SAVONIA

THESIS - **BACHELOR'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

TRANSFORMATION CAUSED BY 3D MODELING AND ADDITIVE TECHNOLOGIES IN THE FIELD OF MECHANICAL ENGINEERING

Author/s: Polina Danileva

SAVONIA UNIVERSITY OF APPLIED SCIENCES	THESIS Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Mechanical Engineering			
Author(s) Polina Danileva			
Title of Thesis Revolutionary Alterations That 3D Modeling and Additive Technologies Brought to Mechanical Engineering			
Date	11.11.2020	Pages/Appendices	40
Supervisor(s) First: Anssi Suhonen Second: Mikko Nissinen			
Client Organisation /Partners			

Abstract

This researching material is aiming towards describing the alterations the mechanical engineering industry faced with the development of 3D modeling. As the new technology is applied, it needs time to be adapted to the existing structure, therefore, it changes the arrangement of the system and brings new possibilities as well as questions to the industry. The material covers all the aspects of the affect the CAD method brought or will bring, existing issues at hand etc. Even though the potential of 3D modeling and its aspects implies the revolutionary possibilities, there is still more to go through before reaching the peak of advantages.

Keywords
Mechanical Engineering, 3D Modeling, CAD, Additive Manufacturing

CONTENTS

1 INTRODUCTION

1.1 Motivation and Purpose

I would like to start off with the motivation towards the choice of this particular topic for the Thesis. The main reason is the fact that 3D modeling and engineering technical design is the most attractive sphere of professional orientation which I would like to join in the future. Thus, this research will help me get in-depth and thorough understanding of the certain field I am considering working in as well as will provide an additional practical information about it. I believe that 3D modeling together with 3D printing have the biggest future potential in terms of building and creating, hence, it is essential to point out the current progression in comparison with the past technological and engineering processes which were replaced due to development of the whole field.

1.2 Briefly about Thesis topic

The topic implies research of the overall impact that 3D modeling has on the Mechanical Engineering field. As the 3D technology considered modern, engineering industry altered a lot in a relatively small time period. The changes are reflected in a vast amount of factors, which should be considered by those who are already in the industry and also the freshmen interested in making it to the field as professionals. This research covers the information on the previous states of the industry, current and, also, the future perspectives for the engineers.

All in all, the topic consists of the research on the topic from several sides as well as comparison of methods and stages of development in terms of progression.

2 HISTORY OF ENGINEERING DRAWING

2.1 Antiquity and the Basis

"Engineering Graphics" is an essential and unique so-called language of humanity in general, which is capable of uniting civilizations without words. Being one of the oldest languages in the world, it is distinguished by its accuracy and clarity. Engineering Graphics can be simply described in only two signs – dot and line. If you trace the development path of the drawing from ancient times to today, we can distinguish two main areas. Firstly, construction drawings, intended for the construction of housing, industrial buildings, bridges and other facilities. Secondly, industrial drawings, which created various tools and machines.

Long time before people created writing, they learned to draw objects surrounding them. At first, the soil, cave walls as well as stones served as a material, on the surface of which the drawings were scratched out with use of a simple stone. Then, with further development of tools and civilization in general, dwellers were using birch bark, leather, papyrus, paper and other materials in order to imprint drawings with an ink on it. Only at the end of the 18th century the pencil started being usable to draw graphics.

The necessity of construction drawings dates back to the time when people were making real-size plans directly on the land for the construction of dwellings, premises for storing utensils as well as wintering livestock. This was done using primitive devices. Linear dimensions were made with marking compasses, circles were drawn using a rope and two pegs. One peg was driven into the ground as a center and the one, which was on the other side of the rope, drew a circle.

In V - IV millennium BC in Egypt and Babylon, in connection with the construction of irrigation systems, people of that time began to use various land surveying tools and other aids such as measuring poles as well as leveling with water. During this period starts the development of measurement of flooded areas, which laid the origin of geometry. For the construction of large facilities such as, for example, the pyramids, temples, dams and canals, drawings and sketches were essential in order to create a fully functioning facility. The oldest evidence of the appearance of the drawings is the plan of the house from the XXIV-XXIII centuries BC which was taken from the area of Mesopotamia and is still preserved. The ancient Egyptians had a well-developed idea of planning and spatial relations as well as technical sketching skills. The excellent examples would be various preserved building plans and the secondary aiding sketches of those times, for example, the plan of the tomb of the Egyptian pharaoh Ramses IV (about XII century BC) or Nubian gold mines dated XIII century BC.

A graphic display of architecture on a plane surface is a distinguishing feature of an ancient Egyptian art which was based on the following of orthogonal projections principle. Thus, it was appearing in certain methods of planning, for example, usage of rectangular grid pattern in order to achieve organized layout, mark it accordingly to the main purpose, transfer configuration, modules, and apply geometry rules. As the result, there were two approaches to creation of graphics on the plane. The first one is plastic, which was used for the identification of a three-dimensional image. Secondly, the schematic approach, which aided to identify the objective characteristics of an image.

In ancient Greece, graphics were used in the design of different monumental structures to show the purpose and use of mathematics. The foundation of precise and natural sciences made a big leap for the development of graphics.

A major contribution to the theory of technical image was made by Leonardo da Vinci which was a genius of that time, the artist and scientist of the Renaissance, French geometer and architect Girard Desargues, who managed to give the first scientific justification to the rules of perspective drawing, and, last but not least, is a French engineer Gaspard Monge, who published his work "Descriptive geometry" in 1798, which is the basis of the projection drawing. Gaspard Monge’s publications are still used nowadays as he generalized the method of rectangular projection of objects on two mutually perpendicular planes.

2.2 Techniques

Continuing about the origins and foundations of the technical graphics, it is necessary to sum up and describe thoroughly the techniques, which were created during the last millennium, creating sophisticated methods to solve the designing issues on different levels of difficulty.

2.2.1 Perspective

This technique was founded in the Renaissance due to the fact that at this period of time the trend for realism in art reached its peak. This system of transmitting the visual perception of spatial forms and space itself on a plane surface made it possible to solve the problem faced by architects and artists. Many of them used glass pieces to determine the perspective as they traced the view of the required objects in its natural form without any possible mistake whereas, for example, if they were only drawing by observing the objects and simply putting them down on paper, it would have taken much more time to comprehend and master the basics.

In a nutshell, perspective can be described as a method of transferring an image of an object on a plane surface exactly as it appeared in a certain position in a three-dimensional space from a certain angle of view. This method contains various types in it. Firstly, one of the most important is the direct linear perspective, which can be described as a method of assuming that every line of the object is connected to a certain point on the horizon, where they all connect if prolonged to it. Therefore, the object is getting smaller the further its facets get to the horizon point. Also, the method implies the use of several points of perspective in the more complicated compositions.

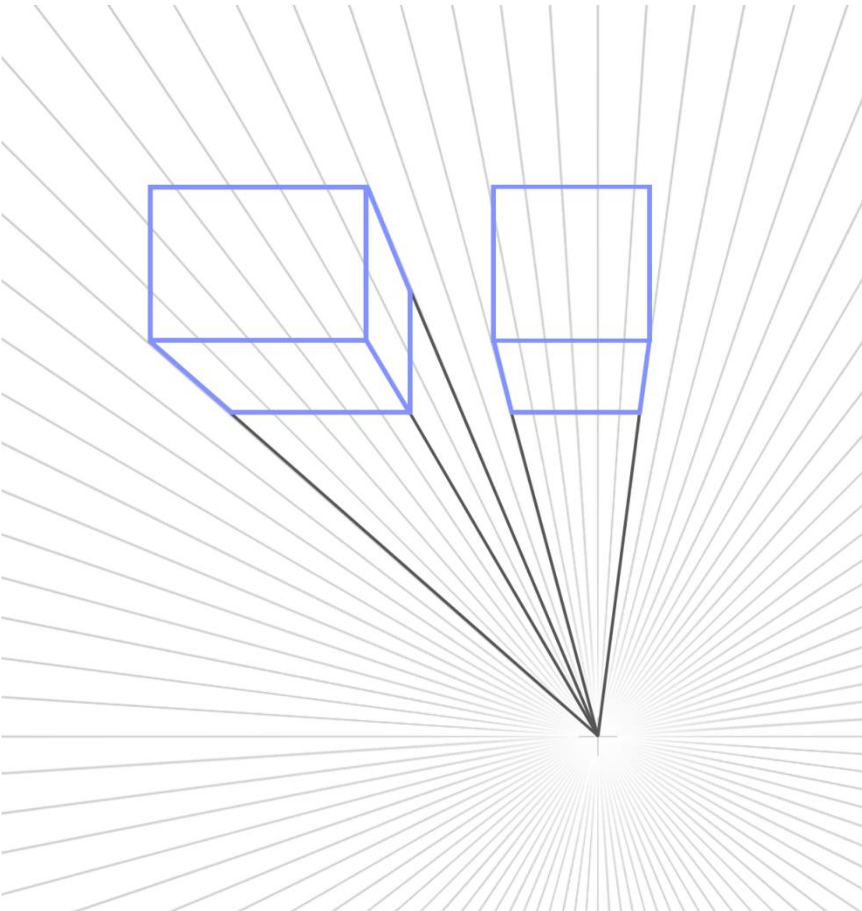

Figure 1: Direct linear perspective to one point

2.2.2 Descriptive geometry

As it was mentioned above, the founder of the descriptive geometry is Gaspard Monge, who published his studies in 1798 after a long research on a topic. This study can be characterized as the base of technical drawing. It represents the geometrical principles of spatial figures which are studied by projecting with perpendiculars on planes in order to achieve all sorts of necessary side views of an object. So, to put it simply, the views created with the knowledge on descriptive geometry represent all the required information to create, for example, a device, part piece, mechanism or, in that case, anything that can be manufactured.

