The 3D Printer Farm – function and technology requirements and didactic use

Farma drukarek 3D – założenia funkcjonalne i techniczne oraz wykorzystanie w dydaktyce

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Described in the article is a 3D print lab, as launched at the Warsaw University of Technology, at the Faculty of Automotive and Machinery Engineering. Presented are its functional and technical requirements and the current and future use for students' education. Also, several similar arrangements of the worldwide installed and tested 3D printers are described.
KEYWORDS: 3D print lab, FDM, FFF, additive manufacturing, integration

On May 12, 2017, at the Department of Automotive and Machine Tools of the Warsaw University of Technology (hereinafter referred to as SiMR PW), an extensively developed 3D laboratory, commonly called a 3D printer farm, was opened. This name means to bring together and integrate with each other using a large number of machines incremental technology.

The idea for farm 3D printers were taken from the Silesian University of Technology, which last year opened a laboratory in a historic building, which housed the laboratory Machining [1]. Then the prototyping machines in technology FFF [2] were supplied by 3DGence [1].

History of 3D printing at the Department of SiMR PW

The newly opened 3D printer farm has been designed as an extension of the 3D Lab, which has been in operation since around 2008. At that time, a 3D professional printer from Stratasys – the Dimension 1200BST (using the FDM method [2]) and the 3D scanner Smarttech, ScanBright model with software. The 3D laboratory was and is used in the education of students, especially in the field of „Computer Engineering Support" in the field of „Mechanics and Machine Building". Each student in this field (subject to „Computer-aided Design and Manufacturing Integration") had to perform a part or mechanism design that was then produced using FDM 3D printing. The limitation was to use up to a dozen or so cm3 of model and support material as the students tested in 3D CAM software. In such a way, a number of interesting objects were created.

The mentioned prototype machine was used for many theses, and some of the results described in this work have been published in scientific articles, among others, in [3-5].

Easily available publications in Poland have become an impulse to start a wider cooperation with several doctors from Warsaw Medical University. As a result, in 2014 the 3D lab was equipped with two 3D printers: Prime 3D from Monkeyfab and Builder Dual Feed. Both machines have open control and use of 3D CAM software, which has non-commercial versions. This allowed us to increase the number of student workloads and research workloads, and to reduce material costs and to start testing the modified control code and new model materials, such as PCL polymer. At that time, a dozen or so physical bone models were created for two hospitals. The models were made for specific surgical operations and served to physicians for preoperative planning. Some of these works have been described in scientific publications. In [6, 7].

In the middle of 2016, Prof. Stanisław Radkowski, Dean of the Faculty SiMR PW, decided to expand the lab to form a 3D farm 3D printers, and its inclusion in the education process of students in all fields of the Faculty SIMR PW.

Functional assumptions of a 3D printer farm

It has been decided that students will be able to work on the prototype machines, after appropriate training, students who, within the selected design objects and the semester and transcript work, will be able to produce prints. For safety reasons, FDM/FFF technology has been decided because it is not dangerous for operators of lasers, UV lamps or toxic gases. Organizational issues were also important – the FDM/FFF method does not require such care as other incremental technologies using SLA (PJM) or powders (CJP, SLS) [2], and does not need costly additional equipment, pressure washers, dustproof chambers, lifts or vacuum cleaners. For students who are already familiar with 3D printing technology, step-by-step visual effects and lower print accuracy are not critical, so FDM/FFF technology is sufficient.

