IO1 – Guide for teachers about how to develop designs of didactic exercises suitable to be 3D printed.

- O1A4 -

Identification of 3D printing most suitable technologies for education.

3D4KIDS

Secondary Education for and through the 3D Printing.

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1. INTRODUCTION

1.1 3D Printing Technologies Comparative Table

TECHNOLOGIES	Process	Materials used	Complexity	Speed	Max Part Size (cm)	Accuracy	Surface Finish	Strengths	Weaknesses	Pricing	Application Area	Application Examples
Fused Deposition Modeling (FDM)	Layers of melted plastic	ABS Filaments, Polycarbonate, Resin, Nylon	●●●●	Fair	30x30x50	Fair	Fair	Durable; ideal for conceptual models	Low resolution	€€	Aerospace, automotive, industrial, medical	Wind turbines, aircraft components
Selective Laser Sintering (SLS)	Plastic powder melted by laser	Paper, plastic, metal, glass, ceramic, composites	●●●	Fast	34x34x60	Good	Fair	Resistant, durable, flexible	Needs post-processing	€€	Automotive, consumer products, aerospace	Small production batches and prototypes
Stereolithography (SLA)	Polymerization scanned by UV laser	Liquid photopolymer, composites	●●●	Fast	30x30x50	Very good	Very good	High res; complex geometries	Only photopolymer materials	€€€	Aerospace, automotive, consumer goods	Medical models of anatomic human parts
Photopolymer Jetting (POLYJET)	Inkjet method with liquid photopolymers	Metals, plastic, wax	●●●	Fast	39x31x19	Very good	Good	More materials at the same time	Only photopolymer materials; not durable	€€€	Medical devices, multimaterial prototypes	Medical stethoscopes
Selective Laser Melting (SLM)	Metal powder melted by laser	Metals: copper, aluminium, tungsten etc.	●●	Fair	28x28x36	Fair	Fair	Manufactures high density parts	Price; needs post-processing	€€	Dental products, mechanical components	Lightweight components for aircraft
Electron Beam Melting (EBM)	Melted powder selected by electron beam	Metals: cobalt, chrome, nickel	●●●	Fast	20x20x20	Fair	Poor	Less thermal stress	Limited set of metals	€€€	Dental, medical implants, automotive	Bone tissue medical models
Electron Binder Jetting (BJ)	Powder distributed by jetting machine	Ceramic, metals, plastic, sand, composite	●	Fast	40x20x10	Fair	Fair	No support structure; multicolour prints	Fragile with limited mechanical properties	€	Architecture, mechanical structures	Pots and general home furniture
Continuous Fibre Fabrication (CFF)	Double nozzle laying/melting method	Plastic, carbon composites, nylon	●●●●	Fair	32x43x16	Fair	Fair	Robust parts, no post-process needed	Limited fibre placement	€€€	Aerospace	Lightweight components
Material Jetting (MJ)	Inkjet method with wax materials	Wax	●●	Slow	30x18x20	Very good	Good	High resolution	Limited wax-like materials; requires support structure	€€	Prototypes for form, fit testing; Casting patterns	Lost Wax Casting in Jewellery and Medical fields

LEGEND:
● = Simple;
●● = Fair;
●●● = Complex;
●●●● = Very complex.

€ = Cheap;
€€ = Fair;
€€€ = Expensive;
€€€€ = Very expensive.

Figure 1: Comparative Table [10]

1.2 Additive Manufacturing in Education

Additive manufacturing, commonly called 3D printing, is a process that creates a physical object from a digital design. This production technique has become more and more popular over the last decade and it has arrived to almost all sectors of industry and society.

3D printing technologies offer a wide range of advantages from the practical part of the creation of objects. Its main properties (commented on the following point) of speed and affordability are strong pillars for the technical development of this technology, but there is also a huge potential on the creative and innovative side of it, and that is why it seems as interesting for the education sector as it is going to be explained next.

This technique serves for many purposes; within the industry, producers look at 3D printing for ways to save time and money. They also wish to produce more and to preserve high quality results. It can as well be used for civic purposes and it is starting to be included in education by making it easier for students to acquire knowledge and information, improving the learning path for pupils, especially for those with attention deficit.

