Visual systematization in tech diffusion management

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Abstract. The aim of this article is to structure additive technology aids of visual systematization, to determine the impact of visual systematization on innovation diffusion management. The authors deals with scenarios for managing the technologies diffusion in enterprises of various industries, including the construction industry, using a system and an additive technologies matrix that allow for the optimal choice of technology in existing production conditions. The main advantages provided by the use of additive technologies in industrial production are determined. The system and matrix of additive technologies developed by the authors make it possible to obtain a comprehensive view of existing additive technologies and evaluate their applicability for obtaining business effects. The types of business effects that company managers can get when using matrices are systematized. The use of visual systematization tools allows companies and their managers to improve the labor productivity, increase the company's production potential, and ensure economic.

1 Introduction

In unstable economic conditions, the main goal of manufacturing enterprises is the formation of production systems to increase labor productivity, improve quality and improve the manageability of production processes.

The solution to such problems is the creation of digital platforms for production systems [1].

The creation of digital platforms can rely on accessible and inexpensive tools to engage people in company improvement and development, to have a significant impact on the operational efficiency of the business, to increase digital maturity and manage cutting-edge tech diffusion and adaptability.

Systems build on the basis of such aids are aggregated into such initiatives and methods as Smart Lean, Lean Digital, which are successfully being implemented by Russian industrial corporations and businesses.

Increasingly, leaders are taking active steps to implement industrial digital technologies involved in the creation of tangible products. Additive technologies (3D printing (3DP)

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technologies) now significantly shifting conventional production approaches and are already in use at a huge number of enterprises.

Examples of the distribution of innovative products that significantly affected productivity and ways of doing business were presented by E. Rogers in 2002 [2]. He determined that the perception of innovations and new technologies by people occurs according to the law of normal distribution. This distribution shows the speed and stages of diffusion of innovation in the community, and is consistent with the well-known "forgetting curve" Hermann Ebbinghaus psychology expert from Germany. But for the corporate segment, this distribution appears to be manageable; it depends on the estimated business yield that a particular technology is able to ensure.

Now the use of additive technologies brings obvious business surplus- speeding up time to market (T2M) and the development of operational efficiency (work less - gain more). For instance, these are: reducing processes duration, balancing cycles, eliminating no-value-yield losses, reducing expenses for testing complex equipment.

The additive or sequential method of material layer-on-layer adding gives manufacturing companies new opportunities that commonly have the following key distinguishing features:

1) Designing highly complex products that often (especially in case of bare metal products) underwent topological optimization; generative design; filling certain prototype volumes with mesh structures (including those with gradient transitions) specified by various mathematical algorithms. Such products often look quite different from what we have become accustomed to over the years of industrial production, and these can be 20 to 60 percent lighter. Design in the framework of a new engineering thinking inspired by the "creativity" of nature, shifts the boundaries of the classic production approaches. The new design approach allows only additive equipment production.

2) You'll have a customized product in just one cycle of printing. For instance, progressive treatment institutions today have the possibility of producing custom spinal cages for each patient in a single build using 3DP. Similar practices can be cited for printing dental implants, orthoses, maxillofacial prostheses, kneecaps, etc. Healthcare is one of the first industries indeed striving for transition to additive technologies, significantly reducing the time it takes to prepare and perform surgeries, as well as the post-operative rehabilitation of patients.

3) It implies output of unique, small batch products, pilot series without long cycles and corresponding costs to create tooling. Again, here the additive technology are different from the conventional ones. Certain customers expect acceptable production timing, minimum tool production and - as a consequence - cut of costs. This may be necessary for a proof of concept, prototyping, a pilot series to pass a number of tests to be approved for serial production. Conventional concepts are matter: early check of fitness for assembly, shape and design evaluations. It is common for the prototyping stage to reveal defects in the product designed, especially if expensive (machine) tooling is used to produce it.