At the Faculty of SiMR PW is studying more than 1000 students, so it was important that the emerging 3D printer farm offered high performance. So it was decided to buy several smaller prototype machines instead of several large work spaces. Such solutions are already tested (and even sold) by several companies [8-11]. Typically, these are integrated installations of separate, small printers, such as the Ultimaker Print Management System [8] (fig. 1) or the Chinese Vertical 9 units 3D Printer [9]

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Fig. 1. Ultimaker Print Management System [8]

Fig. 2. Vertical 9 units 3D Printer [9]

Fig. 3. Voodoo Manufacturing [12]

Fig. 4. Continuous Build 3D Demonstrator from Stratasys [13]

(fig. 2). Processes are also used to automate the process, e.g. using a robot (as in Voo-doo Manufacturing [10] – fig. 3). Another noteworthy solution is the use of post-modular foil sheets that are then retracted and cut off – Stratasys ContinuousBuild 3D Demonstrator [11] (fig. 4). Such a continuous manufacturing system is fully scalable. One of the installations is being tested at the Savannah School of Art and Design in the USA. It seems that compared to other technologies FDM method is better suited for integration and automation of 3D printing. These 3D printers allow you to produce hundreds or thousands of pieces (in series) or individual designs and can be one of the ways to develop 3D printing.

Use of 3D printing in didactics

To determine the technical requirements to be fulfilled by the farm 3D printers, analyzed the current use of the prototyping machines in the process of educating students at the Faculty of SiMR PW.

For several years, 3D printing has been taught in the course of Advanced Geometric Modeling (hereinafter referred to as ZMG), which is conducted in the form of a computer lab in the third semester of engineering studies [14], in all fields of study. Normally, the student groups are about 25-30 people, so the computer classes are run by two academic teachers. In full-time studies, they last three hours per week and consist of two practical parts: the first takes place in a computer room and the other is in a 3D printer farm. For several 3D CAD models, students generate STL files and learn 3D printing programming in a 3D CAM environment – they learn the influence of STL orientation on the fiber layering and surface quality (so-called step effect) and the placement of support structures, print and consumption model and supporting material. Lecturer together with students perform two printing facilities. The first object is a small, L-shaped column, printed in three basic orientations with respect to the machine table. Each student gets a hand to three such prints and trying to break them. Another object is a thin-walled packaging container (as described in Section 8.1. In [2]) in two versions: with splines unsupported (practically difficult to remove support structure with the interior of the object) and a phase of 45° (no need to use supports). Its shape students alone model in a 3D CAD system. In the context of the show several objects are printed in two versions. Ultimately, the projects are to be printed (and forwarded to the authors) at least five students who do the task quickly. It is estimated that, for the four classes are required for the machine working space approximately 200×200×150 mm. Due to the fact that the various groups exercise dean of 3D printing in the classes of ZMG held for 10 weeks, five machines in the winter semester must be reserved for this purpose (see Table).

For about five years, classes entitled „Computer-aided Design and Development", conducted for the 3rd-year students within the scope of the „Computer Engineering Support" specialization, includes student projects. In the summer semester this course usually go two or three groups dean population of approximately 25 students, and in the winter semester – one group. Modeled in 3D CAD and printed designs are mostly simple mechanisms or individual components with more complex shapes. All are subject to the following restrictions: maximum volume of used materials – 25 cm^3, maximum diagonal of one print – 150 mm, maximum printing time – 2 h. Two machines with working space of approximately 200×200×150 mm were used. Models usually printed with the PLA polymer in the last month of the semester, so at that time followed the accumulation of work.

In the coming years, the Department of SiMR PW plans to use 3D printing also in other project activities. In addition, a dozen or more diploma theses will be held in a 3D printing farm every semester. It is estimated that the average total volume of items will be 1 dm^3, which gives 15 kg of PLA material, and in total with test prints and errors – 40 kg. The estimated time of printing (including machine operation) of one project is 40 hours, so the time of machine loading in the semester is estimated at approximately 600 hours. Because most of the projects in the semester will be done in the last five weeks and the weekly working time is Approximately 30 hours, a minimum of four machines will be required for the diploma thesis. At present, ZMG classes take place in the first half of the semester, so graduation facilities can be produced on the same machines in the second half of the semester (see Table).