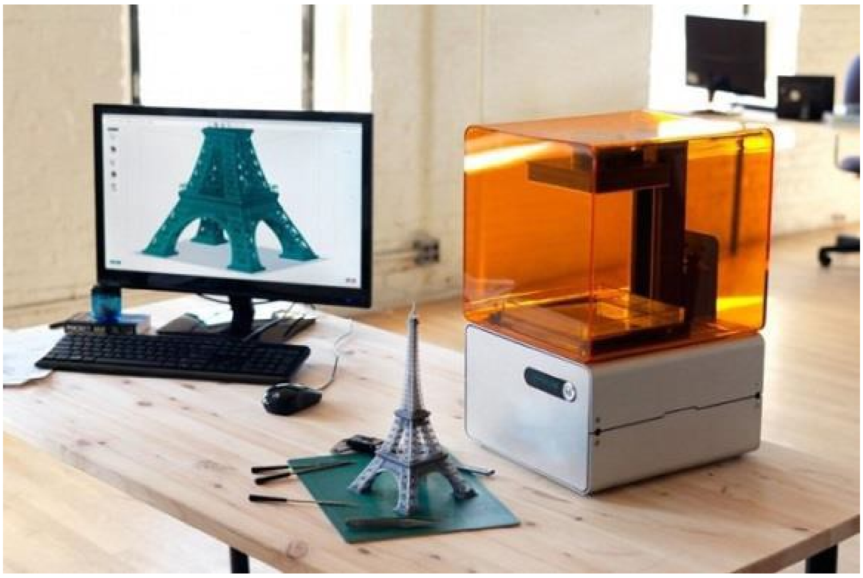

Figure 2: SLA technology and printing machine [1]

The implementation of 3D printing in secondary schools, universities and VET centers can (and will) make the difference in future education, leading to an easier, more practical and, in short, better education. Through 3D printing technologies and their endless possibilities, teachers will be able to offer a totally different approach.

The advantages in the learning process seem to be notorious. Teachers would have an infinite source for creating their own material in many different subjects: Engineering, Maths, Design, Physics, Geography and more.

They will also have several options in the customization of this technique, for example when it comes to software, including different open source software programs. At the same time, there are also many materials currently available and each of them presents different prices and properties. As for hardware, 3D printers are generally easy to be purchased, with different choices and prices for any kind of pocket. 3D printing can be definitely serve to teachers who want to create an effective and innovative education.

1.3 Available Technologies for Education

In order to facilitate the understanding of the 3D printing world focused on the education sector, the following paragraphs will focus on the available technologies.

A first comparison is offered within paragraph 1.1. Based on statistics, nowadays FDM, SLS and SLA are the three most used 3DP technologies:

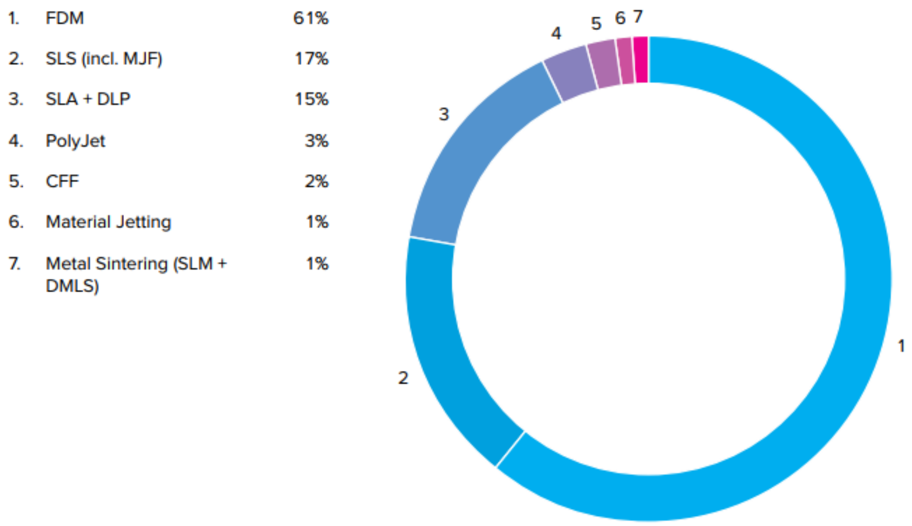

Figure 3: Most used technologies [3]

The combination of Fuel Deposition Modeling (FDM), Selective Laser Sintering (SLS) and Stereolithography (SLA) hoard over the 90% of the total usage of the 3D printing, especially for beginners in non-high-requirement pieces.

