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ELEMENTS OF INDUSTRY 4.0 IN OBRUM'S ACTIVITIES

Abstract. This article discusses some new challenges posed by the ongoing fourth industrial revolution. The technological areas that make up Industry 4.0 are shown. One of these areas of technology, 3D printing, which is one of the dynamically developing pillars of Industry 4.0, is synthetically described. Examples are given and described of components made in 3D printing technology in the course of OBRUM's completed projects. The importance of the issues and necessary changes in the Polish industry and education system is accentuated in the summary.

Keywords: Fourth Industrial Revolution, Industry 4.0, 3D printing, additive technologies, Silesian Competence Centre for Industry 4.0, Future Industry Platform.

1. INTRODUCTION

Rapid changes in manufacturing processes and management methods in modern industrial facilities are associated with the widespread introduction of new technologies and production organization. For instance, use is made of: elements of artificial intelligence, or mobile communication for the transmission of data that allows devices to communicate with each other using the Internet of Things. Robots and robotic production lines are being used increasingly.

All of these changes, referred to as the Fourth Industrial Revolution and dubbed Industry 4.0, are widely discussed in numerous publications [1, 2, 3, 4, 5, 6]. It has been assumed that the term Industry 4.0 was adopted at the Hanover Fair in 2011 [1]. Other terms used as synonyms include: Factory 4.0 [5], or Industry of the Future [14].

The changes that are taking place are characterized mainly by progressive digital transformation, creation of a network of connections between products, value chains and business models. Industry 4.0 also collectively describes the automation associated with data exchange, as well as new technologies and methods of production supervision [4].

Industry 4.0 may be portrayed as an advanced digital transformation of value chains, products, services and business models. Graphical representation of the links between the elements of Industry 4.0 are shown in Fig.1 [4].

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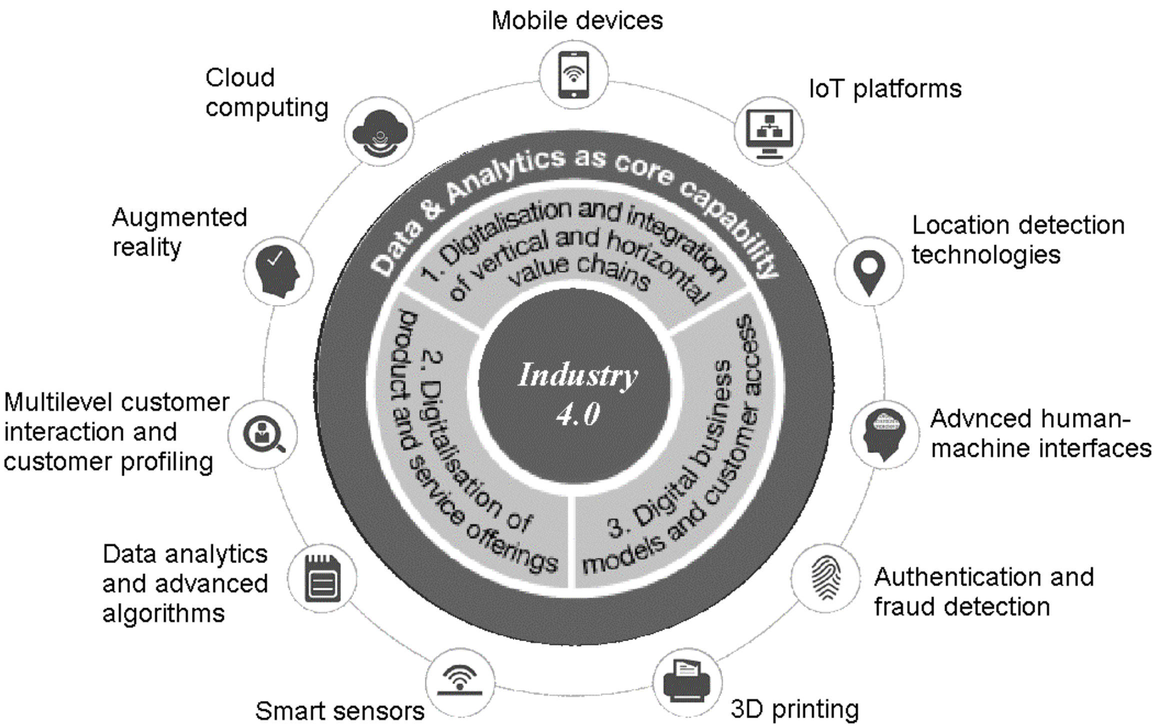

