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EDUCATIONAL MODELS FOR REPRESENTING SECTIONS USING FDM TECHNOLOGY

Abstract: *The paper presents a didactic method for teaching section representations in technical drawing, using physical models made with 3D FDM printing technology. Educational models were developed for three types of sections: front-plane section, stepped section and quarter section. The models are made of two components printed in contrasting colours that allow direct visualization of the sectioning path, facilitating the understanding of the inner contour, the outer contour and the hatching surface. The study demonstrates that the use of models significantly improves the understanding of abstract sectioning concepts, reducing the difficulties encountered by students in interpreting classical two-dimensional representations. This approach offers an economical and replicable solution for modernizing the educational process in the field of engineering graphics.*

Key words: *Technical sections, Engineering graphics, Didactic Model, 3D printing, Sectional views.*

1. INTRODUCTION

Section is the representation, in orthogonal projection, of a part on a plane, as it would appear if it were sectioned with a fictitious sectioning surface and if the portion of the part located between the observer's eye and the sectioning surface were removed. The sectioning surface can be a portion of a plane or portions belonging to several planes or it can be cylindrical (Figure 1), resulting in the sectioning path (dotted line with thick segments at the ends and changes in direction) [1], [2].

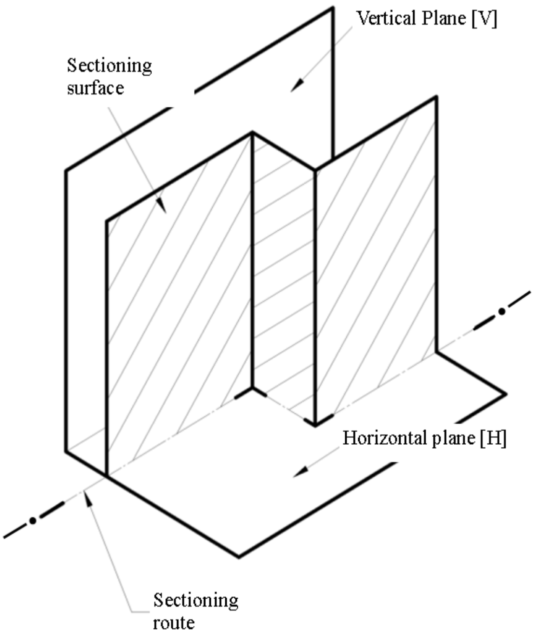

Figure 1 Sectioning surface and sectioning route. The sectioning surface consists of three planes [2].

In industrial technical drawing, there are several types of sections, but in the educational process, three categories are predominantly used due to their frequency in practical applications: the front plane section, the stepped section and the quarter section.

The front plane section is a vertical section, made when the sectioning surface is a front plane (parallel to the vertical projection plane and perpendicular to the horizontal plane H), frequently used to highlight interior details in the main view. This type of section is fundamental in the representation of parts with axial symmetry and allows clear visualization of interior geometric elements located in a single vertical plane [3].

The stepped section results when the sectioning surface is formed by several consecutive planes competing at an angle of 90°. This type of section is used when the interior details of the part are not located in the same plane, allowing the simultaneous highlighting of several geometric elements located at different depths or heights. An important peculiarity of this type of section is the offset representation of the hatching in places where the sectioning surface changes direction [2].

The quarter section is a partial section in which the sectioning surface is formed by two concurrent planes that form an angle of 90°, removing only a quarter of the part. This type of section is used exclusively for parts that have in their composition geometric shapes symmetrical with respect to a single axis, combining the advantage of the external view with that of the section, saving representation space [2].

3D printing technology using FDM (Fused Deposition Modelling) consists of depositing a molten thermoplastic filament, layer by layer, through a heated numerically controlled nozzle, to manufacture three-dimensional objects of varying complexity (Figure 2). FDM technology, accessible through printers with relatively low purchase prices, allows rapid prototyping with adjustable parameters, being ideal for didactic models in engineering due to its low cost and geometric fidelity [4].

Recent research demonstrates that implementing 3D printing in engineering education brings numerous advantages, facilitating the understanding of complex concepts and improving students' motivation for learning [4]. Studies show that 81% of students believe that 3D printing should be included in the educational process, the main reason being a better understanding of the studied components and the possibility of applying knowledge in industry [6].

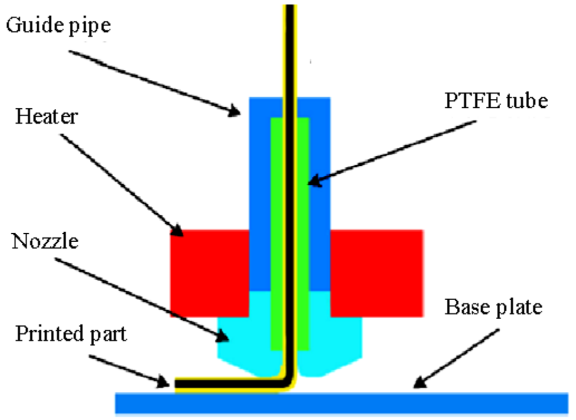

Figure 2 FDM process principle, schematic [5].

In didactic use, the model facilitates the understanding of the inner contour, outer contour and hatch surface in frontal, stepped and quarter-sections, unlike traditional static 2D representations. Sectioned elements maintain geometric accuracy during repeated manipulations, and the use of contrasting colours allows immediate differentiation of the portions retained from those removed by sectioning[4].

2. MATERIALS AND METHODS

2.1 Equipment

The Creality Ender-3 V3 SE 3D printer uses FDM technology, which deposits molten thermoplastic filament through a 4mm diameter heated nozzle (Figure 3).

Figure 3 3D printer Creality Ender 3 V3 SE [4].

The equipment features a numerically controlled extrusion system, heated bed for superior adhesion and improved print quality, as well as a 220 × 220 × 250 mm build volume. It is equipped with silent stepper motor drivers, allowing smooth, quiet and precise operation even at high printing speeds.

The study uses PLA (Polylactic Acid), a biodegradable thermoplastic polymer obtained from renewable sources such as corn starch or sugar cane. PLA is the predominant material in 3D printing due to its low melting point, between 180 and 230°C, low shrinkage and good adhesion between layers, making it ideal for detailed prototypes, educational models and functional parts. Compared to other filaments such as ABS or PETG, PLA has good mechanical strength and high stiffness, although it is more brittle and withstands lower temperatures. All prints were made using a storage system to protect the PLA filament against moisture absorption, which deteriorates the print quality.

The combination of the Creality Ender-3 V3 with PLA filament offers an economical solution for making models with close tolerances, complex geometries and quality surface finish.

2.2 Designing educational 3D models

For each type of section, educational models were designed that consist of simple pieces with representative geometry, made in two distinct components that are joined along the sectioning path.

The model for the section with the front plane was designed as a part with a parallelepiped base with internal geometric elements, a cylindrical blind hole. The model is composed of two parts: the rear component, printed in colour, which represents the portion retained after sectioning, and the front component that is printed in contrasting colour, which represents the imaginary removed part. At the interface between the two components, the sectioning path is visible, which corresponds exactly to the front plane used in the technical representation.

The stepped section model has a more complex geometry, with interior details located at different heights, requiring a sectioning surface formed by consecutive planes perpendicular to each other. The part includes a vertical hole in two sections and a recess, positioned so that they are not coplanar. The two differently coloured components allow for a clear visualization of how the sectioning surface changes direction in steps to intersect all the elements of interest.

The quarter section model was designed as a part with complete axial symmetry, consisting of a cylinder with a square base and interior details symmetrical about the vertical axis. The sectioning surface is formed by two perpendicular planes intersecting on the symmetry axis, removing only one quarter (25%) of the part volume. This approach allows simultaneous observation of the outer contour, on the three remaining un-sectioned quarters, and the inner contour, on the sectioned surface, perfectly illustrating the applicability of this type of section for parts with complete symmetry.

All models were designed in CAD (Computer-Aided Design) software with dimensions of approximately 60–80 mm in maximum size, ensuring optimal visibility of geometric details and ergonomic handling during teaching activities.

2.3 Slicing and printing parameters

The slicing software used is UltiMaker Cura 5.6, configured with optimized parameters for maximum quality and geometric fidelity. The printing parameters were:

- Extruder temperature: 205°C;
- Bed temperature: 60°C;
- Printing speed: 50 mm/s;
- Layer height: 0.2 mm;
- Fill density: 20%, gyroid infill model;
- Number of perimeters: 3;

For the front plane section educational model, the un-sectioned component required 143 minutes (2h 23min), 36 grams of material, equivalent to 11.87 meters of PLA filament. The sectioned component required 85 minutes (1h 25min), 19 grams of material, equivalent to 6.15 meters of PLA.

For the stepped section model, due to the more complex geometry with changes in direction, the total printing time for both components was approximately 4 hours, consuming approximately 65 grams of PLA filament.

For the quarter section model, being a partial section that only removes 25% of the volume, the total print time was approximately 3.5 hours, with a consumption of approximately 55 grams of PLA filament.

The selected parameters ensure an optimal balance between quality, mechanical strength and manufacturing time, allowing for the production of models with smooth surfaces and adequate durability for repeated handling in an educational context..

2.4 Making physical models

Two physical versions were manufactured for each section type, using contrasting colour combinations to maximize visual clarity.

These physical models allow observers to better understand the differences between the inner and outer contours of the part resulting from sectioning. The use of contrasting colours facilitates immediate identification of the areas that remain after sectioning versus those that are imaginary removed.

The models can be manipulated, taken apart, and reassembled, providing a tactile and visual experience superior to the classic two-dimensional representations found in technical drawing textbooks.

Each set of educational models serves a specific teaching purpose: the front plane section models demonstrate the fundamental principle of simple plane sectioning, the step section models illustrate the necessity and methodology of sectioning with surfaces composed of multiple planes, and the quarter section models highlight the efficiency of partial sectioning for symmetrical parts.

The red component represents the portion removed by sectioning, and the blue component represents the part to be kept. At the interface between the two components, the sectioning path is visible (Figure 4).

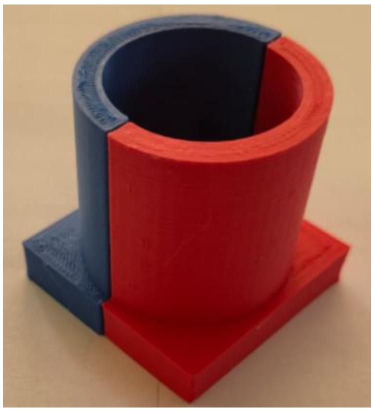

Figure 4 Educational model for the front plan section – overview.

Removing the red half will provide the sectioned view. This representation allows for clear observation of the sectioned surface and the internal geometric details exposed by the sectioning (Figure 5).

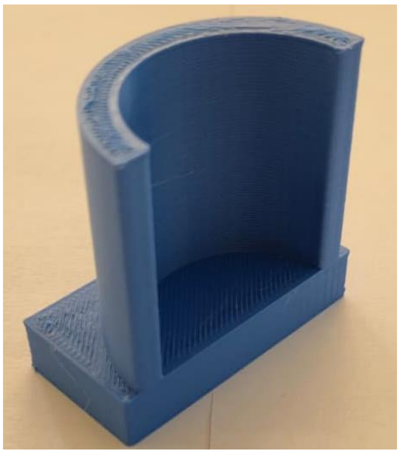

Figure 5 Educational model for the front plan section – separate component.

The black and orange components illustrate partial sectioning, in which only a quarter of the part is removed, allowing simultaneous visualization of the outer and inner contours (Figure 6).

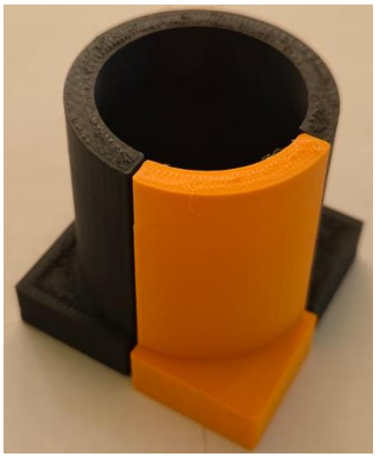

Figure 6 Educational model for quarter section – overview.

Removing the orange component results in a quarter-sectioned piece. This representation highlights the partial nature of the sectioning, specific to pieces with complete axial symmetry (Figure 7).

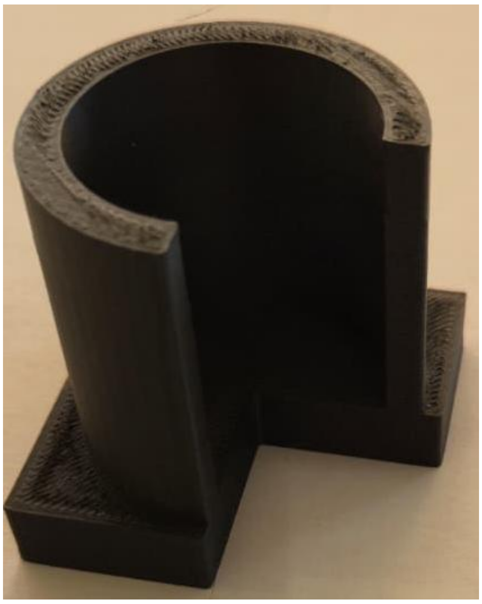

Figure 7 Educational model for quarter section – separate component

The two components (orange and black) illustrate how the sectioning surface changes direction in steps to intersect interior details located inside the part (Figure 8).

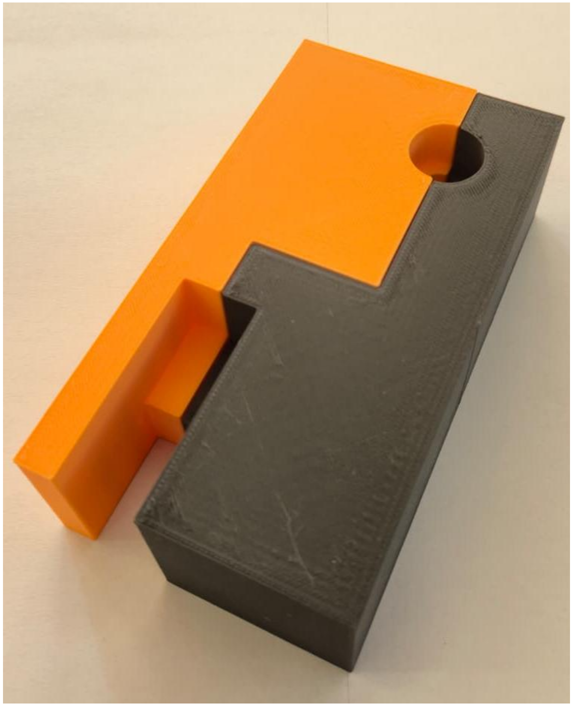

Figure 8 Educational model for the stepped section – overview.

By removing the black half of the piece, the interior details resulting from sectioning and the change in the path of the sectioning surface can be observed (Figure 9).

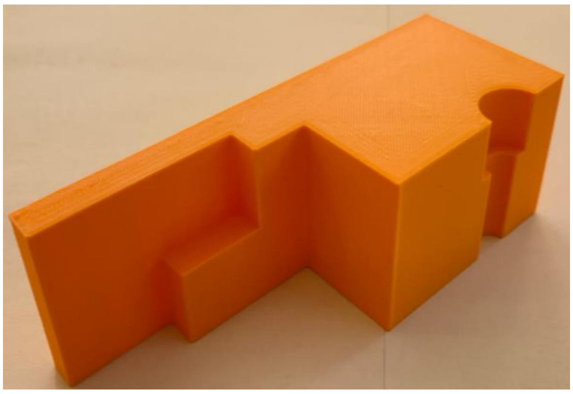

Figure 9 Educational model for the stepped section – separate component.

3. RESULTS AND COMPARATIVE ANALYSIS

The manufactured educational models were evaluated from the perspective of geometric quality, didactic clarity and applicability in the teaching–learning process. In addition to the purely dimensional aspects, particular attention was paid to how intuitive the models are for first–year engineering students who usually encounter sectional views for the first time.

Table 1 summarizes the main technical and didactic characteristics of the three families of models. The printing time and material consumption confirm that the manufacturing effort remains moderate, even when multiple sets are required for several student groups. At the same time, the geometric complexity varies from medium to high, which allows the teacher to gradually introduce students from simple to more complex sectioning situations.

Table 1

Comparative characteristics of the educational models

Parameter	Front plane	Steped	Quarterly
Total printing time	3h 48min	4h 00min	3h 30min
PLA material	55 g	65 g	55 g
Approximate cost	2,75 RON	3,25 RON	2,75 RON
Geometric complexity	Average	High	Average
Ease of assembly	Very good	Good	Very good
Visual clarity	Excellent	Excellent	Excellent

All models exhibited high dimensional accuracy, with deviations below 0.2 mm from CAD–designed dimensions, confirmed by digital calliper measurements. The contact surfaces between the two coloured components mated smoothly, allowing for repeated assembly and disassembly without damage or noticeable wear of the contact edges.

The finish of the printed surfaces was of good quality, with the 0.2 mm layers visible but not affecting the geometric understanding. Edges and corners were reproduced with sufficient sharpness to make the identification of geometric elements (holes, recesses, planes) straightforward, even when the models were observed from a distance in a classroom environment. Only minor stair–stepping effects were observed on strongly curved surfaces, which did not compromise the didactic purpose of the models.

The mechanical strength of the models proved adequate for repeated handling in an educational context. PLA filament provided sufficient rigidity, with no plastic deformation at ambient temperature after several weeks of intensive use. Accidental drops from desk height did not cause cracks or fractures, which indicates that the chosen printing parameters ensure a robust enough structure for everyday laboratory activities.

From the didactic point of view, the chromatic contrast between the differently coloured components proved essential for clarity. The orange–black and blue–red combinations allowed for instant identification of the removed portion versus the preserved portion through sectioning. Informal observations during laboratory sessions showed that students were able to correctly indicate the sectioned area and the remaining volume after only a short explanation from the teacher.

Qualitative feedback was collected using a short questionnaire at the end of the laboratory. Most students reported that the physical models made it easier to understand the relationship between the sectioning surface, the section path and the hatched area in the drawing. Several respondents explicitly mentioned that they were finally able to “see” why the hatching is applied only on the material and not on holes or cavities, which is a frequent source of confusion when learning solely from 2D textbook examples.

4. DISCUSION

Implementing 3D educational models in teaching technical sections brings significant benefits to the learning process, confirming recent research on the effectiveness of 3D printing technologies in engineering education. The models act as an intermediate layer between abstract theory and real industrial parts, offering a controlled environment in which students can experiment and make mistakes without consequences on real components.

The main advantage of physical models is the transformation of abstract concepts into tangible objects. Students who have difficulty visualizing space and interpreting two–dimensional representations benefit significantly from the ability to manipulate the models, observe them from multiple angles and understand the relationship between the section path and the resulting surface. For many of them, rotating the model in their hands and then comparing it with the corresponding 2D views leads to a “moment of clarity” which is difficult to achieve using flat images alone.

The differentiation of section types becomes evident by directly comparing the three models. Students can concretely observe the difference between: the front plane section – where a single vertical plane intersects the part; the stepped section – where the sectioning surface changes direction to intersect details located at different levels; and the quarter section – where partial sectioning preserves information about the outer contour. This comparative approach helps them decide which type of section is the most appropriate in a given design situation.

Didactic applicability manifests itself on multiple levels. In lectures, the teacher can visually demonstrate theoretical concepts by showing the models to the entire class or by projecting photographs of the printed pieces. In the laboratory, students can work individually or in small groups, each group handling a complete set of models. During assessment, the same models can be used in practical tests where students are asked to draw the corresponding sectional views or to identify the type of section represented.

The economic aspect is a major advantage. The total cost for making a complete set of six models, two for each type of section, is approximately 17–18 RON, considering only the PLA material. This value is comparable to or even lower than the cost of purchasing one commercial didactic model or a single laminated teaching board. Furthermore, once the CAD files are available, the models can be reprinted whenever necessary, which eliminates the risk associated with damage or loss of a single unique model.

The replicability of the method is another key benefit. CAD files and slicing parameters can be freely distributed between educational institutions, allowing identical models to be manufactured wherever there is access to an FDM 3D printer. This feature facilitates the standardization of teaching materials and the exchange of best practices among educators. In addition, students can be involved in the improvement of existing models or the design of new ones, integrating the learning of descriptive geometry, CAD modelling and additive manufacturing into a single coherent educational activity.

Identified limitations include the need for access to 3D printing equipment and basic technical skills for operating it. For institutions with a large number of students, the relatively long manufacturing time required for multiple sets may also become a constraint, especially during exam periods when printers are heavily used. Another limitation is related to the intrinsic properties of PLA, which has lower impact resistance and heat resistance compared to engineering plastics; therefore, models must be stored and used under adequate conditions.

Future developments may include creating an extensive library of models for all types of sections described in technical drawing standards, as well as for more complex situations where several section types are combined in the same part. Modular models, whose components can be rearranged to simulate different sectioning scenarios, would further increase flexibility and reduce the total number of printed parts needed. The integration of magnets or mechanical clips could improve the assembly of the pieces and accelerate their use during fast classroom demonstrations.

Compared to traditional teaching methods (blackboard drawings, printed boards, PowerPoint presentations), 3D physical models provide a kinesthetic learning experience that simultaneously engages the visual and tactile senses. This multimodal approach facilitates long–term memorisation and a deeper understanding of complex geometric concepts. The observations made during this study are consistent with other reports in the literature, which highlight that students exposed to 3D printed didactic models perform better in spatial visualization tests and show a higher level of confidence when solving problems involving sectional views.

5. CONCLUSION

The present work demonstrates the feasibility and effectiveness of using FDM 3D printing technology to create educational models for teaching technical sections. Physical models were successfully developed and manufactured for three fundamental types of sections: front plane section, stepped section and quarter section. Each model was designed as a pair of contrasting coloured components that separate exactly along the sectioning surface, making the section path and the resulting sectional area immediately visible.

The manufactured models exhibit high geometric accuracy, adequate mechanical strength and very good visual clarity. The low material cost and the moderate printing time make the proposed approach economically attractive even for laboratories with limited budgets. Once the digital files are prepared, additional copies can be produced on demand, which allows several student groups to work simultaneously with identical didactic resources.

From an educational perspective, the models significantly reduce the time required for students to understand the basic concepts of sectioning. The possibility to manipulate the objects, to separate and reassemble the components and to compare them directly with the corresponding 2D representations leads to a more intuitive and lasting understanding of the relationships between projection planes, sectioning surfaces and hatched areas.

The methodology presented is fully replicable and can be implemented in any educational institution that has access to FDM 3D printing equipment. The favourable cost–benefit ratio, combined with the positive feedback obtained from students, supports the integration of such models as a permanent component of technical drawing and engineering graphics curricula.

Future work will focus on extending the library of models to cover additional types of sections, on designing modular and reconfigurable models and on performing a quantitative evaluation of the impact on student performance through controlled experiments. In the broader context of engineering education, the results confirm that 3D printing is not only a prototyping tool for industry, but also a powerful ally in modernizing teaching methods and making abstract geometric concepts accessible to all students.

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