3D PRINTING AS NEW TECHNOLOGY IN PERSPECTIVE OF INDUSTRY 4.0

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Abstract: The development of technology has contributed to the creation of new products and ideas. Changes are not only visible in the area of industry, but also in 3D printing. This production method is constantly evolving, because of better printers and materials are available. Opportunities offered by 3D printing are noticed by enterprises, which constantly looking for new innovative solutions. In particular that, the development of enterprises is increasingly seen by the perspective of the Fourth Revolution and Industry 4.0. The possibilities and brief of characteristics 3D printing, as well as a brief of history industrial revolution with the technologies, that characterize Industry 4.0 has been presented. These solutions are basis for further development of enterprises. Enterprises, which will be functioning as factories of the future. The concept of managing the printout process has been presented too. This solution is intended for systematize and make the single steps of the printing process, easier for users.
Key words: smart factory, digitalization, 3D printing, manufacturing, Industry 4.0.

1. INTRODUCTION

In recent years, rapid manufacturing progress, can be observed in many fields of science and technology, associated primarily with modern information technologies, that have a very wide social impact and are also used in industry. It can be said that:" We are currently witnessing another industrial revolution", knowing under the slogan of Industry 4.0. Industry 4.0 (originally German - Industrie 4.0), comes from the design of modern industry development strategies, promoted by the German government and appeared for the first time in 2011, at the Hanover industrial fair. Since then, the slogan "Industry 4.0" has become popular and more attention has been paid to various aspects of the new industrial revolution, and similar slogans have emerged regarding for example: Education 4.0 and Logistics 4.0 [8]. Due to the wide range of changes, which are currently appearing, new challenges connected with management of organizations and enterprises arise in the 21st century. These challenges are perceived differently by different authors, so currently there is need to consider enterprise's production capacity, access to resources, as well as the level of development of enterprises and further opportunities. Currently, enterprises are trying to fulfil the requirements of customers, for example by introduce automation and robotization, but this is increasingly insufficient [17, 20, 23]. That's why, the idea of implementing technologies, related to Industry 4.0 and factories of the future is needed.

In the article, in addition to described issues, authors focused on the analysis and use of specific technology. In particular, authors focused on technology related to 3D printing. The physical part of modern and intelligent factories is limited by the capabilities of production systems implemented in the factories. Due to the need for mass adaptation of processes and products in the 4.0 Industry, there is a need for continuous development of new, unusual production methods. In this way, 3D printing has become a leading and promising technology for producing customized products, because of its ability for create personalized products with advanced properties [14, 30]. Authors [33] suggest, that the impact of 3D printing, can be crucial and revolutionary, and that, this impact can last for decades in the areas of: manufacturing, value chains, environments and world economies, which are related to the paradigm of Industry 4.0 [14, 30 33]. Nowadays, more companies use this type of solution, because this solution has many advantages and possibilities to use. And also, because of more technologically advanced printers and better filaments, that are available. In the article, the concept of using 3D printing in connection with interactive instructions for using printer for employees is proposed. These concept supports and improve activities related to 3D printing, and is also the basis for the further development of the proposed concept. Because of these solutions, employer, can save the time during training a new employee. And second, it can be the basis for further development associated with the transformation of the enterprise into a factory of the future, used interdisciplinary solutions, connected with the fourth Industrial Revolution.

However, the biggest barriers for manufacturers for implementing 3D printing are: long printing time of complex elements, high cost of industrial printers or specific materials needed for printing.

1.1 The basics of the problem

In the history many of revolution changes can be listed, which were differently captured by various authors, who often focused on selected aspects and areas. Currently, there is need to a systemic and interdisciplinary approach [7].

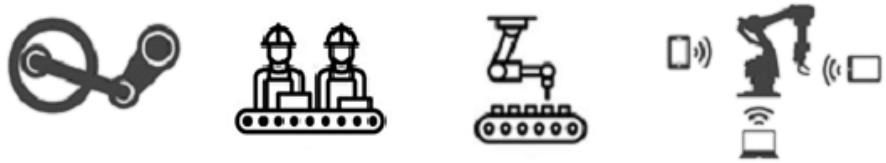
Jack Goldstone [9], identifies four "generations" of scientists, who have studied the theory of revolution. First generation, scientists, mainly described in their approach, and their explanations of the phenomenon of revolution, usually referred to social psychology (for example, Le Bon crowd psychology theory). The next generation of scientists had to face new, revolutionary events, which were unable to define with earlier theories.

A comprehensive approach to the phenomena of the spread of revolutionary changes is presented by Alvin Toffler [30], who identifies three great waves of change that changed the existing order and contributed to building a new social organization. Author presents conclusions and prediction for future social changes, related to the digital revolution, which are now largely successful.

