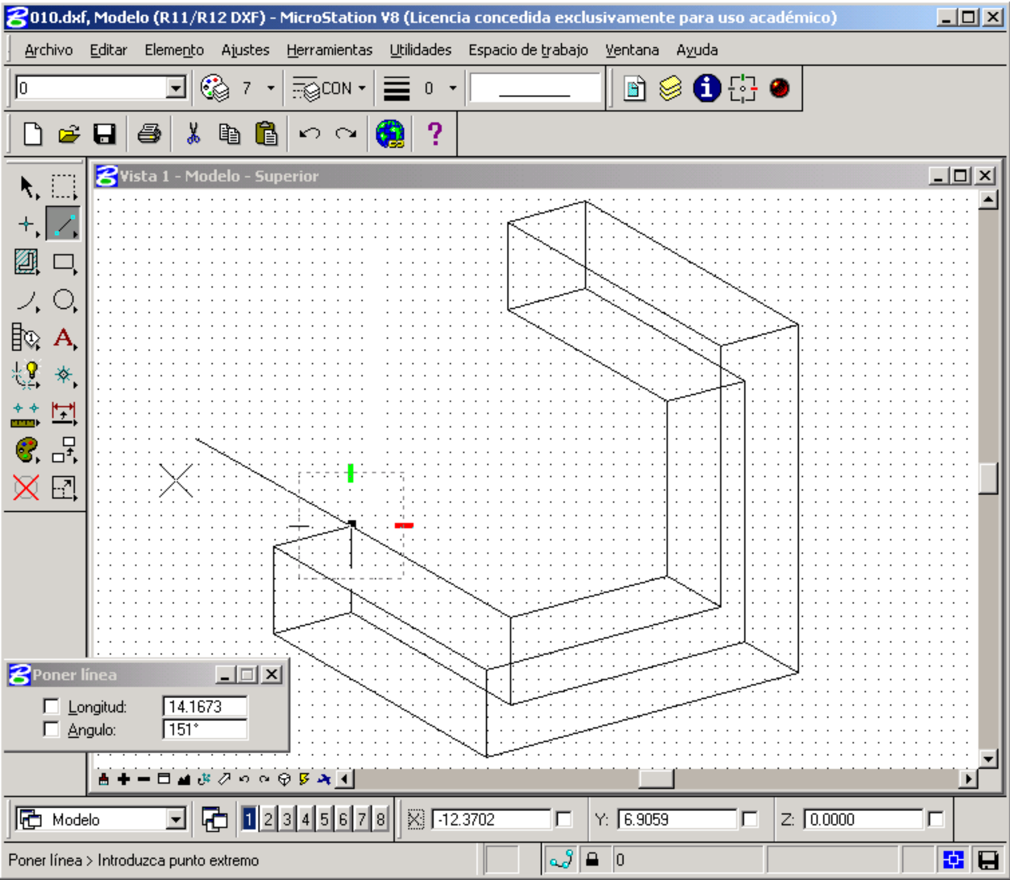


Figure 8.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Vista 1 - Modelo - Superior
Poner línea
Longitud: 14.1673
Angulo: 151°
Modelo
X: -12.3702
Y: 6.9059
Z: 0.0000
Poner línea > Introduzca punto extremo

Figure 9.

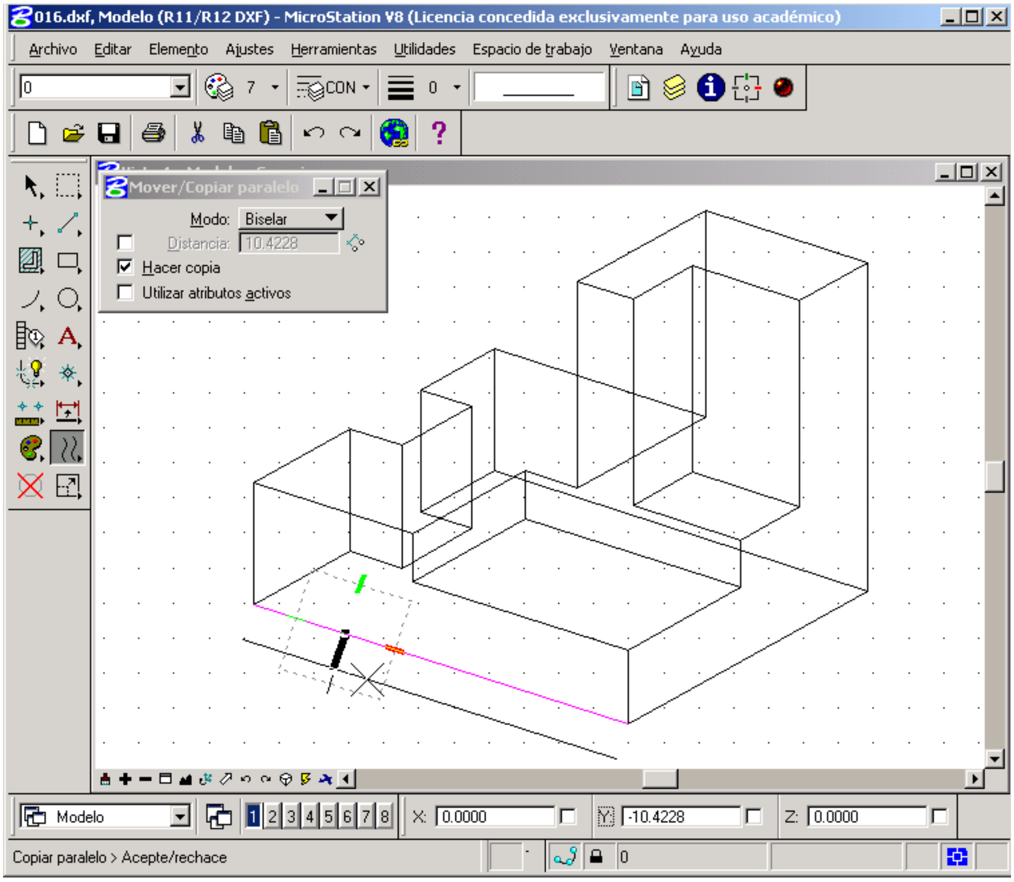
016.dxf, Modelo (R11/R12 DXF) - MicroStation V8 (Licencia concedida exclusivamente para uso académico)
Archivo Editar Elemento Ajustes Herramientas Utilidades Espacio de trabajo Ventana Ayuda
Mover/Copiar paralelo
Modo: Biselar
Distancia: 10.4228
Hacer copia
Utilizar atributos activos
Modelo
X: 0.0000
Y: -10.4228
Z: 0.0000
Copiar paralelo > Acepte/rechace

Figure 10.

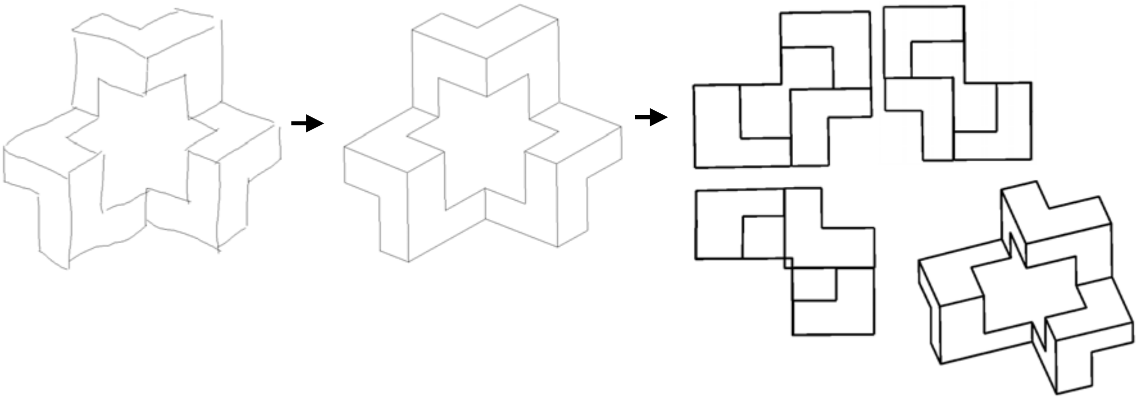

Figure 11.