4) Simplifying logistic routes and minimizing force majeure when delivering parts from a remote manufacturing site by printing parts in-house or at nearby digital factories is a way out. This also includes independence on foundry production- the part is easier to print using a fairly wide range of feed materials, than to wait for an order to be fulfilled by some busy steel mill (often it also has a limited range of feed materials). This is helped by the active development of manufacturing as a service (MaaS) business models [3-5] - online platforms without own production equipment, but having access to a network of partner factories, acting as an aggregator or marketplace that works on demand. They collect orders and pass them on to factories, with customers, the site, and contract manufacturing all benefiting. There are several dozen such MaaS aggregators in the world

today, the largest of which is Xometry having raised USD 197.2 million from 13 investors since 2013, and Fictiv having raised USD 92.6 million from 15 investors, also since 2013.

5) Maintenance and repair. Problems on the agenda in this area are becoming more topical in this area due to poor delivery times and lack of spare parts in stock. In this case, often the only possible option (here we do not consider the purchase of new equipment): reverse engineering, study-in-depth to get the same origin, failed parts and printing the same quickly without any special tooling. Here, there may not be time for its testing or certification, especially if some other material is used than the original product designer conceived. However, even this simple approach allows quick, or just short-time, getting the conveyor or node assembly working again, and then look for the ways to solve the problem thorough a holistic way.

6) Using new materials. On the one hand, materials with new properties are created and applied in order to obtain new product properties. On the other hand, the material composition needs to be adapted to the requirements of additive manufacturing. Now leading scientists of materials, metallurgists, and technologists are doing a lot of work, in fact, redefining the long way of creating materials.

Aggregating or combining products in an assembly. This is one of the most distinctive features of additive manufacturing. It allows minimizing the number of assembled parts for a unit and literally dozens of times reduce the number of components required. It's important for demanding industries such as airspace, outer space and rockets. By reducing the number of parts, the cycle time is also significantly reduced, as well as the expenses do; and it is due to the smaller number of process operations, preparatory and intermediate times. It also reduces the number of labor time involved and eliminates one of the reasons for the low productivity of enterprises - selective assembly due to a process pattern.

In general, when it comes to the benefits of additive technologies, these are the advantages listed above. The mass production inherent in traditional technologies is not yet on the list of additive technologies features. Nevertheless, the productivity of 3D printers today is the priority of developers, and the additive manufacturing industry grows noticeably in this direction every 2-3 years. 3DP technology compound annual growth rate (CAGR) is a proof of this development (Figure 1).

Knowing how to navigate in additive technologies today is a vital necessity for tomorrow. Today the annual 3DP market growth of 20% is already taken for granted by many, and is actively supported by businesses.

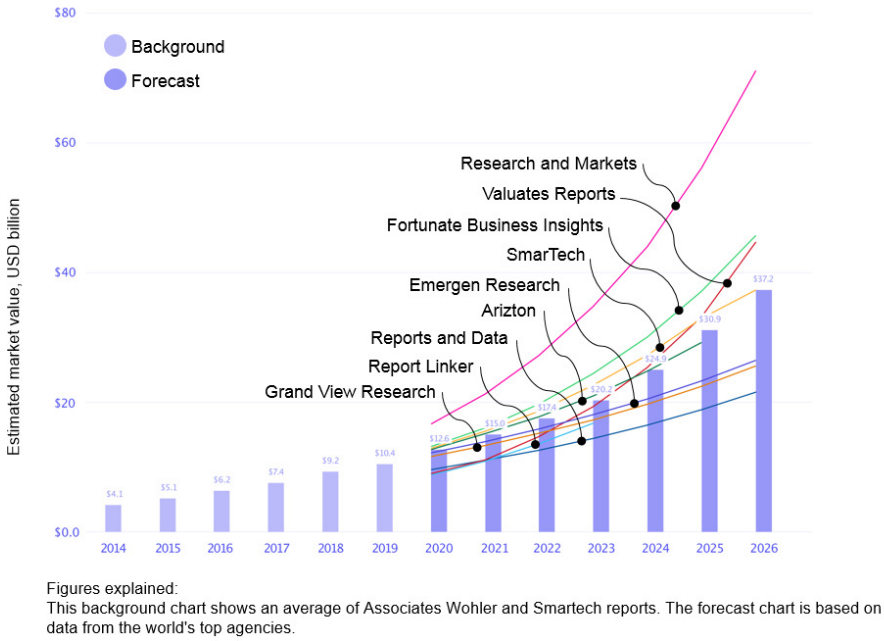

Fig. 1. Forecast and background to the value of the additive technology market [6].