Fig. 1. Elements of Industry 4.0

In its current research and development activities OBRUM makes use mainly of two areas of technology distinguished in Fig.1: Augmented Reality (AR) and 3D printing. The latter of these areas is described in this article. AR, due to the different nature of the issues, requires a separate discussion.

2. MACHINE AND EQUIPMENT MANUFACTURING TECHNOLOGIES [9]

In the processes of making parts of machines and equipment from various materials, both on an industrial scale and in small-lot production, three basic manufacturing technologies are used: casting, plastic working and subtractive processing. In addition to these, incremental/additive techniques are also used (additive manufacturing). Widely used manufacturing technologies also include: heat treatment, thermochemical treatment and coating. These technologies are not applied in the processes of part forming.

Below (Fig. 2) is a block diagram of the classification of product manufacturing technologies, where additive manufacturing is included.

metal alloys casting: sand, continuous, chill, centrifugal, pressure die, shell, lost model and other	**Manufacturing methods**
metal alloys plastic working: stamping, open die and closed die forging, bending, rolling, extruding, spinning, stretch drawing and other	
subtractive processing: machining (turning, milling, drilling, chiselling, planing, broaching and other), grinding, die-sink and wire-cut electrical discharge machining	
processing with concentrated energy flow (laser beam, electron beam, plasma cutting), welding (gas, electric), spot welding, soldering, adhesive bonding, depositing	
plastics processing: preform blowing, thermoforming, laminating, rotational moulding, casting in silicone moulds, pressure injection and other	
heat and thermochemical treatment: (hardening, nitriding, annealing, ageing), coating (painting, metallizing, galvanizing)	
powder sintering: powder metallurgy	
additive methods: (SLA, LOM, FDM, JM, SLS, SDP, DLP and other)	

Fig. 2. Classification of forming/manufacturing technologies [9]

3. ADDITIVE MANUFACTURING – 3D PRINTING

Additive manufacturing, in contrast to subtractive processing, consists in applying building material or combining previously prepared pieces of materials. In additive manufacturing use is also made of sintering, hardfacing and irradiation (laser, UV lamp, projector). In additive manufacturing the model is created as a result of adding material, although it may also be the result of curing a liquid (resin) or sintering a powder [9].

Rapid progress in 3D printing is, among others, the effect of industry's demand for quick access to prototypes of new parts and subassemblies, as well as of the development of modern software for spatial surface and solid modelling.

The physical model is built based on a design created on a computer using 3D CAD software.

The designed geometry of the object is subjected in the next stage to processing with the use of slicing software. Processing of the 3D model of the object with that software consists in "cutting" it into layers (slices) and transcribing into a machine code (.gcode) which controls the printer.

There are a dozen or more additive manufacturing methods. Not all of them have found wider application. The following are the better known [8], [9]:

- FDM (Fused Deposition Modelling) is a method where modelling is done with liquid thermoplastic which is extruded in the form of a filament. The method was first developed in 1992 and it was patented in USA.

- SLA (or SL, stereolitography) is a method of rapid prototyping. It is based on resin polymerisation initiated by UV radiation. The method, invented in USA, has benn known since 1986. There are variations of the method which differ in the radiation source used: SLA (laser), DLP (projector), LCD (LCD panel).

- SLS (Selective Laser Sintering) is based on laser sintering of powders of various materials. The technology emerged in USA in 1989.

  One variation of this method, where only metal powders are sintered, is DMLS (Direct Metal Laser Sintering).
- JM (Jet Modelling) covers methods where the model is created from drops of fluid material ejected from a nozzle (like in an inkjet printer) and cured afterwards.

