TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue Special IV, December, 2021

A NEW APPROACH FOR TRAINING 3D PRINTING IN THE UNIVERSITY

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Abstract: *3D printing technology has proven to be an emerging one of real utility, supporting the realization of manufacturing processes in different industries. Including the field of engineering education, it has enjoyed investments and the development of laboratories, Makerspaces, or FabLabs that are equipped with 3D printing printers. The way they work, their exploitation has created an interesting and very attractive world for the training of engineers who have been challenged not only to imagine but also to create artifacts. This approach is successfully implemented in most technical, polytechnic universities because the learning experience created is particularly efficient and effective (develops imagination and creativity through 3D CAD drawings and artifacts). This research analyses the situation of learning, education in the field of 3D printing in universities and beyond (other training providers). Finally, the case of implementation of the INNO3D project (2019-1-IE203-000693INNO3D) at the Politehnica University of Timisoara, Romania, is presented, which led to the diversification of the services offered to users of the Central University Library. The final conclusions focus on the main advantages of the 3D printing education for engineers and brief presentation of the Timisoara new Makerspace at the Central Library Politehnica University of Timisoara (Romania) that has been co-financed by the "3D Printing Support Service for Innovative Citizens"- INNO3D project.*

Key words: *Engineering education; 3D printing; training, new library service, makerspace, INNO3D project*

1. INTRODUCTION

Recently (despite the pandemic restrictions in the universities) the positive trend and attractiveness of engineering education for additive manufacturing and 3D printing technologies have been recognized. These offer educators a quick demonstration of engineering activities from ideas (good and bad, innovative) to artefacts (real models of products) by offering new and challenging opportunities for new teaching – learning – assessment approaches that could be adopted and adapt to a wide variety of subjects [1]. Thus, the new required engineering knowledge and skills are quickly achieved by students. Furthermore, studies presented in the literature or company reports related to these educational practices are also emerging.

The engineering practices of today required new interdisciplinary skills and competencies (transversal, trans-sectoral), which require the ability of a person to connect and integrate knowledge from different fields and couple them to a specific context; this approach involved a lot of creativity, agility, and innovation. This is the actual ways of acting in design, manufacturing, logistics, data analysis, etc. The question that arises is: How to educate such specialists quickly and efficiently? How can engineers demonstrate that they hold both specialist-discipline knowledge, abilities to solve practical problems, competences on using mathematical, scientific, and technological tools, and the mindset for undertaking lifelong learning? "All these competences can be developed through effective physics instruction, which would guide the students towards a deeper understanding of the fundamental concepts of the discipline and, at the same time, would strengthen their reasoning abilities and transversal skills" [2]. Furthermore, recent updates of pedagogy procedures, standards of science education strongly encourage the design and use of instructional environments focused on participation in the engineering practices, as a more efficient and effective way of teaching and learning students enrolled in engineering programs [2]. In this regard, the use of 3D printing technology placed in a problem/project-based learning approach, to foster engineering education has been shown to be a feasible solution.

In this context, the present article synthesizes the dispersed studies to provide a brief state-of-the-art literature review (based on publications available in the last ten years) of where and how 3D printing is being used in engineering education in universities. It has been recognized that 3D printers are a fascinating tool for engineering teaching and education (that could be applied in a large variety of teaching subjects and engineering fields). More and more universities are integrating not just the topic of additive manufacturing but 3D printers to create great learning experiences and thus increasing pertinency and effectiveness of their bachelor and master programs.

Thus, the paper, first, presents different studies in the literature referring to teaching and learning 3D printing in European universities, focusing on the advantages, particularities, and the involved actors. The ideas that through 3D printing, students can translate their ideas directly into reality, and spatial imagination will be supported. Second, the case of teaching and learning 3D printing at the Politehnica University of Timisoara (Romania) will be discussed with the support offer from the “3D Printing Support Service for Innovative Citizens” (2019-1-IE203-000693INNO3D).

