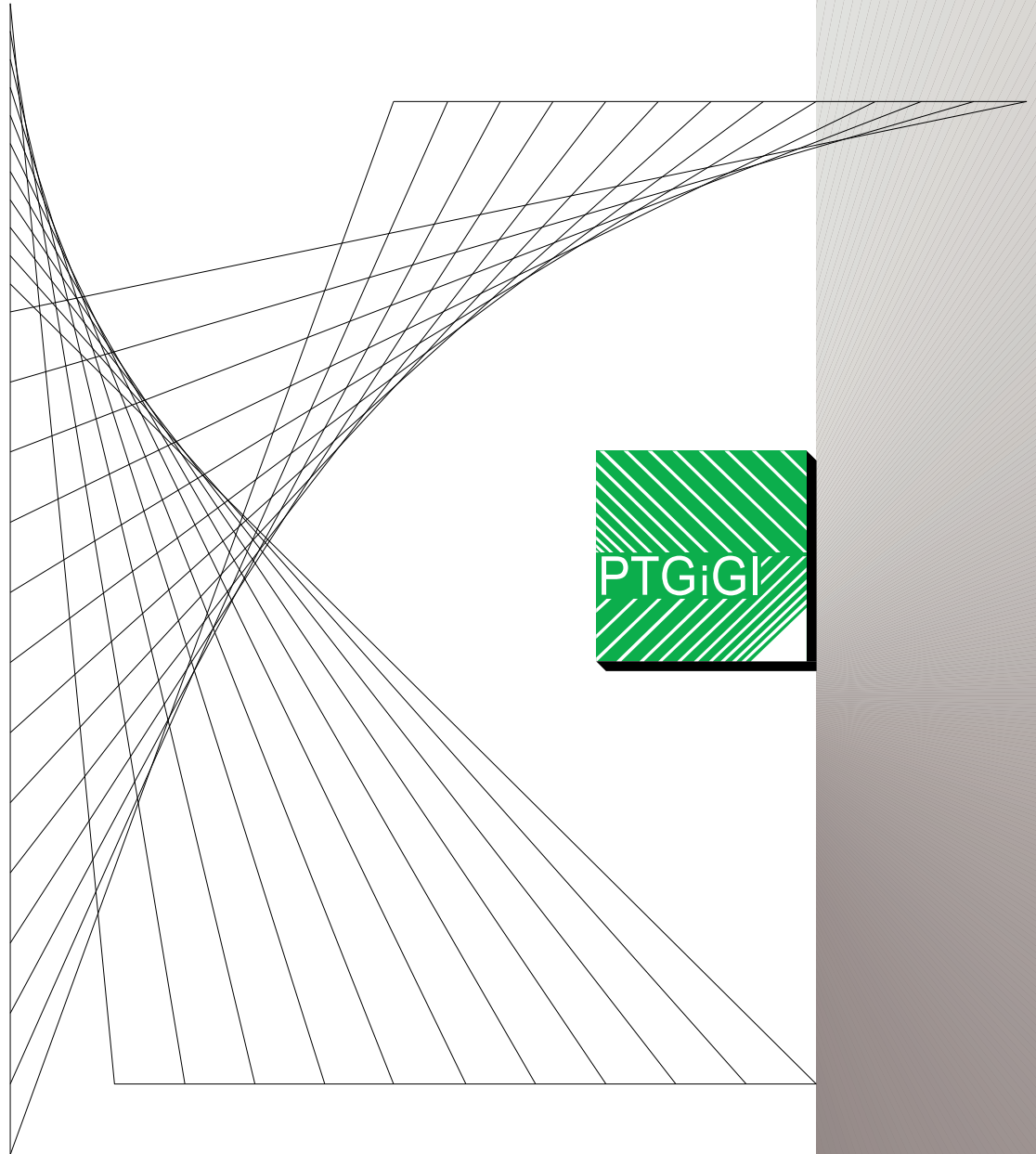


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3D MODELS OF REGULAR POLYHEDRONS IN: RHINOCEROS 3D, AUTOCAD, 3DS MAX – POSSIBLE APPLICATIONS IN THE TEACHING OF ENGINEERING GRAPHICS

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Abstract. The article presents possible applications in the teaching of engineering graphics of regular polyhedrons 3D modeling with the use of Rhinoceros 3D, AutoCAD and 3ds Max. The three software applications have been compared in terms of their functionalities with respect to the creation of 3D models of regular polyhedrons. It has also been demonstrated how the Rhino can be used for creating projections, plane sections and nets of regular solids on the basis of their 3D models. The article also gives some suggestions on how the above mentioned functionalities of Rhinoceros 3D could be used as teaching tools at technical universities. Firstly, they could help in the visualization and solution of descriptive geometry problems. Secondly, they could serve as tools for creating practice tasks and illustrations to supplement lectures or publications on descriptive geometry or engineering graphics.