2.2.3 Manual Drafting

Not that long ago, there was no 3D modeling to assist production of technical documentation. Therefore, in order to somehow speed up the process, various tools were made to help engineers. All sorts of rulers, pens, pencils and compasses were upgraded for multitasking purposes as well as templates in all shapes and forms had a good use in the industry. In addition, drafting machine played a big role in hastening of the processes, eventually replacing some of the devices which were no longer efficient for a greater production.

3 COMPUTER AIDED DESIGNS

3.1 History

The formation of the theoretical foundations of CAD began in 1950s. The concept is based on a variety of mathematical models, such as, for example, the theory of B-splines, which was developed by Isaac Jacob Schoenberg in 1946. In a nutshell, B-splines theory is based on the principle of the curve degree being related to the amount of dots and their position. As the computing power is not limitless, especially back then when systems were less developed, this solution was optimal to reduce the number of dots needed to be comprehended by the system. So, the work of P. Bezier, who gave the name to B-splines, in the 60s was devoted to modeling curves and surfaces of any shape and was taken as the starting ground for the computer designing. Therefore, during this period, the structure and classification of CAD was formed.

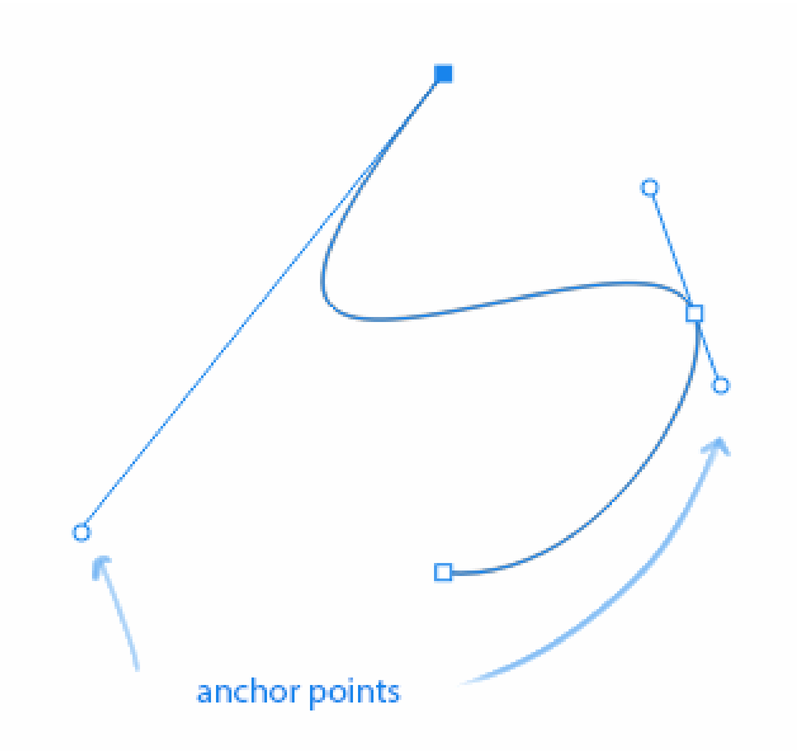

Figure 2: Example of a spline

At the first stage of development, the capabilities of the systems were largely determined by the characteristics of the under-developed computer hardware available at that time. To work with CAD systems, graphic terminals connected to mainframes were used. The process of designing mechanisms and their parts starts with determining the geometry of the future product, so the history of CAD systems began with the creation of the first graphic station. The first interactive CAD station was called Sketchpad, it was founded by Ivan Sutherland in 1963 and utilization of it required a light pen in order to draw on its display.

This technology was a leap for the designing at that time, opening new horizons for various examples of use.

As the system was developing, it started to be considered a valuable tool for the various fields of science. During this period the basic CAD subsystems were sorted into geometric, strength, aerodynamic, thermal, technological, etc., later they began to be classified as CAD, CAE, CAM, PDM.

CAD is based on the subsystem of computer graphics which main design procedure is to create a geometric model, since any material objects are described mainly by geometric rules and parameters.

CAD systems for technological preparation of production or Computer Aided Manufacturing (CAM) carry out the design of technological processes, modeling of mechanical processing, etc. in accordance with the created geometric model.

CAD systems of engineering analysis or Computer Aided Engineering (CAE) allow you to analyze, simulate or optimize the mechanical, temperature, magnetic and other physical characteristics of the developed models, to simulate various conditions and loads on the parts.

Last but not least is the engineering data management system or Product Data Management (PDM) provides storage and management of design documentation for developed products, maintaining documentation changes, preserving the history of these changes, etc.

The further innovations of computer graphics were held back not only by the hardware capabilities of current computing power, but also by the features of the overall system. Since the end of 60s and the beginning of 70s of the last century, a standard for graphic programs has been developed. Ivan Sutherland together with David Evans started the first company which goal was in producing 3D graphics software. This successful example led to a several other opportunistic founders who started developing their own concept based on that idea. Eventually the market has received several other products programmed to help with designing. Not only the actual entrepreneurs were interested in developing 3D software, but also university students were putting their minds into it. Thus, students of Utah University came up with the shading method which allowed to make the process of rendering more comprehensible and obtain better visualization of an object.

Simultaneously, as the CAD-systems were developing, CAM-systems utilization for the automation of technological production processes was rapidly spreading. In 1961, the programming language called Automatic Programming Tools or APT was finalized and, later on, it has been stated as the basis for various other programming languages. As the researches were situated not only in USA, USSR inventor Goransky soon presented the results for the first programs which were assigned to calculate for different cutting modes.

The 1980s were revolutionary for 3D modeling field in terms of optimization and spreading. The invention of IBM PC as well as UNIX workstations, which were the most productive of all at the time, increased the usability and efficiency of CAD systems. Later on, the world has witnessed the first 2D AutoCAD software, the first out of the most popular developers, being operated on IMB PC as well as having a more affordable price, than all the similarly packed utilities.

The next step of development was providing better experience of a personal use. The existing software were constantly being updated and optimized. Moreover, several new programs were released on a free-to-use basis, such as, for instance, Blender, which is widely used to this day as a good alternative to its pricey competitors. The 3D modeling became not only a professional tool, but also a widespread utility for those users, who were not related to any kind of company.

To sum up everything, the technology development rocketed relatively fast, just in the half of a century from bulky workstations to personal computers at home, which are operating much complicated and capable utilities than it was ever before. Digital age brought many possibilities to learn programs at home with the aid of online guiding. However, the possibilities are accompanied by the complexity and higher standards of a current state of development.

3.2 Role in Mechanical Engineering

Nowadays, the majority of companies uses automatization in terms of drafting, slicing etc., meaning that the CAD systems are the necessity which cannot be competed with the manual drawing. Even though the brainstorming and sketching part is still better to be kept as the hand-made thing, all the upcoming steps are faster and more convenient to be created with CAD software.

The step after the sketching and putting together the actual idea is to create a prototype in CAD software. Not only it is quicker than drawing a proper blueprint by hand, but it is also a good solution in terms of finding the flaws in design, as the programs usually calculate and provide the information on the reliability of certain joints, forms and so on. Another thing is that 3D model can be obviously seen as the superior representation of the idea, allowing to be observed from all the directions and, also, captured in different sections if needed.

As previous steps are suitable for all the types of companies in general, the next one would be the most important for the mechanical engineering department. The crucial feature and possibility of CAD systems is the provision of the simulation for the 3D model of a certain mechanism created. It allows to prove whether the calculations are ideal for the conditions or something needs to be quickly fixed. In that case, there is no need to waste time, materials and overall costs on creating the real prototype to see if the idea is working, hence, saves the enormous amount of time on the development stage. Also, not only it can be checked on flaws and the reliability, the simulation can be stretched further to check the endurance and durability of, for instance, an engine as well as its behaviour in possible extreme conditions which can happen in real life and should be considered. As with the prototype, some simulations either hard or not even reproducible, therefore, the features provided by CAD to the modern engineers are essential and irreplaceable in order to maintain higher expected standards. Last but not least example of a right CAD exploitation is the possibility to assign materials to the parts, checking if something can be switched to more efficient in terms of productivity or even in terms of costs.

