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Innovative solutions need an innovative approach – 3D printing technology, example of use and conclusion from implementation in an organization

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Abstract:

3D printing is a very popular technology for rapid production and prototyping. The rapid development of various 3D printing techniques began at the beginning of the 21st century. The concepts of rapid manufacturing and prototyping have gained new meaning due to unlimited shaping possibilities and the wide range of printing materials available. The possibility of obtaining a material object in accordance with the documentation relatively quickly, redefined the production process, especially in the case of a unit or small-lot production. One of the variants of 3D printing - FDM (Fused Deposition Modelling) technology has become the most popular, thanks to the wide possibilities of hardware modification and the low price of printing devices. 3D printing is used in almost all industries. The article presents examples of 3D printing applications in various areas of engineering activities, including medical applications. An example of an approach to implementing 3D printing technology in an organization was also presented. A description of the developed training resources is provided to quickly train all process participants - the people responsible for the 3D printing process itself and potential recipients. The implementation of 3D printing technology in an organization is not only associated with the purchase of appropriate equipment, but it is also necessary to ensure an appropriate level of knowledge, which avoids confusion and makes the expectations of potential technology recipients real.

Streszczenie:

Druk 3D to bardzo popularna technologia szybkiego wytwarzania i prototypowania. Szybki rozwój różnych technik druku 3D rozpoczął się z początkiem XXI wieku. Dzięki praktycznie nieograniczonym możliwościom kształtowania i dostępnej szerokiej gamie materiałów do druku, pojęcia szybkiego wytwarzania i prototypowania nabrały nowego znaczenia. Możliwość stosunkowo szybkiego uzyskania obiektu materialnego zgodnego z projektem, przedefiniowała proces produkcyjny zwłaszcza w przypadku produkcji jednostkowej czy małoseryjnej. Dzięki szerokim możliwościom modyfikacji oraz niskiej cenie urządzeń drukujących jedna z odmian druku 3D - technologia FDM (Fused Deposition Modelling) stała się najbardziej rozpowszechniona. Druk 3D znajduje zastosowanie praktycznie w każdej gałęzi przemysłu. W artykule przestawiono przykłady zastosowań druku 3D w różnych obszarach działalności inżynierskiej, w tym w zastosowaniach medycznych. Przedstawiono także przykład podejścia powalającego na wdrożenie technologii druku 3D w organizacji. Przedstawiono opis opracowanych zasobów szkoleniowych pozwalających w szybki sposób przeszkolić wszystkich uczestników procesu - osoby odpowiedzialne za realizację samego procesu wydruku 3D jak i potencjalnych odbiorców. Wdrożenie technologii druku 3D w organizacji, nie wiąże się jedynie z zakupem odpowiedniego sprzętu, konieczne jest zapewnienie odpowiedniego poziomu wiedzy, co pozwala uniknąć nieporozumień i urealnia oczekiwania potencjalnych odbiorców w zakresie rzeczywistych parametrów wydruków 3D.

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1. Introduction

Computer-aided design is currently a standard. In certain cases, projects of new solutions of technical means, technologies, or complex mechanization systems can be created without the need for experimental tests or constructing the physical prototypes. Computer support can begin at the stage of concept creation and ends at the stage of creating technical documentation - necessary to produce the first unit of the machine. But in fact, such an approach is possible to implement only in certain situations, mostly in the case when data from real tests carried out earlier, are available. Experiences from testing similar design solutions that have been developed using a standard approach, based on bench tests and physical prototype tests, are still important aspects of the development of the new solutions. Another important aspect is access to experience from exploitation in real conditions, that allow the identification of criterion states [1], which cannot be predicted in a virtual environment. Additionally, in systems operated by humans, several additional factors should be taken into account to prove the safety [2], usability of designed structures [3] and properly shaping the user training process [4]. Typical engineering activities like the assessment of structural strength – is simulated by FEM (Finite Element Method), analysis of the interaction of system components – may be assessed by MBS (Multi-Body Simulation), ergonomics aspects may be tested using the parametric 3D model of the human body (for testing the field of view, reachability, and comfort of use of the analysed object) are possible to simulate in a fully virtual environment. In case of new product testing engaging end-user, or testing the new idea concepts, the real prototype is more usable than even the most advanced simulation. It shows, that physical prototyping is still an important aspect of design activities. We can say that nowadays the physical prototypes are built only to test the precisely selected group of features or functionalities, see Fig.1.