1.3.1 FUSED DEPOSITION MODELING

Fused Deposition Modeling (FDM) is a technique that works by extruding a thermoplastic polymer through a heated nozzle which gets deposited on a building stage. It typically involves plastic filaments (usually PLA or ABS) and it is known as the most affordable technique (especially for domestic environments) that can create complex forms within a fair accuracy, despite sometimes sacrificing the surface quality.

FDM is often used in the area of non-functional prototypes in order to produce concept parts, functional models, prototypes in general, manufacturing tooling and modeling, and end use parts. More specifically, it can be used for low-volume production and prototypes aimed at form, fit and function tests. This orientation makes interesting the choice of this technology in the education field.

Many brands are offering pre-built 3D Printers like MakerBot and Ultimaker, two of the most popular desktop-based. This does not exclude the possibility to build one from scratch using DYI kits.

1.3.2 SELECTIVE LASER SINTERING

Selective Laser Sintering (SLS) is a technique that uses laser as power source to form solid 3D objects. Unlike others, Selective Laser Sintering does not require the use of support structures. The object is, in fact, printed while being constantly surrounded by not sintered powder. This fact can facilitate the freely usage of the technology by not experts in the field.

Just like in FDM, the use of SLS technology makes it possible to involve a variety of materials which range from nylon, glass and ceramics, to aluminium, silver and even steel. However, some of them, like ceramics, are not laser sintered. A binder, in this case, is used to glue parts together and this is usually known as “Powder & Binder-based 3D Printing”.

This technique is considered as one of the cheapest ones and one of the easiest to implement because of the lack of supporting structures, which also enables the development of really complex geometries. Its only disadvantages is that the resulting pieces need post-processing, meaning cleaning, retouching and/or adjustments.

1.3.3 STEREOLITHOGRAPHY

The third technique is the **Stereolithography** (SLA) which is a light-based process that builds individual layers of a model with liquid polymer, hardened by a laser beam. It is the oldest technology in the history of 3D printing, but it is still very much used nowadays.

SLA offers one of the highest accuracies and best surface finish, being one of the fastest techniques and offering the possibility to have different levels of opacity in the pieces. The disadvantages are that it is not as affordable as previous techniques and it can only be used with materials like photopolymers.

1.4 Other Properties: Materials, Price, Speed and Accuracy

3D printing, as part of Additive Manufacturing, provides a production method that is, in general, fast and cheap. It provides the user with a very flexible process, being able to develop complex figures within a high-relative accuracy (depending on the exact printing technology selected). All these parameters can be adjusted with the use of different techniques and materials, which will need software and printing hardware.

The existing different techniques enable teachers and students to select from multiple choices. Price, speed and accuracy are somehow related to each other. In general, a high quality with very accurate surface is not needed when it comes to teaching, making 3DP rather cheap on a pricing level. Costs rise when it comes to more demanding requests.

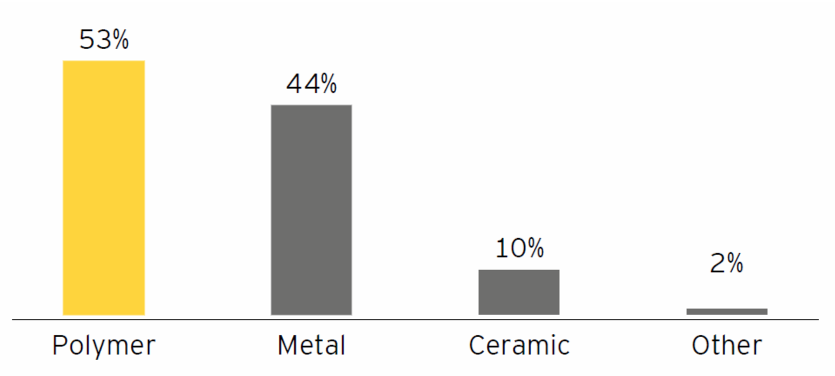

Figure 4: 3DP materials used (%) [2]

Another crucial pre-printing choice is the selection of the materials; from polymers (plastics) to metals or ceramics, they will offer advantages and disadvantages. Polymers, the ones with the highest use percentage [2] usually suppose lower costs (because of cheaper raw materials and simpler printers needed), offering an average item/result. Metals offer excellent physical properties, as well as complex geometries, but with higher costs.

