KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

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THE DEVELOPMENT OF MANUFACTURING COST ESTIMATION MODEL FOR 3D PRINTING

Final project for Bachelor degree

Supervisor
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Supervisor (minor studies)
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KAUNAS UNIVERSITY OF TECHNOLOGY

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(Title and code of study programme)

The development of manufacturing cost estimation model for 3D printing

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ECONOMICS AND BUSINESS FACULTY

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SUMMARY

This bachelor work is done with the purpose to develop manufacturing cost estimating model for 3D printing. The model would be used to forecast manufacturing cost at the early stage of products creation, when there is no digital models file created. The first step towards models creation is to analize two chosen printing technologies. Technologies in question are: polyjet and fused deposition modeling technology. Advantages and disadvantages are established of the techologies. Following step is the data collection from 3D printers software, for the chosen quantity of random parts and analysis of it. From the data anglysis, manufacturing cost influencing factors are determined for the different technologies. Economical 3D printing technology field is discussed, calculations of the experimental parts price, were printed using different technologies was done and comparison of the given prices.

Stropus, A. Gamybos sąnaudų prognozavimo modelio kūrimas 3D spausdintuvui. Bakalauro baigiamasis projektas / vadovas doc. dr. Marius Rimašauskas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, Gamybos inžinerijos katedra.

Kaunas, 2015. 60 psl.

SANTRAUKA

Šio bakalauro baigiamojo darbo tikslas sukurti gamybos sąnaudų prognozavimo modelį 3D spausdintuvui. Šis modelis būtų naudojamas padedant prognozuoti 3D spausdinimo gamybos sąnaudas ankstyvoje gaminio kūrimo stadijoje, kol dar nėra sukurtas virtualus gaminio modelis. Pirmas žingsnis ,kuriant gamybos sąnaudų prognozavimo modelį, išanalizuoti pasirinktas 3D spausdinimo technologijas. Nagrinėjamos technologijos: polyjet ir FDM technologijų spausdintuvai. Surandami šių technologijų privalumai ir trūkumai. Surenkami duomenys iš atsitiktinai parinktų detalių tyrimui, naudojant 3D spausdintuvų programines įrangas. Duomenys yra ištiriami ir remiantis gautais rezultatais nustatomi, abiems technologijoms, gamybos sąnaudoms įtaką darantys faktoriai. Ekonominai 3D spausdinimo aspektai yra aptariami, paskaičiuojama ir palyginama eksperimentinės detalės kaina, atspausdinta naudojant skirtingas technologijas.

KAUNO TECHNOLOGIJOS UNIVERSITETAS
MECHANIKOS INŽINERIJOS IR DIZAINO FAKULTETAS

Tvirtinu:

Gamybos inžinerijos katedros vedėjas

_________________________ *(parašas, data)*

_________________________ *(vardas, pavardė)*

PAGRINDINIŲ UNIVERSITETINIŲ STUDIJŲ BAIGIAMOJO DARBO UŽDUOTIS

Studijų programa EKSPORTO INŽINERIJA

Universitetinių pagrindinių studijų, kurias baigus įgyjamas bakalauro kvalifikacinis laipsnis, baigiamasis darbas yra taikomojo ar tiriamojo pobūdžio projektas, kuriam atlikti ir apginti skiriama 12 kreditai. Šiuo projektu studentas turi parodyti, kad yra sukaupęs pakankamai žinių, yra įgijęs pakankamai gebėjimų ir turi pakankamą pasirinktos studijų krypties analitinio ar projektavimo darbo patirtį. Baigiamuoju projektu bei jo gynimu studentas turi parodyti savo kūrybingumą, socialinės bei komercinės aplinkos, teisės aktų ir finansinių galimybių išmanymą, informacijos šaltinių paieškos ir jų analizės įgūdžius, gilų nagrinėjamos temos supratimą, projektavimo ir inžinerinės analizės įgūdžius, informacinių technologijų naudojimo ir rašytinio bendravimo, taisyklingos kalbos vartosenos įgūdžius, gebėjimą tinkamai formuluoti išvadas.

1. Darbo tema:

Gamybos sąnaudų prognozavimo modelio kūrimas 3D spausdintuvui.
The development of manufacturing cost estimation model for 3D printing.

Patvirtinta 2015 m. gegužės mėn. 11 d. dekano įsakymu Nr. ST17-F-11-1.

2. Darbo tikslas:

Sukurti gamybos prognozavimo modelį, gebantį padėti prognozuoti 3D spausdinimo gamybos sąnaudas ankstyvoje gaminio kūrimo stadijoje. Uždaviniai: išanalizuoti pasirinktas 3D spausdinimo technologijas, nustatyti šių technologijų privalumus ir trūkumus, išanalizuoti gamybos sąnaudas pasirinktam kiekiui detalių, nustatyti svarbiausius veiksnius lemiančius gamybos sąnaudas, palyginti pasirinktas technologijas ekonominiu aspektu.

3. Darbo struktūra:

Įvadas. Teorinė dalis. Modelio kūrimo dalis: pasiruošimas analizei, analizė. Ekonominė dalis. Išvados. Literatūra.

4. Reikalavimai ir sąlygos: Modelį charakterizuojantys faktoriai, turi gebėti prognozuoti gamybos sąnaudas, pasirinktoms technologijoms.

5. Darbo pateikimo terminas 20_m. _____________ mėn. _ d.

6. Ši užduotis yra neatskiriama baigiamojo darbo dalis.

Išduota studentui: UA-1 grupės studentui Andriui Stropui

Užduotį gavau Andrius Stropus (studento vardas, pavardė) _______________ (parašas, data)

Vadovas Doc. Dr. Marius Rimašauskas ____________________
(pareigos, vardas, pavardė) (parašas)

Contents

INTRODUCTION

Technology become a part of our everyday lives. It affected human history probably more than any other.Sometimes even few decades passes while trully important peace of technology is created. Now there is widely believed that one of them is so called additive layer manufacturing (ALM). 3D printing or ALM technology is taking the world by storm. The technology expanding into new markets, pushing out tradicional manufacturing.

Relevance of research. Consideration to use 3D printing for mass production, has set the target to be not only flexible is creation of new shapes, but also efficient and economically appropriate. One of the keys to efficiency is the determination of manufacturing cost.

Problem of research. Now, there are many types of 3D printers and its software's that can precisely to determine manufacturing cost from the uploaded digital model file. But as I mentioned, there must be a digital model CAD file, and if at an early products creation stage, when there is no digital model and between several design options we must to choose the most economical one, there's no way to do it. For this reason, the development of manufacturing cost estimation model for 3d printing technologies is started.

Aim of the work. To develop manufacturing cost estimation model for 3D printing which would be able to forecast 3D printing cost at an early stage of products creation.

Objectives of the bachelor thesis: 1) Determine advantages and disadvantages of the chosen technology; **2)** Analyze manufacturing cost for the chosen quantity of random parts; **3)** Determine the most important factors which influences manufacturing cost; **4)** To compare chosen technologies in economical area.

Methods of the research. Analysis of the data, that were collected from the different 3D printer's software's. Comparison of the given results.

3D PRINTING THEORETICAL ASPECTS

Additive layer manufacturing (ALM) or more widely used term 3D printing was created in l980‘s, but at the time there was no major interest in this tecnology, just in early 1990‘s manufacturers, engineers and architects paid attention into it as alternative in prototype making. In the last few years situation has changed and the popularity of 3D printing reach it‘s peak, now it is covered in many television channels, newspapers and across online recourses. In May 2013, 3D printing came to the public’s attention and made headline news when instructions for making the liberator, a plastic handgun that could escape detection by conventional airport security techniques, were made freely available to download from the internet by anti-government activists in the USA.

The increasing choice of available materials and the numerous finishing processes available for the produced part’s, greatly increases the range of the application areas for 3D-printers.