Fig. 1. Remote controller prototype – prototype including only external features of the device, with buttons mock-up - for testing the product comfort of use [5]

Delivering innovative products and technologies is the biggest challenge for designers [6]. Innovativeness is defined as a process that delivering the new method, technology, or product (depending on the area of implementation) which is better than already used for the same purpose. The development of innovative solutions is not only associated with the need to solve new problems but also with finding new (cheaper, faster, easier to apply) solutions to known problems. This approach requires using the techniques that will allow testing selected featured of newly developed products in a short time with minimum investment (without incurring the costs of having to build full-size prototypes with the parameters of the final product). Utilizing 3D printing technology [7], as an element of rapid prototyping workflow may shortening the whole product development process giving possibilities to test various design variants proposed by the team of designers. Currently, practical implementation of prototyping is a fusion of virtual and real testing methods incorporating advanced simulation methods and rapid prototyping technologies in a proportion defined by the possibilities and needs of an organization [8]. In the article, the KOMAG's and the 3DSPEC project partner experiences of implementation of the 3D printing technology will be presented.

2. Own 3D printing facility as the basis for rapid prototyping of new design solutions

The high costs of producing the fully functional machine prototypes, which are particularly evident in the case of large-size machines designed to work in special conditions, have forced a change in the approach to prototyping. Currently, the physical prototyping is limited, mostly to completely new construction nodes or technologies, and is used to confirm theses whose verification is impossible or difficult employing computer simulation. Most often the first copy of the machine (prototype), after passing the test procedure, becomes a fully functional product.

With the popularization of 3D printing technology, the possibilities for rapid prototyping have significantly expanded, and the prototyping process itself has changed dramatically. The price reduction of 3D printers and the constantly growing range of available materials for printing make this technology affordable not only for producing elements for testing but also as a technology to produce the final product. In some cases, 3D printing technology is the only way to produce e.g. complicated patterns of the internal cooling system, or impossible to produce by CNC technology object internals shapes. In 2015, the KOMAG Institute of Mining Technology began work on including additive technology into the design process. The FDM (Fused Deposition Modelling) additive technology was selected as the most affordable and cost-effective one. A relatively low level of investment to start the process and the construction simplicity of 3D printers used in the FDM method was the key benefit. The 3D printing facility built-in 2017 covers the internal demand, and provide services to external clients, Fig. 2. shows the equipment included in the 3D printing facility.

Fig. 2. 3D printing facility equipment

The equipment was selected to cover as wide as possible range of 3D printouts size, and a possibility to use all available on the market materials. Currently, available devices allow printing elements up to 500mmx500mmx500mm size, from materials such as ABS, PLA, Nylon, as well as water dissolve support material and two-colour printouts. Each of six, 3D printers have different features and ensures optimal printing quality in a different range of dimensions and accuracy. This allows for optimal adjustment of the printing process to the expected results. After testing the mechanical properties of 3D printouts made in FDM technology, this workflow is also used to produce prototypes that are subjected to perform the functional tests similar to real conditions. Supplementing the KOMAG's research facilities with new manufacturing capabilities, significantly reduced the duration from concept to prototype (in a situation where a material prototype and tests are required and limitations of the FDM technology are acceptable).

3. A different scenario of using 3D printing technology in own 3D printing facility

3D printing is used at every design stage - from concept to marketing activities related to the presentation of the new product. It allows presenting initial concepts in the form of the easy-to-understand form (this is especially important for people who cannot read standard technical drawings, and thanks to 3D prints the concept becomes clear to everyone). Using hi durability filaments gives a possibility to produce prototypes of system components, and machine parts which may be as real parts (typically made from steel). In a typical way, the process of productions the metal parts engaged the external manufacturer, by using own 3D printing facility the whole process may be realized internally by an organization's workforces. Even in the mining machinery industry is possible to use simple FDM technology to prototype system elements, to test in environments similar to real conditions.

3.1. The use of 3D printing to test new construction concepts

3D printing technology is characterized by potentially unlimited possibilities in the field of shaping, there is no need to take into account the specific conditions associated with the production technology, e.g. CNC. At the conceptual stage, a designer can focus only on solving a specific problem. A good example of using 3D prints is quick testing of new design concepts for spraying nozzles, see Fig. 3.