CAM or Computer Aided Manufacturing also crucially speeds up the manufacturing processes. Instead of constantly measuring everything before and during cutting as with the manual operation, the engineers can just make a proper formatted file for their 3D model and use it as so-called stencil for, for example, the laser or plasma cutting machine, which will do the operation automatically based on the file. The format for such files is DXF and it can be easily converted from the DWG file of the 3D model. Therefore, the automation processes based on 3D modeling reduce the large amount of time consumed from all the stages in total.

3.2.1 Computational Fluid Dynamics

Stretching the idea of simulations further, there are several particular examples of benefits mechanical engineering has in its possession. CFD or Computational Fluid Dynamics includes in it the flow simulation of heat, gas, air as well as other substances. The obvious opportunities led to the several exploitation examples that are going to be described below.

3.2.2 Pipe fluid flow

The simulation of pipe fluid flow is based on the laboratory experiments and the results are compared to the existing data. The process identifies how the fluid will behave inside the pipe in terms of pressure as well as velocity of it. Additionally, there are the measurements of the heat that has been distributed within the system during the test, water hammer effect as well as material concentrations. Moreover, the test computes all the edges, junctions, curvatures, bottlenecks and possible valve fluid passes, affecting the final results of it.

3.2.3 Heat exchanger

To simulate the work of heat exchanger the software performs the energy transmission between substances of different temperature. The testing covers several different types of real-life process reconstruction in heat exchangers, such as, for example, uneven distribution of a fluid flow, fouling or the clogging, rapid decrease of pressure and so on.

3.2.4 Internal Combustion engines

In this particular example the simulation is targeted at implementation of the spark ignition engine. The simulation provides data on heat exchange, working processes, fluid motion behaviour etc.

3.2.5 Aircraft design testing

The aircraft aerodynamics is essential for its manufacturing. Therefore, CFD software provides the simulation of airflow towards fuselage, showing the level of design streamlining. Also, not only the body of the vehicle is the subject of testing, but the chassis can be checked as well in order to receive the full aerodynamic data in all the stages of a flight.

3.2.6 Other examples of usage

Besides all the examples above, CFD has numerous other applications in mechanical engineering. Firstly, automotive industries can combine the need for aerodynamic testing as well as engine testing. Secondly, any model could be checked for its hydrodynamic properties in order to detect design flaws or test the possibilities. Thirdly, the airflow in any kind of turbines, pumps etc. could be tested as well. Last but not least is the measurement of the heat transmission of power plants as well as reactors.

3.3 Challenges

The development of something always implies that there would be complications regarding the overall usage or issues that were not covered yet, all this is due to the fact that there is no ideal system in the world which would not reveal any of its flaws with the time. The CAD systems are not the exception, hence, let me continue with the subject of what are the problems that technology had previously or currently has, even in modern times.

3.3.1 Shape control

During the development of the CAD systems there was a question over preserving the exact shape that is required. As for the hand-drawing methods, the shapes can be certainly represented as they are, because, obviously, people are having a direct control of the shapes they are creating on paper. However, for digital designs there was an issue of finding a right algorithm for the curves to be processed without any mistakes as well as for it to be optimized, considering the state of technology. The B splines, which are the core of curvatures in CAD, are created through inflection points, which indicate the location and the angle of a curve, therefore, the system needed the ideas to make the system work as intended.

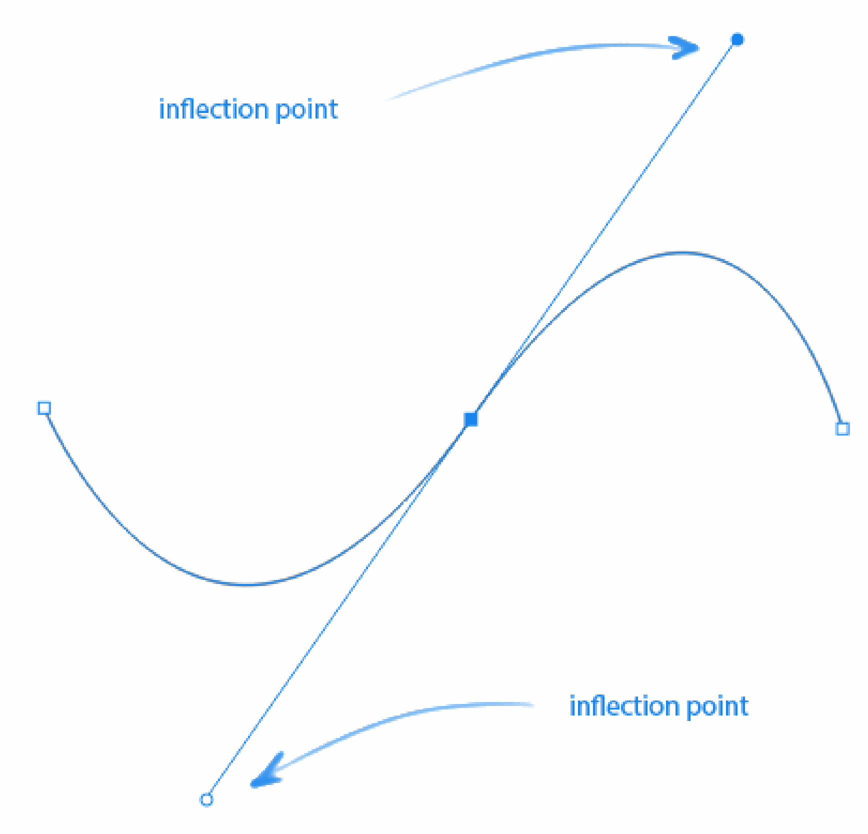

Figure 3: Visualised example of the inflection points principle

The majority of ideas implied the recognition of a flaw in design and then it required a manual intervention to fix the mistake. As the question was exponentially growing in its importance for engineers, the solution found for this was to make the corrections not manually, but rather with the help of a third-party program, where the supposed erroneous design will be corrected afterwards. However, instead of getting invested in those transfers between the software, it was decided to maintain the main goal to find a right coding and methods to acquire the flawless shape control or at least the consistent state of it.

The search for a right decision led to a realization that the basis which were used before should have been almost fully replaced. The methods were not so greatly accustomed to the actual CAD environment and in 1980 they were reconsidered in order to make the progress. Therefore, it can be said that even if the system seems to have a solid basics between the structure of it, sometimes the roots of the problem could be in the core of the initial ideology.

3.3.2 Interoperability

Decade ago, there was a wide-spread problem considering the transferring of a CAD model to CAE environment, for instance, to CFD (Computation Fluid Dynamics), as models were not watertight most of the time due to the state of compatibility. Now the problem is less likely to appear, when there is only one type of CAD software involved, however, there are still difficulties even in the current state of development.

The usage of several different CAD software can appear in companies as well as in educational environments such as school projects. The conversion of the model to be used in another program can cause holes and gaps in designs. This occasion can occur due to the differences in tolerances from one software to another as well as the variation in algorithmic processing of geometrical forms. Even without problems with conversion user must make sure the right tolerances are applied in order to avoid further interruptions and errors.

The complexity of geometry also plays its role. Thus, simple 3D objects and assemblies are most likely to be compute properly in terms of tolerances, when assemblies with a vast amount of parts or complicated joints and intersections could be followed with the imprecise recalculation within CAE environment. Moreover, what makes it more difficult is that CAE systems require a high level of computing power, which can be not so easily affordable for some of the users, hence, affects the possibility of transferring.

3.3.3 Learning Curve

As the layers of software possibilities and functionality growing, it causes the learning curve to increase exponentially. The inevitable complexity will always lead to the difficulties in obtaining the skills to operate the system.

Talking about the basics, the time consumption to learn the first level of tools and techniques is not that high. However, more thorough and professional level of software operation requires not only the bigger amount of time, but also comprehensive tutoring. The companies usually provide their workers with training if needed, but it will not cover all the proficient knowledge needed.

Some programs require a lot of time and dedication to master, especially if the goal is to be able to work in several conjugated systems. Even learning the software which is in the familiar category could be difficult due to differences in engines and interface designs. In addition to that, none of the competitive main CAD systems is stagnating in their innovations, something is consistently being added throughout the years. Thus, even the proficient users are sometimes obligated to learn new features to be in touch with all the aspects of the program they are using.