2. UNIVERSITIES AND THE 3D PRINTING

In 2014, 3D printing has been reported to directly support the teaching process [3]. From the idea to the printed part: Keeping the previously virtually created file printed in your hand motivates students and promotes understanding of the creation process and enhances students” participation in class. Furthermore, through 3D printing, students can translate their ideas directly into reality and spatial imagination is promoted [3]. Usually, in the early years, teaching begins with physical objects and later deals with abstract, virtual 3D models. 3D printing allows a reversal: From drawing (3D CAD) to the physical object. It is now possible to directly link the two processes during the learning phase, stimulating creativity and improving imagination [4].

The involvement of 3D printing in education and training is growing rapidly. In all over the world, higher education institutions are developing new curricula and purchasing equipment, software, and materials to support research and instruction. In response to the growing opportunities in the additive manufacturing job market, interest among students in AM-related manufacturing and design courses has increased dramatically [5].

Education and instruction can be benefited through additive manufacturing by creating excitement in learning and educational practices, supporting and complimenting STEM (Science, Technology, Engineering and Mathematics) curriculum, opening new possibilities for learning, critical and analytical thinking, innovation, and entrepreneurship, giving access to new materials and applications not available before, and promoting problem-solved skills and methodologies. One great feature is that additive manufacturing supports students in taking their design to the next level by allowing them to participate in the fabrication stage [5].

In many universities and higher education institutions, additive manufacturing has been integrated into conventional undergraduate and graduate programs, offering advanced additive manufacturing courses and additive manufacturing areas of concentration as part of their engineering, technology, and design curricula [5; 6]. AM is currently being integrated into higher education teaching in very different ways and to different degrees. In universities, an important use is to integrate additive manufacturing into sciences. Models are fabricated to support student learning in the classroom or lab [7; 8; 9], and, for example test models can be used for experiments and test specimens for learning about the mechanical properties of materials [1; 10].

Furthermore, the infrastructure created using FabLabs or MakerSpaces is based on
techno-creative activities and spaces of universities [11], where students could develop

their technical skills and competences by practical exploration of the 3D printing technologies and thus better connect theoretical knowledge with applications. Furthermore, in a recent published study [11], it has been recognized that FabLabs and MakerSpaces “spaces go beyond digital 21st century skills as they are mixed digital and physical environments”. The learning solution has expanded internationally, being recognized that FabLabs are those makerspaces that have signed the Fab Charter of the Fab Foundation; actually, there are more than 1,750 active FabLabs centers all over the world (as supported by the Fab Lab Network [12]).

The approaches differ sharply in duration, learning objectives, and competencies that are to be taught. The following list (Figure 1) is intended to provide an overview of different tools, formats, and instruments that universities use today are used at universities to teach additive manufacturing technology.

Fig. 1. The typology of teaching and learning 3D printing in universities.

Recently, [13] have provided a comprehensive overview of “the current state of education and dissemination of educational practices related to the training of young engineers in university on the issues of AM and related to Industry 4.0. The results show that the introduction of AM education represents an important leverage in the preparation of young engineers who benefit from it both in terms of personal preparation and in terms of learning and refining different skills. However, certain aspects, related to the need to have adequate equipment and properly trained teaching staff, should not be overlooked “.

Aside from universities and companies, there are some relevant examples of public libraries offering 3D printing trainings (together with related services). In 2017, the 3D printing media network has recognized that there were more than 800 3D printers in libraries worldwide and public needs and interests for this domain of services are increasing (3D printing Media Network [14]); the dynamics of this field of services is positive, related to 2015 when 250 3D printers have been reported 250 3D printers in libraries in the United States supporting related services to users, according to data published by the American Library Association (ALA). Researchers have found that most printers and services are provided by libraries located in the United States and other English-speaking countries (e.g., United Kingdom, Australia), but

"Chinese libraries alone could have three to five times as many".

Other geographic areas such as South America are also very likely to be offering 3D printing through libraries, and European countries, which only recorded a few dozen in this map, are likely to have several hundred (or even thousands) already. Definitively, the Covid-19 pandemic has positively impacted the use of 3D printing technology due to the increase interest and the huge number of medical shields, 3D respirator, valves, and other devices that hospitals used by hospitals and were donated by public (such as universities) or private providers around the world (as is demonstrated by the implementation of the INNO3D project implementation during the pandemic period, [15]).

