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Product development and design inside Industry 4.0 from rapid prototyping to additive manufacturing

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Abstract: *The paper explores importance of rapid prototyping technology, as an important part of Industry 4.0, in product development and design process. Current state of this technology is explored in detail, with special focus of places and processes where this technology plays important role inside Industry 4.0. Paper answers several questionssuch as: does this technology have its future inside Industry 4.0, is this technology integral part of Industry 4.0 or just one aspect, has the time come to call this technology rapid manufacturing (of final products) instead of rapid prototyping (of prototypes)?Industry 4.0 implies rapid prototyping of final products, not only its prototypes. Main representative of rapid prototyping technology is additive manufacturing. Today, additive manufacturing technologies do not only serve for prototyping. They are becoming increasingly used for manufacturing of final fully functional products. Product development and design process inside Industry 4.0 must be adopted to new market demands which implies fast development and design and fast manufacturing. The time from initial concept design to the final product manufacturing must be as short as possible. The paper provides answers to the above stated questions. In addition, real examples of product development and design of prototypes and real fully functional products are presented, with a special focus on products and prototypes developed in Bosnia and Herzegovina.*

Keywords: *rapid prototyping, additive manufacturing, product development and design*

1. Introduction

There were several periods in which important changes have happened in industry throughout history. These changes have divided industry in several periods, called Industry 1.0, 2.0, 3.0 and 4.0 [1]. Nowadays, manufacturing plants are operating in the period of Industry 4.0 which is characterized by robotization, automation and rapid manufacturing. In addition, Industry 5.0 has already starting to take shape. Main characteristic of Industry 5.0 is digitalization of complete product development and design process and manufacturing process [2]. Development and design process is one of the most important parts of every period in industry. This process has changed according to the demands and needs of every industrial period. The first technology that completely changed development and design process is technology of Computer Aided Design (CAD) [3]. Through development of modern CAD software packages in the early 1990s, designers and engineers had an opportunity to make real visuals of their ideas using computer software. Today, this software has developed up to the stage where classical CAD software like CATIA, SolidWorks, Inventor, etc., isseparated from the software for design like 3Ds Max, Maya, etc. In addition, new modeling principles called Building

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Information Modeling (BIM) become most important parameter for integration of Industry 5.0. In comparison to CAD modeling which is focused on design, shape and materials, main focus of BIM is information, which is very important in today's industry. CAD and BIM technologies solved the problem of idea visualization. However, the problem of manufacturing that idea into the real product or prototype still remained. Prior to 1990s, manufacturing of prototypes was very expensive and lot of ideas from that time were never developed and manufactured as real products because their creators did not have enough funds to implement them. At the end of 1980s first machines for additive manufacturing were developed [4]. In that period, additive manufacturing has become main and most important technology for rapid prototyping [5]. High market demands for high productivity and short period of product development and design contributed to the development of these technologies. In the last decade, these technologies have become more available to the wide range of users through the development of desktop additive manufacturing machines. Additive manufacturing is an integral part of Industry 4.0. Full implementation and integration of Industry 4.0 in production process requires incorporation of additive manufacturing. Full transmission to digital hybrid manufacturing is expected by future development of additive manufacturing machines for metal materials and for hybrid manufacturing [6]. Prices of these machines are still too high. Additive manufacturing technology completely transforms product development and design process. Unique characteristics of these technologies bring a lot of advantages which are described in detail in the next chapter of paper.