In turn, Peter Drucker [7] analyses the changes, that have taken place in the field of management since the first industrial revolution and presents the challenges for management at the threshold of the 21st century. According to Peter Drucker, the second industrial revolution took place gradually, starting from the second half of the nineteenth century and began with the establishment of research laboratories by the leading enterprises, such as Edison, Bell, Siemens. The culmination of many studies and works, was the begin of the idea of Henry Ford, to start the mass production of cars. Since then, the automotive industry has become a leading industry and set directions for changes in work organization and management.

Although Jeremy Rifkin [26] used the term of third industrial revolution, but he described it more narrowly and focuses mainly on the problem of digital integration of energy networks (Smart Grid), which is currently considered to be complementary to Industry 4.0.

It is now recognised, that the third industrial revolution was related to the technical applications of computers and microcomputers, to control machines and robots in the mid-20th century [13]. One of the precursors of the digital revolution in industry was August-Wilhelm Scheer [28], who formulated the vision of the Computer Integrated Manufacturing (CIM - Computer Integrated Manufacturing) of the future, in both way, in production and management areas. The idea of the fourth industrial revolution, initiated by Henning Kagermann (who is considered to be the main initiator of Industry 4.0), is an industrial development programme, that is to lead to the construction of modern factories of the future by using digital technologies and distributed (decentralised horizontal integration) control systems knowing conventionally as the Internet of Things [25]. The use of such systems opens up completely new possibilities in the organization of production processes. Description and characteristics of individual revolutions are shown in Figure 1.



Revolution 1.0	Revolution 2.0	Revolution 3.0	Revolution 4.0
Steam engine, Mechanical loom, Mechanization of work.	Electricity, Conveyor belt, Mass production, Work standardization.	Industrial use of computers, Microcomputers for controlling machines and robots, Automatization and robotization of work.	Cyberphysical systems, Vertical and horizontal network integration, Internet of Things, Intelligent machines and robots, Self organization of processes.

Fig. 1. Diagram of the industrial revolution phases (own, based on [7, 15])

1.2 Characteristics of the fourth industrial revolution and Industry 4.0

The concept of Industry 4.0 covers a wide range of different concepts of factories of the future, i.e. unmanned factory, a digital factory, a smart factory, a virtual factory and others [2]. The implementation of the factory of the future, will certainly involve organisational changes, which will also force changes in the way such as organisation is managed. Therefore, the question about the nature of changes related to the introduction of the Industry 4.0 concept arises.

1.3 Changes in industry

The concept of Industry 4.0, includes decentralised control and horizontal information exchange between machines, robots, other production resources, AGVs and mobile robots, enabling better coordination and organisation of production processes. In the I4.0 concept, there are also specific technologies that are already being used by individual enterprises, namely [24]:

- Simulations,
- Additive manufacturing - 3D printing,
- Big Data,
- Autonomous robots,
- Cyber Security,
- Horizontal/vertical integration,
- Industrial Internet of Things,
- Augmented reality.

Technologies that are still being developed are intended to improve the planning and manufacturing processes in enterprises. Moreover, these technologies are the basis for further development of the enterprises and an opportunity to be more competitive in order to become the factory of the future.

Further opportunity for businesses is development of RFID tags. Tags that make easier use the storage/logistical space of an enterprise. Additionally, thanks to this solution, employees can easily track, where the right components, needed for production or printing are. They don't have to use cards, but can use for e.g. tablets. The information obtained, can be used to flexibly control and monitor the production process of each product individually. This is done by saving process information in a very small RFID chip, attached to the components [4].

Using the available technologies and constantly evolving the Industry 4.0, several factory concepts of the future, can be identified [19]:

– Large intelligent automated and robotized factories - customization mass production (mass customization)

– Mobile modular factories - smaller scale of production, close to the market, lower distribution costs

– Small digital factories - production of special products on request - e.g. 3D printing.

Other authors [12] distinguish four concepts of the factory of the future, according to four areas of application (Figure 2).