Since the inception of the Toyota Production System (TPS) by Taiichi Ono, the concept of visual decision management has been widely known and accepted. Many years of expert background of authors of this article with 3DP have been systematized and published for additive technologies in System and Matrix as well. The proposed use of visual technology systematization aids allows assessing the market quickly and realistically, without wasting time on a long and expensive independent search for solutions and analysis.

The article discusses the possibilities of using additive technologies in production, presents a system of additive technologies, describes the methods and algorithm for using this system. The use of the system is carried out on the basis of the Matrix of additive technologies, which allows you to quickly navigate the existing technologies and make a decision on their implementation. The effects that the use of the developed matrix and system of additive technologies gives are determined.

2 Materials and method

The authors studied 30 large and medium-sized enterprises of various industries that can use additional technologies in the course of their activities. The respondents included 15 heads of companies, 15 heads of production departments of companies. Respondents belonged to the following industries: mechanical engineering, construction industry, instrument making. The purpose of the study was to identify a rapid approach to the spread of technology in enterprises.

A survey of forecasts and indicators of employment of personnel showed that workers do not experience a significant increase in the likelihood of developing industrial production and their economic efficiency.

The questionnaire consisted of 20 questions, which made it possible to get an idea of how interested the employees of enterprises are in the introduction of new technologies, how often they make rationalization proposals, and how ready they are for changes.

About 80% of respondents answered that they are ready to introduce new technologies if they understand that this will optimize their activities, increase productivity and increase wages.

The study was based on the use of methods of system analysis and synthesis, expert assessments.

Based on the results of the study and using the Russian and international regulatory framework, the practical experience of the authors, the System of Additive Technologies was formed.

3 Results

The System of additive technologies (the System) (Figure 3) is a graphical representation of in-demand 3DP technologies, united by seven process types (GOST R 57558-2017/ISO/ASTM 52900:2015. National Standard of the Russian Federation. Additive manufacturing processes) [4].