TABLE. Estimated minimum number of 3D printers with a working space of 200×200×150 mm needed to complete the didactic process in the semester (15 weeks of classes) and predicted consumption of model material

Subject	Minimum number of 3D printers per week			Consumption of filament, kg
	1.–5. Week	6.–10. Week	11.–15. Week	
ZMG Laboratory	5	3	0	2
Classes “Computer-aided Design and Manufacturing Integration”	0	0	3	3
Other classes	0	0	3	3
Diploma thesis	1	3	4	20
Reserve	1	1	1	2
Total	7	7	11	30

According to the table, the consumption of model material in the semester can be up to 30 kg, which means expenditure of several thousand zlotys. In case of using Dimension 1200 BST – over PLZ 20 000. However, cheaper models can be used in the education of students, preferably in a few basic colors (white – due to the ease of measurement with an optical 3D scanner – as well as gray and black, as there are no dirty marks in the machining and assembly of the prototype machines). 3D printers farm should therefore be equipped with machines that do not require the use of specially designed, secure electronic model materials.

Wider use of 3D printers farms in the process of educating students requires changes in curricula. Ideally, the farm should be used for design activities, because then it is possible to book a time for consultations on 3D CAD/CAM systems and incremental technologies.

In the next few years, the 3D printer farm will be used more intensively for research and production of parts needed in other teaching or research facilities built at the Faculty of SiMR PW. In the case of PCL polymer research for Warsaw Medical University, in addition to special, efficient cooling is necessary lower than the standard print temperature. Performance of such a process is very low, so for this purpose would be to allocate several separate machines that could not be used for printing of other materials.

3D printers with one extruder are usually required for these tasks, but two-extruder machines are required for specific projects, so that a single print can be made from two materials – model and support – or one material in two colors.

When planning a farm equipment 3D printers, it was decided to open prototyping machine control, to allow manual control code modification process of 3D printing and to change the factory settings and thereby conducting a broader study of the various materials and the impact of technological parameters on the mechanical strength and precision metrological prints. Open systems tend to have a 3D printer with numerical control derived from the RepRap project. Machines of this type can be programmed using many different programs 3D CAM (such as Slic3r, CURA, KISSlicer) allowing for modification of a much larger number of technological parameters than in the case of proprietary software, and in addition are relatively cheap in repair and modernization.

It was decided that the machines should be free of cushioning (which would be limited in the case of printing with polymers with higher shrinkage, e.g. ABS) or with transparent guards that illustrate machine design to facilitate the training process.

Functional and technical guidelines for machines

Taking into consideration the needs of the SiMR Dept. of PW and the funds held, a tender for 15 FDM/FFF 3D printers was opened in 2016 with open and non-protected filament storage. It was determined that each machine should be able to print from a variety of model materials (such as PLA, ABS, TPE, PET and HIPS), so the temperature of the nozzle must be 260 °C and the filament should not be fed through the Bowden tube due to the possible use of TPE). Several machines must be capable of printing with PCL having two heads arranged to filament having a diameter of ⌀1,75 mm (with the option of adapting to ⌀3 mm) used in the other machines and allow to change the nozzle diameter in the range 0.1÷1 2 mm. The minimum working space of the machine is 200×200×150 mm. It is recommended that the machines be integrated and can be controlled from one computer (without the use of a memory card or a USB cable). Two companies came to the tender. You have chosen an offer on a 3D printer – Prime 3D model – the company Monkeyfab [15, 16] (fig. 5).

Purchased machines operate in a separate, secure computer network – configured so that out-of-network SiMR PW can monitor the progress of the print or stop

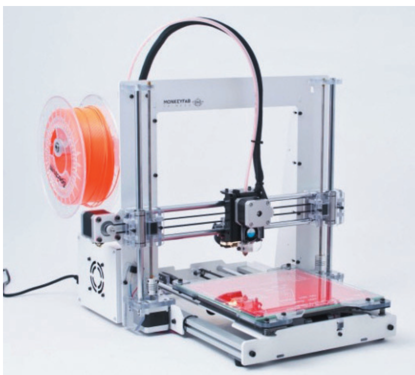

Fig. 5. 3D Printer – Monkeyfab's Prime 3D model [15]

the machine. The printers were placed on two steel shelves (Fig. 6), which provided free access. At present, there are two 3D scanners in addition to 20 prototype machines (including a professional printer and two student-built components). The 3D lab has a permanent technical maintainer. A powerful air conditioning system is installed in the room, effectively draining the heat generated by 3D printers. Two workshop stations were also prepared for cleaning prints from support structures.

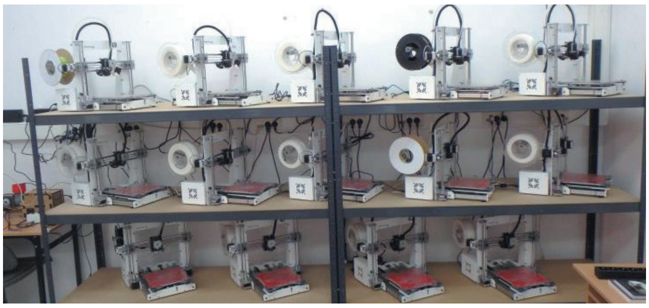

Fig. 6. 3D printer farm at the SiMR PW Department

Machines are controlled by HTTP, i.e. through a web browser from any computer in the local LAN (where the printers are connected). The network is powered on by a Wi-Fi router that allows you to control your printers through smartphones connected to your wireless network. To log into a machine, enter your IP address in your web browser. Then you can control the machine parameters (e.g. set axis alignment or preheat the nozzle and table) and upload NC programs (G codes).

In the faculty labs, for preparing 3D printer control programs, KISSlicer is most commonly used, and for SolidWorks 3D CAD modeling (less commonly CATIA V5 or Siemens NX). Filastruder extruders are used for the preparation of filaments and the printed structures are tested on a strength machine with a measuring range of 1 N to 1 kN (fig. 7), designed and manufactured by MSc. P. Mężydło within the master thesis [17].

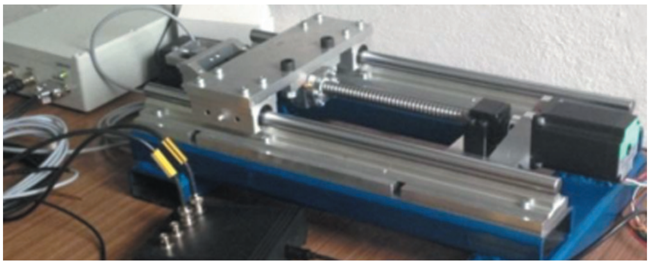

Fig. 7. Strength machine with a force range from 1 N to 1 kN, used for testing 3D-produced samples [17]

Conclusions

In the near future, several machines from the 3D printer farm will be equipped with transparent poly-acryl shielding to produce ABS. In addition, it is planned to mount an IP camera (permanently connected to a computer network) monitoring the machine working space so that, in case of printing problems, the machine can be stopped.

The challenge seems to be the organization of the 3D printing farm business including: acceptance, registration and acceptance of projects to be produced; selection of model material; validation of STL files; orientation of printed model and technological parameters; launching and supervising the printing process; Removing an object from the work table and possibly cleaning it from the support structures after the process. To this end, it is planned to start a semester (transient) or diploma work, which will build a database system that takes into account all these activities. The system would allow you to generate reports on each machine separately – time spent working, consumption of model materials, applied print parameters, names and authors of printed objects. The system would check if the filament was loaded, suggesting a test print to verify the machine's calibration repetition, and would remind you of the timing of the service. Ultimately, the system could report the total usage of the 3D printer farm during the semester to facilitate: modifying the organization of the course, planning the supply of model materials, and even requesting a possible expansion of the farm with additional machines.

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