The obvious decision is to specialize on a certain part of CAD and operate in a certain domain of it. It might sound right, but such isolation has its own disadvantages as well. Most of the separate CAD software do not have a high value in applying for a job: it is much more reliable to get acquainted with several systems rather than one, as the full designing is often cannot be processed through a single CAD program. In addition to that, working environment requires cooperation between its parts and therefore the knowledge of the processes within the design department is essential in terms of communicating the troubleshooting during all the stages of idea development.

The developers of CAD systems are aware of the high learning curve implied. To compensate for it, some of the programs such as, for example, SolidWorks, have embedded tutorials with detailed steps and hyperlinks in order to fasten the learning process for the users. This type of approach is very helpful, especially towards the new users.

All in all, the learning process of CAD software is indefinite. The size of an issue depends on the personal conditions: whether the person is willing to get in-depth knowledge or just basic skills to operate the program for a personal use. The latter situation can be easily solved by using the tutorials provided directly by software as well as online sources. However, the former learning strategy requires investment of time and, probably, money in order to obtain all the professional skills needed by, for instance, receiving a proper training from a competent tutor.

3.4 Generative Design as a Future of 3D Modeling

3.4.1 What is Generative Design

Generative design is based on the idea of accumulating all the requirements for the specific design needed then for the program to create several possible outcomes in correlation with the information provided. This creates possibilities to automate the whole process even more, as this approach eliminates some middle steps between the idea and its realization.

To utilize generative design algorithms engineers need to add required boundaries and characteristics for the system to be able to generate some valid options. For instance, the parameters can be cost limitations, materials used, environmental specifications, strength conditions, weight, methods of production, size etc. Then, after the solutions for the design are created, engineers can decide which one suits better for the production.

3.4.2 Benefits

As the generative designs core simulation is embedded with machine learning, the program learns on its own mistakes, repeating algorithm to reach one or several flawless outcomes. Depending on the amount constraints, the software can quickly generate numerous well-functioning designs for the designers to choose from. Instead of sketching and brainstorming, algorithm solves everything in no time compared to humans. Even the smallest alterations in design from one example to another can be vital to the final product. Additionally, not only AI can generate more solutions, it can also potentially go beyond human cognitive functions. Therefore, faster, wider and more creative range of solutions which do not exceed requirements is obviously something promising.

The most noticeable advantage of generative design in comparison with current mainstream way of designing is the fact of preemptive simulation and elimination of the possible flaws in a final product. In the current system the designing starts with idea gathering, then transforms into modeling and, after that, simulation, which can be run with the help of software, with the use of prototype or both. Generative design software forestalls the simulation by using its knowledge, accumulated with the machine learning. As it was previously mentioned, the more constraints specified, the more ideal and close to flawless the design will be. For example, specifications can include the methods of casting in order to prevent the flaws during manufacturing due to insufficiency of certain part structures, which cannot be created with the method at hand.

The use of generative design method is a great solution to consolidation of parts. It is common for engineering to have complicated designs with various parts in one assembly. The reasoning for that is also behind human's cognitive abilities to grasp a complex problem and find a proper solution. On the contrary, computers most certainly do overcome people in problem solving, hence, are able to make designs with fewer excessive parts or even include all desired functions in a single part. This approach leads to increase of cost and time efficiency of the whole system.

3.4.3 Current state in Manufacturing and application

Nowadays, there are still limitations to the utilization of generative designing in mass production, hence, more common use for it is in pair with additive technologies to produce unique parts or those created in small batches. However, the technology is rapidly evolving and eventually will be adapted to the full use.

The one of the famous examples in manufacturing would be reinvention of the design for a partition of plane cabin in Airbus aircraft in cooperation with Autodesk team. The reinvention aided to reduce weight, which is especially crucial for the aircraft.

Another instance for mechanical engineering industry is the General Motors rethinking of belt bracket. Even though this may seem less important, the most fascinating thing about this redesign is the fact that the design provided by generative designing software consolidated eight parts of the whole assembly into single structure, decreasing overall weight as well as adding more strength to it.

Future perspectives are definitely inclining towards generative design method of handling pre-manufacturing. In the nick of time companies will be implementing the technology to their systems, allowing AI to work for them, searching for the best material, ergonomy, cost solutions available. Some of the decisions, forms, constructions made by artificial intelligence are difficult for humans to wrap their mind around it even post factum. The unique designing of common things, which previously could not be imagined even more convenient, will become the next step towards entire positive effectiveness, meaning less harm with less required.

4 3D PRINTING

3D Printing is currently the newest and the most prospective method of computer aided manufacturing, everything since the formation of technical drawings led to the technology we have nowadays. The automatization of the manufacturing is spreading rapidly and simultaneously developing in terms of its capabilities and efficiency.

4.1 History

The origin of 3D printing dates back to the 1980s and specifically to the invention of stereolithography, which is commonly abbreviated as SLA. The stereolithography can be described as an automatic continuous creation of 2D image layering one on another in order to achieve a certain 3-dimensional shape. To achieve a solid state of the model, the material, liquified photopolymer, is exposed to ultraviolet (UV) light and the reaction causes the material to switch its state of aggregation. The SLA printing was right away based on a 3D model, which had to be converted to STL format. Moreover, STL is still a standard and the most used format for printing to this day.

Even though the SLA technology was ahead of its time, it still had competitors on that close-range market. Another type of printing received its patent in late 80s and was called FDM or Fused Deposition Modeling. The working principle of the system, in contrast to SLA technology, is based on exploiting of the filaments with the use of heat treatment. This type of printing is probably the most used in comparison to others.

Another technology which was arising simultaneously with both previously mentioned ones is SLS or Selective Laser Sintering printing. This one is similar in the working pattern to SLA method, but in that case instead of liquified substances the printer solidifies polymer powder.

The first FDM 3D printer was built in 1991 and it should have worked as a catalyst for other competing sides. FDM produced more reliable geometries in terms of durability and chemical resistance, however, SLA had an advantage in the time-consumption per similar unit. One year after that the patent owner of SLS printers released first brand new model. The invention was as bulky as its competitors in comparison to a modern state of space-saving descendants.

All of those printers were massive as well as the costs for a single unit left much to be desired. Thus, the usage of the 3D printing methods was only feasible on a company level during those times.

As the interest to the new technology grew, the possibilities to find an application in various fields arose. The spreading of the awareness of 3D printing capabilities started the wave of prototyping for medicine. Already in 1999, the first patient received a successful surgery with implanting a 3D printed bladder. Three years later there was a successful creation of a first full-functioning 3D kidney. Even though the kidney was designed for a smaller body of an animal, it was certainly a leap towards a new curve for medicine. This experience caused even a stronger attraction towards the new technology, as the possibility of printing anything with a rather little recourse utilization was found tempting by many.

After receiving enough worldwide publicity, 3D printers became a dream for a lot of fascinated people. Eventually, with enough simultaneous projects around the world, the concept of a Replicating Rapid-Prototypers or RepRap was initiated. In a nutshell, RepRap was creating a printer that would be capable of almost duplicating itself. This idea implied that printers that are hard to obtain could have become more affordable in terms of various material use. So, RepRap introduced the first SLS (Selective Laser Sintering) fully working low-cost prototype in 2006, which opened new opportunities for printing considering manufacturing, prosthetics etc. Two years after that, the team managed to introduce the printer called Darwin with the ability to recreate most of its own parts by itself. All the produced parts were suitable for repairment of existing printers or for the build of the new ones with addition of missing parts. Everything related with 3D printing was a hot topic after the RepRap well-known innovations. At last, the desired 3D printing machine could be produced at home with the reliance on RepRap designs and concepts. Even though homemade printers were not looking as good as produced ones, the functionality was on point for its price. The concept was so that after getting the parts for building the machine the person had to recreate another set of assembly for the next enthusiast to do the same.

Another foundation worth noticing is the creation of a website called Thingiverse. The concept was built around sharing the models and designs for 3D printers for free. Nowadays there are not only free models, but also guides shared from people that built their own printers in order to help others to recreate the similar machine for themselves.

As the RepRap innovations paved the way to a more affordable 3D printing, the results did not keep the world waiting. The arm prosthetic was not only created solely on a printer, but also did not require any post-assembly as all the joints were printed as they are. This level of efficiency has once again proven the prospective possibilities awaiting the world in the future with the use of 3D technologies.

In addition to that, medicine has received another enhancement. The company called Stratasys came up with the filament for the FDM printers, which is fully bio-compatible. Therefore, it opened more doors for regenerative medicine.

The RepRap experience gave a start to various relatively low-cost 3D printer kits. One of the first examples of such kits was BfB RapMan, which was released in 2009. It is probable that this kit was in development simultaneously with the Darwin initiative, however, as it came out later, it received less points for uniqueness of the idea. Another instance is the Cupcake CNC created by Makerbot DIY. They were first to get their concept to Thingiverse, as all the models needed for the assembly were provided on the website by the team.

4.2 Types of 3D Printing

There are several different 3D printing methods that are currently in the lead of the overall field or those which were put to a hold due to irrelevancy. As the systems were developing, some of them received a vast amount of different application variations in all the aspects from medicine to decoration. The diversity of printing technologies can be justified by the search of an optimal method which would be quick, accurate, affordable as well as compact at the same time. However, the nowadays state of 3D printing still implies the further development in order to achieve the sustainable efficiency of it. Some of the methods are having different characteristics, which, in summary, complement one another, but there is still no sole decision to all the design problems addressed by all types of production.

4.2.1 Fused Deposition Modeling

To start with the description of this creation technique, it is only fair to mention that FDM is commonly stated as the most spread type of 3D printing. In comparison with all other methods, this one is the most affordable one. The reason for that would be the idea of kits for the assembly of the desktop-size printer as well as the simplicity of obtaining the models for the parts of it, if there is a possibility to print the assemblies on an already existing machine. Even though it is good for its price, it cannot be objectively compared to specialized machines conveyed by specialized companies.

The working principle is based on consistent feeding of material through an extruder embedded with a heating element in order to soften, for example, plastic, so it would be flexible enough to form a shape needed. The extruder can be described as a printhead mounted on poles together with a motor for it to be able to move around putting the material in a right place. The main function of extruder is in the name: it has to extrude melted material out of a nozzle.

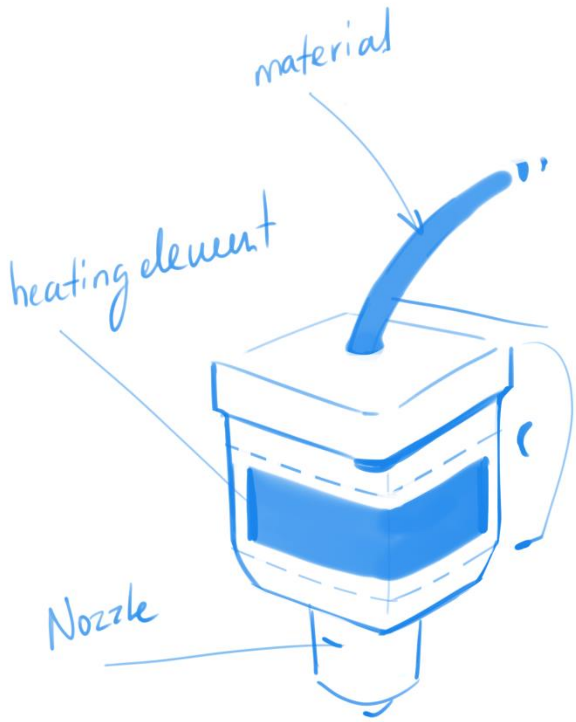

Figure 4: Simplified representation of an extruder

Extruders are also having side fans in order to fasten solidification after the extrusion of a material in its place as well as to achieve a smooth material feeding.

To describe the process a bit further, the printer is having a bed which is situated on a bottom side of the machine on the opposite to the extruder to form a model directly on it. The bed provides additional heat if required, as some materials might be getting solid too quickly even with the help of the heater.

This method is based on layering of the 2D shapes one by one in order to achieve 3-dimensional shape. The model should be sliced in advance converting into STL format.

FDM has several advantages in comparison with other methods:

- Relatively affordable
- Wide range of materials – the FDM is compatible with all colours of plastic, different types of polymers, metalized plastic, the plastic mixed with wood etc.
- Cost-to-quality ratio – the printing provides accurate models for its price

4.2.2 Stereolithography

SLA is the first method of 3D printing patented and even with that it is still relevant to this day. Opposite to FDM, no material is extruded to form a shape, but rather solidifies with the time and exposure to a laser, eventually forming a desired shape. In addition, FDM models are usually having ribbed surfaces due to the layering of material, when the geometries created with an aid of SLA are usually smooth.

As the method is widely used as well, it obviously has its own advantages:

- High accuracy and smoothness
- Low material wastes
- Wide range of form complexity (thin layers, extremely small pieces)
- Low noise levels

4.2.3 Selective Laser Sintering

As was stated earlier, SLS utilizes powdered materials to create models. The unique feature of this printing type is that it does not require any structure beneath the model being created, the formation is going on within the excessive powder. The range of powder material consists of metals (e.g. steel, aluminum), glass, nylon etc. Unlike previous examples, which could be built at home or obtained in a shape of a kids' toy, this technology requires relatively large investment, therefore, more spread among the companies and factories.

Advantages of this technique are highly related to its higher price:

- Almost non-waste production
- Excellent accuracy, quality and durability
- A large chamber allows to build several parts simultaneously
- Less time-consuming

4.2.4 Selective Laser Melting

SLM is one of the less discussed types of printing, which eventually became obsolete or are used in a close range of fields. The principle is based on melting and fusing of metal powders with the use of a laser in order to achieve certain shapes.

Even though SLM printing method is not widespread, it has its own niche advantages:

- Creation of complicated shapes
- Saving of materials
- Weight reduction with the implementation of hollow designing

4.2.5 Electron Beam Melting

EBM is commonly used to produce metal parts. The making process is featuring similar principles as in SLM, but the main difference is in the environment in which the geometry is forming: EBM proceeds in a vacuum with the use of an electron beam, whereas SLM uses a laser in the surrounding of inert gas.

The pros of the technology are the following:

- Creation of complex designs
- High levels of endurance

4.3 Application in Mechanical Engineering

At a certain degree of development, additive methods of 3D printing started to be considered useful for the Mechanical Engineering industry as well. The technology brought in new possibilities to solve designing, testing and manufacturing problems more effectively, easier as well as with a higher quality.

4.3.1 Prototypes

To start off, the first obvious opportunity 3D printing brought to the field is prototyping. In order to check the designs of the future part or assembly it is often useful to print out a desired 3D model beforehand. The reason for that would be the possibility to prevent some flaws and save the time on producing a prototype manually or on the reconsideration of an idea only after the work was already at the stage of manufacturing when the problem appeared. The manual creation of a prototype is usually time-consuming as well as costly to the production. 3D printing aids to save the time on test models as it is capable of creating shapes of various complexity in a relatively short period of time. The prototyping with the use of 3D printed models is beneficial to following types of testing:

- Testing of an assembly
- Checking for durability as well as strength
- Test of a new engineering concept
- Checking of the aerodynamics properties

Among the advantages of such method for testing is an essential feature: time saving. Sometimes the deadlines are harsh on production processes and the opportunity to reduce time consumption could be very aiding. Another convenient characteristic of 3D printed model is precision. If the machine is properly set, the accuracy of the produced prototype could be almost flawless, insignificant deviation could differ from an actual design only within the range from 15 to 20 micrometers (µm). In order to create a prototype, a company may resort to the cooperation with a third-party contractor. This occasion can be harmful in terms of the safety of an intellectual property the company has to hand on to an uninvolved figure. Thus, with the use of internal 3D facilities the privacy of companies' ideas could be safely secured.

4.3.2 Repairs and replacements

All the mechanisms have their own durability limits, after some time the parts inevitably wear or even break. The repairment or replacement of some structures could be very money consuming as well as complicated to perform. 3D model online libraries can offer a vast amount of designs for the various purposes. The design for a desired part could then be downloaded and set to the printer. Therefore, such repairment excludes the full replacement of the machinery as well as provides the quicker solution for a problem.

Another problem which could be solved with the use of 3-dimensional printing methods is the lack of a very specific part that is difficult to obtain. Sometimes the part is so particular that it is complicated or even impractical to buy. In this situation 3D printing is tremendously helpful as the part needed could be created from scratch. Similar to the repairment case, the model could be either downloaded from the Internet resources or even specifically designed by the CAD user. For instance, some supporting parts that are required for the building of a personal desktop 3D printer are in open access and due to that can be produced right away.

4.3.3 Creation of plastic casings

The traditional production of casings for the components or electronics could be very expensive to obtain. Also, the efficiency of some classic methods could be very questionable for a complicated design. Therefore, 3D technology could be a better, more affordable opportunity with increased and more flexible capabilities. Not only the printing can produce the ready-to-use model right away, but also can be utilized to create a casting shape for future casings if the material needed is not used for printing or, for some reason, not obtainable.

The most suitable circumstance to use such technique is in the case when the production features high customization of the components. Also, it is fair to use to perform one-time designs. In a nutshell, this method allows to decrease the costs of the production, create parts, which are ready to use right after the printing, as well as have a reliable accuracy and durability of the produced materials taking into the account the time and money spent.

4.3.4 Casting

Another beneficial aspect of 3D printing for the mechanical engineering production is the ability to create casting forms. Casting forms are used to mold different shapes with the principle of pouring the liquified material directly into the recesses of the form. In comparison with the traditional methods, the additive technology is proven to be much more effective. The reason for that would be the fact that 3D printing provides more complicated precise designs, which cannot be created with any of the established procedures. Thus, the optimal option would be the creation of complex shapes, whereas plainer geometries are more appropriate to be created with the technologies such as CNC machines.

The forms could be created with plastic, silicone as well as wax. The technology saves the tremendous amount of time and budget required, eliminating additional steps. The range of utilization is unlimited: all sorts of parts for engines, fuselages, pumps and other machineries are produced in a more precise and faster manner.

4.3.5 Burnout casting with the use of SLA

This example of casting is separated from the previous section due to the fact that the SLA model that is created for this method is not used as a mold, but rather plays a role of a shaping geometry around which the casting form is created. So, the principle is based on a production of a metal part, where an SLA model is getting immersed in a molding substance and then treated with high temperatures up to 1000 ° C. After that, the plastic model completely burns out and imprints its shape so that the metal could be poured into the form under vacuum conditions. When the metal successfully hardens, the form is getting destroyed and the part is ready to be removed. The afterwork may require further processing with grinding, but this method is most definitely helpful to the mechanical engineering production.

4.4 Restrictions and Challenges

The current state of 3D printing technology definitely brings in a lot of benefits to production and society overall. It took a long time and a lot of researching to accumulate that much possibilities since the foundation of technical drawing principles. Without a doubt, 3D printing deserves to be called a revolutionary phenomenon. However, there is still much to strive for in terms of optimization and overall capability even nowadays.

4.4.1 Technology adaptation

Additive methods seem to be effective in replacing the traditional methods from what has been discussed so far. Although it may not be obvious, but sometimes reconsideration of the core method could be difficult in terms of already running manufacturing. The best option for the 3D printing technique to be applied to the production is right from the start, when the product is at its designing stage rather than already being conveyed.

Even though there are plenty of models in online libraries, it might be a struggle to find the specific designs the concept demands as well as well as the majority of them are not followed with required parameters such as, for example, tolerances and material characteristics required for the manufacturing. Moreover, when the part or assembly is already being manufactured with the use of established methods, it is safe to say that existing tolerances and materials must be reconsidered, especially the former parameter mentioned. These specifications are essential in terms of receiving a product, that needs less processing afterwards or even a fully usable design right after the printing.

Another challenge which the implementation faces is the fact of relatively low awareness of possibilities. As 3D printing is still not a common technique for manufacturing in comparison with traditional ones, the designs are safely to be considered with the use of conventional methods rather than application of something new and rather rare. Thus, the overall production constrains itself from innovative approaches and development acceleration of 3D printing.

4.4.2 Quality of produced models

The various post-processing procedures are almost always expected when it comes to production with the use of 3D printing. The choice of a printing method affects the final result as much as the material being used. For instance, FDM produced models are usually having ribbed surface due to layering of the material, whereas SLA geometries come in a much smoother form due to the difference in processes. Also, the slight deviation in parameters could damage the intended design which will lead to the necessity of remaking the whole model as well as to the obvious waste of material. As for now, some of the patterns of deviations from one design to another are not quite covered, excluding the malfunctions and wrong parameter calculations.

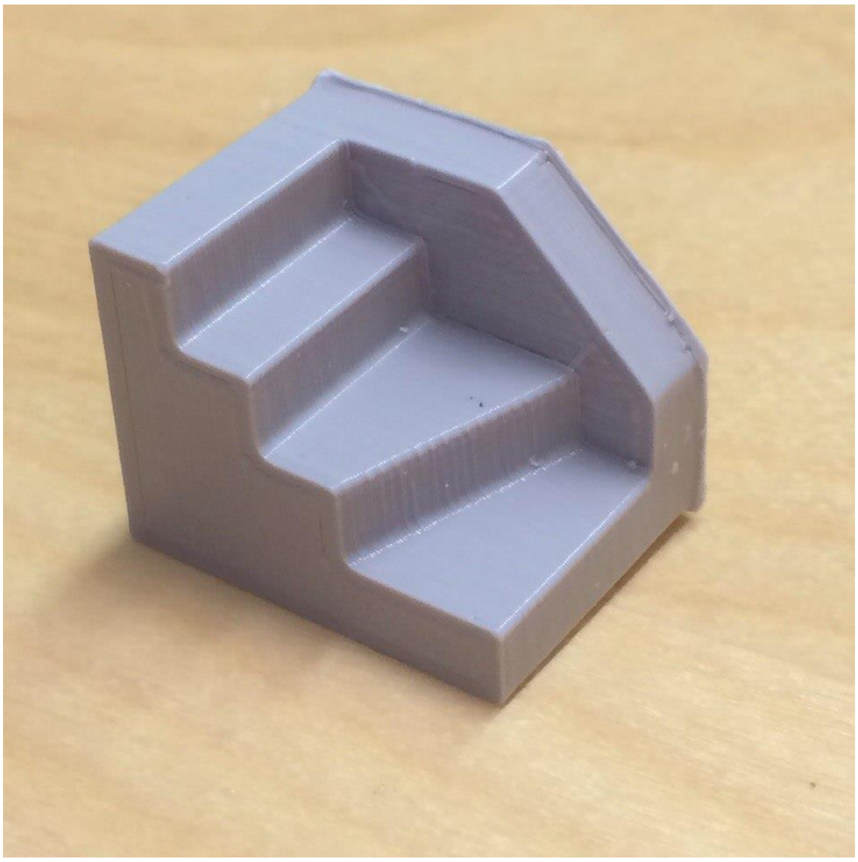

Figure 5: The texture of a model produced on an FDM printer

Post-processing probably affects the metal printing technology the most. After the model is ready it often needs to be proceeded with grinding, polishing, heat treatment etc. In addition, the small geometries get clogged with the excessive material and not only it is applicable for printing with metal, but to other materials as well. For instance, the heated material that did not solidify properly floods the small significant gaps and openings that were needed to be left open.

Last but not least parameter is the strength of the designs produced with 3D printing. For the economical purposes, the insides of produced part could be altered to achieve an internal grid with bigger spacing between the material. The model gets cheaper with less use of material as well as lighter in its overall weight. However, some parts in practice are exposed to high affecting forces, which can potentially break the altered design.

4.4.3 Preparation

For most complicated cases, as for machineries and their parts, the preparation before the actual printing takes a lot of effort. As produced mechanisms in utilization are going to be under a constant amount of pressure from various circumstances, the designing must go through several stages. The steps consist of, firstly, creating the model, then prototyping, optimization of the design and the simulation. The stated earlier material describes the issues with the transmission of models between the software and the interoperability. If the failure occurs on the last stages, all the previous manipulations needed to be reconsidered and run again as well as it is also required to identified what caused the actual failure of the result. Some of the software developers are trying to embed more specifications in their CAD programs in order to ease the processes for designers. Simultaneously, 3D printing companies are also releasing additional applications in order to fasten and simplify the utilization of their machineries. The solution for that problem should be developed in the matter of eliminating the conversion routine as well as providing better CAD conditions for the 3D printing specifications.

4.4.4 Lack of Standardization

Standards are crucial in terms of quality, safety, unification and regulation. Even though the additive methods exist for approximately three decades already, there are still not enough standards for them. With the solid state of norms and regulations, the technology will be getting a lot more recognition than now, as it would get more reliable and stable as a tool.

ASTM and ISO are constantly providing the development of the standards for post-processing, heat treatment, designing, prototyping, materials and many more aspects of 3D printing. However, there are still much more to be created in order to strengthen the positions of the additive manufacturing in the industry.

Materials and Processes

Designation	Title
F2924 - 14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
F3001 - 14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
F3049 - 14	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
F3055 - 14a	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
F3056 - 14e1	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion
F3091 / F3091M - 14	Standard Specification for Powder Bed Fusion of Plastic Materials
F3184 - 16	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
F3187 - 16	Standard Guide for Directed Energy Deposition of Metals
F3213 - 17	Standard for Additive Manufacturing – Finished Part Properties – Standard Specification for Cobalt-28 Chromium-6 Molybdenum via Powder Bed Fusion
F3301 - 18a	Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion
F3302 - 18	Standard for Additive Manufacturing – Finished Part Properties – Standard Specification for Titanium Alloys via Powder Bed Fusion
F3318 - 18	Standard for Additive Manufacturing – Finished Part Properties – Specification for AlSi10Mg with Powder Bed Fusion – Laser Beam
ISO / ASTM52901 - 16	Standard Guide for Additive Manufacturing – General Principles – Requirements for Purchased AM Parts
ISO / ASTM52904 - 19	Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications
ISO / ASTM52903 - 20	Additive manufacturing — Material extrusion-based additive manufacturing of plastic materials — Part 1: Feedstock materials

Figure 6: Example of standards already provided by ASTM and ISO - From ASTM.org

4.4.5 Geometrical limitations

First of all, the printers' capabilities are often limited by their sizes. Some parts, that are too large to be produced, are manufactured by sliced pieces which are later connected together to form a needed model. This issue consumes a tremendous amount of time, as if the design is not suitable or applicable, then it has to be remade in the similar manner once again.

Another restriction is a curvature of a surface. The spline curves are needed to be comprehended with the appropriate number of polygons taking into the account proportions of a model as well. If the parameters are low, the curvatures will not come out as intended, showing the hard edges between the polygons.

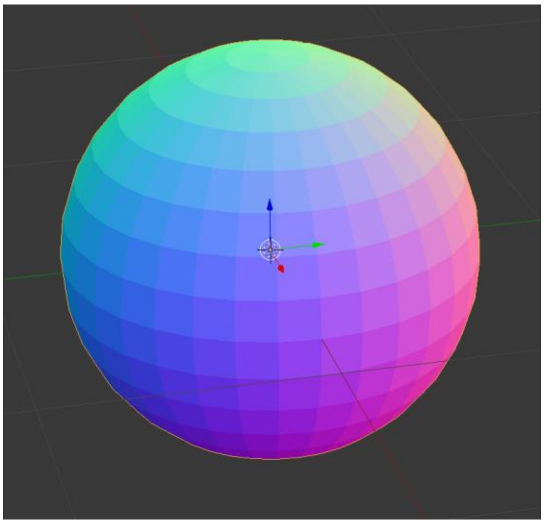
Figure 7: Low poly surface

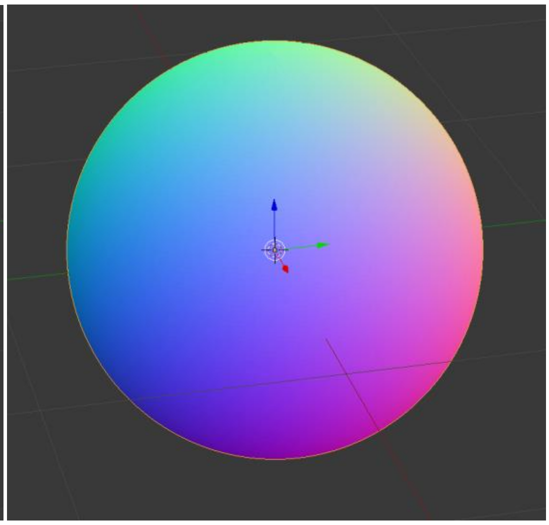
Figure 8: High poly surface

On the other hand, the issue that high polygon surface brings is that the file of the design would be significantly larger than the original, which can cause some inconvenience. However, the majority of 3D programs are featuring exporting options that are able to identify the suitable number of polygons based on the sizes and geometries of a model.

Lastly, additive technologies imply that all the models manufactured should be perfectly sealed or watertight. Surely, the geometry can contain gaps and holes intended by design, but no unconnected polygons should be left. Mistakes in design will lead to an incorrect printing, causing unwanted holes and inconsistency or even layer displacements.

4.4.6 Limitations in materials

The conventional techniques for manufacturing can offer various options when it comes to materials, unlike 3D printing. Plastic is the most widespread material when it comes to additive technology and for some instances it is an only operating option. Even though there are a wide range of plastic materials, plastic mixed with other substances, wax, powders, silicone, certain metals and so on, it is still much more constrained than so-called old-fashioned technologies.

5 IMPLEMENTATION NUANCES AND OVERALL COMPARISON

The technical drawing and designing in general came a long way from its formation. Mechanical engineering altered drastically with the implementation of digital technologies, looking back on how it was before. Still, for some time, as with 3D printing, CAD systems were only getting adapted and had some issues and concerns due to the early stages of development. It is fair to say that hand-made designs at some point were still more useful with more complex geometries. As it was discussed before, there was an issue with the implementation of a suitable algorithm which would allow to preserve an intended shape precisely in terms of curvatures. In contrast, hand-drawn curvatures could be fully controlled as well as adjusted with the technical drawing tools available.

The study from 1990 provides some statistical information on the productivity of CAD in comparison with standard board drafting at the time. It is said that 3D modeling increases the productivity by 25% - 350% with the direct dependence on the difficulty of the task as well as its repetitiveness. However, a wide range of companies reported indefinite results, meaning no productivity gains or even the decrease in skills of the engineers due to the use of CAD. Nevertheless, some of the results appeared to be showing the positive effect of CAD with the use of particular type of technology. The IBM computers, which were mentioned earlier as the most effective at a time, replacing the bulky workstations, were showing good results in cost-savings within developing department by 65%. CAD/CAM were mentioned to be increasing developing capacity by 150% in a company named Bull. All in all, it can be said that indefinite implementation of technology depended on the overall state of the companies which were adapting the technology, hence, the most profitable ones were receiving better results than others reporting.

CAD was stated as more time-consuming by some engineers, but more precise in terms of shape representation, as the 3-dimensional model could show how the product will look, ideally. Another thing is that with drafting board designing engineers could get away with not specifying certain parts that are difficult to draw, whereas 3D modeling was not allowing to leave the uncertainty. Thus, CAD was stretching the work for designing department and fastened the processes for the next steps of production.

The simulation providing the test of the design beforehand was significantly increasing chances of a first prototype to perform flawlessly or at least close to it. For instance, even at that time, an engineer of an automotive industry was able to simulate the bumpy road conditions in order to get the information on where the malfunction has the most probability to arise. The real-life simulation which could deliver the same results would have consumed a lot of time, effort and money to recreate, as it would take approximately half a year. In contrast, the processing of a car suspension with an axle he performed through the software was conducted in no more than 2 days. Nevertheless, the comprehension of the results took enough time to delay the creation of a prototype and affect the schedule.

It was noticed that CAD was considered hard to adapt, hence, caused the loss for some companies implementing it. Those assumptions were wrong, as the innovative software actually was bringing overall changes into the structure, which, eventually were providing drastic capacity grows. The company had to alter and support the processes in order to fully obtain advantages CAD brings. Moreover, the decreases at the start were needed to be considered as a minor sacrifice for achieving the revolutionary development with CAD properly involved.

Reflecting on the nowadays state of the CAD involvement in comparison to the old times, it can be said that it eventually supplanted the traditional drafting methods as a superior approach to designing.

The documentation for the designs can now be much easily produced. For instance, the assembly and its parts are needed to be done once and then the technical drawings of various views can be created almost in no time. Also, the huge range of different templates accessible provides possibilities to design an accurate as well as conformable to the standards product. Decrease of the time consumption in case of design mistake is incomparable: with manual drafting the design should be fully redrawn including all the views of it, when with CAD it only takes to fix the already existing model. Another obvious advantage which was foreshadowed in the previous paragraphs is that a faster design implementation with the use of 3D modeling benefits is crucially accelerating overall production, hence, letting engineers perform their work in much smaller amount of time than it was before.

The new step for the development is obviously 3D printing, which already aids manufacturing processes and contains tremendous potential to continue changing the industry.

6 FUTURE PERSPECTIVES

The nearest realistic future perspective for 3D modeling is to fix the existing issues regarding all the challenges listed in the research. For example, better interoperability should me more than achievable with the current state of development. The solution would provide faster and smoother transferring between the manufacturing processes, which will lead to even more productive system in the industry.

Talking about the 3D printing, it is still difficult to forecast its pattern of development. However, it is surely going in the direction of being a future so-called "game-changer" in terms of manufacturing. As the system is still rarely adopted, it requires a lot more effort to establish the production based on it. The technology needs to be optimized in order to be competitively stable, filling in all the manufacturing process demands, but with much more efficiency than traditional methods. The nearest future will, most probably, not surprise the industry with the major domination; it will take more than that to surpass well-established techniques. Although, it is safe to say that as it was with CAD dominating over the traditional drafting, so it would be for the additive manufacturing. So far, the most innovative things 3D printing brought to the society are related to other fields, but the potential will eventually burst out in mechanical engineering as well.

The most important part is to consider the impact of AI technologies on the future Mechanical Engineering field. It covers both 3D modeling and additive technologies, optimizing the processes, saving consumption of resources, time and workforce. Moreover, it is integrated in various departments and stages of mechanical engineering, not only previously mentioned two. AI gives opportunities to quicker and much more precise analytics in comparison with human capacities.