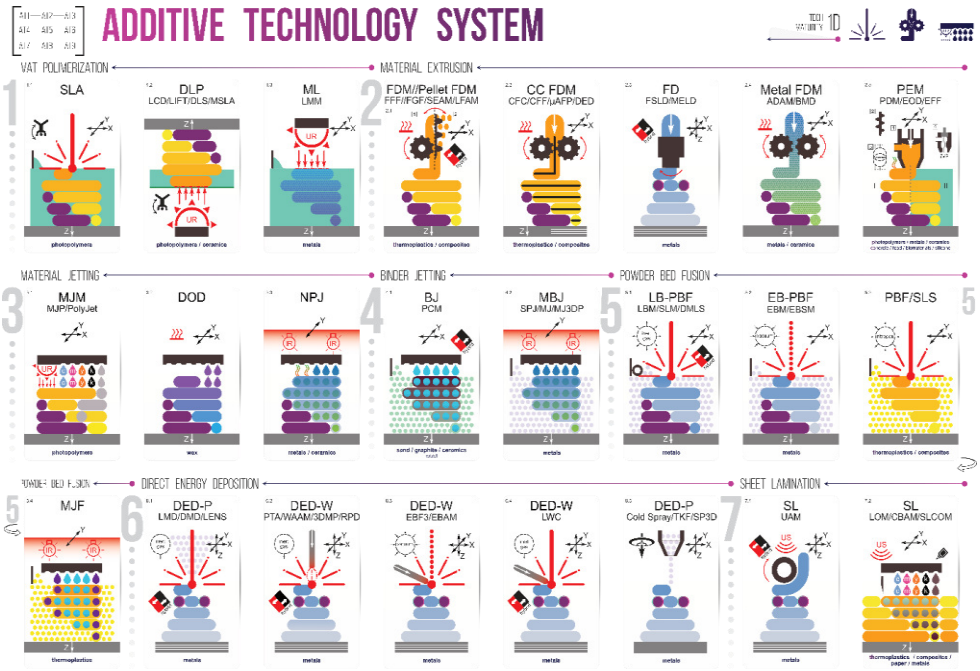

Fig. 2. System of additive technologies: reduced & adapted for the article version [6].

Here are their names with a brief process specification:

1) Binder jetting: an additive manufacturing process in which powdered materials are bonded together by selective application of a liquid binder.

2) Direct energy and material deposition: an additive manufacturing process in which energy from an external source is used to join materials by fusing them together during the application process.

3) Material extrusion: an additive manufacturing process in which material is selectively fed through a nozzle.

4) Material jetting: an additive manufacturing process in which an object is made by applying droplets of build material.

5) On-substrate synthesis: an additive manufacturing process in which energy from an external source is used to selectively fusing/melting a pre-applied layer of powder material.

6) Sheet lamination: an additive manufacturing process in which a part is produced by joining sheet materials layer by layer.

7) Bath photopolymerization: an additive manufacturing process in which liquid photopolymer is selectively cured (polymerized) in a bath by light.

The user of the System is given the opportunity to constantly keep the focus and develop knowledge about features and capabilities of technology. For schools, universities, and research institutes, such a presentation can be useful for evaluating and developing academic and scientific potential of development projects. And companies with the help of the System obtain an opportunity to plan the development or consciously select and order prototype parts from order production enterprises and contract manufacturers. The maturity of a technology in the System is linear and represented as a one-dimensional vector. Here the maturity (the icon in the upper right corner of the System) means the degree of technology development enabling to create business effects for companies. Each process type - grouped in order from 1 to 7 - is represented by two or more process flow charts. 3DP technology maturity of each process type grows from right to left and has a maximum at the very beginning of the group.

An example of such a scheme is shown in Figure 3.

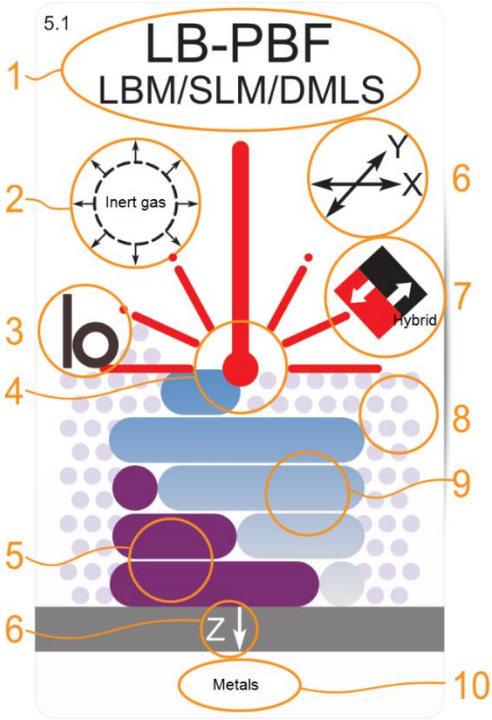

Fig. 3. Example of LB-PBF additive technology chart.

The system comprises visualization:

1) Generally accepted and patented technology abbreviations;
2) The use of vacuum or inert gas in the build chamber;
3) The way the materials are applied;
4) The way the materials are applied/cured;

5) The presence and complexity of support structures;
6) The motion axes of the print head, build platform or table;
7) Possibilities of hybrid use with conventional technologies (e.g. subtractive, blade metalworking, bending, shaping);
8) State of modeling materials: pellets, yarn, paste, powder, liquid-fluid, wire, sheet, etc.;
9) Complexity of products to be made from model materials: simple, medium, high;
10) Type of modeling materials: thermoplastics, photopolymers, composites, ceramics, wax, metals, etc.;
11) Multi-component, multi-material and multi-color print capabilities;
12) Other features and elements of a technology.

Using the system is the following steps. At first, you are considering a production method for some product. By interacting with the full version of the System, the layout and material that can be used for potential product manufacturing is visually identified [5-10]. Then the technology is referred to a certain process type. In the technology specification column on the left side of the chart, find the abbreviation (for example, LB-PBF/LBM/SLM/DMLS) for a particular technology. The abbreviation and this specification can be used to expand the knowledge of the technology and to search the Internet for more detailed information about it.

Additive Technology Matrix (Matrix) (Figure 4) is an applied management aid used to assess the applicability of a technology for business yields. A quick and deep dive into the capabilities of additive technology and the Matrix's scrupulous and logical information will serve as a benchmark for strategic decision-making at the highest level of companies that use or plan to use additive technologies in their business.

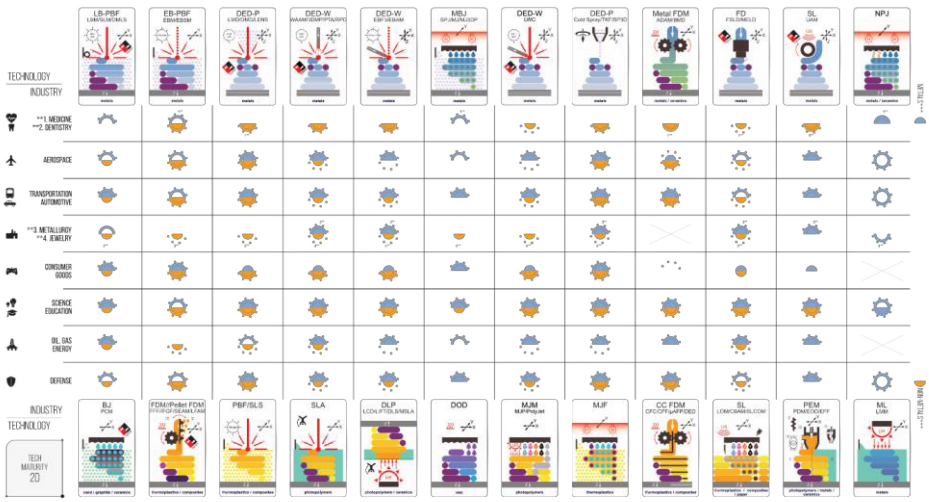

Fig. 4. Additive technology matrix: adapted for the article version [6].

While with the Additive Technology System described earlier, we can attribute a technology to a process type, the Matrix enables quick navigation through their capabilities and selecting the most beneficial technology for a particular plant and application. The Matrix allows you to make this choice taking into account the time and production peculiarities of the enterprise development at the moment of analysis.

The main emphasis in Matrix is on the trinity of products obtained through additive technologies: prototype parts, production tooling, and final products. It is known that today

more than 50% of all parts produced with the help of additive technologies are prototypes, serving to test hypotheses about the functionality of future final products. The goal of accelerating the time to market (T2M) through prototyping has been set by most developers and manufacturers of 3D printers. At the same time, when managing the diffusion of 3DP in companies, it is not an easy task to calculate the economic benefit from prototyping. Therefore the main work that is being done now is the adaptation of 3DP for the production of complex tooling and quality end products. Each of the additive technologies in the Matrix is visually related to industries, as well as to vectors of technological maturity (here they are represented in two axes, see bottom left corner). The upper line of technologies is represented by metallic processes, and the lower line predominantly refers to non-metallic ones. The symbols on the main body of the Matrix are colored blue (metals), or orange (non-metals). In this way, the Matrix explorer can learn the right technology by various criteria: materials, industries, technological maturity. The selected technology may also be the primary factor in the study, for example, when planning the implementation of a production program.

Scenarios of work with the Matrix:

1) Scenario #1: Technology ► Industry
2) Scenario #2: Applicability of technologies with MPC (metal powder compositions)
3) Scenario #3: Tech maturity
4) Scenario #4: Tech maturity ► Material ► Industry
5) Scenario #5: Tech maturity ► Material ► Dimensions

Let's take a closer look at Scenario #4: Tech maturity ► Material ► Industry (Figure 5). Suppose we have the following input data:

1) Production of medium- and large-sized end products and tooling from metal materials,
2) The industry branch for the use of the technology is airspace,
3) The tech maturity level of the technology is high.

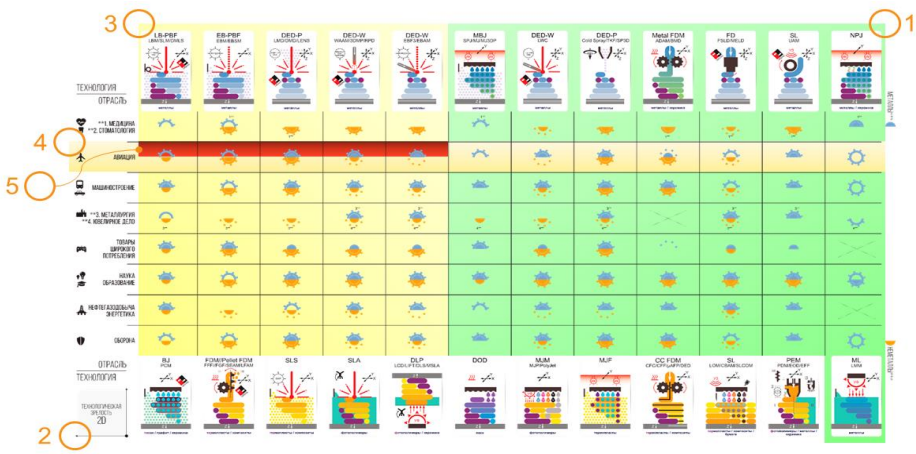

Fig. 5. Matrix reading scenario.

Primarily, we consistently select the full range of 3DP metal technologies (light green area 1). According to the highest technological maturity level (gray area 2), we select, for example, five technologies disposed closer to the left half of the chart, as the most developed and commercially successful ones (yellow area 3). Next, choose an industry, such as airspace (orange area 4). Finally, let’s pay attention to icons (Figure 6) and analyze

only the blue color (top), which represents metallic materials. Our searched interest lies in the red area 5, depending on the technology to some extent reflecting the possibility of making prototypes, tooling or final products.

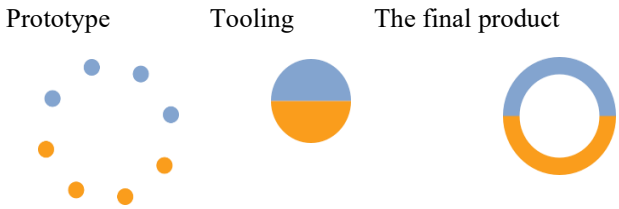

Fig. 6. Symbols showing the ability to produce prototypes, tooling, final products using the given technology.

Then the researcher can study in depth any of technology analyzed, paying attention to the external and internal quality of products, material cost, material state (powder composition, solid state, etc.), cost and flexibility of equipment, volume of subsequent finishing machining, etc. The last questions can be solved either independently with the existing knowledge or by asking experts in the market.

It is possible to get the following quick results when working with the System and the Matrix:

1) Fluent knowledge of schemes and ways of working of basic additive technologies.
2) Predicting the development of 3DP and, as a consequence, a more informed choice of technology and equipment today or in the future. Choosing a non-optimal and non-promising technology can affect the leadership of a customer whose production is based on additive processes or uses them as an aid.
3) Fluent knowledge of generally accepted world-renown 3DP technologies for independent analysis and itemization.
4) Comparison and choosing technologies for manufacturing parts at custom production MaaS aggregators.
5) Planning the development of in-house 3DP technology and platform, including one that uses the principles of a cyber-physical system [11-13].