  This group of methods includes MJM (MultiJet Modeling) where multiple jets of liquid polymer are used. The polymers usually used include waxes, which can be melted, or acrylic resins, which can be cured with UV light.
  An interesting variation of MJM is PJM (PolyJet Modelling), and its expanded version - PolyJet Matrix. Here several different construction materials can be blended to attain desired mechanical properties.

The technologies/techniques named above differ between themselves in:
- the manner in which the objects are created, e.g. melting, irradiation, deposition, sintering;
- the type of material used for creating the object, e.g. plastics, metals, resin;
- limitations determined by the geometry of the object created;
- post-processing.

Additive techniques, as compared to "traditional" methods of manufacture, are usually less accurate, and the objects created are less durable. Additive manufacturing has found wide use in the construction of mock-ups for fairs and exhibitions. In everyday language this mode of fabrication is referred to as rapid modelling [9]. The techniques used nowadays in fact enable fast and repeatable manufacture of parts and subassemblies. This mode of processing is called rapid prototyping [9]. There are variations among the rapid technologies: RP, RM, RT [9]. In the case of additive manufacture of components assembled in final products, it can be assumed that they are implemented by rapid manufacturing techniques. This group includes FDM.

3.1. The principle of additive manufacture using FDM

3D printing in FDM technology is the most economic and one of the simplest methods of creating objects with additive methods. Here the thermoplatic material is fed in the form of a filament (Fig. 3, item 1) by means of a knurled roller to an ekstruder (Fig.3, item 2). There a heating unit (Fig.3, item 3) heats the material to the desired temperature and the heated material is pressed through a nozzle (Fig.3, item 4) directly onto the object being created layer upon layer (Fig.3, item 6). In the nozzle (Fig. 3, item 4) the thickness of the filament bundle (item 1) is reduced as desired.

Fig. 3 shows a diagram of a 3D printer which uses the FDM technology.