3. TEACHING AND LEARNING 3D PRINTING – A PROPOSED APPROACH

3.1 The INNO3D project

The present study has been associated with the implementation of the INNO3D project ("3D Printing Support Service for Innovative Citizens") through the support of a European international consortium of libraries, companies, and universities. The methodology used for the implementation of the project implementation is based on six core activities that will deliver the outcomes of the project, as follows [15]:

1. Project management: this is an ongoing activity throughout the project's life. It ensures smooth implementation and achieves the proposed results.
2. Map 3D printing education in libraries and at the university level.
3. Develop, test, and implement 3D printing training curriculum.
4. Develop 3D printing trainers" toolkit for theoretical program.
5. Validate quality assurance and improvement of the 3D printing curriculum and 3D printing training materials.
6. Transfer of project results and best practices. Institutionalizing 3D printing in libraries of each partner in the project to ensure ongoing training of librarians and library users for future generations.

Running this project within university and public libraries will lead to an increase in the number of library users in these institutions, but also to an increase in the promotion of these innovative technologies among the citizens (library users).

Assimilation of these innovative technologies by librarians will lead to the personal development and lifelong learning of citizens in general and to the diversification of the services offered to users of public and university libraries, increasing their attractiveness to the younger generations for such institutions. By default, this will increase the visibility of these institutions, not only locally, but on the international level.

As can be seen from the previous presentation, this project represents an opportunity not only for technical students, but for anyone who wants to carry out various projects specific to their specialties using 3D printing [15].

3.2 Teaching and learning 3D printing at Politehnica University of Timisoara (Romania).

As a preliminary conclusion from the literature review and the investigations related to companies support for 3D printing training programs dedicated to industry, there have been clarifying the way in which the knowledge acquisition process is developed. In addition, a preliminary analysis of these papers revealed that 3D printing was being adopted by universities, public libraries that were able to create FabLabs or MakerSpaces as innovative and creative education capabilities, supported frequently by companies.

Through a category selection process, in Figure 2 the holistic answer to the research question is given: How is 3D printing used in the university? Further to these, the new international context offered by the INNO3D project has provided the following challenges:

- Innovation transfer related to teaching and learning 3D printing (between the project partners);
- New skills acquisition in the field of 3D Printing (skills on operating with new and emergent technology);
- Skills related to work and interaction in an international project team (multicultural

skills development, awareness of cultural differences and the need for tolerance).

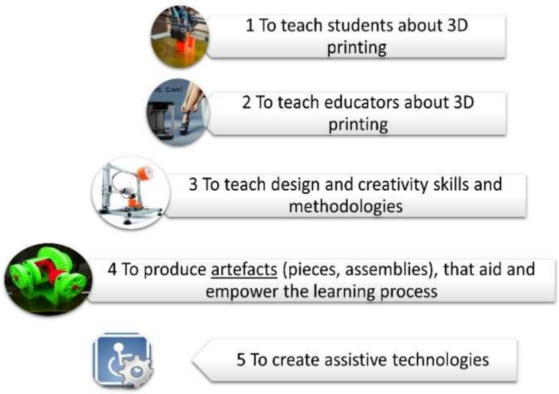

Fig. 2. Categories selected for describing the teaching - learning process of 3D printing in universities

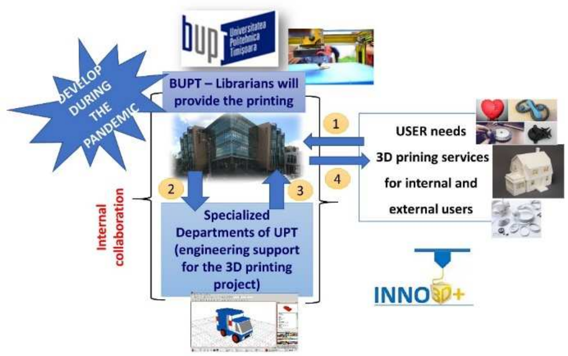

Fig. 3. The proposed "reengineering model" of library services Politehnica University of Timisoara, Romania

Furthermore, a framework on teaching and education 3D printing was created, and each partner institution has benefitted from the inspirational ideas of teaching and learning 3D printing of the others. Most, because the project target group was defined by librarians, the INNO3D project aims to create, through librarians and library partners (from Ireland, Romania, Portugal, Slovakia, and Greece), a critical mass to accelerate the transfer and implementation of 3D printing technologies in engineering education. The proposed model adopted by the Politehnica University of Timisoara, Romania, will be discussed below (Figure 3).