4 Discussion

Using the visual systematization of 3DP technologies, an enterprise can obtain the following long-term business benefits

1. Reduced time to market (T2M) through accurate selection and use of currently available 3DP technologies. For example, the use of available FFF or LCD technology will make it possible to obtain a prototype part in a shorter time and quickly make a decision on putting it into production. On the other hand, printing and repairing mold elements, fixtures, and mold tooling will make it possible to start the production with minimal time and material losses. The visual systematization of the Matrix and the System helps to choose the right technology.
2. ROI (Return on Investment) and RoCPS (return on cyber-physical systems, see 6) are the most important metrics for analyzing any innovation. Without a scrupulous assessment of the consumption market and capabilities of an additive technology and equipment in question, one can get into a conditional infinite state, when every year the

demand for an unpromising technology will fall due to the emergence of more "vigorous" and cheaper ones. If your company pursues the goal of scientific research and cooperation with business, it is possible to use even outdated solutions for a long time, debugging technological processes, selecting and improving new ones, including META-materials. In most cases, businesses tend to "fit" "heavy" equipment payback period in the time frame of 2-5 years. But in fact for additive technology in the Russian Federation, this figure in most cases is doubled (it is affected by the not so high capacity of the Russian market and the possession of expensive industrial 3D printers mainly by government corporations). And only the segment of affordable home, office semi- and professional 3D printers that create products from thermoplastics and reactoplastics, with appropriate approaches and business models, can pay off in just 1-10 small and medium cost projects [8, 9]

3. Space efficiency is a mandatory metric in traditional mass production. However, with the rapid development of 3DP, the evaluation of this metric began to be actively used by those who decided to introduce additive processes into production. The obvious thing here is that 3DP technology is able to consolidate many technological production processes, which in routine classical approaches require large areas. Today, for example, LB-PBF selective laser fusion technology, which combines traditional foundry, tooling and partly machining production, allows to be placed, sometimes on a space of only 150 square meters and to produce complete, highly complex products without tooling with minimum cooperation and inter-workshop logistics with the highest level of each part individualization. Obviously, if series production is needed, that it will be necessary to buy a larger number of 3D printers with higher performance, and place them - if their design allows - in multi-level farms. Robotization and automation of such solutions, in turn, creates positive business effects. For example, if the equipment is properly loaded, productivity per square meter - taking into account the main and auxiliary areas - depending on the class of 3D printer can range from USD 50 to more than USD 300. More and more often we see examples of 3D printers placed in office premises, which demonstrates striving of equipment manufacturers to its simplicity and safety.

4. Production per employee when using 3DP depends primarily on the amount of equipment served by that employee. As far as is known, additive technologies are fully digital and have a high potential to automate production. Even though today only rare implemented projects can boast an acceptable level of automation with 3DP, nevertheless, robots and conveyor systems start to appear when several units, dozens or hundreds of 3D printers are installed. One technician can service several devices at the same time, and with the use of automation this number can reach dozens of units of complex equipment. The role of accelerating the diffusion of 3DP technology in eliminating the shortage of highly skilled machining and assembly workers is not unreasonable here [10].

5. Another approach to product design when using 3DP equipment, abandoning tooling in some cases, allows reducing production preparation cycles by 10-50 times and accelerating the introduction of new products to the market.

5 Conclusion

The article considers visual management aids to accelerate the diffusion of additive technologies for business effects of industrial enterprises.

With the large variety of 3D printing methods, materials used, capabilities and performance characteristics of equipment and print products, it is often difficult to navigate through the vast flow of information. For this reason, visualizing additive technology capabilities in the form of appropriate aids, the Additive Technology System and the Additive Technology Matrix, can offer an effective way of interacting with the target audience and getting results.

The visual organizing systems presented in this article will be useful aids for accelerating the diffusion of technologies and achieving business effect for enterprise teams.

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