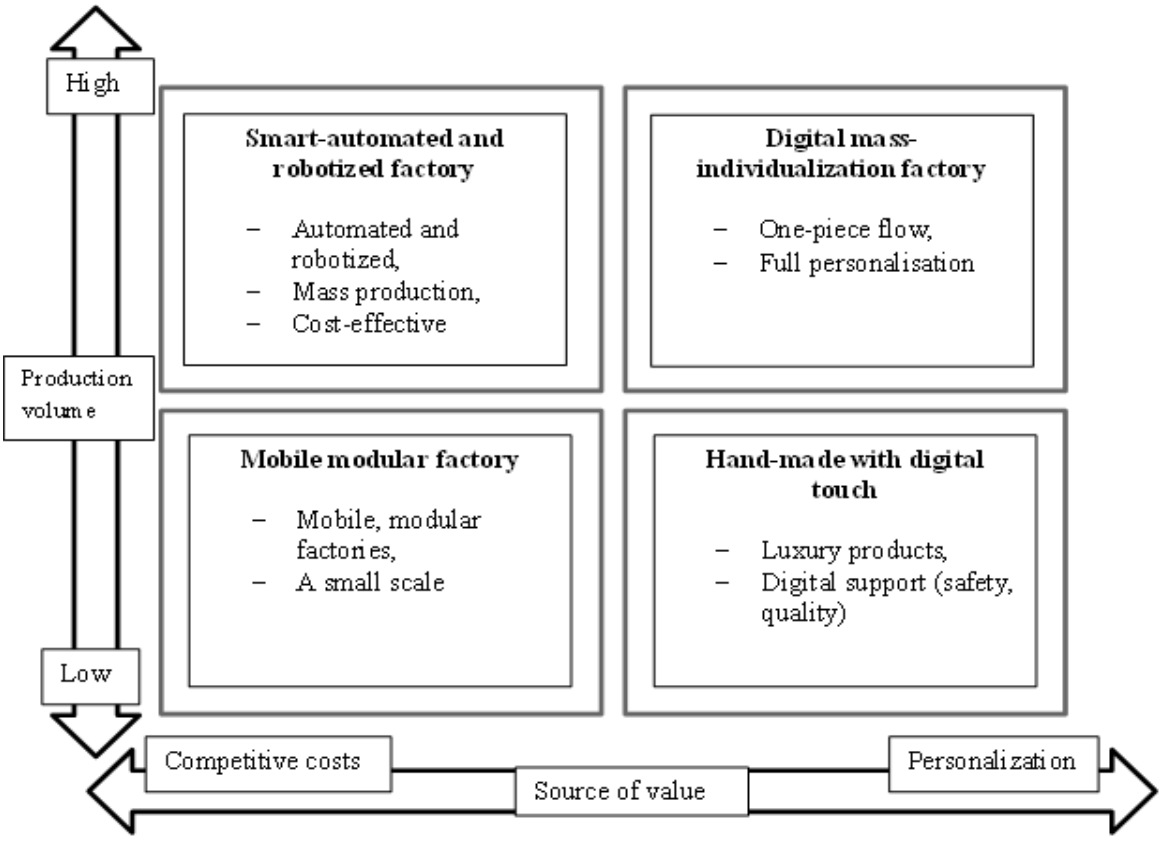


Fig. 2. Four concepts of the future factory [9]

These factories are ultimately to be smart factories. Currently, enterprises are at the stage of implementing particular technologies, related to the Industry 4.0. Technologies, that give a chance to survive in the currently difficult and demanding market. The 4.0 Industry combines many technologies such as automation, robots, 3D printing and cyber-physical systems. These technologies may require a change of operating procedures in production system. It is necessary to analyse, how the production system adapts to the environment with new technologies and customer demand aspects.

2. THE IDEA OF 3D PRINTING IN INDUSTRY 4.0

A variety of manufacturing technologies are used in industry. Classical cavity techniques are still dominant, but other modern technologies are constantly developed. The technologies of the future are referred to as incremental shaping technologies, e.g. 3D printing. But for the time, were mainly used for rapid prototyping, and are constantly developed and improved. The spread of 3D printing techniques has the potential to provide very large opportunities for small and medium-sized production enterprises. It enables to production of single products with complex geometries, that cannot be produced with traditional technologies or require multi-stage processing on different workstations. Popularization of 3D printing technology and lowering costs of this process, creates the possibility of producing not only prototypes, but also small batch production (rapid manufacturing) [1, 6]. Three-dimensional printing technologies are very different, both in terms of their functioning and operation methods and productivity [21] and also through the use of various materials, including plastics, metals, and biodegradable materials [3].

2.1 Advantages and disadvantages of 3D printing

Technological development has advantages, but there are also disadvantages. The positive aspects of 3D printing and its development include [12, 32]:

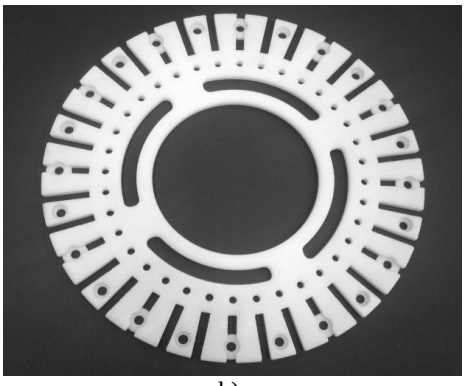
- quick making of a prototype,
- the possibility of analysing the prototype before starting production,
- printout of elements in increasingly better quality,
- the ability to print increasingly complex elements,
- access to various materials,
- access to different types of printers,
- possibility of prototyping and printing in one place,
- development of print libraries,
- access to libraries from any computer (data storage in the cloud),
- possibility to observe the printing,
- interactive help for the operator,
- vertical and horizontal integration production processes control,
- basic employee training.