1.1. 3D PRINTING TECHNOLOGY

Rapid prototyping systems like 3D-printers are effective tools for quick product development. Over the last few years, 3D-printer technology has made significant contributions regarding print rates and print cost in rapid prototyping procedures.[24]

Three dimensional printing is an example of solid freeform fabrication (SFF) or layered manufacturing technology.[20] To add more, 3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the entire object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object.[21]

Manufacturers have long used these printers in their design process to create prototypes for traditional manufacturing and research purposes.[21] Besides rapid prototyping, 3D printing is also used for rapid manufacturing. Rapid manufacturing is a new method of manufacturing where companies are using 3D printers for short run custom manufacturing. In this way of manufacturing the printed objects are not prototypes but the actual end user product.[25]

From the user’s point of view, the additive manufacturing (AM) market can be basically divided into two sectors: the market for plastic printers that are now also affordable for private consumers, and the market for professional devices that are used in industry to “print” with materials of all kinds, including ceramic and metal powder.[23]

Today’s 3-D printers are concentrated at two ends of a spectrum: high cost–high capability and low cost–low capability. High-end printers are generally targeted at enterprises and 3-D printing service bureaus; low-end printers, which are often derivatives of open source RepRap3 printers, are targeted at consumers and hobbyists.

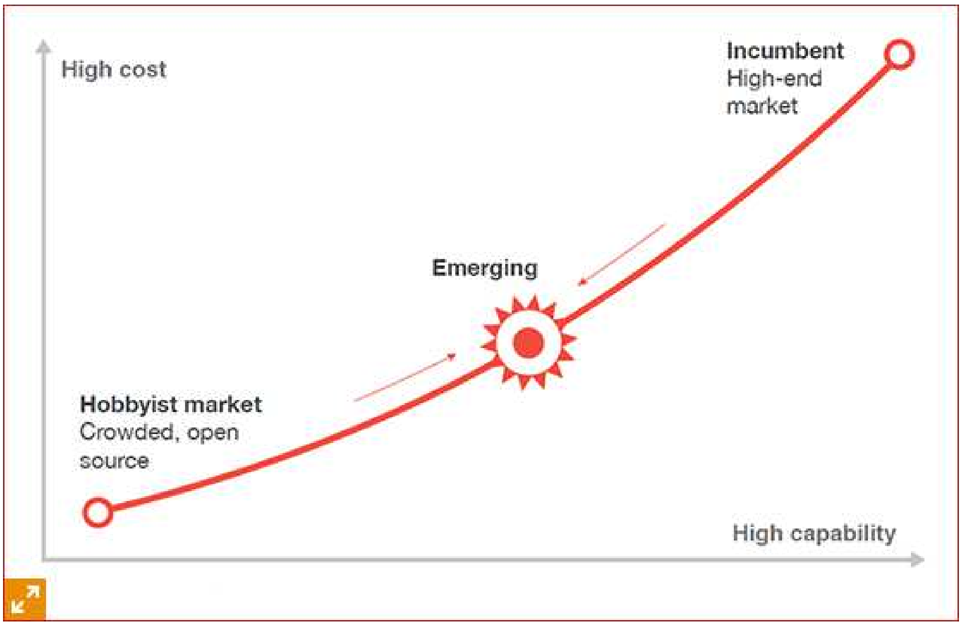

Figure 1. The emerging market for printers is defining a new category that has high capability at lower cost.

Gartner predicts that 3D printers with the value (capabilities and performance) that is demanded by businesses and other organizations will be available for less than $1,000 by 2016.5 It is fair to expect that printer improvements will accelerate in the next few years, although the degree and nature of these changes will vary considerably across printing technologies and vendors.[3;5]

1.2. THE 3D PRINTING PROCESS

The 3D print process produces workpieces in layers. The principle of 3D-print is to distribute or print a liquid binder onto a loose plaster or cellulose powder bed. The print process is based on the ink jet technology.[24]

The main components of a 3D-printer are: feed piston with powder reservoir, print piston, roller and the print heads.[24] However, not all 3D printers use same technology. There are several ways to do it. Some techniques use melting or softening material to produce the layers and most common technologies of this technique is selective laser sintering (SLS) and fused deposition modeling (FDM). There is another different printing method stereolithography (SLA) in which liquid materials is layed and treated in different technique. Similar technique is used in polyjet technology. In the last few year even more types of 3D printers were born, such as: Electron beam Melting (EBM), Selective

Deposition Lamination (SDL) and the Inkjet technology printers, but we leave them behind, without further investigation because of youg age and unpopularity of this technology at the time.

SLS technology is based on powerful lasers that fuses small particles of plastic, ceramic, metal or glass powders creating required three dimensional shape.The laser traces the shape of cross-section which is covered with powders in order this fuses the powder and create one layer of solid cross-section. After each of cross-section is scanned with laser, the powder bed is lowered by size of one layer thickness. Than this process is repeated, new layer of powders are fused on top of previous until the final product shape is reached. When the sand mould is taken out, powder is still compacted around the printed object and works as a support structure. Therefore it is not necessary any support structures, also when the object is gently removed from the powder mould, these powders can be used again in new printing operation, that causes almost no waste of material which is advantage over FDM.

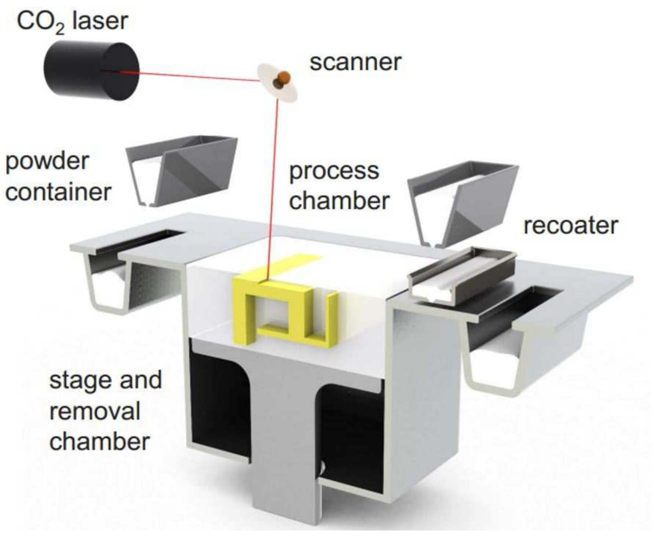

Figure 2. SLS 3D printing

FDM technology uses a plastic filament or metal wire which is rapped around the coil and supplies material to an extrusion nozzle which has the fuction to control the flow. The extrusion nozzle is heated until suplied material reaches it's melting point,usually FDM printers are left power on, that keep the material in a liquid form. The nozzle also can move in horizontal and vertical directions, this process is controlled by computer aided manufacturing software. The principle of this method is that the obeject is created by nozzle which moves in shape of cross-section and extrudes melted material on it, which hardens immediately after extrusion from the nozzle.

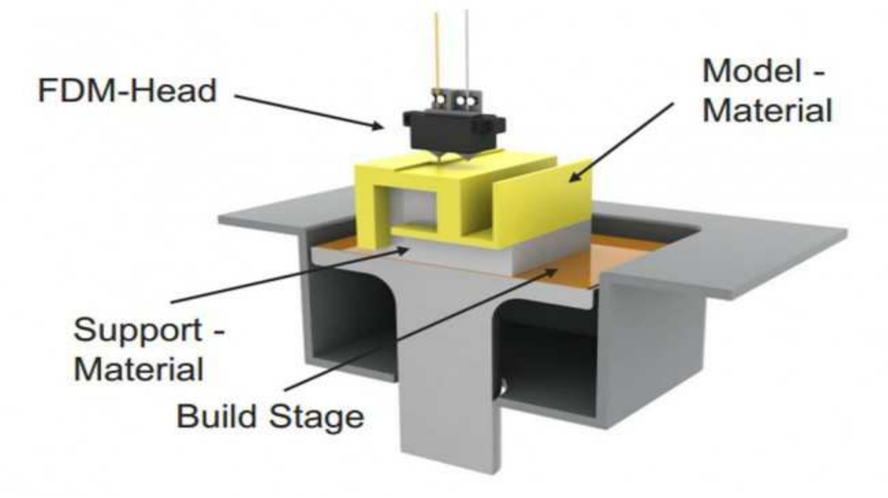

Figure 3. FDM 3D printing

SLA is based on photopolymerization process, which is used to produce solid part from a liquid. This technology uses a bath with a liquid ultraviolet curable photopolymer resin and an ultraviolet laser which creates layers one at the time. By tracing the cross-section of the part patern with a ultraviolet laser light which solidifies the pattern. After this process had been done and new layer is finished SLA‘s elevator platform decends or rises, it depeds of the design of a printer, by the distance of one layer thickness usually from 0,05 mm to 0,15 mm. Then if the SLA printed is old type a resin-filled blade sweeps across the cross-section of the part, re-coating with a new layer of liquid material. If the SLA printer is new type, the object bottom part is immersed into liquid photopolymer bath and elevated from it by the distance of one layer thickness. For the stereolithography is necessary supporting structures which serve to attach part to the elevator.

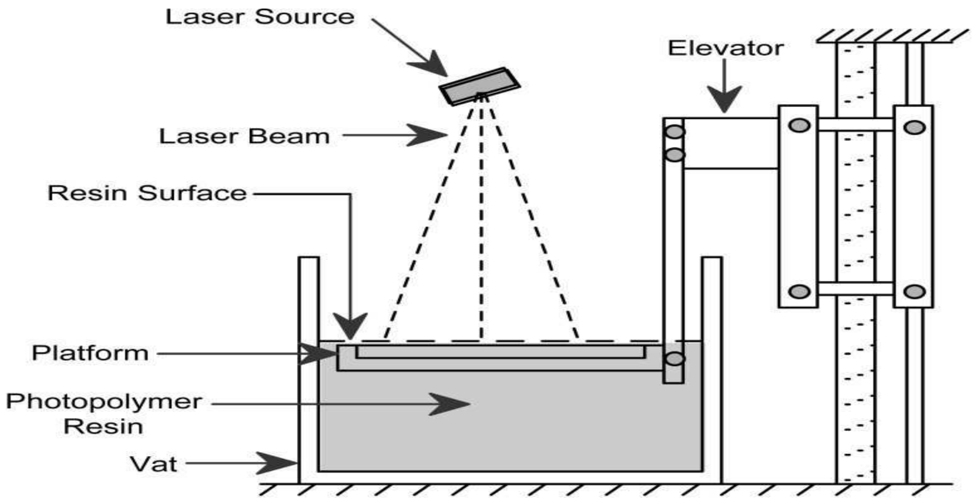

Figure 4. SLA 3D printing

PolyJet 3D printing technology is a powerful additive manufacturing method patented by Stratasys. 3D printers powered by PolyJet technology feature 16-micron layers with accuracy as high as 0.1 mm for smooth surfaces, thin walls and complex geometries. It is the only technology that supports a range of materials with properties from rubber to rigid and transparent to opaque. And with Objet technology, multiple materials can even be printed simultaneously in the same part. PolyJet 3D printing is similar to inkjet document printing. But instead of jetting drops of ink onto paper, PolyJet 3D printers jet layers of liquid photopolymer onto a build tray and cure them with UV light. The layers build up one at a time to create a 3D model or prototype. Fully cured models can be handled and used immediately, without additional post-curing. Along with the selected model materials, the 3D printer also jets a gel-like support material specially designed to uphold overhangs and complicated geometries. It is easily removed by hand and with water.

PolyJet 3D printing technology has many advantages for rapid prototyping, including superior quality and speed, high precision, and a very wide variety of materials.

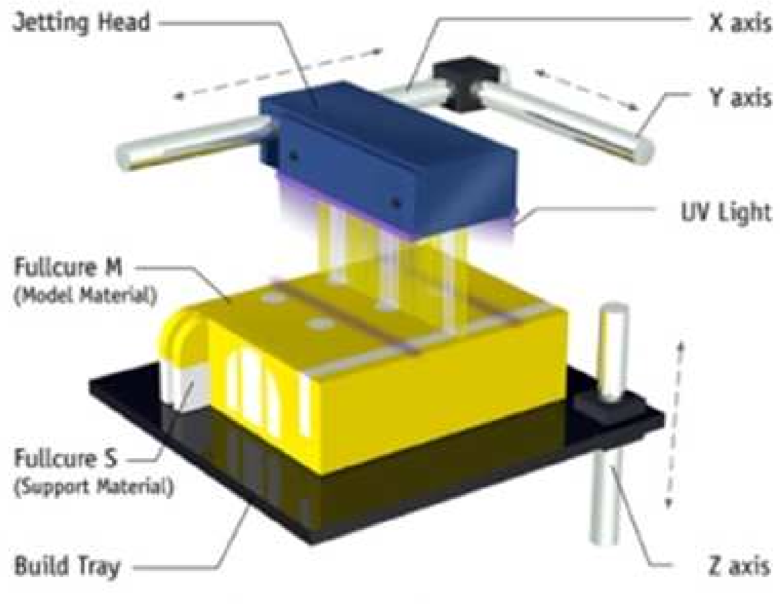

Figure 5. Objet PolyJet 3D printing

The basic printing process goes like this [7]:

1. You create a 3-D model of your object in a CAD program
2. A piece of software chops your CAD model up into thin layers -- typically five to 10 layers/millimeter
3. The 3-D printer's laser "paints" one of the layers, exposing the liquid plastic in the tank and hardening it
4. The platform drops down into the tank a fraction of a millimeter and the laser paints the next layer
5. This process repeats, layer by layer, until your model is complete

Most printing techniques require computer aid design (CAD) file to process the object. This file contains information about dimensional representation of an object. CAD file must be converted into a format that a printing machine can understand.[4]

IT companies like Microsoft and Google enabled their hardware to perform 3d scanning, a great example is Microsoft’s Kinect. This is a clear sign that future hand-held devices like smartphones will have integrated 3d scanners. Digitizing real objects into 3d models will become as easy as taking a picture. Prices of 3d scanners range from very expensive professional industrial devices to 30 USD DIY devices anyone can make at home.[21]

3D Printing is not a particularly quick process. Depending on the size and number of objects being created, the laser or extrusion nozzle might take a minute or two for each layer. A typical run might take six to 12 hours. Standard manufacturing times is from 2 days on (24 hours for Next Day models), depending on the size of the parts and the number of components.

From the literature it is well known that the accuracy of the 3D-printer is affected by different factors. These factors are:

- material used;
- nominal dimensions;
- workpiece orientation within the 3D printer;
- geometric features and their topology, e.g. open or closed contours;
- wall thickness – shell, solid;
- post treatment procedures; and
- binding agent.

1.3. THE ADVANTAGES AND DISADVANTAGES OF 3D PRINTING

With the growing popularity in the consumer market, 3D printing is certainly one of the printing innovations to follow in the 21st century. Here's a look at some of the real benefits of 3D printing. Cost and flexibility considerations show a further increasingly growing market for AM.[11]

By Wohlers Associates (2013): "Produce 3D parts and assemblies made from various materials in a single build. Reduces the need fo tooling, machining and handcrafting prototypes. Also, reduces the need to maintain an inventory of physical molds. Suggest more efficient designs, design changes and more effective experimentation." Instead of having to raise capital to set up a production line, 3D printers offer a cheap and less risky route to the market, particularly when a product requires extensivemarket testingprior to full-scale production. In the manufacturing context, the technologies are particularly well suited to the production of components with complex geometries such as internal passageways, undercuts and other features that are difficult or even impossible to manufacture with conventional techniques.[6]

New Structures and Shapes. Traditional manufacturing methods depend on cutting and moulding technologies to create a limited number of structures and shapes, with more intricate hollow ones having to be formed from a number of parts and assembled together. However, 3D printing technology transforms this process—the nozzle of the 3D printer can create many complex figures, being confined only by a person's imagination. This method gives them higher structural integrity and more durability.[8]

Cheap Manufacturing. The essential economic issue behind 3-D printing is that the price per unit produced is higher than traditional manufacturing, but the tooling cost is zero. 3D printing helps companies save up to 70 percent of their manufacturing cost. This is attained through lower packaging and shipping costs related to more reliable and cheaper raw materials and lesser workforce needed, as well as overseas parts suppliers. In the end, this technology makes progressive companies more profitable.[8;9] 3D printing reduces your prototype costs as much as tenfold. Your material costs are finite, and can be accurately budgeted before prototype design. ZPrinters will display how much material will be used for your design, and an exact cost can be determined.[2] Also, Since 3D printers can "print" products as and when needed, and does not cost more than mass manufacturing, no expense on storage of goods is required.[3]

The cost of 3D printing is expected to fall within the means of most businesses as well as consumers. Typical 3D printer costs range from hundreds of dollars to hundreds of thousands of dollars. Large, high-end 3D printers serve the needs of industry manufacturers. Smaller scale models are used by businesses. Less sophisticated assembly kits are used by some consumers.

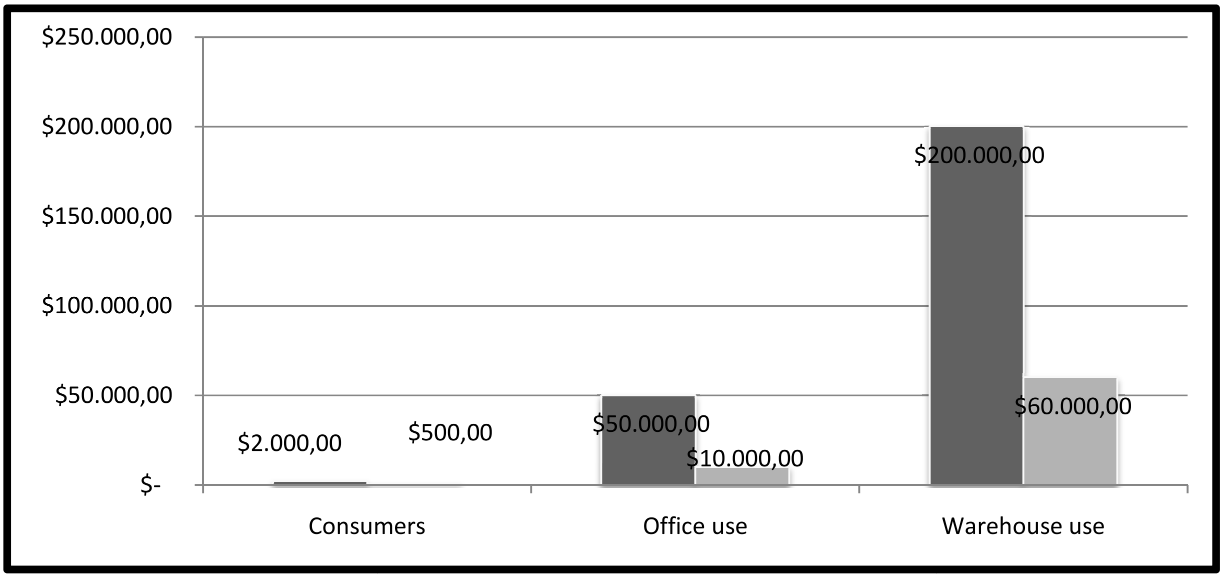

Figure 6. The cost of 3D printing.

3D Printers Can Reduce the Cost of Finished Products by More Than 4 Percent.[13] "In global manufacturing environment, high product quality, manufacturing flexibility and low production cost are the main keys to competitiveness."[22]

Quick Production. The speed of 3D printing is quicker as compared to the traditional method. It's similar to comparing the top speed of a sports car to a horse cart. They both take you to your destination, but the travel period differs significantly. With industrial 3D printing technologies being able to create an object in a few hours, the traditional manufacturing methods, taking up to two or more days (from prototype to finish product), are gradually becoming obsolete. This leads to an on-demand manufacturing model and to considerable cost savings.[8] 3D printing takes hours. When your designer is finished the CAD file, they simply send the file to the printer, and the part gets produced with little or no involvement from anyone. If a build is started at the end of the day, the part is fully manufactured, or printed by the next morning. No one is held up waiting for prototypes, your customers receive answers quicker, your products can be first to market, and you no longer wait weeks, or possibly months to perfect your designs. Business and clients are not a slave to the delays of prototype tooling. Quick turn arounds improve customer relationships, product evolution, company focus and morale, and business grows. Traditional prototype manufacturing requires tooling and machining by people and very expensive equipment. This process takes weeks.[2]

Forbes (2015) highlights the following reasons of pursuing 3D printing: "Prototyping (24.5%), product development (16.1%) and innovation (11.1%) are the three most common reasons companies are pursuing 3D printing."

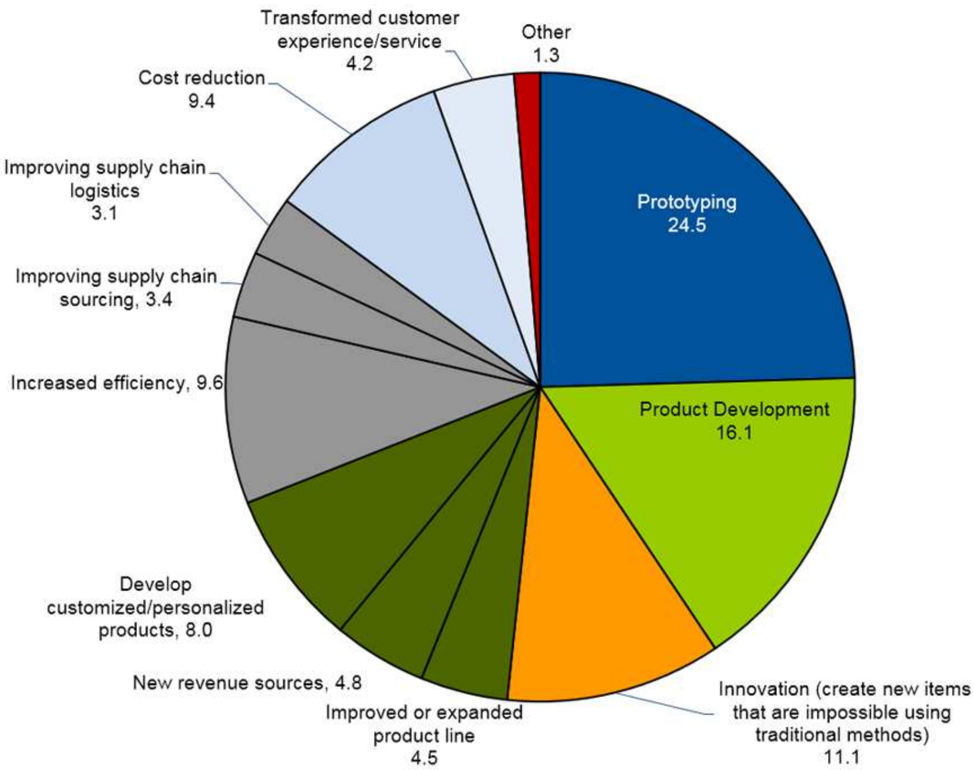

Figure 7. Reasons of pursuing 3D printing

As with any technology that seems to garner a lot of attention all at once, there is reason to be skeptical of the claims that 3D printing will bring about a manufacturing revolution. Here are just a few reasons that 3D printing might not produce the sudden, rapid industry change than many have predicted.

Sixty percent of organizations said high start-up costs are a main factor in the delay of implementing 3D printing strategies, according to a new survey by Gartner, Inc. However, the survey also found that early adopters of the technology are finding clear benefits in multiple areas.[13]

A 3D printer and its materials can still be quite expensive, and operating one requires some training and technical ability. The CAD software that is most frequently used to design models for printing requires a good level of technical literacy, practice, and experience before a user will be able to print a useful product. In order to produce one item virtually from start to finish, the printing process can take anywhere from a few hours to a few days and can cost thousands of dollars depending on the materials used.[16] At present, 3D printers can work with approximately 100 different raw materials. This is insignificant when compared with the enormous range of raw materials used in traditional manufacturing.[3]

Fewer Manufacturing Jobs: As with all new technologies, manufacturing jobs will decrease. This disadvantage can and will have a large impact to the economies of third world countries, especially China, that depend on a large number of low skill jobs.[18]

Though 3D printers may mean that many factories will be able to shut down parts of their operations and remove shipping steps, 3D printing still requires a large amount of energy. Because the 3D printing process is quite slow, the printers need to be on and running for hours or days at a time. This can represent a significant energy drain, particularly for a larger printer running a more complex task. This will eventually mean that much of the energy consumption of the manufacturing process is passed off to the consumers and small manufacturers running printers from their homes and offices.