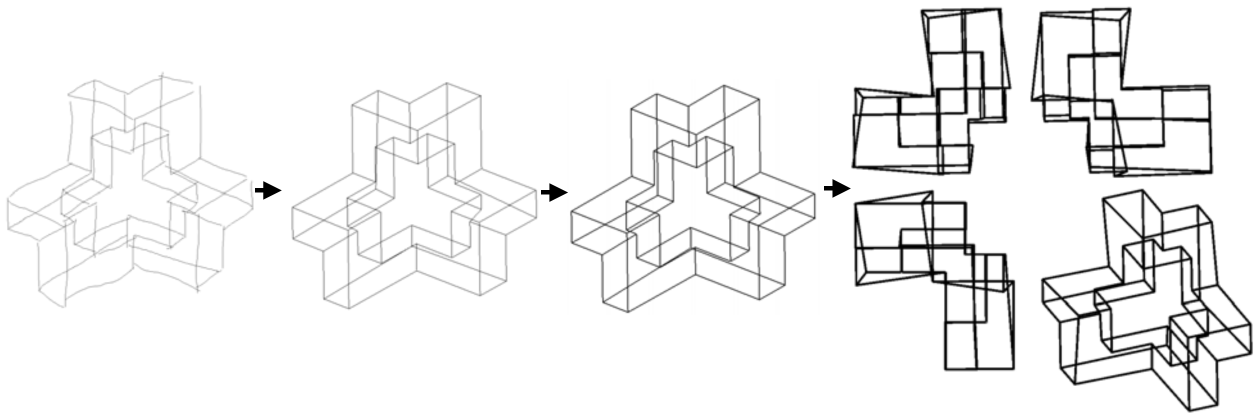

Figure 12.

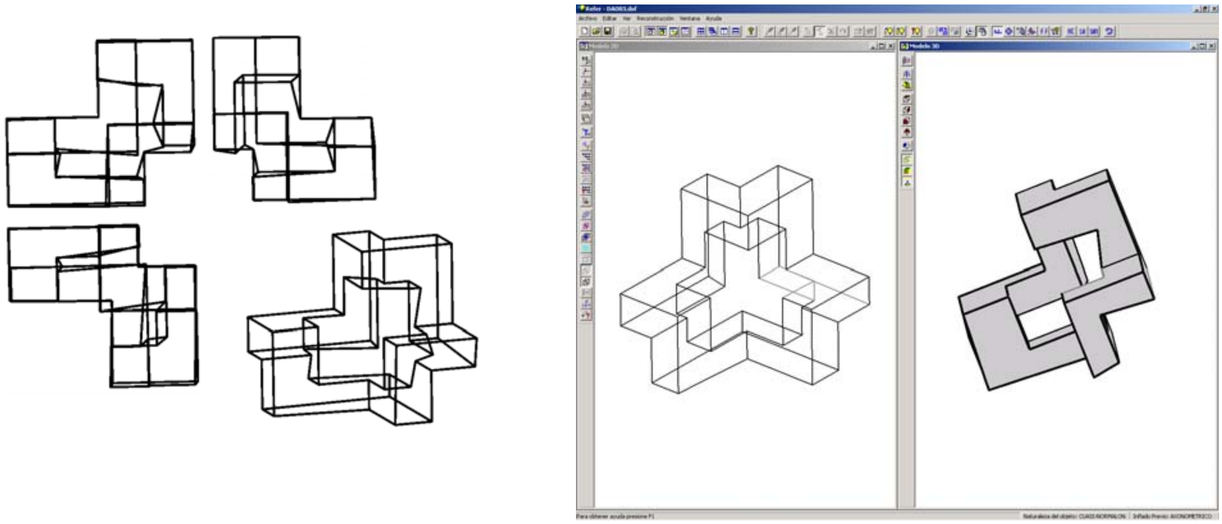

Figure 13.