But the 3D printing disadvantages are:

- specific properties of the used materials,
- possible defects in the printed elements,
- long printing time of complex elements,
- possibility of hacking data from the system,
- specialist printers,
- high cost of printers.

3D printing gives the possibility to produce products in a non-standard way. Due to the increasing of need to produce personalized products, manufacturers are increasingly using technologies from the Industry 4.0. Development in the field of 3D printing, indicate increasing possibilities of using this technology. Changes in this area are very visible. Nowadays it is possible to print the complete house, where only a few years ago, small and simple elements were printed. A comparison of sample prints is shown in Figure 3 (a), (b) and Figure 4. Example of print from Figure 3a) is a prototype made in FDM (Fused Deposition Modeling) technology – used PLA material. Examples from Figure 3 (b) and Figure 4 are made from ABS materials. Example from Figure 3 (b) was produced as unit production. But example from Figure 4 was produced in series, as functional element – element of oxygen systems.

a)



b)

Fig. 3. Example of 3D printing

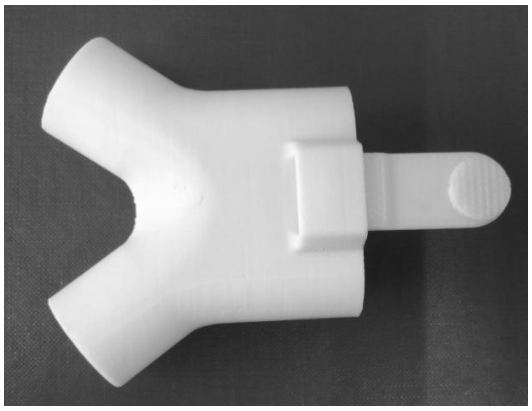


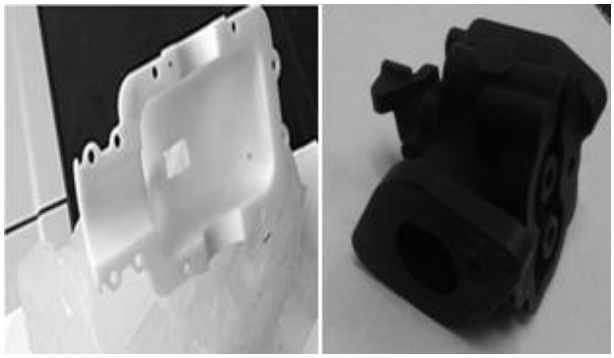
Fig. 4. Example of 3D printing

However, it should be remembered that, this solution is also possible thanks to better printers, but also to the filaments, which have better quality. Also in this area, based on the need for non-standard production, the development of materials and techniques are important.

2.2 Materials used in 3D printing

Due to the growing needs for production of personalized products, related to the technologies of Industry 4.0, and thus the development of non-standard production through, 3D printing, the issue of materials, used for this type of production also becoming important. Currently, there are many materials available, which have different properties and applications. Beside of such materials as ABS (acrylonitrile butadiene styrene), PLA (polylactide), the ASA (acrylonitrile styrene acrylate) and PMMA (poly methyl methacrylate) or LayWood (60% of PLA and 40% of wooden powder, which is an admixture) are also used. Therefore, the field of testing the individual materials for analyses strength and application becomes important. Authors [11, 16], made tests of the above mentioned materials for the strength of individual materials and the possibility of their application. In particular, that, these materials are thermoplastic, and more, for example PMMA is also a transparent material.

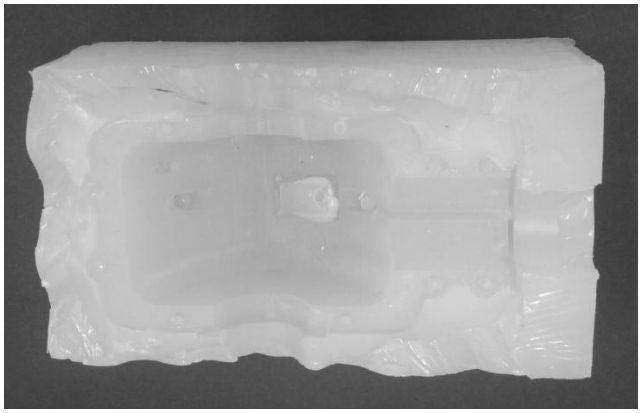
Just as 3D printing is an increasingly developed and accessible way of customizing products, the vacuum casting method becoming also more popular. It is a method, that begin the production with a master model (the so-called mother model). Often it is created using two technologies: SLA (stereolithography) or SLS (selective laser sintering). The next step of the process is creating a silicone form and flood the mother's detail, which takes place in a vacuum, to avoid the formation of air bubbles. After hardening, the silicone mould is cut according to pre-established surfaces and the master model is removed, leaving space for casting in a wide range of polyurethane resins [10, 34]. An examples of models, achieved by this method are shown in Figures 5 (a) and 5 (b). For example, Figure 5(a) shows a model of product - upper part of the gear transmission body. The mixing operation lasted 2 minutes and the whilst degassing 10 minutes. After casting operation, the mould is degassed for 20 minutes in the vacuum system. Next step – cured, was in temperature 70◦C, for 2 hours. These models and forms were made in Department of Engineering Processes Automation and Integrated Manufacturing Systems, in Rapid Prototyping and Reverse Engineering Laboratory.



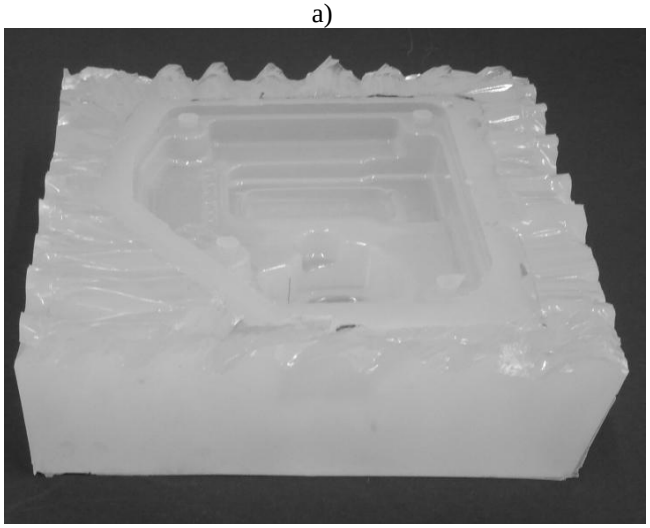
a) b)

Fig. 5. Examples of product taken from silicone form

The example of forms made in Laboratory to, are showed in Figure 6 (a) and 6 (b).



a)



b)

Fig. 6. Example of silicone form

Use of these techniques have become a leading and promising technologies for producing customized products, because of ability for create personalized products, with advanced properties, but vacuum casting is useful to, for example for:

- product validation before offering it to the market,
- small batch production,
- final details, conceptual models or prototypes.

And also, personalized products making by vacuum casting method, can be made from various materials, for example include PP (polypropylene), ABS (acrylonitrile butadiene styrene), or PC (polycarbonate) and rubber.

However, regardless of the form, in which new and personalized products are made, it is also important to focus on the steps, taken during 3D printing, as well as the planning of the entire process. Going one step further, in order to maintain the quality and standards of the products, it is necessary to develop planning, operating systems and standards for starting up, such a diverse production.

2.3 3D print planning/making system

3D printing, offers many possibilities, in particular, that there are different filaments available on the market.

While of planning a 3D printing, many aspects must be taken into account. The basis is the information about: which product is going to be printed, from which filaments, in which colours, etc. It is also based on prepared CAD models. The general 3D printing diagram is showed in Figure 7.

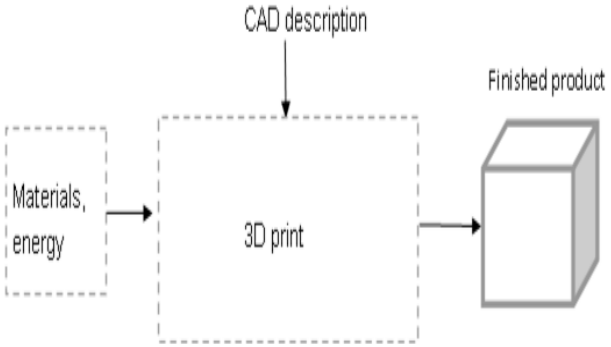


Fig. 7. General diagram of 3D printing (own)

In combination with the information, on which parts will be printed, enterprises can carry out specific orders according to the diagram in Figure 8.

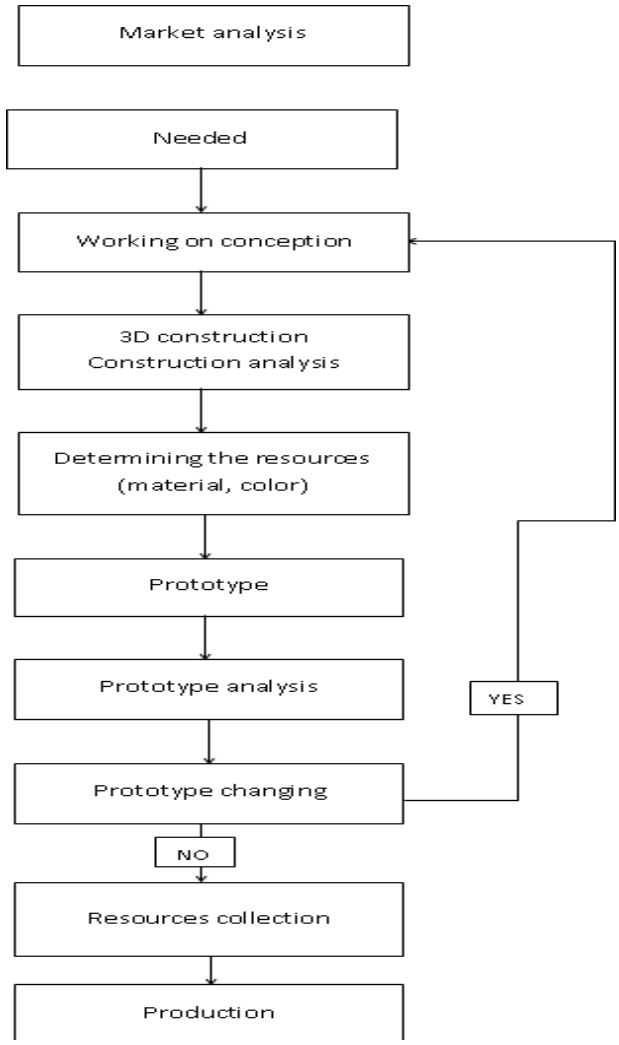


Fig. 8. Diagram of creating a product by 3D printing (own)

The diagram (Figure 8) showed how the basic process of making a prototype using 3D printing looks like. After realization of a several concepts, the specific solution is chosen, and then 3D model is developed. Next on the basis of the 3D model, a prototype is made. The prototype is tested for performance/quality. If the prototype fulfils the requirements, is put into production. If the prototype has defects or need corrects, then corrections are made, until satisfactory results are achieved. However, this diagram has evolved in some ways to these days, because of that, the idea of 3D printing is still being developed, and enterprises often aspire to the name of production in the area of 4.0 Industry. So, the printing process should be more automated in compared with the current printing procedures. Decision making and access to data, should be based on a decentralised level, and next, the process operator, should also have access to the entire printing process.

In the next section the possibilities/concepts of planning and implementing 3D printing, based on the opportunities introduced by the 4.0 Industry, are described. Especially, concerned in area of special, customized products - make to order.

2.4 Printing monitoring

With the development of certain solutions, there are also a number of the areas that need to be worked on further. Nowadays, the possibilities offered by technology, allow introducing of solutions that were just a concept. However, further technological developments, including 3D printing, the possibility of printing a dedicated product for the customer, should be taken into account. But customer, who will have a ready idea for the product, must prepare model, according to the company's requirements. Hence, in Figure 9, showed step-by-step diagram, indicate, how will look like company/customer prepare and print product. In addition, this diagram is the beginning of the creation of an interactive basic user manual, within the framework of 3D printing by an employee. Based on the developed diagram, an employee, without detailed training, will be able to operate a 3D printer and make a product that fulfils the criteria.

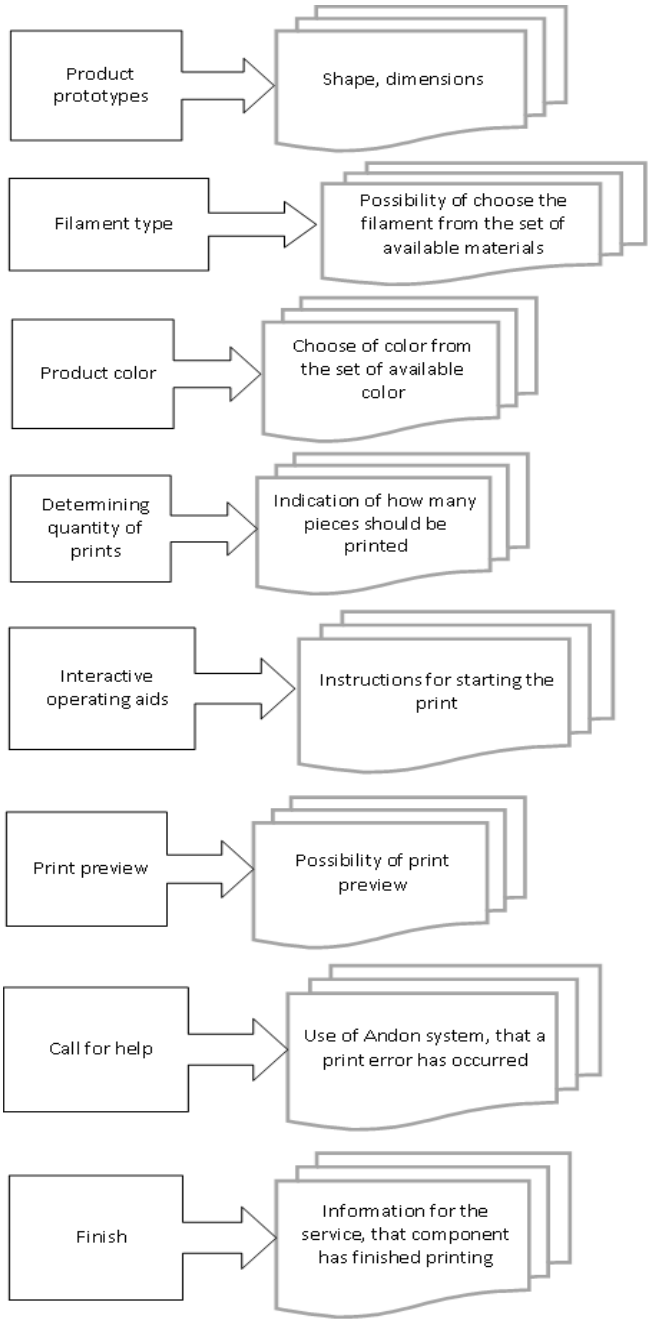


Fig. 9. Basic diagram of the interactive manual support for 3D printing (own)

The described diagram (Figure 9) is the beginning of the system, which will also help the employees in their work e.g. from maintenance in the company. In case of a problem, the employee will read e.g. from the tablet, what to do when the problem appears. Additionally, if an error appears, the maintenance staff, will see, that something is happening at some workstation and could fix the problem. The diagram

is also the basis of the integration system, which will be available to everyone involved in the process employees, and ERP, CAD systems and work safety. And also, the data, will be stored in cloud. In addition, the workstation, will be connected with the system Andon [15, 22] and to the interface, that loaded onto the tablet. With this solution, maintenance workers, will see a mark on the tablet indicating an error. However, no matter, how the system will be developed, and which materials will be used or sizes the printout will be made, data integration are also important. Enterprises use different MRP/ERP systems, while access to data and its appropriate use, should be taken to a higher level. Level, that should ensure direct access to data to any person, who is responsible for selected field. This data are collected in cloud, but should be also properly saved and secured [18, 27, 31].

2.5 Data integration in 3D printing

However, before moving the area of management and planning in the enterprises to a higher level, the areas, related not only with 3D printing, should be change. At the moment, enterprises are following the module showed on the diagram in Figure10.

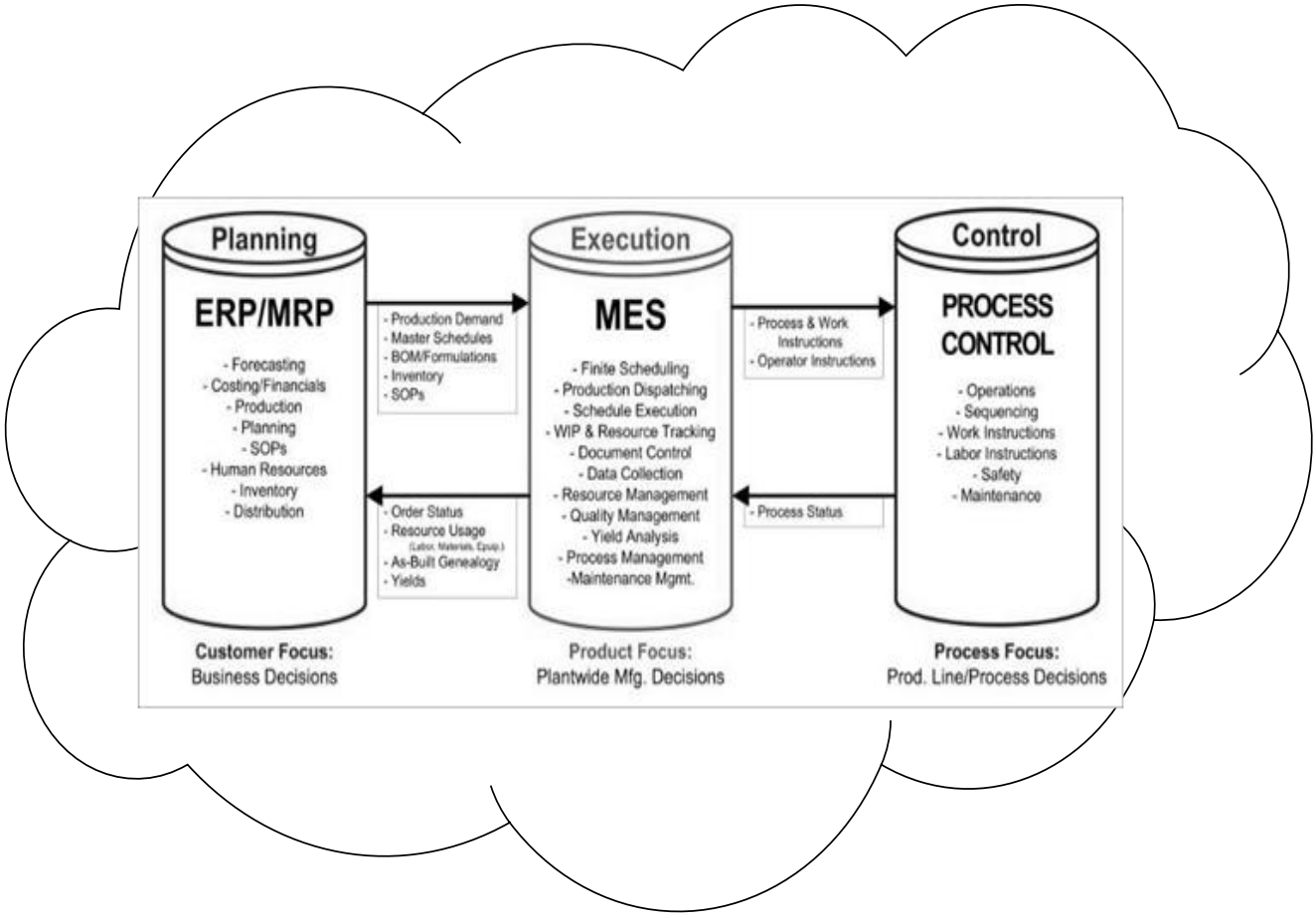


Fig. 10. Data from production in cloud [17]

But, over time and with changes in production systems, the ways and methods of management are transformed. This concern also in applies to production planning or manufacturing forms. Therefore, the diagram in Figure 10 is constantly modified. These changes are most visible on the level of data analysis/data use and data access.

2.6 Further development of 3D printing technology

Taking into account, all the advantages and disadvantages of the 3D printing, this technique is becoming more recognizable, which makes the company more competitive. Especially that, the area of 3D printing is constantly being developed. The combination of 3D printing and interactive information system, will make this technique easier to introduce for the employee, and also, to find their way in the world of 3D printing. The interactive instruction could be a help for employees, who suddenly have to do something on printer and never have contact with such solutions like this before. The idea of 3D printing has an additional advantage, which is in favour of developing this solution. This advantage is the idea of "zero waste" [29]. Living in era, where ecology is a priority, 3D printing has a chance to become, a typical production. Especially,

because of developing new materials, which gives a new opportunity for this solution. But also, new emergence of 3D printing processes - more efficient are required.

3. CONCLUSIONS

The changes in the market, influence on the functioning of enterprises. Both, in terms of technology, managed and acquired data. Nowadays the possibilities offered by technologies, are an opportunity to implement more dedicated products. Taking advantage of these opportunities, enterprises are increasingly implementing solutions dedicated to Industry 4.0 and the factory of the future.

The article describes the historical background of the develop of the fourth revolution and the changes, that took place in there. Also describes technologies that are the basis of Industry 4.0. However, in article focused on one of the technologies, namely 3D printing, which is still being developed. Nowadays, this manufacturing technique is more popular, especially, because of ability for create personalized products, and also because of the materials-filaments used in this technique, which have a better quality. The development of 3D printing and filaments have caused that, this technology have many areas of application, not only in the context of machines and their components, or marketing, but also in medicine and civil engineering. Applied of 3D printing and its further development perspective in the context of Industry 4.0, makes possibility to continue looking for solutions dedicated to this technique.

In the article, 3D print connected with possibility of context Industry 4.0 implementation, and with author's solution for monitoring and management of printing process is presented. Likewise, the concept of interactive basic user instruction, within the framework of 3D printing by an employee is presented. This is important from the point of view of quality of products and the possibility of printing personalized products.

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