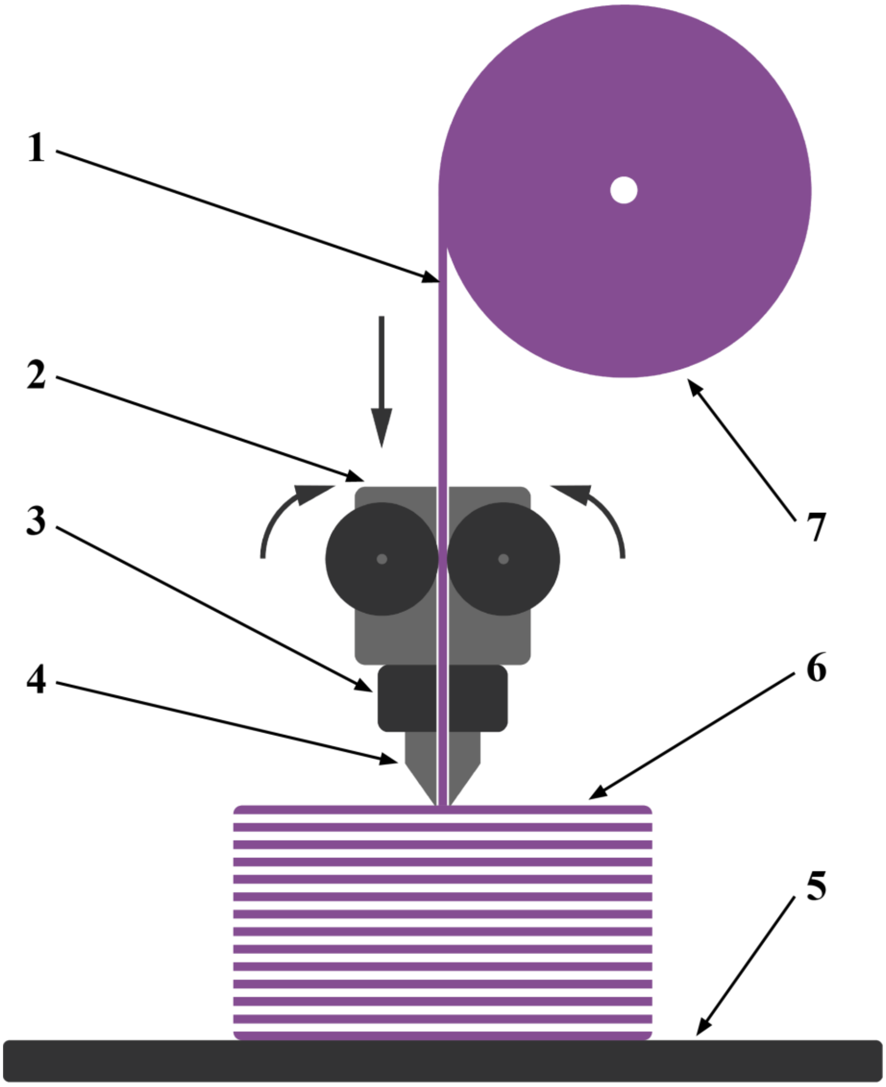

Fig. 3. 3D printer – structure and operating principle

1 - filament
2 - extruder
3 - heating unit
4 - nozzle
5 - print bed
6 - printed object
7 - filament spool

Major advantages of FDM include:

- low cost equipment and consumables;
- object is complete and ready right after printing;
- wide range of available materials and colours;
- object may be hollow (substantial time and material savings).

This manufacturing method has also its disadvantages:

- the layers of the building material are discernible;
- there are limitations on the geometry of the object.

The device used at OBRUM for additive manufacturing, a 3D printer, is shown in Fig. 4.

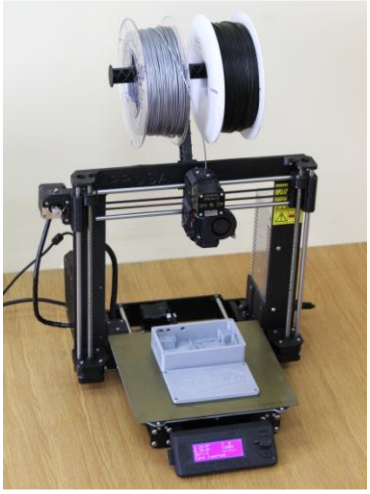

Fig. 4. 3D printer
(photo by OBRUM sp. z o.o.)

3.2. Application of the FDM technology in OBRUM's projects

In OBRUM's completed development projects, rapid manufacturing techniques were used to manufacture parts and subassemblies of the LEO 2A4 tank driving simulator. The important parts included:

- covers for control and measurement instruments (Fig. 5)

Fig. 5. Control and measurement instruments

a – CAD models **b – final products**

Parts (Fig. 5) were made using 3D printing due to the lack of original parts and their replacements which are no longer produced. The devices also required redesigning, as the previous were analog devices, and the new ones had to be digital. The application of the additive method allowed to reduce manufacturing costs and shortened the time needed for designing, fabrication and making final corrections in the elements made.

- moulds for silicone castings – Fig. 6

Fig. 6. Silicone castings

a – rear headrest **b – upper headrest** **c – night vision eyepiece**

For the manufacture of flexible elements (Fig. 6), even though they were made using the casting method, 3D printing technology was also used. Unlike in the case of control equipment, this technology was not applied to directly make parts. 3D printing technology supported the process of fabricating rigid moulds as well as elements for fabricating flexible moulds.

Here again the original parts could not be used in the simulator as such were no longer manufactured. Individual parts found in warehouses were expensive and did not satisfy the current needs of the project, as well as the next batch of simulators. The optimal solution was therefore to make new elements using the casting method. Thanks to the use of 3D printing, the cost of manufacturing plastic moulds has been significantly reduced compared to the cost of manufacturing metal moulds made using subtractive methods. As in other projects, the time needed to create new elements that were missing has also been shortened. All of the manufacture could be effected at OBRUM, with no need for contractor work. Contractor participation would involve the release of data to the outside which, in view of the nature of the project (a simulator for training on military equipment), would pose an additional difficulty.