Even with the great opportunities that AI brings, there is an obvious double-edged-sword dilemma which needs to be considered. Nowadays, restrictions and regulations are already being set towards AI utilization ethics and norms. Essentially, the restrictions should not restrain the development of AI integration as well as should be considered wisely, whether it will be necessary to regulate every aspect with the same number of rules or not. As the AI stands for Artificial Intelligence, it aims to replicate human thinking, but being drastically quicker at learning, which implies far better capabilities. Even though current AI cannot fully replace humans as it lacks «humanity» in terms of critical thinking, decision-making with the consideration of social standards and norms as well as autonomy. It still depends on human inputs and overall regulation, not creating a fully-automated circle.

The further development of AI in the future can lead to the completion of the full circle and is speculated to be dreadful to the overall working environment and even humanity in general. However, the assumptions are made that it will create other opportunities for people, not fully replacing all the human workers. The probability of either of events is indefinite, as speculations vary from one study to another — there is much to be considered and the effects as well as outcomes cannot be fully predicted. Statistically, looking back at the previous automation steps, such as, for example, robotics integration, it brings more work opportunities for humans even with the replacement of others.

On the other hand, the future AI can still remain a tool, being in need of human hand to work properly. Not being able to fully grasp the emotional side of processing, only operating on statistics and probabilities, AI will not surpass the impact of people. Even though it can cut the need of workers in manufacturing, the regulation, processing and implementation will still need workers, especially in information technology field. For the Mechanical Engineering field, the regulations most certainly will be provided by people as well. New regulations will change the overall structure of handling the job, leaving the decision-making as well as other correlating aspects to people in charge of it.

The drastic change of the structure implies the adaptation period to be situated. The workers will need to be educated on the matter of AI, both freshmen and seniors. Alterations that are inevitable require flexibility of the system and its workers, being able to navigate and manage provided aid from the automation tool.

The future possibilities will improve the quality of manufacturing, enabling the fourth industrial evolution, which is already happening, to the fullest. Automation will take over the assembly, manufacturing processing, operating of machineries etc. However, the skills and the knowledge of mechanical engineers will still be required in-place, with the addition of new learning curves in terms of robotics and other automation aspects.

All things considered, the future of mechanical engineering is, by all means, correlated with additive technologies and AI. 3D Modeling can be almost fully automated with the use of generative design, which will lead to most efficient 3D printing options. This and other optimizations will cause further opportunities for the field to ponder upon.

7 CONCLUSION

The initial understanding of technical drawing required for manufacturing differs a lot from what we have now. With the development of the technological world the humanity has made a huge leap in innovation for the past half of the century. The possibility to go further is currently limitless; it only takes time to reach another level of innovation with the higher amount of automation in manufacturing with the use of 3D printing.

Previously, CAD was a questionable application when it just arrived. The imperfections in utilization as well as poor establishment due to novelty of the experience were leaving a question, whether it is more reliable than traditional drafting tables or not. It took some time for the technology to settle in after the productions figured out how to implement CAD in their system properly. Simultaneously, the software was getting constantly updated and the developers were fixing existing issues of the utility, providing new features, which were increasing the visualization as well as convenience of use. Although, even nowadays CAD has some troubleshooting questions to it, without a doubt, it is a well-rooted reliable aid used by the majority of engineers, replacing the conventional methods of drafting.

Nowadays, the same issue is applied to the injection of 3D printing in mechanical engineering and other fields of manufacturing. The nearest future goal is to make additive manufacturing as fluent and flexible for the industry as the current common methods, which are still preferred right now. Thus, 3D printing will allow another revolutionary leap towards even more effective methods of engineering.

Talking about the most modern integrations, implementation of AI in 3D modeling and other aspects of Mechanical Engineering provides further automation and manufacturing development trajectory. This technology crucially expands possibilities, eliminating routinary processes in order to hasten manufacturing and create space for the innovations. Although the field is going to undergo considerable amount of changes once again, it will most probably not be abolished or fully automated because of it.

8 REFERENCES

1. Warren J. Luzadder, Fundamentals of Engineering drawing.
2. В.С. Левицкий, Машиностроительное черчение: учебник для студентов вузов. (Mechanical Engineering Drafting: Student Book).
3. Аксёнова Е., Аксёнов Ю., Перспектива (Perspective).
4. Curves and Splines in CAD. Available online: https://www.wirebiters.com/curves-splines-cad/
5. Jitendra Raghuwanshi, Yogesh Dewang, Ram Kumar Raman, A review on applications of computational fluid dynamics. Available online: https://www.researchgate.net/publication/326264731_A_review_on_applications_of_computational_fluid_dynamics
6. Gaurang Trivedi, Problems in Dealing with CAD Interoperability Today. Available online: https://www.digitalengineering247.com/article/problems-in-dealing-with-cad-interoperability-today
7. Frank Bliss David, J. Kasik, The Boeing Company; William Buxton, Bluxton Design; David R. Ferguson, DRF Associates, Ten CAD Challenges. Available online: https://www.billbuxton.com/10CADchallenges.pdf
8. COMSOL, Model Transport Phenomena and Acoustics in Pipe Systems with the Pipe Flow Module. Available online: https://www.comsol.com/pipe-flow-module
9. Radu Crahmaulic, Simscale, 5 Ready-to-Use CFD Simulations for Aircraft Designs. Available online: https://www.simscale.com/blog/2017/01/5-cfd-simulations-aircraft-design/
10. Ed Cotey, AutoSpec Corp., Create a Learning Plan Before You Take a CAD Class. Available online: https://www.autospeccorp.com/create-a-learning-plan-before-you-take-a-cad-class/
11. Bitfab, The History of 3D Printing. Available online: https://bitfab.io/blog/history-of-3d-printing/
12. 3Dsourced, The Complete History of 3D Printing: From 1980 to 2020. Available online: https://3dsourced.com/guides/history-of-3d-printing/
13. UFO3D, History of 3D Modelling: From Euclid to 3D Printing. Available online: https://ufo3d.com/history-of-3d-modeling
14. Kseniia Snikhovska, PenandPlastic, Seven Types of 3D Printer. Available online: https://penandplastic.com/3d-printer-types/
15. 3Dinsider, The 9 Different Types of 3D Printers. Available online: https://3dinsider.com/3d-printer-types/

16. Top3Dshop, Применение 3D-Технологий в Машиностроении (Application of 3D Technologies in Mechanical Engineering). Available online: https://top3dshop.ru/wiki/3d-print-machinery.html
17. Pick3DPrinter, Ten Limitations of 3D Printing Technology. Available online: https://pick3dprinter.com/limitations-of-3d-printing/#consumes-a-lot-of-energy-for-operation
18. Robin Brockotter, 3D Hubs, 3D Printing Geometry Restrictions Available online: https://www.3dhubs.com/knowledge-base/3d-printing-geometry-restrictions/
19. Mika Salmi, Jouni Partanen, Markku Mikkola et al., Digital Spare Parts. Available online: https://www.researchgate.net/publication/323556916_Digital_Spare_Parts/references
20. AMFG, 10 Biggest Challenges in Scaling Additive Manufacturing for Production [Expert Roundup]. Available online: https://amfg.ai/2019/10/08/10-of-the-biggest-challenges-in-scaling-additive-manufacturing-for-production-expert-roundup/
21. Material and Porcesses Standartization Table, ASTM. Available online: https://www.astm.org/Standards/additive-manufacturing-technology-standards.html
22. David C. Robertson, Thomas J. Allen, Evaluating the Use of CAD in Mechanical Desing Engineering, 1990. Available online: https://dspace.mit.edu/bitstream/handle/1721.1/47689/evaluatinguseofc00robe.pdf?sequence=1&isAllowed=y
23. Dean McClements, 3D Printing and the Future of Manufacturing. Available online: https://dspace.mit.edu/bitstream/handle/1721.1/47689/evaluatinguseofc00robe.pdf?sequence=1&isAllowed=y
24. Dalako, G. History of Computers. Ivan Sutherland is working with a Sketchpad on Lincoln TX-2.
25. AutoDesk, Generative Design. Available online: https://www.autodesk.com/solutions/generative-design
26. NED, What Generative Design Is and Why It's The Future of Manufacturing. Available online: https://www.newequipment.com/research-and-development/article/22059780/what-generative-design-is-and-why-its-the-future-of-manufacturing#:~:text=Generative%20design%20leverages%20machine%20learning%20to%20mimic%20nature's%20evolutionary%20approach%20to%20design.&text=That's%20the%20power%20of%20generative,solutions%20to%20one%20engineering%20problem

27. Smlease Design, What is Generative Design: Benefits Applications. Available online: https://www.smlease.com/entries/technology/what-is-generative-design-benefits-applications/
28. VDMA, Artificial Intelligence in Mechanical Engineering. Available online: https://euro.vdma.org/documents/106103/6850470/Artificial%20Intelligence/41cd7af5-5836-feaf-3848-9395b38910b8