Keywords: visualization, Platonic solids, polyhedron nets, AutoCAD, 3ds Max, Rhinoceros 3D

1 Introduction

The article shows how 3D modeling of regular solids with the use of Rhinoceros 3D, AutoCAD and 3ds Max could be applied in education. The teaching of engineering graphics on the basis of virtual space modeling software has become a current procedure as schools get more and more computerized. Regular solids and related issues such as drawing their Monge projections or creating their nets are standard elements of descriptive geometry or engineering graphics courses in the syllabuses of technical universities.

Regular polyhedrons have been thoroughly researched and described in literature on the subject. The publications fall into two categories: chapters on regular solids in descriptive geometry textbooks or complete popular science publications. The first group includes textbooks by the following authors: Anna Błach [4], Harold Coxeter [7, 8], and Renata Górńska [10], or by Beata Vogt [23]. The second group is represented by the publications of Zdzisław Pogoda [19, 20], as well as Piotr Pawlikowski [17]. The author has also written about polyhedrons in architecture and developed their graphic systemization. [15].

Another area considered in our work is application of CAD software to the creation of regular polyhedrons in the form of virtual models. Numerous literature references have been dedicated to the subject of CAD software. They present the methods of operating the computer aided design software. The basic knowledge related to CAD software can be found in the textbooks by: Andrzej Jaskulski [12], Andrzej Pikoń [19], as well as James Bethune [3]. Work with 3ds Max software is presented, in turn, in the manuals by: Joanna Pasek [16], Kelly Murdock [14], or Randi Derakhshani and Dariush Derakhshani [9].

The basics of work with Rhinoceros 3D can be found in the book by Ron Cheng [6], but also in numerous Internet references, for instance by Jacek Bedynek [1], or Kamil Grzelak [11].

General aspects related to engineering graphics and their basic rules are outlined in the book by Gary Bertoline, Eric Wiebe, Nathan Hartman and William Ross [2]. Modern approach to teaching engineering graphics is demonstrated in the publications by: Robert Mazur [13], Sławomir Bogacki and Ewa Terczyńska [5] or in the book by Geoff Petty [18] who discusses general problems of modern teaching.

The majority of authors present the question of regular polyhedrons exclusively from the geometrical standpoint without making any reference to the methods of their creation and transformation in the CAD- type software. However, because of the specificity of these applications, it is very important to use their functionalities (listed below) as teaching tools at technical universities.

2 3D modeling of regular polyhedrons with the use of CAD and 3ds Max

The creation of regular solids is made possible owing to many software applications. However, the article discusses only the CAD type software since it is commonly taught in university engineering courses and generally used by engineers in their work. AutoCAD software cannot automatically generate regular solids (except for a cube which can be created by selecting the cube option of the BOX command and providing three sides). Other solids need to be created geometrically following the steps below. A tetrahedron, for example:

- can be built by creating first an equilateral triangle of the base (using the command POLYGON with indication of the length of the side),
- then heights of the tetrahedron are constructed and it is turned to a vertical position (3D ROTATE with indication of the axis and the angle of the turn),
- one of the side walls is next outlined (3D POLYLINE),
- a surface is placed over the previously outlined wall (PLANAR SURFACE indicating the previously created 3D polyline (Fig. 1),
- the side walls are then replicated (ROTATE indicating the centre of the base and the number of elements equal 3), and in the end the actual solid is created based on the surface of the tetrahedron (SURFACE SCULPT)

A solid generated in this manner can next be used as a basis for creating projections and sections (Fig. 2). However, AutoCAD is rarely used for the creation of more complex regular solids as the procedure is very complicated.