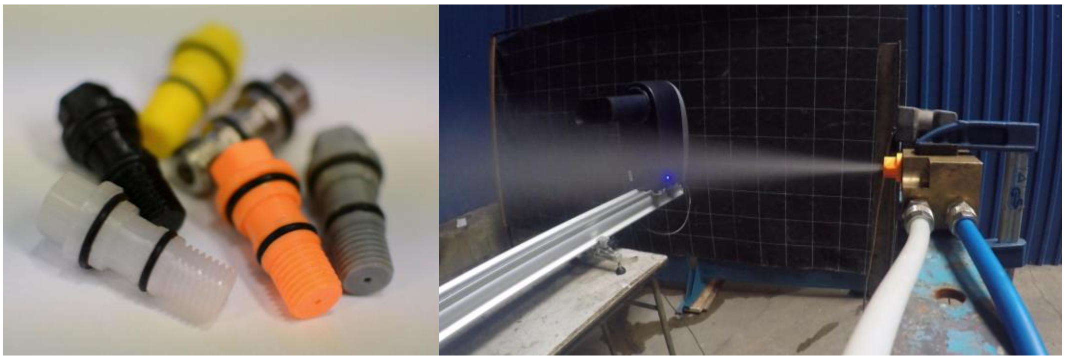

Fig. 3. Material prototypes of spraying nozzles made in FDM technology, view of the test stand [9]

With the appropriate testing facilities, it is possible to conduct a full test cycle - using the test bench - in one day. The model printed in FDM technology has lower material properties than that produced from the target material, however, its strength allows conducting preliminary tests to determine further directions of action. The development of innovative construction solutions may require verification not only of the construction form but also verification of physical phenomena that cannot be simulated without specialized knowledge and computer software. An example of such an application is the verification of the magnetic coupling. the operation being developed at the KOMAG Institute, where the test system was designed and 3D printed for the verification of theoretical assumptions, Fig. 4.

Fig. 4. 3D printout of the magnetic coupling, view of the test stand [10]

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The mechanical properties of the 3D printed prototype allowed for positive verification of theoretical construction assumptions and determine the directions for further research in this area. If the material properties of 3D printed implemented in FDM technology are not sufficient to carry out the full test procedure, it is possible to use additional supporting elements (e.g. reinforcing bars) to increase strength, without affecting the external geometric features of the printout. The prototype can also be made as a modification of an existing solution, by adding 3D printed elements to change the shapes/profiles of the examined objects. An example of such an application can be printouts for the purposes of carrying out research procedures of the new design of high-performance fans, Fig. 5.

Fig. 5. 3D printouts of fan blades with space for reinforcing bars, the fan modified by adding prints changing the shape of the blades [11]

The construction of custom design solutions and the implementation of complex test procedures requires the use of specially designed auxiliary elements, in this area 3D printing technology works perfectly well and allows the rapid production of support elements, holders, housings, for the purposes of carrying out research procedures, Fig. 6.

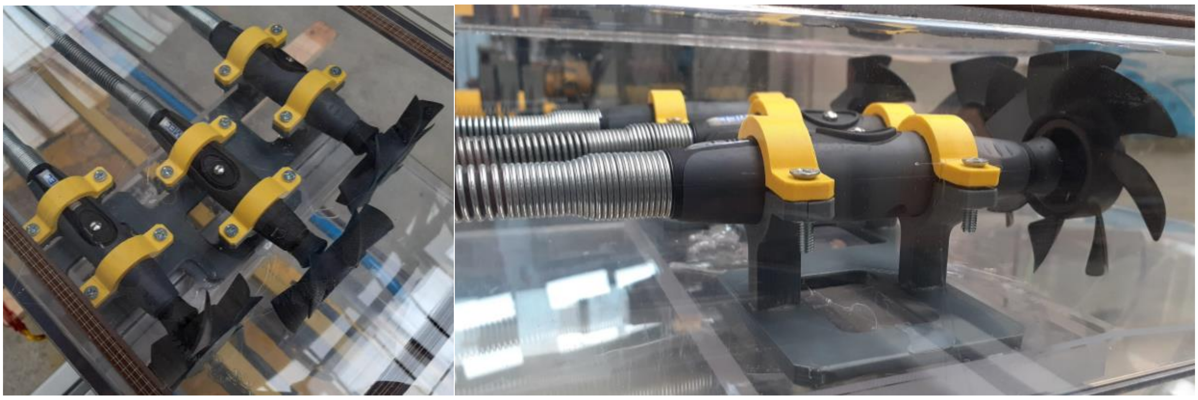

Fig. 6. 3D printed support brackets for the construction of the test stand

Such implementation is highly recommended for producing elements that do not carry high loads.

3.2. The use of 3D printing for special applications

3D printing technology is used in various areas of life, including health care. Due to the fact that materials used for creation implants must be certificated, and its composition is closely monitored throughout the production process, simple 3D printing technologies can only be used as an intermediate element, supporting the formation of the final product. For example for the purpose of mould making foundry, from which the final product is cast using the target material. Figure 7. Presenting example of using rapid manufacturing technology such as stereolithography used for manufacturing the cranial implant positive mould.

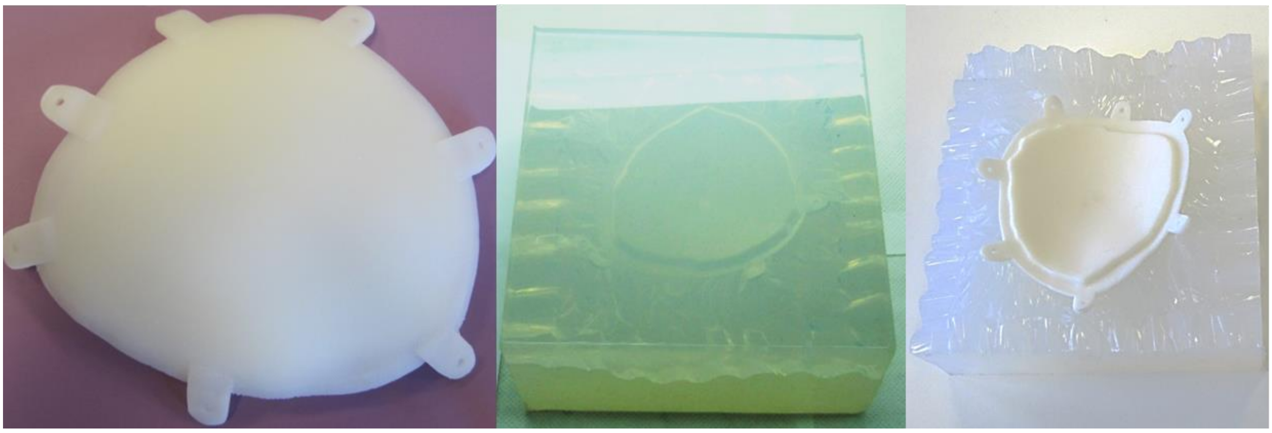

Fig. 7. Implementation of 3D printing technology to produce a positive mould for cranial implant manufacturing [12]

It is also possible to use 3D printouts made in FDM technology to support therapeutic activities in the treatment of complicated bone fractures. 3D printing technologies are used to produce personalized splints, tailored to the specific patient. In this case, 3D prints replace the standard stiffening using plaster casts, and due to the low weight and openwork structure significantly improve wearing comfort and accelerate the treatment process itself. The leader in the practical application of 3D printing for fracture treatment is the EXOVITE company, which has implemented an innovative manufacturing process in which a personalized splint is produced based on scans of the limb undergoing treatment.

3.3. The use of 3D printing as a medium for presenting new construction solutions

One of the most common applications of 3D printing is the preparation of advertising printouts, keyrings, figurines, etc. This approach may be applied also in the area of mechanical engineering marketing activities. It is possible to use 3D printouts as a form of presentation of innovative construction nodes, elements distinguishing a given construction solution, or presentation of the cooperation of entire systems. The possibility of presenting a new design takes on special significance when presenting large size machines, where 3D printing made on a scale, in some cases is the only possible form of product presentation. 3D models printed based on manufacturing documentation, are characterized by mapping accuracy consistent with the original. By adding the miniature drives and control systems, it is possible to map the ranges of motion of individual elements and to present the principle of operation of the machine. In Fig. 8 a scale model is presented. The model, in addition to mapping the external geometric features of the machine, thanks to the use of a control system (based on the Arduino module), allows us to present the range of movements and basic machine functionalities. The model is equipped with a control panel that allows selecting one of the developed demonstration programs covering various motion sequences characteristic of specific work activities.

Fig. 8. Scale model presenting the principle of operations of new construction solution

4. The conclusions from the implementation of the 3D printing technology in the organization

Implementation of the new solutions in an organization requires proper preparation on both the hardware and organizational side. Since the development of hardware infrastructure is most often associated with significant costs resulting from the need of the equipment purchase (3D printers, instrumentation, tools, and filaments), it is necessary to analyse potential areas of application (internal use only or commercial offer, small series or multiple printouts of single part), expectations regarding the accuracy and maximum dimensions of the expected 3D printed parts (analysis of the available printer's working area versus the cost of the 3D printing machine), as well as materials that can be used (testing the mechanical parameters of printouts made from various materials). All such considerations should be made before the process of 3D printing technology begin. It is necessary to analyse the market in terms of the purchase costs of specific printing devices, which should take into account not only the cost of equipment, but also the cost of consumables, and the possibility of possible independent repairs or replacement of components that may be damaged during operation. In the field of typical engineering applications including functional tests and marketing demonstration, FDM technology gives relatively the best results at a low cost of equipment purchase. In addition, due to the high popularity of FDM technology, consumables are easily available, in a wide range of achievable mechanical parameters and colours. Due to the simplicity of the design of the printing device itself, service operations can be performed without the need for external companies, which additionally affects the overall cost of a single printout.

An important aspect of using new technologies is to familiarize the design teams (i.e. potential internal customers) with the possibilities, potential benefits, and, what is most important, the limitations of the used technology. It is a mistake to assume that the technology well known and widespread on the market is also well known to all persons involved in a given process. 3D printing technology is a good example of this, although it has been developed since the 1980s, and the first 3D printer solutions available to private customers appeared at the beginning of the 21st century, and more precisely in 2001, many understatements arose around its possibilities. Because the majority of potential 3D print users shape their knowledge, about the possibilities and limitations, based on marketing presentation, their expectations usually exceed real possibilities. As it results from practical observations, most often after the first contact with technology, when it turns out that in practice the printing time is very long (printing times of complex elements may exceed 48 hours at a working field of 200mmx200mmx200mm), and the quality of the print depends not only on the material used but also on the shape of the printed object (large variations in the thickness of the printed object walls may cause internal stresses, and then deformations of the final product), recipients recognize that the technology does not meet their expectations. It is important to ensure an adequate level of knowledge in the organization at the beginning of the implementation process. Organizing information meetings and workshops that allow learning about the real possibilities of hardware facilities available on-site in the company, significantly speed up the implementation process Fig. 9.

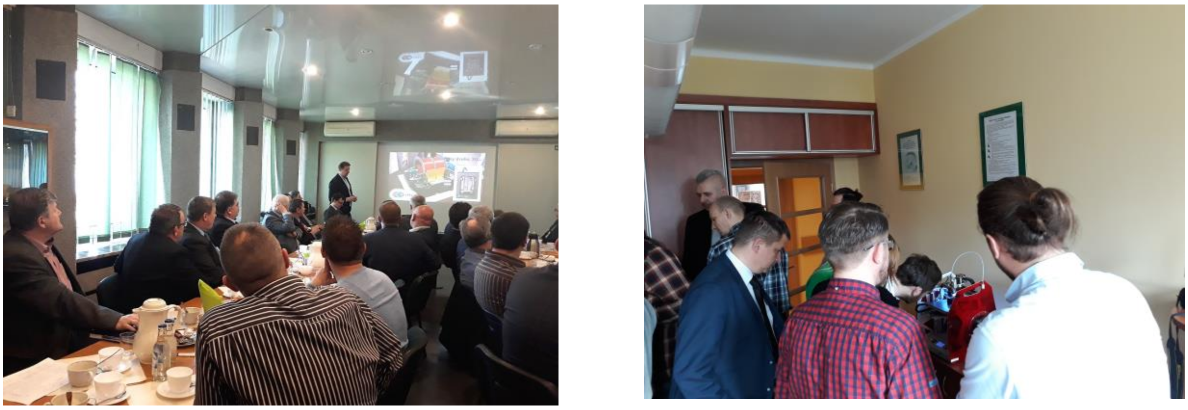

Fig. 9. Information meetings combined with a workshop part organized to disseminate information on the possibilities of using 3D printing with the FDM method in engineering practice - a meeting organized at ITG KOMAG as part of the 3DSPEC project [13]