One of the dangers of 3D printers is that they will be used to create more useless stuff that is bad for the environment and wallets. Fortunately, there are new methods of automatically recycling objects made by 3D printers that hold promise of better recycling in the future.[18]

Parts created additively through 3D printing are also limited in size. For instance, the most affordable, common 3D printing machines typically are small enough to fit on your desktop, meaning they have build chamber sizes of similar proportions. There are 3D printers that are able to create larger parts, but they're much more expensive and thereby an unrealistic option for many companies.[10]

Limits of the 3D printers. Because parts are built layer-by-layer, each layer must be supported by something underneath it. Features that are not directly supported by underlying layers or the build platform are called unsupported overhangs and examples can be seen in the picture 4. Without any supports these features fail to print correctly as seen in picture of the printed part below.

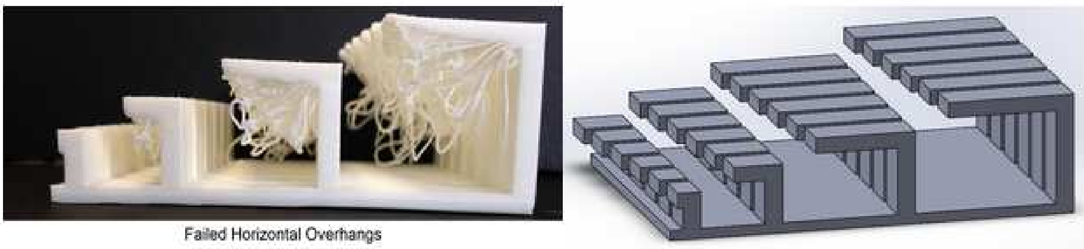

Figure 8. Examples of unsupported overhangs.

3D printing has garnered considerable attention due to its broad applications, its ease of customization, and its increasing affordability. Although the applications of 3D printing in the manufacturing world are evident and numerous, this technology has the potential to have a multitude of applications transcending numerous industries. As with most new technology, 3D printing could change the world–for better or for worse.

1.4. THE TECHNOLOGY FOR 3-D PRINTING IN THE FUTURE

It is predicted by some additive manufacturing advocates that this technological development will change the nature of commerce, because end users will be able to do much of their own manufacturing rather than engaging in trade to buy products from other people and corporations.[21] However, the future of 3D printing lies in companies that provide endless options for consumers who can conceptualize their ides but don't have the means to create it.[25]

Gartner Says (2014): "Worldwide shipments of 3D printers (3DPs) will reach 217,350 units in 2015, up from 108,151 in 2014, according to Gartner, Inc.'s latest forecast. 3D printer shipments will more than double every year between 2015 and 2018, by which time worldwide shipments are forecast to reach more than 2.3 million"[15]

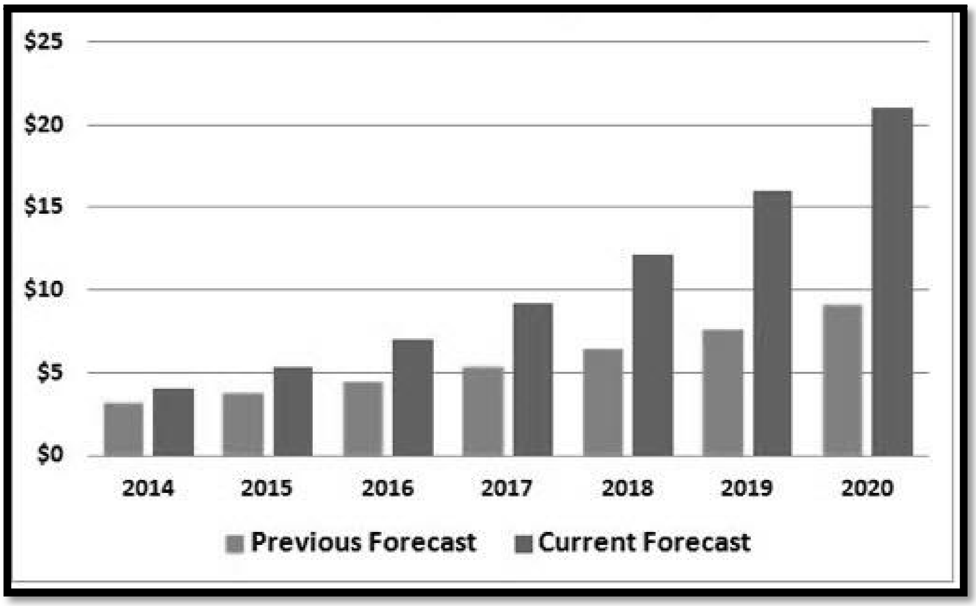

Figure 9. Worldwide 3D printing industry forecast, billions.[14]

Siemens predicts that 3D printing will become 50% cheaper and up to 400% faster in the next five years.

With the 3D printing industry expected to grow by more than 31% per year between 2013 and 2020, and eventually generate more than $21 billion in annual revenue worldwide, there's currently a high incentive for industry players and new entrants alike to improve upon the technology's many shortcomings.

During the past year, a new class of printers in the middle has emerged. These printers from new entrants and established vendors have many of the higher-end capabilities at lower prices. For example, printers from FSL3D and Formlabs deliver higher resolution and smaller size using stereolithography technology and are priced at a few thousand dollars. Printers from MarkForged offer the ability to print using carbon fiber composites in a desktop form factor for less than $5,000. CubeJet from 3D Systems is priced under $5,000, can print in multiple colors, and brings professional features to a lower price point.[12;17]

It is evident that 3D printing technology has evolved dramatically and after 25 years of development and use, principally as an RP technique, the 3D printing industry is rapidly transforming into a manufacturing-focused enterprise.[6] Some industry commentators argue that these technologies have the potential to create a new type of industrial revolution. The new approach and design of a 3D-printer based on a conveyor belt processing system is suitable for production use. Investigations show that the printed parts are comparable in terms of accuracy and strength to their conventional printed counterparts.

2. THE DEVELOPMENT OF MANUFACTURING COST ESTIMATION MODEL FOR 3D PRINTING

2.1. METHOD OF DEVELOPMENT

As I mentioned earlier, cost estimation plays an important role in manufacturing process, because additive layer manufacturing (ALM) is still quite expensive technology. To forecast production output time and cost is crucial, taking in mind that, now ALM technologies are used for mass production. There are several established methods to forecast manufacturing cost:

- Parametric cost forecasting;
- Forecasting by applying artificial intelligence;
- Forecasting based on experts;
- Forecasting by means of knowledge;
- Forecasting by means of classifiers.

Parametric cost forecasting is appropriate method to use, when linear dependence can be noticed between factors affecting the cost. Forecasting by applying artificial intelligence is convenient when there is no linear dependence established. Also method of forecasting by expert means or knowledge is suitable too, but there is major drawback. Because that technology in a first place was created for prototyping and just recently the idea was developed about mass production with ALM, there is a lack of information. Even though all additive layer manufacturing technology share the same principle – layer by layer manufacturing, there still exist differences that have influence to manufacturing cost. The aim of this paper work part is to collect and analyze information about ALM technology, determine the main factors that have influence for both technologies on manufacturing cost and develop a primitive model that would help to determine manufacturing cost at early stages of process, when there is no digital model created yet. This model would help to save money and time at the beginning of the products development process, where could be possibility to determine approximate printing time and material consumption from the dimensions of a part.

2.2. DEVELOPMENT OF COST FORECASTING MODEL STRUCTURE

First and the most important step in models creation is creation of suitable structure, which consist of data collection and analysis of it, appropriate input variables and neural network selection. To find a pattern of cost estimation determining factors, I choose experimental parametric comparative method. Comparing two 3D printers with different printing technologies. Technologies in question are: PolyJet and fused deposition modeling (FDM). I assumed that comparing two 3D printers with different specifications will reveal more details about important factors for cost estimation model creation, such as: time of manufacturing and material consumption.

$$T = T_s + T_e + T_m$$

Where, T – total production time, T_s - set up time, T_e- post processing time, T_m - machining time, in this situation printing time.

$$M = M_s + M_m$$

Where, M – total material consumption, M_s - support material consumption, M_m - model material consumption. Total material consumption in 3D printing usually consists of support material and model material consumption. In the meantime, time is divided into machining time and into time meant for supplement. Supplement time is difficult to forecast, because of the preparation of 3D model and preparation of printer itself, mostly time is dependant from qualification of operator and complexity of a part. Also, one more criteria need to be mentioned, it is the positioning of a detail in a building plane. There are many variations how detail can be positioned on the building plane and different positioning variation causes major differences for the total cost of a detail.

In addition the differences between two printers will be displayed, how they manage to produce the same detail and at what cost. After these two 3D printer analyses, I will be able to describe practical abilities of them in the real situation and for what specific detail manufacturing they fit best. In this particular case, the printers I selected are professional prototyping devices: Objet 30, which uses PolyJet technology and Dimension BST 768, which uses fused deposition modeling technology.

Objet30

Specifications:	
Modeling material	• Rigid Opaque (white, blue, black, gray) • Polypropylene-like
Support material	FullCure 705 non-toxic gel –like photopolymer
Net build size	294 x 192 x 148.6 mm
Layer thickness	0.028 mm
Build resolution	X-axis: 600 dpi; Y-axis: 600 dpi; Z-axis: 900 dpi
Accuracy	0.1 mm
Software	Objet Studio
Material cartridges	Sealed four 1 Kg cartridges
Workstation compatibility	Windows XP, Windows 7, Windows 8
Jetting heads	2 printing heads; SHR (Single Head Replacement)
Power requirements	• 100-120V~; 50-60Hz; 7A • 200-240V~; 50-60Hz; 3.5A
Size and weight	• Tray size: 300 × 200 × 150 mm • Machine: 82.5 × 62 × 59 cm; 106 Kg

Table 1. Specifications of Objet 30

Figure 10. Objet 30

Dimension BST 768

Specifications:	
Modeling material	ABS (white, red, blue, green, yellow, black, gray)
Breakeaway support material	Breakeaway support cartridge
Size and weight	914 x 686 x 1041 mm; 136 Kg
Net build size	203 x 203 x 305 mm
Layer thickness	0.254 mm
Software	CatalystEX
Dedicated outlet requirements	• 100-120 VAC, 60 Hz, 15 A • 220-240 VAC, 50/60 Hz, 7 A
Workstation compatibility	• Windows 2000 • Windows XP Pro

Table 2. Specification of Dimension BST 768

Figure 11. Dimension BST 768

2.3 PREPARATION FOR ANALYSIS OF A DATA

Having all necessary information about the printers for the task and get acquainted with the software of both 3D printers, data input must be collected. For the experiment I gather hundred random Solidworks CAD 3D details, that massively varies in dimensions and complexity. Some details scale was changed in order to fit them on the work plane. Naming all hundred details in random order, in a form of number, I created a list of details. Further step was to change format of the 3D details from Solidworks to STL, because most of the 3D printer's software can only read STL format files. After this operation, details one by one were uploaded into “Objet Studio” program. Determined appropriate scale for the detail dimensions, that do not exceeds determined net build size of 294 x 192 x 148.6 mm we choose automatic placement function that, places detail in most optional way, according to the software. Further step is to run the programs function that estimates: printing time, support material consumption, model material consumption and displays dimensions in X, Y, Z axes. Having done that procedure for all hundred parts I collected all given data. Next step is switch to Dimension BST 768 printer. Using “CatalystEX” software, which is relatively similar to “Objet Studio”, because it's working principle is the same, although technology differs. The program slice given detail into cross-sections and calculates the same factors as “Objet Studio” program: printing time, model material consumption, support material consumption and the placement of the detail on working plane according coordinate axes. After uploading details digital files into “CatalystEX” and selecting identical scale measures for the detail as in “Objet Studio” software, than again using automatic placement function, I noticed that some details were orientated on a working plane differently. An example is shown in figure 11.

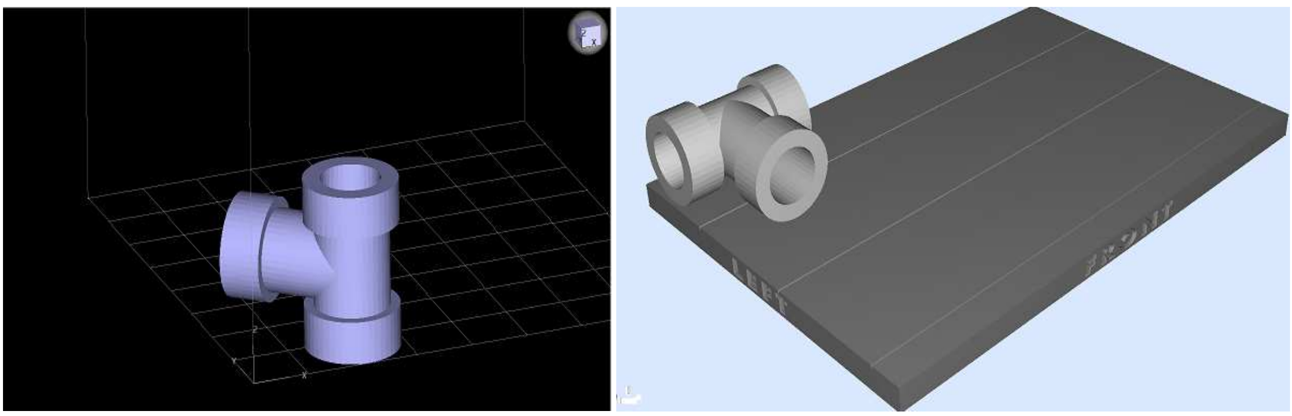

Figure 12. Different positioning of the same detail in “CatalystEX” (on the left) and “Objet Studio” (on the right) software.

Taking in account that, details with different positioning will not be adequately comparable between Dimension BST 768 and Objet 30, because of the positioning major influence to manufacturing cost, I marked them out. After all details were run through the models material consumption and time required for building determination "CatalystEX" programs function, and all data was collected, the total count of differently positioned details were 27 out of 100. One notification needs to be considered that, in "Objet Studio" program material consumption was expressed in grams and in "CatalystEX" in cubic centimeters, to equalize expressions there was selected density value of Dimension BST 768 building material, which is ABS thermoplastic of 1,06 g/cm^3 and all data values converted to grams. I assume that, comparing these two 3D printers material consumption, some error's might be noticed, because of the different model materials and support materials, that also differs in density, so same size detail can weigh more than corresponding detail which in dimensions is equal to the fist one. The expression in grams was chosen, because majority of 3D printers material filament replacements are calculated in grams and in economical part this expression will be useful. Having all necessary data, experimental testing and comparing can be started.

2.4 ANALYSIS OF THE DATA

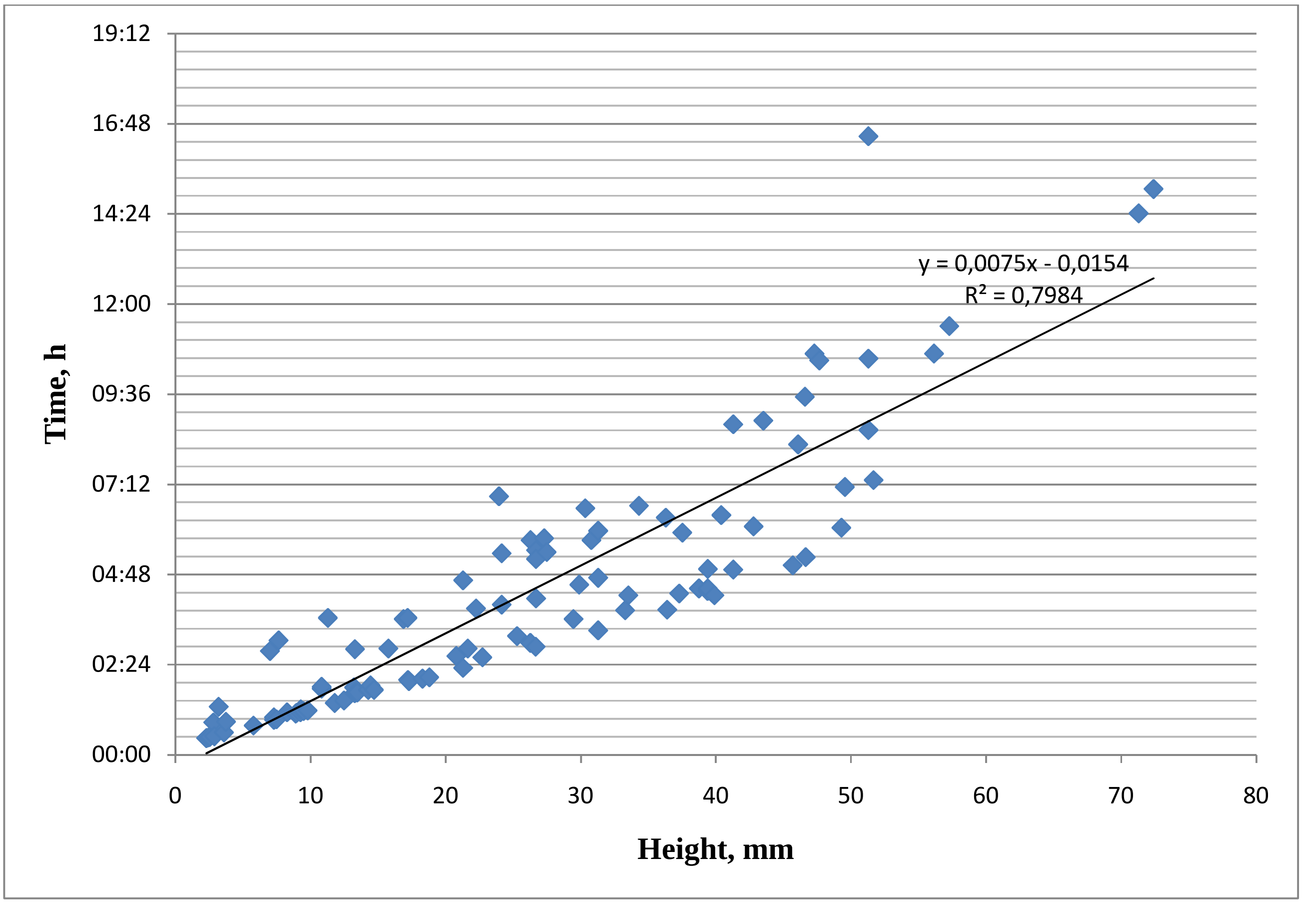

Figure 13. Dependence between part height in Z axis and manufacturing time (Objet 30)

In a figure 13, results of collected data can be seen. In this particular graph is presented dependence of parts height versus manufacturing time. Sorting all hundred details height, from smallest to largest and selecting them as independent variable on X axis and selecting manufacturing time as dependant variable on Y axis, we get this graph. From the graph we can determine that, interrupted linear dependence can be noticed, as details height is growing so the manufacturing time is increasing. Determination coefficient R^2 = 0,798, prove that dependence between variables is strong. To determine what exceptions cause deviation of the points from linearity line, I analyze particular parts that, reflect the most distant points. For example, the point at 51,28 mm height mark takes unusual 16:28 hours to print. By checking data table I found that it corresponds to detail named by number 77, which dimensions are: X = 195,29; Y = 179,69; Z = 51,28, model material consumption – 285 g, support material consumption 506 g.

Taking deeper investigation about Objet 30 printing technology I found that, in order to fully print out one layer of the part with an Objet 30 3D printer, the nozzles must perform four passes. In four passes a 65 mm wide layer is printed. Therefore, the positioning of the part in the work plane is of crucial importance to the production time. A few positioning rules are known that help in lowering the production time. First and most important criterion is the height or the part. If possible, the part should be positioned in such a way that its size on the z axis is smallest in comparison to x and y axes. Secondly, the longest dimension of the part should be parallel to x axis. As mentioned before, printing width is 65 mm therefore; when printing the parts with dimension with respect to y axis is larger it is necessary to perform jetting head movement with respect to y axis. It is necessary to keep in mind that displacement in y axis direction is relatively slow.

From the dimension point of view, printing time is affected by the Y axis dimension, because Objet 30 jetting head in X axis direction is able to jet 65 mm width layer of material, so in order to cover 179,69 mm jetting head have to move in Y direction even two times. Considering that to print one layer of cross-section jetting head have to perform 4 passes in X axis direction and if jetting head have to move two times in Y direction and again lay for each movement 4 passes in X direction that, will massively increase time consumption. From the shape of 77 part, as we can see in a figure below, that it will require huge amount of support material, to support each propeller wing and model it’s self is relatively large, these factors also have influence to printing time.

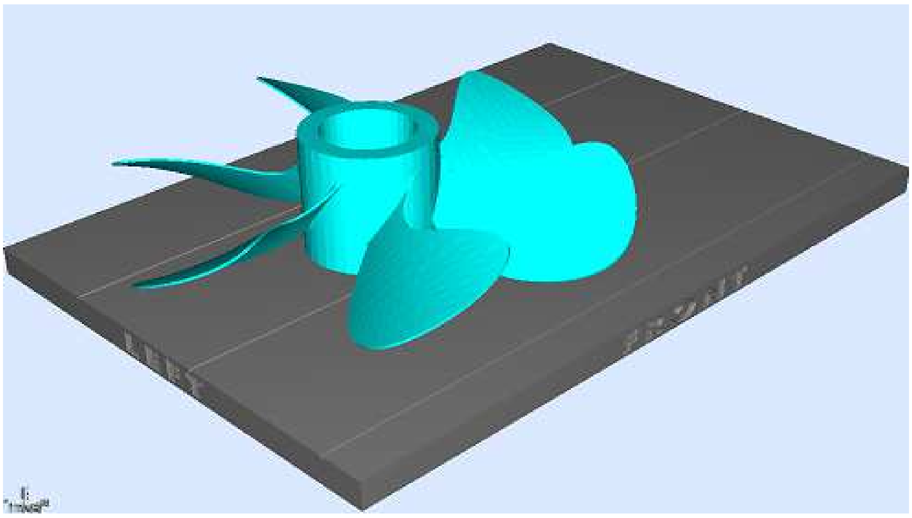

Figure 14. Part number 77.

Obvious example can be presented that, mentioned factors causes deviations from parts height and printing time dependence line.

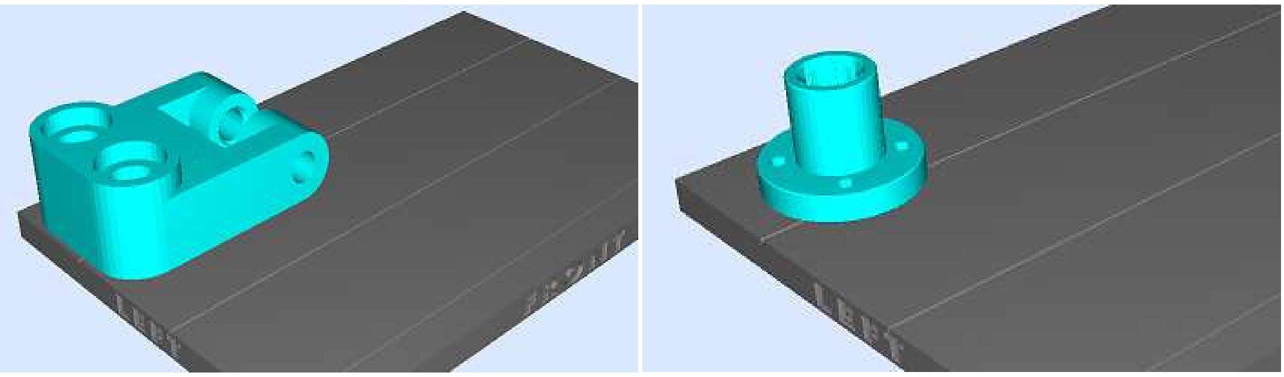

Figure 15. Part number 93 (on the left) and part number 62 (on the right)

Part number 93 and part number 62 are identical height of 41,28 mm, but printing time differs: for part 93 – 8:48 hour, for part 62 – 4:56 hour. This difference can be explained by the Y axis dimension which for part number 93 is 83 mm and for part number 62 is 55 mm. Part's 93, 83 mm dimension in Y axis exceed 65 mm width of jetting heads reach, in order requiring additional movement of jetting head in Y axis, which consumes time. Part number 62 dimension in Y axis is under 65 mm mark, it means that jetting head can work along X axis without additional movement.