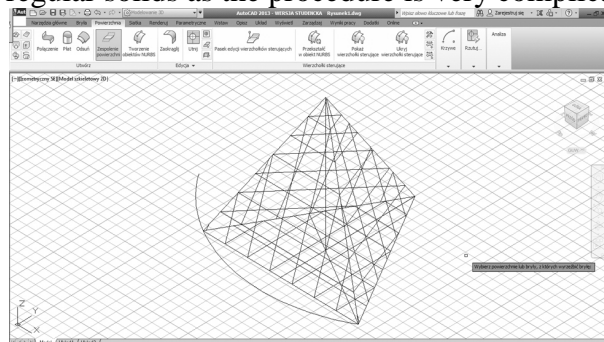


Figure 1: Regular tetrahedron constructed of surfaces – modeling in AutoCAD 2013.

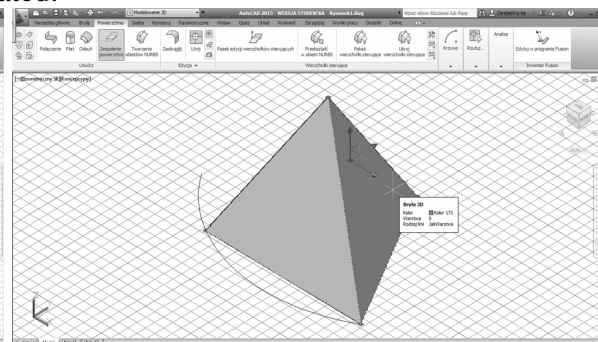


Figure 2: Regular tetrahedron after a conversion into a solid – modeling in AutoCAD 2013.

In 3ds Max program, on the other hand, the creation of regular solids is automated. It is enabled by the HEDRA command in the CREATE/GEOMETRY/ EXTENDED PRIMITIVES pallet. Using this command it is possible to create all Platonic and Kepller solids as well

as other non-regular solids. The creation of solids involves selecting one out of five object types – a tetrahedron (Fig. 3) or one of four pairs of dual polyhedrons¹: cube/octahedron, dodecahedron/icosahedron, star 1 (great icosahedron (Fig. 4) great stellated dodecahedron) and star 2 (great dodecahedron/small stellated dodecahedron) – and specifying parameters P and Q (if the parameters equal 1 and 0, the created solids are regular whereas the settings between 0 and 1 generate non-regular solids).

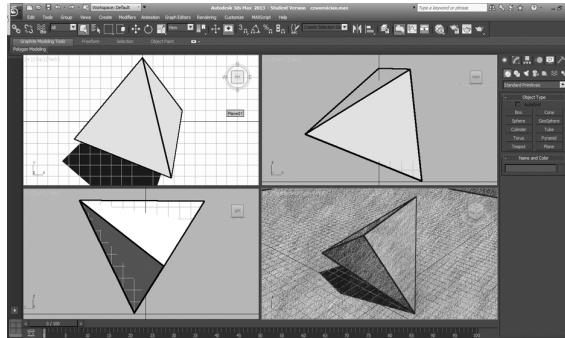


Figure 3: Projections and a model of a regular tetrahedron in 3dsMax

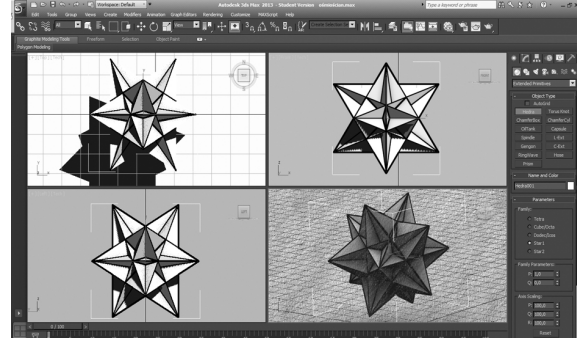


Figure 4: Projections and a model of a great icosahedron in 3ds Max

The objects created in this way can be displayed as projections, perspectives or axonometric views. The solids can be stored in DWG format which enables AutoCAD to read them. The program interprets them as nets, which makes the creation of their sections impossible. For a model of this kind to be fully functional in AutoCAD, it is necessary to convert the net to a solid using the SURFACE SCULPT command. Although the modeling of regular solids in 3ds Max is simplified, the specificity of the program itself does not encourage its use in engineering practice.