3D printing was also used to fabricate housings:

- electronic equipment housing – Fig. 7 (MS-20 project)

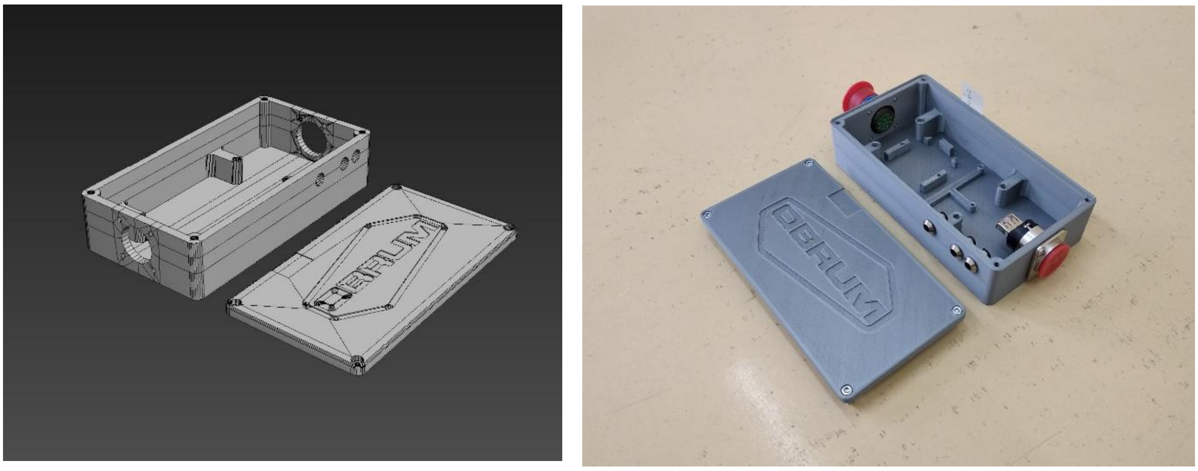

Fig. 7. Electronic equipment housing

a – CAD model **b – final product**

Elements (Fig. 7) made with the use of 3D printing were used for installing electronic systems of the MS-20 wheeled bridgelayer diagnostic system. Although housings of similar purpose are commercially available, OBRUM decided to make them on their own. The fabricated complete housing did not require any machining. It had all the necessary supporting components and mounting holes.

4. 3D PRINTING APPLICATIONS

After years of trial and error, additive technologies, mainly implemented by 3D printing, are now being implemented for use in large-scale industrial production. A large market for manufacturers of printer using additive technologies, including FDM methods, has been created. The degree of complexity of printers varies from those intended for mass production [8], [9] to simple printers that can be constructed and used by individuals at home [10].

The range of 3D printing applications [7] is enormous::

- industry - tools, prototype production, unit production, parts of industrial machinery and equipment (aviation industry, automotive industry, space and defence industry, electronics industry);
- civil engineering;
- medicine (dentures, surgical implants, prostheses);
- education;
- food industry.

The problem of intellectual property of a designer or manufacturer of a product is still unresolved and legally complicated Availability of the described technologies allows copying of products, either by illegally obtaining a CAD model or by scanning the body of an item, and then printing a full-value product on a 3D printer.

The broad aspects of 3D printing, including intellectual property rights and the economic consequences of the availability of new technologies are discussed in the literature [7].

5. SUMMARY

Industry 4.0 is developing very intensively, especially in highly industrialized countries like the US or Germany, with high labour costs. More and more elements that compose Industry 4.0 (Fig. 1), in its broad sense, is being implemented into practice in various branches of the economy. Challenges, that the world's fourth industrial revolution brings, apply to virtually all industries, including those in Poland, and the defence industry. One of the most important effects of introducing new technical and organizational solutions is the significant reduction in manufacturing costs. Prospects for cost reductions resulting from the implementation of new technologies in various branches of global industry are shown in a diagram/graph (Fig. 8).