The case study approach is based on the reengineering process which is adequate to a disruptive innovation of the library services [16; 17; 18]. It consists of four phases during which several university entities are involved:

a) User-library process to get and understand the order and need of the user.
b) Library-CAD model designer (from university specialized department) to prepare the STL AMF 3MF file, do the verifications, repair files if needed, action on orientation load and optimization through simulation.
c) CAD model designer-library process to do the 3D printing process in the library INNO3D MakerSpace.
d) Library-user process to deliver the piece and accomplished user need. The "reengineering model" framework of library services is the result of several discussions with related stakeholders on the topic.

The proposed "reengineering model" of the library services Politehnica University of Timisoara, Romania (Figure 3) is based on the inventory created inventory with three approaches identified in the university case on the generation of 3D data and 3D models for teaching and learning 3D printing:

1. Beginners and novice users - Students download existing models/designs from online databases to quickly obtain a printable data set. Therefore, this approach is related to the available technical possibilities that exist in the university (equipment and materials of possible applications). The advantage is that the participants do not have to have any knowledge in the field of modelling and CAD technology, but they can easily adopt the results of 3D printing technologies in their projects.

2. Advance users that have engineering knowledge to design the models in a CAD program – In this case, students or researchers are turned from "passive consumers (database users) into active and creative users grappling with the possibilities and limits of the 3D printing process" [19]. Thus, students and researchers can gain extensive experience in the field of 3D modelling and get to know the limits of 3D printing processes (related to the existing capabilities in the university or that could be used in local companies through collaborations).

3. Advance users that have engineering knowledge to do 3D scanning - In this case, students, or researchers are focus on how the acquired data for the 3D printing process must be prepared in the best possible way.

Even in other studies presented by the literature, these three approaches have been recognized as usual ways to categorize the users of 3D printing technologies, but all should learn what effects technical hardware and software have on component design and properties [18; 19]. Furthermore, the proposed approach to transfer the INNO3D training program was inspired by the previous work of [20; 21].
All existing teaching and learning approaches to 3D printing approaches at Politehnica University of Timisoara, Romania, are focused on the product development process (such as the suggestion of [22]. The approaches of project/problem-oriented teaching - learning approaches are increasingly pursued and implemented, but they will be better supported by the new INNO3D MakerSpace.
Recently (on 22 September 2021, see Figure 4), the Central Library of the Politehnica University of Timisoara (Romania) inaugurated the new makerspace and launched a new service offered to users, 3D printing - confirming once again the status of the most modern university library in Romania.
The new service could be put into operation because of the librarians' involvement in the INNO3D Erasmus+ project. The Library, the Department of Management and the Department of Mechatronics of the Politehnica University of Timisoara are involved in the project.
The new service offered by the Central Library benefits from two PRUSA i3 MK3S 3D printers. The 3D printing services are offered free of charge to students and teaching staff of the university and for a fee to external users, being especially useful for the development of parts, assemblies, models related to various projects, bachelor, master, or doctoral theses.
Users come with the parts, assemblies, and models in *.STL format (Stereolithography), on a memory stick, and the librarian opens each piece in the Prusa Slicer program, checks if the piece is 3D printable, generates the necessary G-code and informs user on runtime. The librarian has no responsibility for the design, but only for the execution of the piece.