3 3D modeling of regular polyhedrons and selected functionalities of Rhinoceros 3D used in engineering graphics

The last program to be analyzed in the article is Rhinoceros 3D 5.0. It is one of the most rapidly developing programs for 3D modeling. Thanks to a very intuitive interface, students find learning its basics quite easy.²

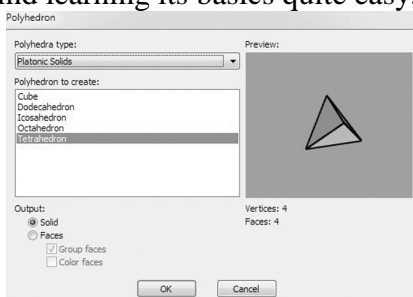


Figure 5: Panel of the RhinoPolyhedra plug-in

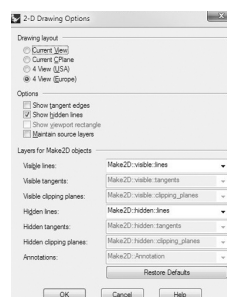


Figure 6: Panel of the MAKE2D command

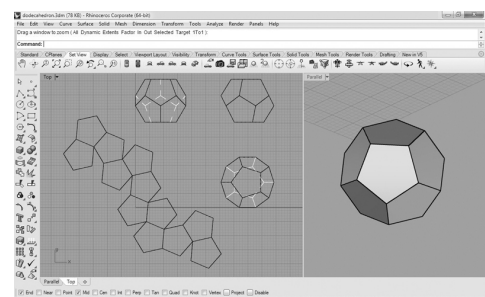


Figure 7: Projections, net and model of a regular dodecahedron in Rhinoceros 3D 5.0

¹ Dual polyhedrons (duals) are pairs of polyhedrons which are subject to the following relations: connecting centers of walls of a given initial polyhedron with the centers of their neighboring walls only creates a spatial net of the target polyhedron [19].

² During the workshops „in[formation] infrastructures” run by professor Gregory Spaw (the University of Tennessee, Knoxville) in collaboration with the author at Cracow University of Technology in April 2014, it took the students 45 mins to grasp the basics of Rhinoceros 3D 5.0.

Owing to recent improvements in the work with NURBS surfaces, the program is introduced into technical universities (e.g. Technical Universities in Warsaw, Gdansk, Wrocław, The University of Tennessee in Knoxville). In its basic version, the program contains no separate tool for the creation of regular solids; however, there exists a specifically designed plug-in – RhinoPolyhedra (Fig. 5). After installation, over 400 types of polyhedrons can be created, including Platonic and Kepler-Poisot solids, by simply activating the plug-in via the POLYHEDRA command and selecting a polyhedron and its size.

An additional advantage of Rhinoceros 3D 5.0. is the possibility of quick generation of projections and nets based on 3D models. Projections of 3D objects are created using MAKE2D command (Fig. 6) which makes it possible to set a number of parameters starting from the applied standard (EU vs. US [2]), to the visibility of lines and the ways of their creation (Fig. 7). The created drawings are then placed on the xy plane as a set of lines, which enables their further edition.

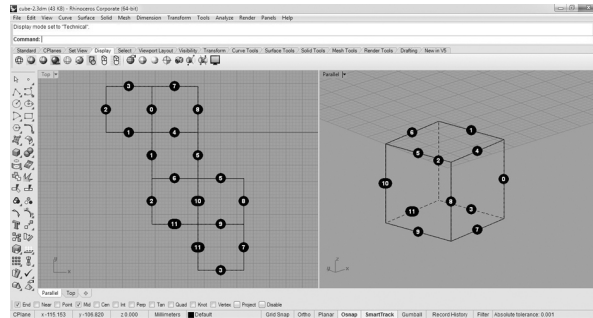


Figure 8: Net of a cube with numbered edges in Rhinoceros 3D 5.0

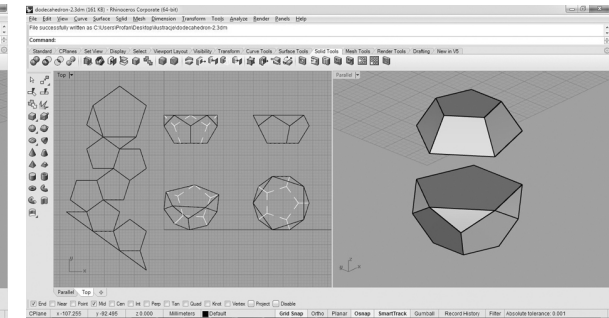


Figure 9: Projections, net and model of a dodecahedron truncated with a plane parallel to its base in Rhinoceros 3D 5.0

The command UNROLLSFR works in a similar way. It creates a polyhedron net based on the very solid. There is a functionality that allows numbering of edges of the net in order to facilitate physical model creation (Fig. 8). The software also permits objects to be divided with a freely defined plane and it enables creation of projections and nets of such truncated objects (Fig.9).

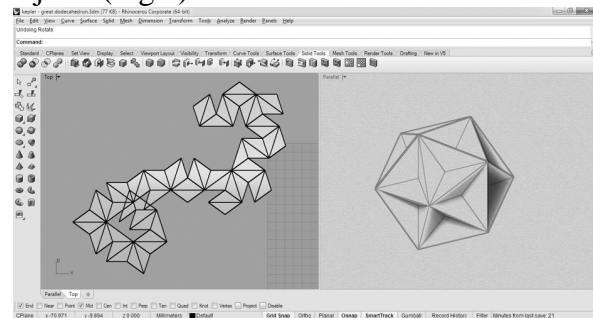


Figure 10: Automatically created net of a great dodecahedron in Rhinoceros 3D 5.0

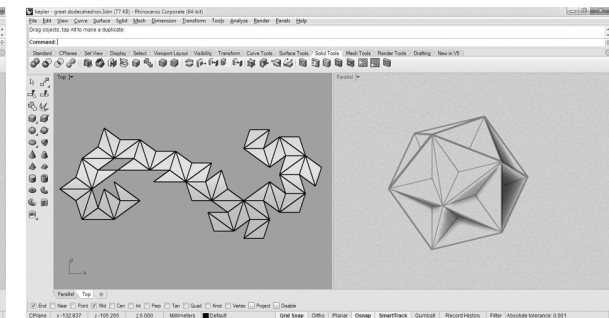


Figure 11: Net of a great dodecahedron after corrections in Rhinoceros 3D 5.0

The automated creation of nets in the case of more complex solids, for example of stellated polyhedrons, does not always yield satisfying effects. The only automatically created net that is suitable for creation of a physical model is the one of the great dodecahedron (Fig. 10) and this is possible only after corrections have been made consisting in the rotation of the overlapping sides. (Fig. 11)

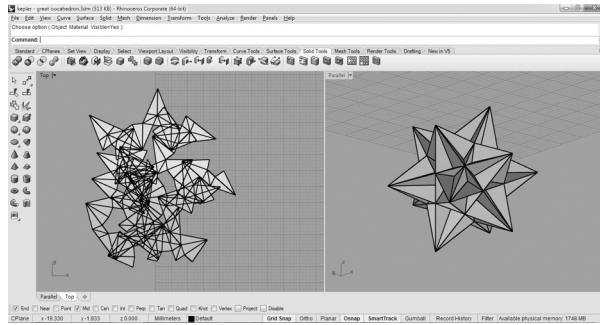


Figure 12: Automatically created net of a great dodecahedron in Rhinoceros 3D 5.0

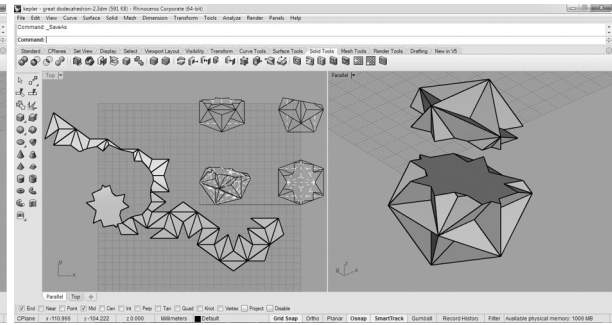


Figure 13: Automatically created net, projections and model of a great dodecahedron truncated with a plane in Rhinoceros 3D 5.0

Nets of other stellated polyhedrons are difficult to decrypt due to overlapping walls (Fig. 12). It is also possible to generate a net of a stellated polyhedron after a truncation with a freely defined plane (Fig. 13).

4 Possible applications of Rhinoceros 3D functionalities in the teaching of Descriptive Geometry and Engineering Graphics

General information on regular solids is included in the courses in Descriptive Geometry or Engineering Graphics (Fig. 14) and students also have to solve various geometric problems based on the solids. (Fig. 15). The scope of the problems depends on the course and faculty and may involve drawing axonometric views, Monge projections onto two or three projective planes, transformations, truncations or creation of nets of the solid.

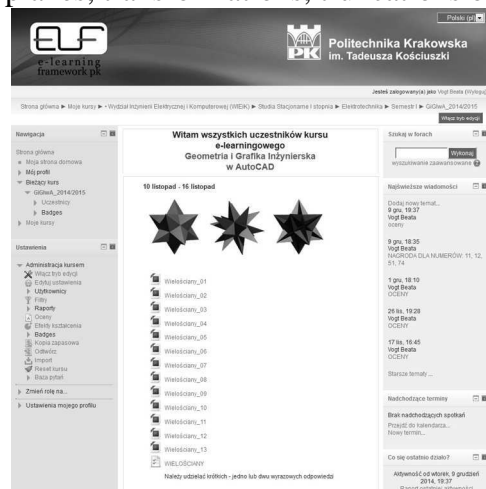


Figure 14: A view of the e-learning course in regular solids providing general information (at the consent of Beata Vogt, PhD, arch)³

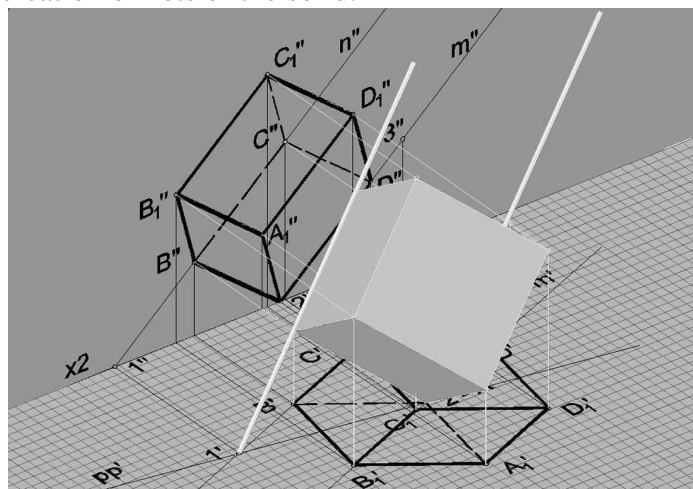


Figure 15: Platonic solids – a topic from the course in Descriptive Geometry and Engineering Graphics in AutoCAD⁴

³ A course is in the syllabus of Descriptive Geometry and Engineering Graphics in AutoCAD at the Faculty of Electrical and Computer Engineering at Cracow University of Technology and is run by Beata Vogt, PhD arch. in the academic year 2014/2015

⁴ A course run by the author for 1st year students of 1st degree studies at electrotechnics division of the Faculty of Electrical and Computer Engineering, Cracow University of Technology in the academic year 2012/2013.

Rhinoceros 3D offers a great potential for teaching thanks to the capabilities presented above such as 3D modeling of various solids and fast creation of their Monge projections. Owing to the program, even the most complex solutions to geometric problems can be presented clearly and comprehensibly in the form of 3D models (that can be rotated in virtual space), which can accelerate the teaching process. Another advantage of the application is the automated creation of a polyhedron net based on the polyhedron which allows students to see immediately the underlying principle of its creation. (Fig. 8). A very useful functionality is certainly the creation of truncated polyhedrons and their Monge projections as well as surface nets for making their physical models. (Fig. 13). The net, which is an extension of all the sides of the truncated solid, also shows the real image of the truncation (Fig. 9) – in other words, it solves a popular problem in descriptive geometry – find the real image of the truncated model. Last, but not least, the application may generate polyhedron penetration views. (Fig. 16). Penetration of polyhedrons is discussed in classes to explain how descriptive geometry principles can be applied to solving engineering tasks. For example, a pyramid and a rectangular prism penetrating into each other may illustrate the following tasks: design a rubbish chute (for students of Environmental Engineering, Cracow University of Technology), design a column with a capital (for students of the Faculty of Architecture) (Fig. 16). Finding the line where the chute-forming solids penetrate into each other and creating the net helps to arrange the chute walls on a metal sheet for the optimum use of the material.

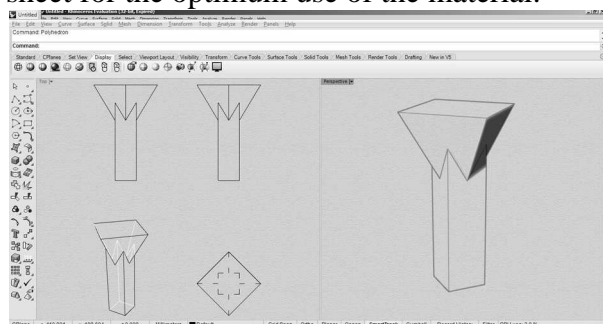


Figure 16: Projections and model of a pyramid and a rectangular prism penetrating into each other in Rhinoceros 3D 5.0

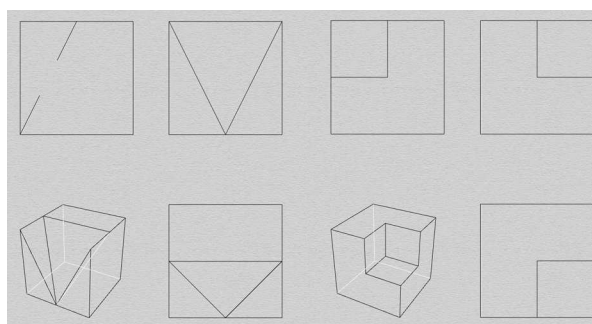


Figure 17: Example of making variants of geometric problems related to drawing set axonometric views of solids⁵

Thanks to the quick creation of projections and axonometric views based on solids, a minor change in 3D solid suffices to create new variants of geometric problems. Therefore the program seems to be an ideal tool for creating individual tasks for students (Fig. 17).

5 Summary

Selected software applications have been compared with respect to their capabilities in the field of polyhedron-related 3D modelling and geometric problem solving. The analysis has revealed the Rhinoceros 3D 5.0. application to be the best. The RhinoPolyhedra plug-in enables automated creation of complete models of regular polyhedrons, which makes it similar to 3ds Max. However, the advantage of Rhinoceros lies with the speed and ease of generation of projections, axonometric views, perspectives (in a format of editable lines) and nets, which neither AutoCAD nor 3ds Max can match.

The efficiency of the Rhinoceros 3D 5.0. application can be used in the teaching of the principles of projection or truncation geometries since the fast generation of models

⁵ Each variant took the author 1,5/2 min to create.

makes possible the discussed geometric and engineering issues to be presented in the form of 3D images.

Rhinoceros 3D 5.0. may also serve as a tool for rapid creation of practice tasks for students as well as illustrations for lectures or publications on descriptive geometry or engineering graphics.

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TRÓJWYMIAROWE MODELE WIEŁOŚCIANÓW FOREMNYCH W PROGRAMACH: RHINOCEROS 3D, AUTOCAD, 3DS MAX - MOŻLIWOŚCI WYKORZYSTANIA W NAUCZANIU GRAFIKI INŻYNIERSKIEJ

W artykule przedstawiono możliwości i sposoby modelowania 3D brył foremnych w programach Rhinoceros 3D oraz AutoCAD i 3ds Max pod kątem wykorzystania w nauczaniu grafiki inżynierskiej. Porównano możliwości poszczególnych programów w tym zakresie. Zademonstrowano tworzenie rzutów, przekrojów zadaną płaszczyzną oraz siatek brył foremnych przy użyciu funkcji programu Rhinoceros na bazie ich trójwymiarowych modeli. Podano również propozycje wykorzystania podanych funkcji programu Rhinoceros 3D na wyższych studiach technicznych jako pomoc przy wizualizacji i rozwiązywaniu zadań z geometrii wykreślnej oraz jako narzędzie do tworzenia tematów, ilustracji do wykładów lub publikacji z dziedziny geometria wykreślna czy też grafika inżynierska.