2. Influence of additive manufacturing technology on product development and design process inside Industry 4.0

Computer development, together with development of Computer Numerical Control (CNC) machines, has brought total shift in the area of production and manufacturingin the middle of the last century. Every new manufacturing technology brings significant impact on product development and design process. Product designis mostly adjusted to the manufacturing technology, which provides better and cheaper manufacturing. Same as CNC machines, additive manufacturing will have major impact on manufacturing processes in the near future. This will especially happen when additive manufacturing of metal materials becomes more common and when integration of CNC machines and additive manufacturing machines becomes reality in a form of one machine for hybrid manufacturing. Additive manufacturing, together with reverse engineering technologies, has the biggest impact on future development of product development and design processes. Main influences can be seen through:

2.1. Faster development, design and manufacturing of products

One of the main advantages of additive manufacturing in comparison to the conventional manufacturing technology is the ability to reduce the time from initial concept design to the final product. Using this manufacturing technology industrial designer or engineer can produce prototype or final product in just few days, without the need to design special tools or to develop special manufacturing process. Fast manufacturing of a

prototype can significantly increase the time of the entire process of product development and design. The speed of new product development and manufacturing becomes especially important in the case of critical situations, like with COVID 19. Because of sudden and fast spread of COVID 19 virus in the world, medical workers around the world were lacking protective medical equipment (masks, visors, ventilators, etc.). In addition, it was impossible to buy this equipment, because only few countries in the world produce them. Similarly, shipping was stopped completely around the world. Today, manufacturing of almost everything is centralized in few countries and few companies (dependingon the type of products). This has become the biggest problem during COVID 19 pandemic. The only available solution was to start local manufacture of protective medical equipment. The beginning of manufacturing of polymer products, like protective visors, glasses, mask, etc., requires the design, development and production of specially designed tools (moulds). Design and development of these tools usually take several weeks in the best-case scenario (if the testing and improvement phases are skipped). Long-term development and design process was solved using additive manufacturing technology. Massive networking of people and institutions (individual makers, faculties, universities, maker spaces, innovation laboratories, private companies, schools, and others who had additive manufacturing machines (3D printers)) was organized in just a few days [7 - 10]. Protective visor, which was mostly produced, was designed and developed by Czech company *Prusa* (shown in Figure 1). This company produces additive manufacturing machines. *Prusa* company developed a CAD model of a visor in just one day, uploaded it online and production could start around the world. In just few days, millions of visorswere manufactured around the world without any development of moulds. This example shows full potential of additive manufacturing. Products are developed at one place and manufactured locally around the world. Laboratory for product development and design and Laboratory for testing of polymer materials at Faculty of Mechanical Engineering in Sarajevo also joined this world movement, as did many other places in Bosnia and Herzegovina. In this case, concept of manufacturing takes the whole new level. Basically, the whole world becomes one digital factory which manufactures the same product. The question is, is the future of manufacturing in decentralization form (again), in which user in need of some product can either buy it, or downloadfreely its data (CAD model) and manufacture it by himself or locally in additive manufacturing shop? Today, products manufactured using additive manufacturing cannot have the same quality as the products manufactured using conventional methods like machining and injection moulding.



Figure 1. Protective visors manufactured in Sarajevo (Bosnia and Herzegovina) using additive manufacturing) [11]

However, they can be functional and usable products, which is most important in the case of crisis such as COVID 19. Taking in consideration above presented example, another question can be asked: has the time come to stop calling these technologies rapid prototyping of prototypes and start calling them rapid manufacturing of real functional products?

2.2. Cheaper product development and design

By using internal departments for additive manufacturing, company does not need to use external companies for prototype manufacturing, which can reduce the cost of product design and development process. Today, most companies have opened their own departments for additive manufacturing. One of the examples is campus for additive manufacturing from BMW company shown at Figure 2. BMW company invested 15 million Euros, and today have 80 employees inside this campus. Internal departments for additive manufacturing provide more flexibility to the engineers for product development and design to create more different prototypes without additional cost for the company. In classic product development and design process only one or few prototypes were usually developed and manufactured, because external company was hired for their manufacturing, thus increasing the costs. Development of new products inside Industry 4.0 is almost impossible without additive manufacturing machines inside departments for product development and design. The next step in developmentfor companies in Bosnia and Herzegovina is to create a product development and design departments with the aim of designing and creating their own products, thus becoming more independent from the big manufacturing companies.



Figure 2. Inside of BMW campus for additive manufacturing [12]

2.3. Increase of product development and design efficiency

Results of product development and design process are not always successful, since final product is not always successful in the market. A lot of them do not reach the market at all. Sometimes errors are found in late phases of the manufacturing process or even after the launch of the product in the market. It is very important to eliminate all errors before the product launches. By developing and manufacturing a large amount of prototypes, errors can be significantly reduced. Using prototypes, it is possible to test the product functionality, shape and market response, even before its launching. During prototype testing, a lot of errors can be eliminated, and efficiency of product development and design process can be increased.

2.4. Design freedom

Before additive manufacturing, industrial designers and engineers were restricted to the conventional manufacturing technologies which cannot provide the answer to the manufacturing of any shape and size with acceptable cost. By using additive manufacturing, it is possible to produce and manufacture any shape of the product or its components. This property of additive manufacturing bringsfull freedom to the industrial and product designers regarding the shape of the product. Figure 3 shows use of additive manufacturing in shoes production. It would be impossible (or almost impossible) to produce this design using conventional manufacturing methods. With better integration of additive manufacturing inside the production process, different and diverse products can be expected in the market. Today, mass produced products usuallylook almost the same by all manufacturing companies, because most of them use the same manufacturing technologies and most of the time they buy certain parts for their products from the same external manufacturing company. In conventional manufacturing technologies every significant change in design would also have significant change in the price of manufacturing. This is not the case in additive manufacturing. Shape of the product is not connected to the production price of that product.



Figure 3. Sport shoes manufactured using additive manufacturing [13]

2.5. Manufacturing of generative design products and products with internal infill structure

Generative (topology optimized) design is basically almost ideal design regarding the stress distribution or minimum material used. It is generated using advanced computer optimization algorithms. Complex geometrical structures are generated using generative (topology optimized) design. These structures are generated according to the natural distribution of stress inside the product. Figure 4 shows brake calipers designed using topology optimized design from Bugatti company. This shape of the calipers can be manufactured only by using additive manufacturing. The shape of the calipers has several advantages in comparison to the regular one. Less material is used, due to which they have less mass in comparison to the regular one. In addition, better cooling can be achieved because the parts have more holes inside.

Furthermore, machine elements and parts can be designed with some kind of internal infill structure inside and manufactured using additive manufacturing. Usually, all machine elements have homogeneous solid body structure with full material inside, even at the places where it usually is not necessary. This is not always the case with additive manufacturing. Inside shape of elements can have any structure designer or engineer wants (taking into consideration all necessary mechanical, design and functional properties of designed element) with the aim to reducing material consumption, thus reducing the mass of the element. Figure 5 shows section view of gear tooth with optimized internal structure. This shape of the gear can be manufactured using only additive manufacturing.
Lots of authors agree that future will bring designs in which internal functional components (machine elements) will be generated using generative (topology optimized) design, while the outer parts will be designed using full freedom regarding the shape of the product body.



Figure 4. Brake calipers for Bugatti sport car [14]

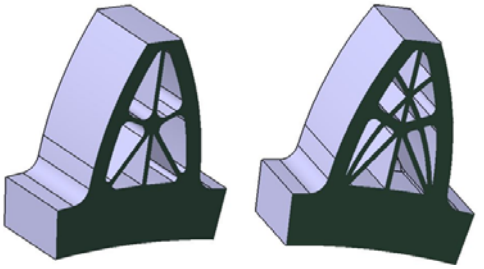


Figure 5. Section view of gear teeth with different internal infill structure [15]

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2.6. Development and design of products adjusted to user needs

Using the advantages of additive manufacturing, specially designed and user-adjusted products can be manufactured without significant price increase in comparison to the regular products. Additive manufacturing uses digital data for manufacturing (CAD models). Adjustment and personalization of that data is easy and it does not significantly affect the manufacturing price. Using this methodology, every product can be specially adjusted to a single user. Oneexample is glasses. There are several companies in the world that produce glasses which are specially adjusted to a single user regarding individual wishes andshape of the head. In the case when glass frame is manufactured using standard injection moulding process, for every shape of the frame new mould must

be designed and manufactured. Mould development and manufacturing is a long and expensive process. Similar cases can be found in medicine in the area of prosthetics. Using reverse engineering technology (3D scanning) it is possible to produce prosthetics parts which are adjusted to the body shape of every patient individually. Products are more comfortable with less material used. In addition to the medical protective equipment, another world movement has starteda few years ago. It's called eNable movement and it exists in Bosnia and Herzegovina also [16]. Main goal of this movement is to develop and manufacture more affordable and cheap prosthetic hands around the world. Prosthetic hand manufactured in Bosnia and Hercegovina by eNable is shown in Figure 6. Products are free for download to everyone. Ifanyone wants to produce it, all they need is one desktop low-cost 3D printer. By using additive manufacturing, it is possible to produce low-cost prosthetic hand, with basic functionality anywhere around the world [17-20]. Figure 6 shows hand cast designed according to the shape of user hand and manufactured using additive manufacturing.



Figure 6. Prosthetic hand manufactured using additive manufacturing [16]



Figure 7. Hand cast designed according to the shape of user hand and manufactured using additive manufacturing [21]

2.7. Development and design of ''multi-material'' products

Conventional manufacturing technologies can produce parts in such a way that whole part consists of only one material, which can then be connected using, for example, welding process. On the hand, by using additive manufacturing it is possible to manufacture one product using more materials during one manufacturing process. This is called Multi Material Design (MMD) and Multi Material Manufacturing (MMM). This property of additive manufacturing opens whole new area of design, where one part of

the machine element can be manufactured using one material and another part using another material. For example, better material with better mechanical characteristic can be used only at the critical places on the part, while the material with poorer characteristic can be used on another part of the product. A lot of different combinations can be achieved regarding mechanical, thermal or tribology characteristics. By the right choice of the material at the specific place of the part, it is possible to adjust that part of the product to the physical properties of that place. Figure 8 shows multi-material design of gears using two materials. Gear toothis manufactured using Polyamide material and the rest of the gear is manufactured using Polyethylene terephthalate material. Polyamide material has great tribology characteristic which is important for the surface of the gear tooth.

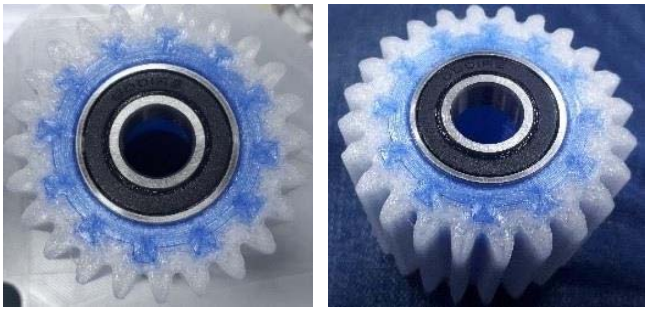


Figure 8. Gears manufactured using two different materials [22]

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2.8. Better and simple assembly using multiple parts integration

During product development and design process, special focus needs to be put on the problems associated with the assembly of each individual part of product. Using additive manufacturing technology, it is possible to simplify assembly of parts using integration of multiple parts into one part. As stated earlier, by using additive manufacturing it is possible to produce almost any shape of the product. By taking advantage of this property, multiple parts can be integrated and manufactured as one part only. This reduces time and saves costs, and at the same time increases efficiency of assembly process. In addition, it significantly simplifies the design. Figure 9 shows example of around 300 parts integrated with only one part which will be manufactured using additive manufacturing.



Figure 9. Integration of around 300 parts into one part [23]

Using this methodology, assembly of these 300 parts is completely avoided. Large number of parts are integrated in this example, since in conventional manufacturing this assembly must have large number of screws and bolts to connect the main parts. Removing screws and bolts, time of assembly process for this product is drastically reduced which also has positive effect on the price of the product.

2.9. Development of low-cost desktop additive manufacturing machines (3D printers)

Today, 3D printers are basically available to everyone, from the individual industrial designers to the product users. Availability of these machines enables individual industrial designers, product designers and innovators to develop and manufacture their products without significant costs. In some cases, not only prototypes, but also final products are ready for sales. As a result, there is growing number of individuals who design, develop and manufacture final products. The following figures show some of the final products designed, developed and manufactured in Bosnia and Herzegovina by the individuals.



Figure 10. Educational version of fully functional endoscope manufactured using additive manufacturing

Figure 10 shows fully functional endoscope developed and designed for European market by one of the authors of this paper (Adi Pandžić) and manufactured using additive manufacturing in Bosnia and Herzegovina. Around 200 copies will be manufactured and used for educational purposes as fully functional products. Figure 11a shows educational version of three axis CNC machine which was developed and designed as a part of Master thesis under the supervision of one of the authors of this paper (Adis Muminović), and manufactured at the Faculty of Mechanical Engineering in Sarajevo using mostly additive manufacturing. Figure 11b shows fully functional air filtration device for small closed spaces like rooms or offices. This device was also designed and developed as a part of Master thesis under the supervision of the same mentor. All these products are great examples of fully functional products which are designed, developed and manufactured by single person without the use of large manufacturing factories and without development of special tools.

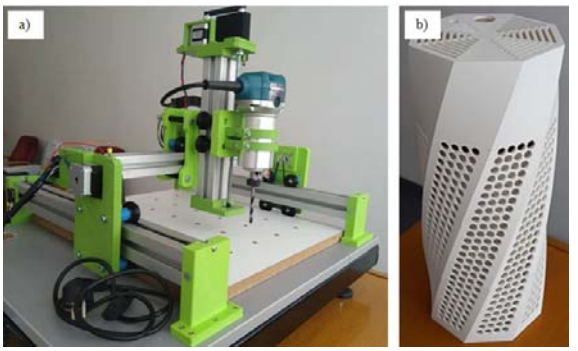


Figure 11. Educational version of three axis CNC machine(a), air filtration device for small closed spaces(b)

2.10. Better and easy ergonomic testing

Ergonomic of the product is one of the fields which is very hard to test using only virtual CAD models. A lot of products visually look great and it seems that they have great ergonomic properties, but after their manufacturing, real ‘’feel’’ for ergonomic properties emerges. Using additive manufacturing, industrial designer can produce large number of different concepts of the product for ergonomic property testing without significant cost. Figure 12 shows prototype of the device which is developed to help visually impaired people to read. This product is developed at the Faculty of Mechanical Engineering in Sarajevo as a part of Master Thesis in cooperation with the Zrakd.d.ompany from Sarajevo. Product is designed with the association to the shape of the company name. Only after manufacturing of first prototype, a lot of bad ergonomic properties were noticed. Product is too large for easy manipulation.



Figure 12. Reading device for visually impaired people

3. Conclusion

Development and design process, as one of the integral parts of Industry 4.0, are going through radical changes today. Time used for product development and design is getting shorter every day. Market demands quality products with rapid development and design process. Time period used for design, development and manufacturing of a prototype in the past can today be used forthe entire process, from initial design up to final product manufacturing. Technologies, usually named rapid prototyping in the past, are called rapid manufacturing today. Additive manufacturing is the only one that can answer the

above-mentioned demands. The paper presents fields of product development and design where additive manufacturing has the biggest influence. Using practical examples, with the focus on products developed, designed and manufactured in Bosnia and Herzegovina, advantages of use of additive manufacturing in comparison to conventional manufacturing technology was presented. Full implementation of Industry 4.0 must include full implementation of additive manufacturing technology in all areas of industry, from product development and design, through manufacturing of final products, to maintenance and logistic for production processes. In future, more replacement of traditional manufacturing processes with additive manufacturing can be excepted, especially in the area of metal materials and hybrid manufacturing. Hybrid manufacturing is a combination of additive manufacturing and conventional machining in one machine. Additive manufacturing is used for production of complex shapes of the product, whereas machining is used to achieve needed surface quality and tolerances.

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