Fig. 4. The new Makerspace in the Central Library of the Politehnica University of Timisoara (Romania)

4. CONCLUSIONS AND FINAL REMARKS

The literature review and industrial trends (before and during the pandemic crisis) have recognized the positive impact and attractiveness of exploiting additive manufacturing and 3D printing technologies for engineering education. These offers to teaching staff the opportunity to quick demonstrate engineering design process started from ideas (good and bad, innovative one) to artefacts (real models of products) by offering new and challenge opportunities for new teaching, learning, assessment approaches that could be adopted and adapt to a large variety of teaching subjects or learning contexts: manufacturing, production engineering (innovative manufacturing for product development and Rapid Tooling technologies), engineering and technologies (Concurrent engineering, methodologies and software tools in design for manufacture and assembly); Biomedical engineering, (prototypes, customized implants, new biocompatible materials), architecture, construction engineering etc.
Through the case study discussion (the INNO3D project and its implementation at Politehnica University of Timisoara, Romania), the need for

the university library system in Romania has been underlined to better support the change management strategies of their organization (adopt the paradigm of library process oriented) to lead them to the present and the future of the digital era. Considering the proposed feasible approach of re-engineering in university library and their associated digital services (that should be representative and dominant in present and the nearest future), it is necessary to rethink on this serious issue and how it will be applied for providing better services to fulfil multidimensional needs of the users.

In conclusion, the main contributions are the fulfilment of the knowledge gap identified in the literature related to the teaching and learning of 3D printing in the universities, presenting the advantages, particularities and the involved actors and proposing a feasible framework of providing 3D printing technologies as a library service. Thus, students' projects (mechanical engineering, automotive, logistics, architecture, construction, civil engineering, or even architectural models, etc.) could easy become a reality and teaching staff of the related disciplines could easily access the INNO3D created MakerSpace for demonstrations and practical lessons (e.g., teaching services using INNO3D training program). Also, MakerSpace is open to industrial applications (external services) or other external user needs (different applications of students from other universities in the city of Timisoara).

5. ACKNOWLEDGEMENT

The article is related to research and dissemination activities related to the “3D Printing Support Service for Innovative Citizens” project INNO3D project (2019-1-IE203-000693INNO3D) founded with the support of the European Commission. This paper and the communication reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

6. REFERENCES

1. Ford, S., Minshall, T., Invited review article: Where and how 3D printing is used in teaching and education. Additive Manufacturing, 25, 131-150, (2019).
2. Pizzolato, N., Limongelli, M., Di Francesca, A., Kirkar, M., Koch, V., Gomez, V. G., ... Silva, R. P., The “E3D+ VET” Erasmus+ project: Interdisciplinary teaching and learning in VET centres through 3D printing. In Journal of Physics: Conference Series, 1512(1), p. 012038. IOP Publishing, (2020, April).
3. Szulzyk-Cieplak, J., Duda, A., Sidor, B., 3D printers–new possibilities in education, Advances in Science and Technology Research Journal, 8(24), 96-101, (2014).
4. Huleihil, M., 3D printing technology as innovative tool for math and geometry teaching applications. In IOP Conference Series: Materials Science and Engineering (Vol. 164, No. 1, p. 012023). IOP Publishing, (2017, January).
5. Wohlers, T., Caffrey, T., Campbell, R. I., Diegel, O., Kowen, J., Wohlers Report 2019: 3D Printing and Additive Manufacturing State of the Industry; Annual Worldwide Progress Report. Wohlers Associates, (2018).
6. Marschall, H., Personal für die additive Fertigung. Kompetenzen, Berufe, Ausund Weiterbildung, Sringer Fachmedien Wiesbaden, (2016).
7. Bagley, J. R., Galpin, A. J., Three-dimensional printing of human skeletal muscle cells: An interdisciplinary approach for studying biological systems. Biochemistry and Molecular Biology Education, 43(6), pp. 403-407), (2015).
8. McGahern, P., Bosch, F., Poli, D., Enhancing learning using 3D printing: An alternative to traditional student project methods. The American Biology Teacher, 77(5), 376-377. (2015).
9. Hall, S., Grant, G., Arora, D., Karaksha, A., McFarland, A., Lohning, A., Anoopkumar-Dukie, S., A pilot study assessing the value of 3D printed molecular modelling tools for pharmacy student education. Currents in Pharmacy Teaching and Learning, 9(4), 723-728., (2017).
10. Golub, M., Guo, X., Jung, M., Zhang, J., 3D printed ABS and carbon fiber reinforced polymer specimens for engineering education. In REWAS 2016 (pp. 281-285). Nashvilee, USA: Springer, Cham (2016).
11. Romero, M., Lille, B., Intergenerational techno-creative activities in a library FabLab. International Conference on Human Aspects of IT for the Aged Population (pp. 526-536). Springer, Cham, (2017, July).

12. Fab Lab Network: https://fabfoundation.org/global-community/
13. Motyl, B., Filippi, S., Trends in engineering education for additive manufacturing in the industry 4.0 era: a systematic literature review. International Journal on Interactive Design and Manufacturing (IJIDeM), 1-4, (2020).
14. 3D printing Media Network There Are 800 3D Printers in Libraries Worldwide (and There Could Be a Lot More) (2017). Retrieved from: https://www.3dprintingmedia.network/800-registered-3d-printers-in-libraries/ (Access 20-09-2021)
15. INNO3D project homepage: https://www.inno3d.eu/ (Access 28-09-2021)
16. Lyon, L. Librarians in the lab: Toward radically re-engineering data curation services at the research coalface. New Review of Academic Librarianship, 22(4), 391-409, (2016).
17. Koltay, T., Accepted and emerging roles of academic libraries in supporting research 2.0. The Journal of Academic Librarianship, 45(2), 75-80, (2019).
18. Junk, S., Matt, R., Workshop Rapid Prototyping - A new approach to introduce digital manufacturing in engineering education. In 2015 International Conference on Information Technology Based Higher Education and Training (ITHET) (pp. 1-6). IEEE, (2015a).
19. Junk, S., Matt, R., New approach to introduction of 3D digital technologies in design education. Procedia CIRP, 36, 35-40, (2015b).
20. Go, J., Hart, A. J., A framework for teaching the fundamentals of additive manufacturing and enabling rapid innovation. Additive Manufacturing, 10, 76-87, (2016).
21. Ullah, A. M. M., Kubo, A., Harib, K. H., Tutorials for integrating 3D printing in engineering curricula. Education sciences, 10(8), 194, (2020).
22. Liou, F. W., Ming, L. C., Landers, R. G., Interactions of an additive manufacturing program with society. In 23rd Annul. Int. Solid Free. Fabr. Symp., Laboratory for Freeform Fabrication and University of Texas at Austin, Austin, USA (pp. 45-61), (2012, August).

O NOUĂ ABORDARE PENTRU FORMAREA ÎN IMPRIMARE 3D ÎN UNIVERSITATE

Rezumat: Tehnologia de imprimare 3D s-a dovedit a fi una emergentă de reală utilitate, susținând realizarea proceselor de fabricație în diferite industrii. Inclusiv în domeniul educației inginerești, s-a bucurat de investiții și de dezvoltarea de laboratoare, Makerspaces sau FabLab-uri care sunt echipate cu imprimante de imprimare 3D. Modul în care lucrează, exploatarea lor a creat o lume interesantă și foarte atractivă pentru pregătirea inginerilor care au fost provocați nu doar să-și imagineze, ci și să creeze artefacte. Această abordare este implementată cu succes în majoritatea universităților tehnice, politehnice, deoarece experiența de învățare creată este deosebit de eficientă și eficientă (dezvoltă imaginația și creativitatea prin desene și artefacte CAD 3D). Această cercetare analizează situația învățării, educației în domeniul imprimării 3D în universități și nu numai (la alți furnizori de formare). În final, este prezentat cazul implementării proiectului INNO3D (2019-1-IE203-000693INNO3D) la Universitatea Politehnica Timișoara, România, care a dus la diversificarea serviciilor oferite utilizatorilor Bibliotecii Centrale Universitare. Concluziile finale se concentrează pe principalele avantaje ale educației de imprimare 3D pentru ingineri și o scurtă prezentare a noului Makerspace din Timișoara de la Biblioteca Centrală Universitatea Politehnica din Timișoara (România) care a fost cofinanțat de „Serviciul de suport pentru imprimare 3D pentru cetățeni inovatori". "- proiect INNO3D.

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