At the KOMAG Institute, the implementation of 3D printing technology was carried out comprehensively. The process of selecting and bought of the 3D printers devices was performed simultaneously with the development of the knowledge resources to train all participants of the 3D printing process. The training materials describing the possibilities of available 3D printers, guidelines describing the requirements for the preparation of 3D models for the printing process, potential problems, and examples of applications from various fields are compiled in a form of e-learning course, see Fig. 10.

Fig. 10. Specialist in 3D printing - specialized training in the application of 3D printing - e-learning course [12]

Activities related to the development of training materials for 3D printing technology were implemented as part of the 3DSPEC project, realized in an international consortium, consisting of representatives of various areas of application of 3D printing, which allowed the development of comprehensive materials covering various areas of implementation, along with specific guidelines for the preparation of 3D models for the needs of 3D printing [12]. The training materials are available free on the elearning.komag.eu platform and contain the following modules:

- Module 1. Introduction: General view of the 3D printing technology - In this module, a trainee will be provided with structured knowledge that describes the basics of 3D printing technology, will become aware of how the whole process works, and will learn the advantages and disadvantages of different solutions,
- Module 2. Preparing the input file for 3D printer - In this part of the course, a trainee will learn how to prepare an input file for a 3D printer. Different ways of preparing a computer 3D model of an object are presented. Also examples of how to adjust models obtained e.g. from 3D scanning process to make 3D printouts. Work in specialist software dedicated for preparing input files for 3D printers (files in GCODE format) is described,
- Module 3. Materials used in 3D printing - Use of proper material for 3D printing is very important in terms of future use of a 3D printed object. In this module physical properties of most often used materials will be presented. Results of research that characterize the strength properties of 3D printouts will be also shown,
- Module 4. Examples of the use of 3D printing in activities conducted in your profession - Examples of application of 3D printing in a trainee's area/s of operation and relevant theory (if necessary) is presented in the module. Procedures to be followed to produce a given, sample 3D printout are presented. In each topic, a trainee gains access to downloadable additional materials – 3D models of an object.
- Module 5. Self-designing and assembling of 3D printers - After a description of 3D printers in terms of their features and possible use, exemplary cases presenting how to build and improve your 3D printers are presented. Materials present step-by-step how to connect any DIY (do-it-yourself) open-source-based 3D printers to the network and also ideas on how to design your own 3D printer are presented.

Despite the fact that many different 3D printing methods have developed over the years, the knowledge of a real 3D printer parameters, possibilities and costs resulting from the use of 3D printing is still at an unsatisfactory level, which raises a number of problems associated with excessive expectations may be a barrier in implementation. Therefore, it is important to ensure the same level of knowledge for all participants in the process. The training resources provided by ITG KOMAG can be a great source of knowledge and inspiration both at the stage of implementing 3D printing technology in an organization as well as at the stage of analysing available solutions and selecting printing technology that fulfils the specific requirements of the organization.

5. Summary

3D printing is used at every design stage - from concept to marketing activities related to the presentation of the finished product. It gives the opportunity to present initial concepts in the form of easy-to-understand printouts (this is especially important for people who cannot read standard technical drawings, and thanks to 3D prints the concept becomes clear to everyone). However, in order to fully utilize the possibilities of this technology, one must become familiar with both the possibilities and limitations of individual variants of 3D printing technology. The article presents a proposal for an approach to the implementation of 3D printing technology in the organization. Due to several understatements and misleading marketing messages, expectations for 3D prints are very high and do not match current print parameters. High expectations combined with a lack of basic knowledge, about how to form the final product, may affect the limited scope of technology application in the organization. The provision of appropriate knowledge resources, with specific examples of applications, and a set of guidelines on how to prepare 3D models for 3D printing are the basis for optimal use of all the possibilities of this technology.

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