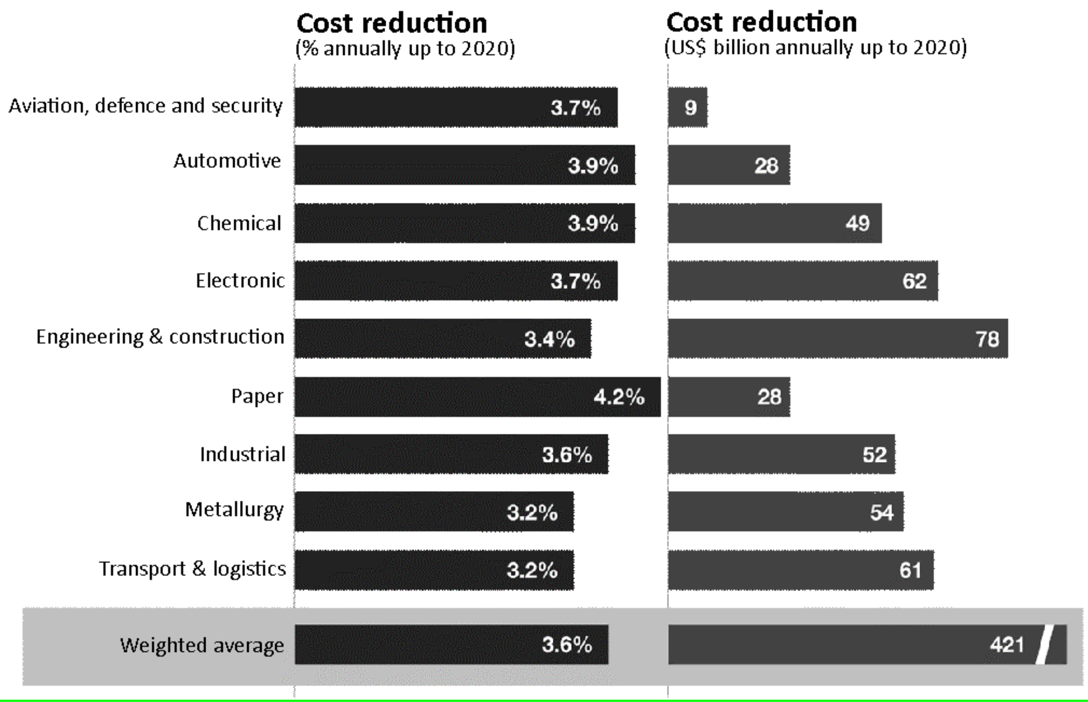

Fig. 8. Reduction of manufacturing costs – forecast [4]

One should be aware that changes that are necessary in businesses that implement new areas of Industry 4.0 require significant financial resources. If Polish companies fail to find external sources of financing, including foreign capital, they may be unable to cope with the implementation of the concept of Industry 4.0 [12].

In Poland, analytical and research work is carried out to assess the possibilities and proposed ways of proceeding to prepare businesses to implement the concept of Industry 4.0 [11], [12]. Implementing new concepts in industrial practice requires the availability of human resources, appropriately trained specialists with new competences [13]. The emerging needs force necessary changes in education at both the higher and the middle level. The Silesian University of Technology in Gliwice has an interesting offer, recruiting managers for "MBA Industry 4.0" post-graduate studies [14].

The importance of the problem in the aspect of the domestic market was also noticed at the state level. In order to enable Polish entrepreneurs consult Industry 4.0 specialists, a special foundation, "Future Industry Platform", was established [15].

Other initiatives are also being taken, the pilot example of which is the establishment of the Silesian Competence Centre for Industry 4.0 in Gliwice. The Centre [6] functions as a consortium formed by the Katowice Special Economic Zone and the Silesian University of Technology in Gliwice.

In 2019 OBRUM entered into the field of Industry 4.0 and started cooperation with the Silesian Competence Centre for Industry 4.0. The first element of cooperation was the signing of a Letter of Intention [16].

Due to the small-scale nature of manufacture at OBRUM (mainly small-lot production and the construction of models and prototypes), 3D printing / additive manufacturing methods (making unique parts and subassemblies) are at the forefront of the Industry 4.0 operations. Another important area of work are design projects where AR techniques dedicated to military customers are applied, mainly for training purposes [17]. Other elements of Industry 4.0 include works conducted at OBRUM in the area of complex automation systems projects, including human-machine interfaces and simulation techniques [18].

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Abstract.

Key words: