Applying Additive Technologies to Teaching Graphic Disciplines in a Technical University

O. Zhuykova*, P. Božek**, E. Sosnovich* and E. Akhmedzianov*

* Kalashnikov Izhevsk State Technical University/ Faculty of Mathematics and Natural Sciences/Department of Engineering Graphics and Advertising Technology, Izhevsk, Russia

** Slovak University of Technology in Bratislava/ Faculty of Materials Science and Technology/ Institute of Production Technologies, Trnava, Slovakia

zhuykovaolga2012@mail.ru, pavol.bozek@stuba.sk, ellasosnovich@istu.ru, akhmedzianov@gmail.com

Abstract—**Over the last few years, additive technologies have been actively adopted in many areas of modern life. This paper discusses how necessary it is for students to develop their innovative thinking and what the role of additive technologies in this process is. The research was focused on the applicability of additive technologies in teaching the students of mechanical engineering, architectural and civil engineering training programs the disciplines "Descriptive Geometry" and "Engineering Graphics" in Kalashnikov Izhevsk State Technical University. The article also demonstrates the samples from the model archive of the "Engineering Graphics and Advertising Technology" department designed with FDM technology of 3D printing which improves visualization of the subject being taught and students' spatial thinking. The computer-aided design systems such as KOMPAS-3D and SolidWorks were used to develop three-dimensional models. A student survey showed that the knowledge and skills used in prototyping sessions are necessary for the successful mastery of the disciplines "Descriptive Geometry" and "Engineering Graphics".**

Keywords: additive technologies, 3D printing, FDM technology, descriptive geometry, engineering graphics, mechanical engineering, architectural and civil engineering training programs.

I. Introduction

Widespread use of information and communication technologies in all areas of modern life requires the corresponding changes in the training of future technical specialists. Technological and scientific innovations emerge constantly and must be timely introduced into the learning process to study new design techniques and develop students' innovative thinking. The development of professional thinking in the engineering domain is facilitated by computer modeling and visualization systems based on computer-aided design (CAD). A relevant trend in design and visualization of material objects is the application of additive technologies. Table 1 shows multiple definitions of the term "additive technologies". Thus, the term "additive technologies" consists of the following units of meaning: manufacturing, class of processes, building an object from a model's data, interindustry techniques, adding layers of material upon one another, process of combining the material, adding the material, digital model, building objects from a 3D model's data, CAD model, modifying the data, transmitted from a CAD system.

TABLE I.
DEFINITIONS OF THE TERM "ADDITIVE TECHNOLOGIES"

№	Definition	Author(s)
1	Additive technologies imply the design of a physical object or a part by adding layers of material upon one another, compared to the conventional subtraction of the material from the solid raw part	M.A. Zlenko, M.V. Nagaytsev, V.M. Dovbysh [5]
2	Additive technologies is a class of processes which automatically construct three-dimensional physical objects without their instrumental manufacturing by modifying the data transmitted from a CAD system	V.A. Valetov [2]
3	Additive technologies is a general name for the techniques of manufacturing based on the data from a digital model (or a CAD model) by adding layers of material upon one another	M.A. Zlenko, A.A. Popovich, I.N. Mutylina [6]
4	Additive technologies is a process of combining the material aimed at building an object from the data of a model, typically layer by layer, unlike subtractive manufacturing techniques	ASTM F2792-12a (American Society for Testing and Materials) 2012 [1]

5	Additive technologies are interindustry techniques of building three-dimensional material objects from a digital model by adding the material layer by layer	V.A. Dresvyannikov, E.P. Strakhov [3]
6	Additive technologies mean the combination of materials to build objects from the data of a 3D model layer by layer. This is how they differ from the conventional subtractive manufacturing techniques which imply a mechanical processing, the subtraction of the material from a raw part	A.V. Ulanov, I.I. Yurov [11]

Layer-by-layer manufacturing techniques based on 3D modeling were introduced in the mid-1980s. These techniques are completely different from a traditional manufacturing approach based on the subtraction of layers of material by mechanical processing. Most of these technologies (stereolithography, solid ground curing, selective laser sintering, laminated object manufacturing, direct shell production casting and multi-jet modeling [2,3]) require the application of expensive equipment and are used only for industrial purposes. The raw materials for manufacturing, in this case, can be plastics, paper, ceramic and metal powders and their combinations (with thermal, diffusion, or glue processing).

Only relatively recently additive technologies have been available to the general public due to the widespread use of fused deposition modeling (FDM) technologies – a layer-by-layer printing with a molten polymer filament which can be used to produce one-off parts similar to standardized ones in their functional capabilities. The cost of FDM printing devices, commonly known today as 3D printers, has dropped to the level suitable for widespread use in educational institutions and at home. A rather high level of quality and performance can be found in the devices at a cost of 15,000 rubles or more (215 Euro). As the cost increases, functional capabilities and performance may be improved (e.g., the use of two or more materials). Expendable materials for this technology (such plastics as ABS, PLA, PETG, TPU, PC, Nylon and others) vary in their functionality and guarantee the required performance characteristics. Their costs are within an affordable range and are about 1-2 thousand rubles (14-28 Euro) per kilogram.

As the availability of the described technology grows, the question of its applicability for educational purposes becomes more relevant [4, 6, 7, 8] for the organization of educational activities of teachers and students using various teaching, teaching and assessment methods aimed at achieving results and forming on their basis competences.

Let us review the key opportunities that additive technologies provide when used in the mechanical engineering architectural and civil engineering training programs for the disciplines "Descriptive Geometry" and "Engineering Graphics" in Kalashnikov Izhevsk State Technical University.

II. The Application of the Additive Technologies for Teaching Graphic Disciplines

One of the main goals of the "Descriptive Geometry" course is to develop students' creative and spatial thinking. The ability to think spatially that emerged as a need for navigation through the objects of the material world is a way to understand various objects and phenomena as well as an important precondition for creative development. Well-formed spatial thinking lays a foundation for the development of technical skills and is a prerequisite for the successful scientific and technological activities in general and professional thinking in engineering and architectural practices in particular.

What tasks does the use of this form of training solve? Carries out more free, psychologically liberated control over knowledge. The painful reaction of students to unsuccessful answers disappears. The approach to students in education is becoming more delicate and differentiated.

For the majority of today's students, the development of spatial thinking is accompanied by a set of psychological and pedagogical challenges related to the development of imaginative intelligence. The most efficient way to overcome these challenges is to increase the visualization of learning content. An important step towards higher visualization is the use of computer visualization equipment in educational activities which is capable to demonstrate the procedure of drawing geometrical constructions and its result at a high quality.

This learning technology allows you to "revive" and visualize objects, learn to recognize, compare, characterize, disclose concepts, justify, apply theoretical knowledge.

As a result of the application of teaching methods with elements of additive technologies, the following goals are achieved:

– cognitive activity is stimulated;

– mental activity intensifies;

– increases the visibility of the representation of three-dimensional models;

– information is spontaneously remembered;

– associative memorization is formed;

– motivation to study the subject increases.

However, for some students, this approach to delivering the information is not exhaustive. In order to perceive an object in space, it is not enough for these students to look at a projection drawing of the object. They need to see its material representation, evaluate its form and geometrical characteristics before they start making their own geometrical constructions.

Some students need to observe a tangible embodiment of abstract geometrical objects used in their assignments, study their shape and geometrical features before performing actual geometrical constructions. For these students, to improve the visualization of such objects, three-dimensional models based on the initial conditions of the problems that students solve in the classroom and the application of additive technologies are used. The set of these models makes up a model achieve for a given discipline. To develop a three-dimensional model, CAD systems such as KOMPAS 3D and SolidWorks are used.

It takes little time and effort to equip a classroom with all the necessary physical models and samples produced by FDM printing.

The range of topics for the "Descriptive Geometry" course where the samples produced by 3D printing can be efficiently used is rather wide:

– projection of a point, line, plane;

– projection of a surface;

– finding the projections of points and lines onto planes and surfaces;

– positional problems:

- drawing the projections of figures with cuts;
- the intersection of a line with a surface;
- the intersection of surfaces of revolution.

Unfortunately, there are the course topics which, due to the complexity of the constructions performed, cannot be implemented via modeling at a given development stage of the technology used.

The models of spatial bodies in most cases are printed as solid ones, without any support structures. When building the models which are related to the projection of points, lines and planes and used to demonstrate the methods of problem solving, for the assembled models it is reasonable to use glue or pins in order to connect its components.

"Engineering Graphics and Advertising Technology" department of Kalashnikov Izhevsk State Technical University has generally formed its model archive mentioned above. The standard size of the models that include projection planes is 100 mm, the standard size of the models of spatial bodies is 70-80 mm. If necessary, when the model is prepared to be printed, its size can be easily modified in any slicer software (Cura and Repetier-Host have been used). Figures 1 and 2 show the samples from the model archive for the discipline "Descriptive Geometry" built as solid and assembled models.

Figure 1. Samples for the discipline "Descriptive Geometry"

Figure 2. Samples of assembled models for the discipline "Descriptive Geometry"

The approach based on the use of samples from the department's model archive which were built by 3D printing is also applicable at the beginning stage of "Engineering Graphics" course. The use of solid and split models of parts and assembly units improves the comprehension of the following topics:

– making drawings: views, sections, cuts;

– types of connections;

– component drawing;

– assembly drawing;

– structural building components:

- stairs;
- trusses;
- windows, etc.

Figures 3 and 4 show the model samples for the discipline "Engineering Graphics".

At present, the process of the development of students' professional competencies often stops after the learners finish studying a theoretical course and solving basic design problems, without an actual application of the knowledge they obtained. When studying engineering graphics, computer graphics is increasingly involved allowing students to automate and increase the quality of their drawings as well as develop a three-dimensional model of a design object. Most universities use Russian and foreign software products such as KOMPAS 3D, Auto CAD, ArchiCAD, SolidWorks and others which are focused on solving these tasks. A 3D model obtained as a result of an exercise significantly increases the visualization of a final design but does not guarantee high accuracy and quality of the design. When building a three-dimensional model in a CAD system on a computer, it is easy to overlook the mistakes, while a ready-made sample can reveal the obvious weaknesses of a construction.

Building a prototype of a design object for most students is an impossible task. The use of 3D printing based on FDM technology makes it possible in many ways to solve this problem. Unfortunately, so far, relatively low printing speed and popularity of this technique along with certain technical limitations prevent us from using prototyping techniques in an educational process during the first years of training to the extent where every student could develop one's design project and produce its physical model.

Figure 3. Model sample of a part with complex offset section

Figure 4. Models for the topic "Types of connections"

The possibility of making a model of a real object is important primarily in students' course projects when they need to use their creativity, from the concept to its solution and manufacturing of a ready-made product. In this case, the classrooms must be equipped with additive technologies. When there is a 3D printer for at least every second student, individual assignments can be completed on a full scale, including:

– making 3D models of parts and objects;
– prepress procedures and 3D printer setting;
– generating G-code (slicing);
– providing the adhesion of a model to a work desk;
– launching and managing the printing process;
– separating the ready-made part and post-processing (removing the support structures, remedial work with surfaces and structural components).

If classrooms are poorly equipped, it is possible to use group learning with separate responsibilities, such as:

– manager or coordinator of the project;
– 3D model developers;
– manager of prepress and printing;
– manager of post-processing and assembling.

In this case, one student may combine different roles if so agreed within the group. The model built as a result of design procedures and with the use of additive technologies can further be used in an educational process for a chosen engineering program as a sample project (see Figures 5 and 6).

Figure 5. Model of an assembly unit "Gear pump"

At the current stage of technological capabilities, a more rational approach would be as follows. To encourage students, the first few of them who complete the given task are granted an opportunity to play the role of a project manager and manufacture their projects with FDM printing. The rest of the students could participate in these projects by building models and manufacturing certain components of construction. The resulting model can further be used in an educational process as an example project (see Figure 6, 7and 8).

In accordance with the aforementioned, the need arose for finding out what impact 3D modeling has on the level of bachelor students' graphics training. At the beginning of the experimental work, a student survey has been conducted to identify their skills and knowledge of additive technologies. In total, 83 students have participated in this survey. The results analyzed led to the following conclusions: 85% of the students know that there are additive technologies and 3D printing, 45% of the students know the names of 3D printer models, but do not have the skills to work with them, 15% of the students worked with a 3D printer in a children's technopark "Quantorium", computer camps, and summer schools at Kalashnikov Izhevsk State University during the summer school holidays.

Figure 6. Students' project: a detail model of a building

Figure 7. Students' project: a complex cut-away model of a building

At the end of the courses "Descriptive geometry" and "Engineering graphics" within architectural and civil engineering training programs in which 3D prototyping techniques were used a student survey has been conducted to understand how effective the use of 3D printing in an educational process was. The survey results showed that 95% of the students believe that the knowledge and skills of how to use prototyping techniques in practice are necessary for the successful mastery of the disciplines "Descriptive geometry" and "Engineering graphics"; 90% of the students think that 3D printing made their learning experience more diverse; 95% of the students said that they had acquired hands-on experience of automated design engineering.

Figure 8. Compound model of a building with a cut

III. TEACHING IN A TECHNOLOGICAL WORKPLACE

At the STU Faculty of Materials Science and Technology in Trnava we also deal with similar issues. Figure 7 shows the virtual concept of a technological workplace. It allows designing the technology in real as well as it permits the definition of the basic principles of the technological process control system. There are three acceptable aspects (3E) of sustainable development:

At present the optimization is used and applied in different information systems oriented on conventional technologies where the possibilities of virtual technologies are neglected. The necessity of a computer-aided tool that will take these aspects into account is vital in national as well as in European research.

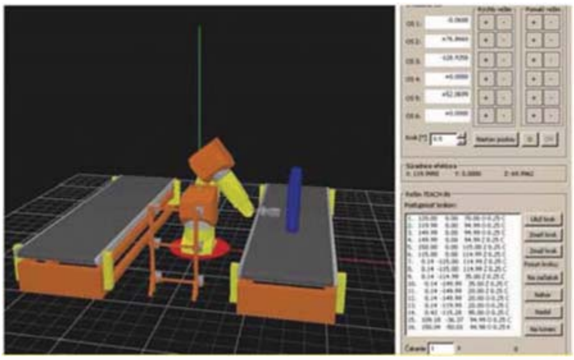

Figure 9. Proposed laboratory computer workplace with an installed virtual robotic workplace with the control training program

IV. BOUNDARY APPLICATIONS

It is essential to define the boundary between the application itself and the application user. The ergonomics of the boundary application is an important point, i.e. the simpler the control the better. Another important condition of an application control overview is represented by the smallest possible number of control units for the user. The control units in the simulation application of the virtual robotic workplace are arranged and implemented in such user friendly.

At present the Institute laboratories of STU MTF in Trnava possess only a small manually controlled study robot which is able to work in an automated regime after the program runs with no simulation and in this case.

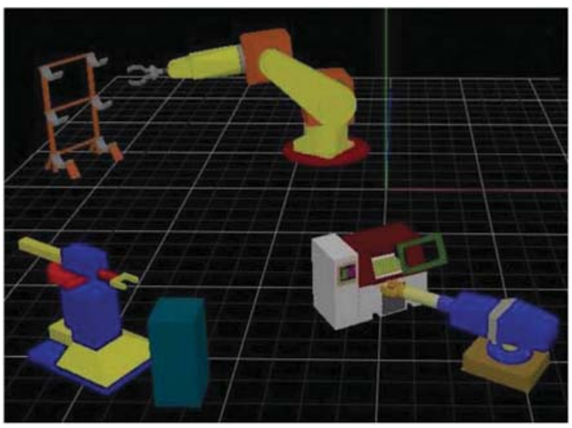

Figure 10. An example of a virtual scene

The robot provides the following standard work regimes:

1 Change of constants, 2 Automated run,

3 Individual blocks, 4 Start, 5 Learning ,

6 Run, 7 Input, 8 Editing, 9 Automated regime run of the user program.

Figure 8 and figure 9 illustrates the virtual scene of a technological workplace with the possibility to generate the user program.

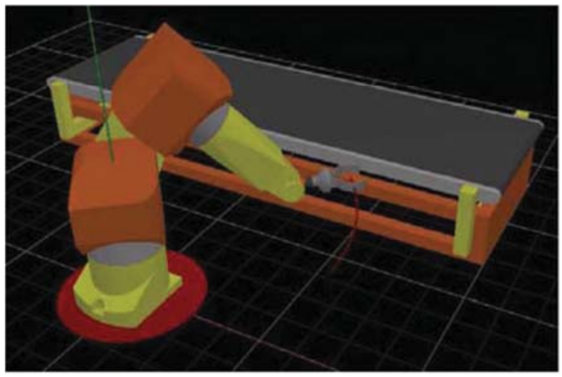

Figure 11. An example of building the virtual scene

following: a general model of robotic workplace, method to investigate the control system of a laboratory robot, method of the effectiveness evaluation of the environment-friendly oriented workplace at universities and companies, possibilities of using the exact methods for teaching at universities, and interface for the user program transfer and control.

The programming itself was carried out with the programming of all the needed functions so that there was no duplication and the application was capable to simulate the industrial robot as well as the entire robotic workplace. After testing the application the virtual application The project "The creation of virtual robotic laboratory for supporting the teaching the subject Robots and manipulators in a newly accredited study program" was aimed at proposing the were transformed into the real robotic workplace.

V. ANIMATION APPLICATIONS AND INTERFACE

Animation illustrates the current state of all units and parts of the robotic workplace. It is impressive not only by the manual control but also by the data processing. The animation is carried out by means of object oriented Microsoft visual C+ with the use of graphic library OpenGL, both providing wide possibilities of the use of a large number of orders and functions .

Related VRML language is the most suitable for the animation of the application. It allows to define all attributes necessary for a realistic display of bodies VRML language allows the description of all bodies (including primitive), and provides reading the data on the vertex positions and count algorithms of their affiliations to object sides. This means that the algorithm of the file data reading can work only with the objects described by their form and not via primitive.

The virtual scene is represented by the data tree, where the scene itself is the tree top located in the uppermost point of the hierarchy. Since there only one scene, it is not represented by any data structure. The scene set up is determined by OpenGL variables, e.g. scene turn, background colour and motion, grid dimensions, light parameters, etc.

The data structures have to include also information on the machine kinematics. By the number and position analysis of these issues we can tell, that the number of characteristic points of an angular robot is identical with the number of axes, in which it carries out rotation motions. This fact is possible to generalise also for mechanism types.

VI. Conclusion

Currently, there is a fairly large number of pedagogical teaching methods, both traditional and innovative. It cannot be said that one of them is better, and the other one worse, or to achieve positive results, only this one and no more methods should be used. According to Chmelíková [18, 21], the development of various skills, which can be provided by various methods, is important for the undergraduates and postgraduates as well.

In our collegial opinion, the choice of a particular method depends on many factors: the contingent of students, their age, level of preparedness, topic of the lesson, etc.

And the best option is to use a mixture of these approaches. So the educational process is mostly represented by the classroom lecture-practical system. This allows you to work according to the schedule with specific audience, or a specific permanent group of students [16, 17, 19, 20, 22].

Based on the foregoing, we want to summarize that traditional and innovative teaching methods should be constantly connected and should complement each other.

Do not abandon the old and not completely switch to the new. We must keep up to date, boldly apply and combine classical, time-tested pedagogical approaches and innovative technologies to achieve high results in education and training of the modern generation of qualified specialists.

Additive technologies represented by FDM printing can be easily adopted by students who have skills of 3D modeling in CAD systems. They do not require any additional training and are rather safe to use.

There is a wide range of suitable software most of which is free and easy to learn. As a result, the university which adopts these technologies can train specialists who are able to solve real-world problems and, thus, enhance its prestige. Also, this may develop students' creative skills and teach them how to implement their projects in real life.

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