2 SURVEY RESULTS

2.1 Introduction

In order to identify the most suitable 3D Printing technologies for education, the 3D4KIDS Consortium has developed and launched an worldwide online survey. The aim was to gain valuable inputs from the academic sector, from teachers or students that might have had contact with the 3D printing world before; but also from individuals from the industry by obtaining their observations about 3D printing educational and training situation as well as potential, main technologies, materials, etc.

The survey was launched via an online web survey tool - 1KA. CEIPES, CETEM, Furness and STP disseminated it within their own countries through an active emailing process, targeting the most appropriate users. It came in four different languages - Italian, Spanish, English and Slovenian, following translation provided by each partner to facilitate its comprehension.

Concerning the results, a total of 60 entries were reached during 2 months. The initial proposed indicator of 10 entries per partner involved within the activity was therefore more than successfully covered.

2.2 Survey - 3D4KIDS: Secondary Education for and through 3D Printing

Almost half of the received responses came from teachers that have already been (or would like to be) involved in the 3D printing sector. The second largest percentage is the student's one, with 25%. The rest are individuals from Industry and companies, hobbyists and others.

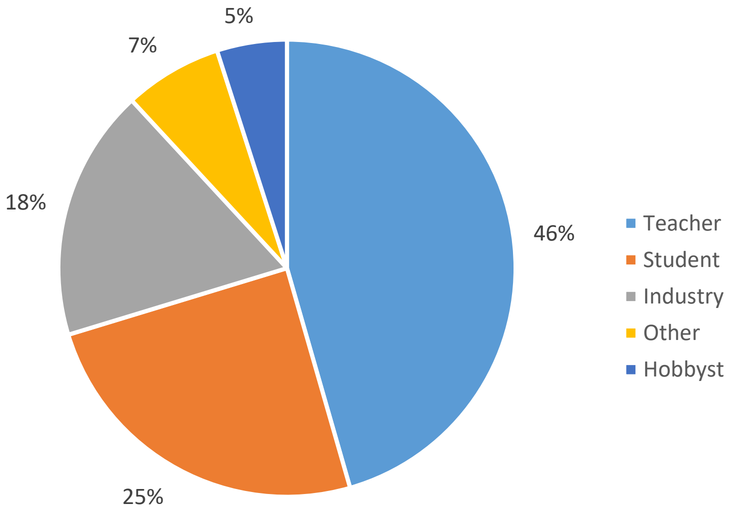

Figure 5: Survey Responses by Role [10]

First, it was important to analyse the grade of knowledge and participation of the repliers in context with the 3D printing technology. Most of the participants of the survey are **beginners** that have been in contact with the techniques for **just a year**, which is an evident point on the recent arrival of 3D printing to schools.

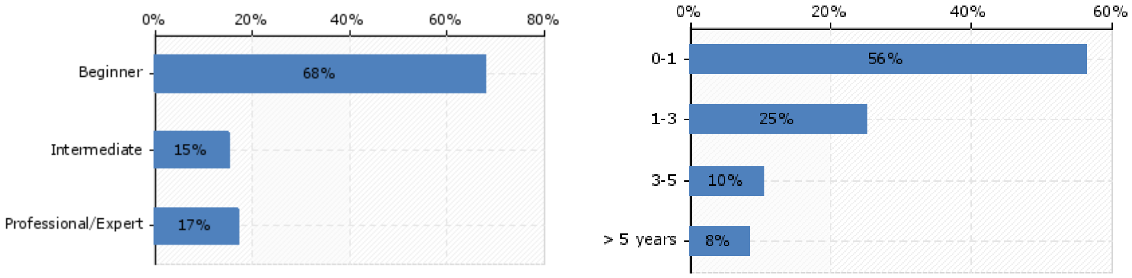

Figure 6: Level of Experience On 3D Printing (left) / Years of Experience On 3D Printing (right) [10]

It was then obvious to understand the grade of difficulty of this techniques apperceived by the users. Most of them, even being beginners, agree in the **ease of installing, using and learning about 3D printing** and 3D printing software programmes:

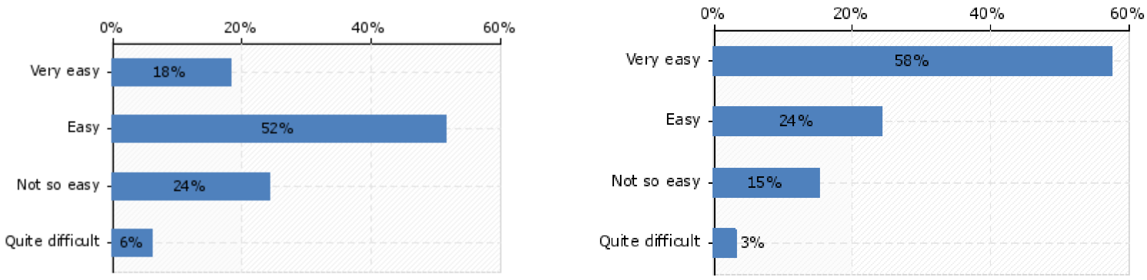

Figure 7: Ease to Learn and Used 3D Printing (left) / Ease to Install the Software (right) [10]

Almost all of the answers confirm that this technologies are considered as Useful or Very Useful (91%) generally speaking, and also a huge percentage of the repliers think that it is Important or Very Important (92%) to include 3D printing in the future school curriculum.

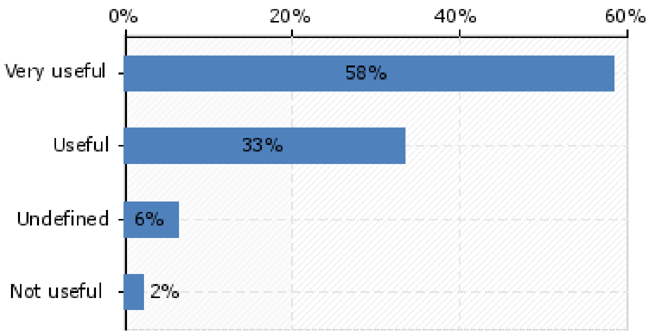

Figure 8: Usefulness of 3D Printing [10]

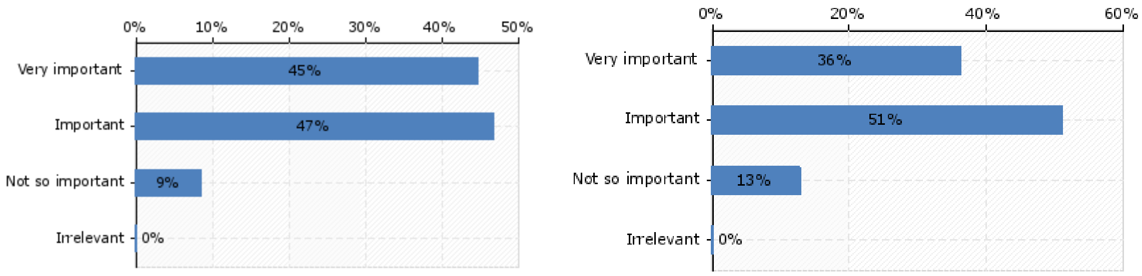

Figure 9: Importance of introducing 3D printing into school's curriculum (left) / Importance of including 3D printing for teaching purposes (right) [10]

The thought's direction of the people of the academic sector that has been in touch with 3D printing is clear: **the majority believes in its future possibilities**.

Once this has been settled, users gave their own opinion on the future of 3D Printing within schools; preoperational trainings should focus on both software and hardware as a complete course. There is a strong believe on the benefits that this technology could provide for the students with **attention deficit**, one of the main advantages that 3D printing offers to the educational sector.

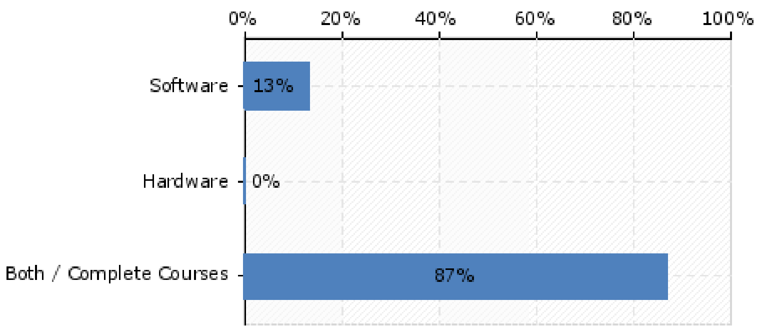

Figure 10: Terms to be focused on future training programmes [10]

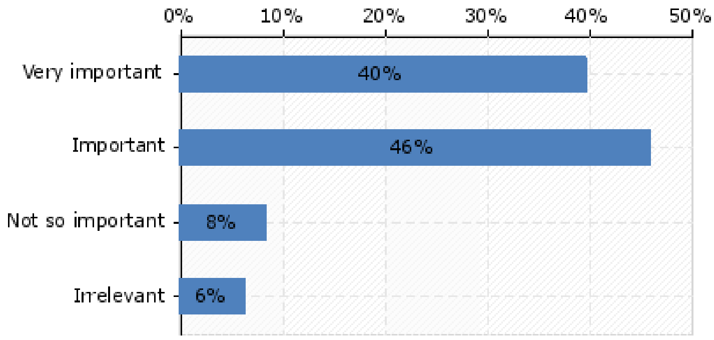

Figure 11: Importance of including 3D printing for students with attention deficit [10]

Getting a little bit closer to the technical part, participants were asked about the main required features when producing a piece on 3D printing.

The majority of them consider the **low time of production** as one of the key factors for this technology, including its **low price** and good quality of the prints. The **ease of use** and the possibilities on the selection of materials are the following most important factors.

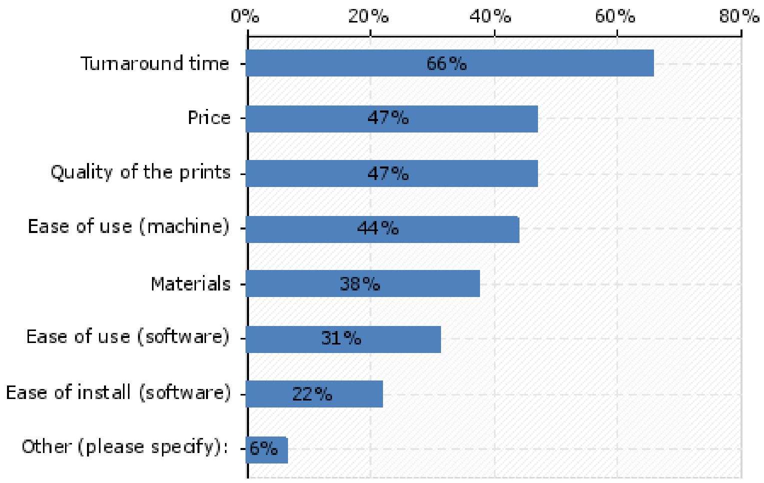

Figure 12: Main valued properties of 3D printing [10]

Another main part of the survey is aimed to find out the usual techniques that the survey applicants are using, in terms of techniques, materials and printers. The results show that 3D printing usage on the educational sector is limited mostly to **FDM and SLA techniques**:

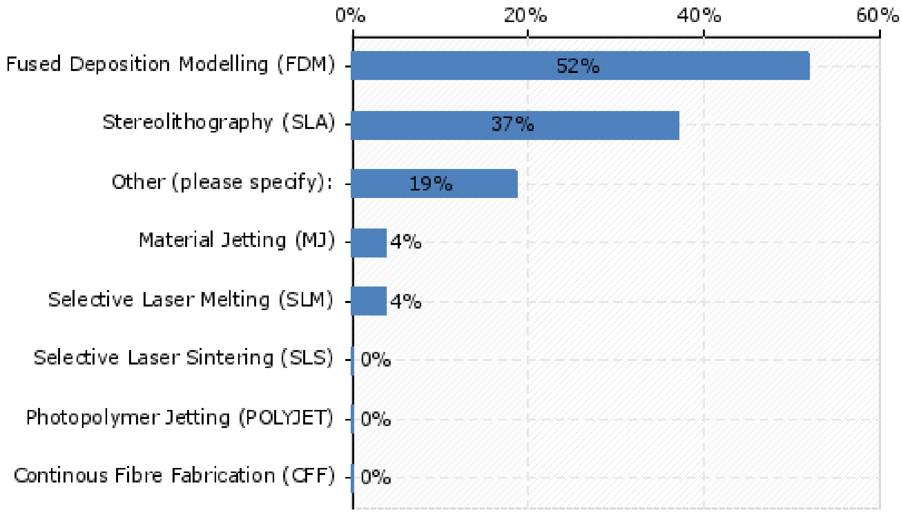

Figure 13: Technologies usually used by the users [10]

For what concerns materials, the two most selected are: **PLA and ABS plastics**, which are commonly used in FDM technology. Regarding the most used 3D printers, in this case there is a larger variety, with Ultimaker (FDM technique printer) as the most popular one with 36%.

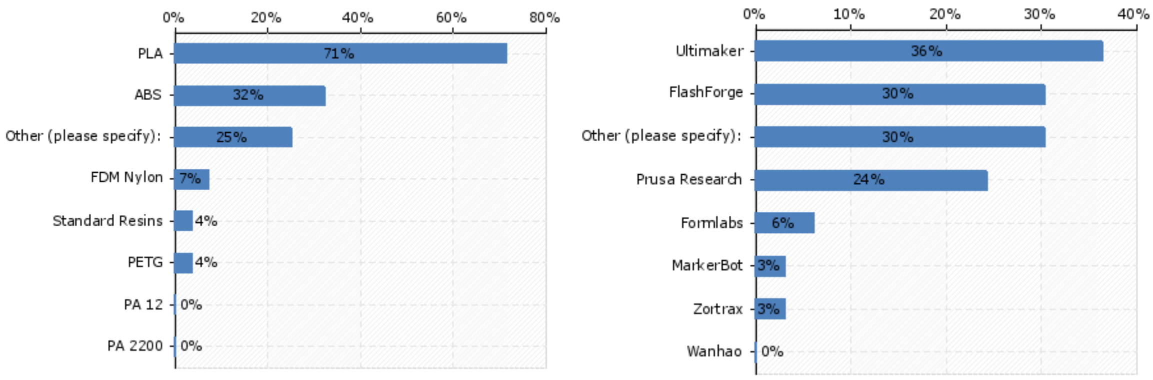

Figure 14: Most used materials (left) / Most used 3D printers (right) [10]

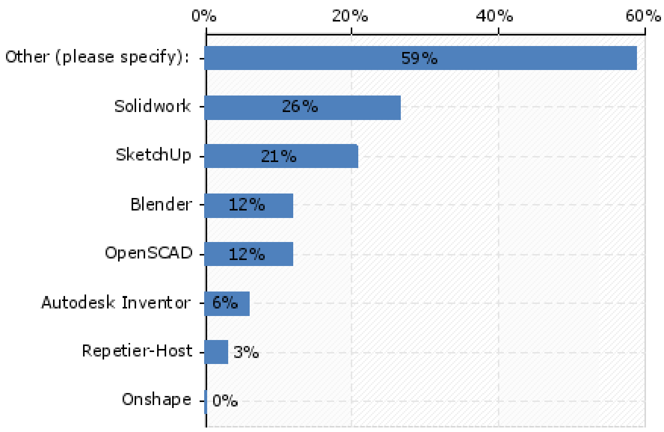

Figure 15: Most used software [10]

Finally, users where asked about the software programmes that are used for 3D printing and the results provide three main ones (that could be specially aimed in future training programmes): Solidworks and SketchUpm, with Tinkercad inputted (21%) in the "other" section.

2.3 Conclusion

The general analysis of the usage of 3D printing shows a recent arrival of these techniques to the education, guided by FDM and SLA as the two main technologies at the moment.

There is an obvious and a real interest in the establishment and incorporation of 3D printing within future methodology as a practical, fast and cheap technique, with a special consideration to its advantages on students with deficit attention.

The different techniques (hardware and software) are considered of an easy implementation and usage and, because of its possibilities, there is a bright future expected for the 3D printing in the education sector.

3 STUDY OF EXERCISES

To the extent of O1/A2 within the 3D4KIDS project, the school partners involved developed **thirty 3D printing didactic exercises**. These can serve to teachers as a baseline for their educational approach; they can be put into practice in class or simply give a general idea on the possibilities of 3D Printing.

The following paragraphs offer tips about technique selection and procedure, as an integrative knowledge for the implementation and development of the exercises.

3.1 Most suitable technology: FDM

Most of the exercises, oriented for teaching in schools, follow a general path. They are visual and practical examples that can be used during lessons in order to improve the students' understanding and attention. Usually, there is no need to produce precise pieces or high-quality ones under severe requirements. Since their idea is to give a visual example of the lesson, the direction for the 3D printing is clear.

The use of **Fused Deposition Modeling technique** appears to be the main solution to provide to schools with the technology and the tools to develop in the most suitable way the introduction of the 3D printing into the classrooms. It is not coincidence that this technology is the most used one, as it is cheap, fast and easy to incorporate for schools and companies and it was declared as the main used one in the analysed survey.

As it has been explained before, this technique would offer to the teachers the possibility to produce their own customized objects and recreations, exploiting the infinite range of possibilities on it. Some of the proposed exercises count with many different pieces, and so, the low production time that FDM offers is another main advantage.

Two of the top 3D printer producer, with the 17% of the market share at the end of 2017 [2] are Ultimaker and Prusa Research. Their printers use the FDM technique and are much recommendable. At the end of 2017 they had printers with the highest market share, Ultimaker 2 had the 6.3% and the Original Prusa i3 the 5.1% (the Zortrax M200, also FDM, is the second in the list with a 5.6%).

Figure 16: Ultimaker 2 (left) [6] / Original Prusa i3 (right) [7]

Both companies have in the market newer models of this successful printers. They are all recommended since a widespread use of them makes easier to find solutions and advices for every kind of possible trouble.

Prusa’s printers, which can be purchased in DIY kits to be assembled by the user, are the cheapest and most affordable option to be initiated in the 3D printing world.

3.2 About the exercises: materials

Taking a closer look to the proposed exercises in O1/A4, and starting from the base of the commented use of the FDM technique, two types of materials can be recommended depending on their goal.

The most used materials in FDM are **PLA and ABS**, both plastics. The survey results show that the 70% of the users usually use PLA material (among others) and a 30% ABS. The third one, to have a general idea of the usage of these two types of plastics, would be Nylon fibres used by a 7% of the users.

Attending to these plastic materials, PLA is a very easy to use material that can be fragile but also quite flexible. It is thinner than the ABS filaments so it is easier to extrude, which means, small pieces would be printed faster (property that would be very useful for some of the exercises).

ABS, in the other hand, is a more robust and resistant material. It is ideal for the printing of mechanical pieces or pieces that need from a mechanized after the printing process (polishing, drilling, painting, etc.).

It is possible to classify the exercises depending on the recommended materials:

- FDM technique using **PLA material** is recommended for Etna volcano, EU Countries, Mont Blanc, the Globe, Composition of the Earth, the Solar System, Flags, Mediterranean Islands, Polygon Dissections, Solids Intersections, Versatile and the Eat well guide exercises. They are exercises of large volume or large amount of pieces, which need from **low production times** without need of any specific mechanical property.

- FDM technique using **ABS material** is recommended for the Buttons, Gumball machine, Money box, Greetings card, Race, Roman shield, Semi-circular arch mould, the Perfect Body (both), Tiling the Plane, Propeller, 3-sided Die, Doric/Ionic Column, Greek Sculpture, Cylinder, Sea depth, The Globe lithospheric plates, Pyramid, Cone, Cylinder and Cone and the Vase exercise. These exercises appear to need a certain customization; they are planned in some cases to act as **mechanical part** of the projects, having to resist to some requirements or just present a less flimsy appearance. SLA could also be considered as a feasible option in case the school want to implement another kind of technology or different features.

3.3 An extra option: SLA

Either if the option of using FDM technique is not available or the desired printed pieces need from a higher quality (that could not be achieved with FDM), schools and teachers should be aware of other options.

Stereolithography is one of the most used technique in 3D printing and the second most used according to the academic survey. It might provide a suitable answer to those special cases. It is a very precise technique that can offer pieces with nice accuracy and resistant to high requirements. Its main problem is that it is sensitive more expensive than FDM technique, although the results can be considered of a better quality. The printing during this technique is also faster than in other technologies, and more complex geometries can be achieved.

Within the market, the company Formlabs (third at highest market share at the end of 2017 with a 5.2%) offers SLA printers such as Form 2, defined as the Industry-leading desktop 3D printer.

Another inconvenient is that SLA printing cannot access to a wide range of materials since technology requires them to be photopolymers, but as commented SLA offer the nice possibility of producing objects with different grades of opacity.

Figure 17: Form 2 [8]

4 SOURCES

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