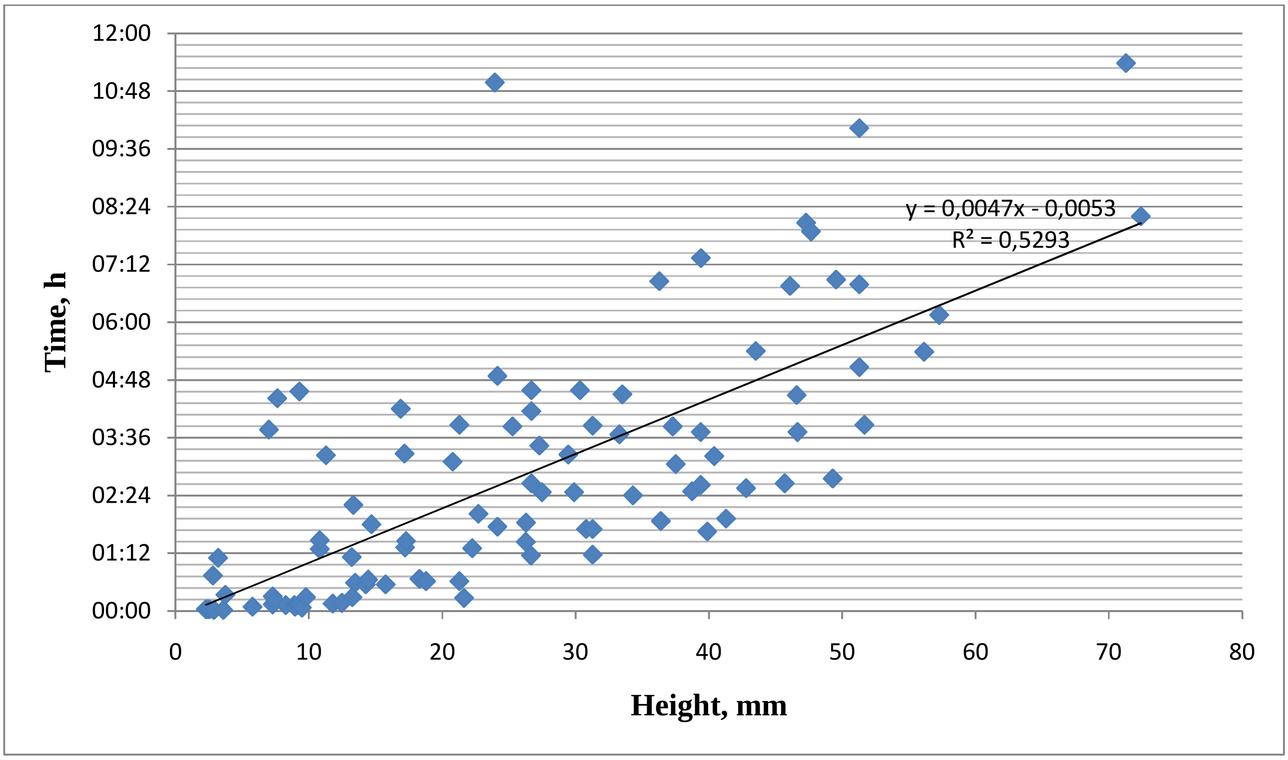

Figure 16. Dependence between part height in Z axis and manufacturing time (Dimension BST 768)

In figure 16, we can see results of same preparation: arranging details in order of parts height according Z axis from smallest to largest and ascribe them as independent variable on X axis, and selecting manufacturing time as dependant variable. Analysis of the graph, show that dependence between details height and manufacturing time also can be noticed. Determination coefficient R^2 = 0,529 show that dependence between variables is weak. Hence, because of large deviation magnitudes, there would be impossible even approximately, to forecast printing time of the particular detail from its height dimensions with Dimension BST 768 printer. To better understanding why, let's examine largely distant point in the middle of a graph, at 24 mm height mark. By checking data table, I found that, this unusual point correspond a part number 25 which dimensions are: 147 x 147 x 24 mm. Models material consumption – 150,73 g, support material consumption – 29,92 g and printing time is 10:59 hour.

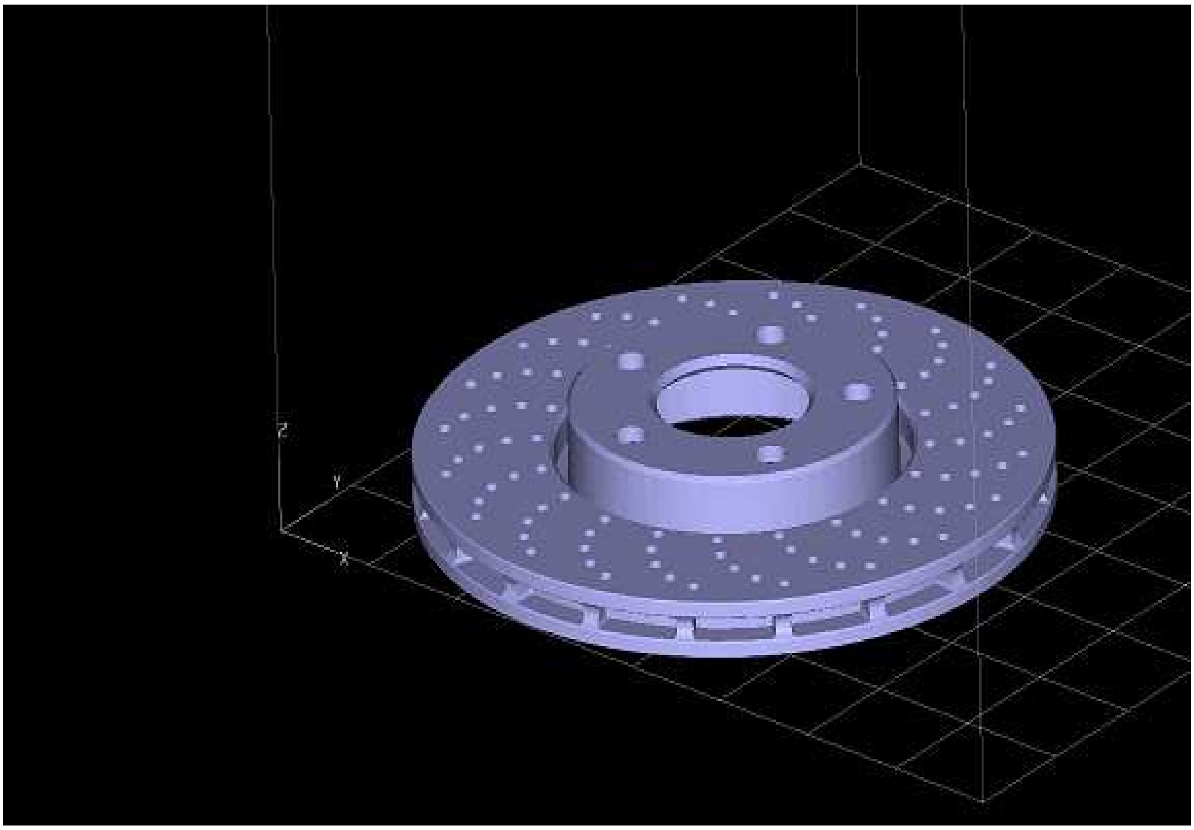

Figure 17. Part number 25.

These dimensions explain why it takes so much time to print the part. Hence, 147 mm in X and Y axes creates massive surface area of a cross-section, comparing to another parts dimensions, so with relatively small height but large other dimensions, FDM 3D printer needs to cover wide surface area, that highly influences printing time. To check this theory we compare part number 25 with another part, which is reflecting in the graph below linearity line at the height axis mark of 41 mm.

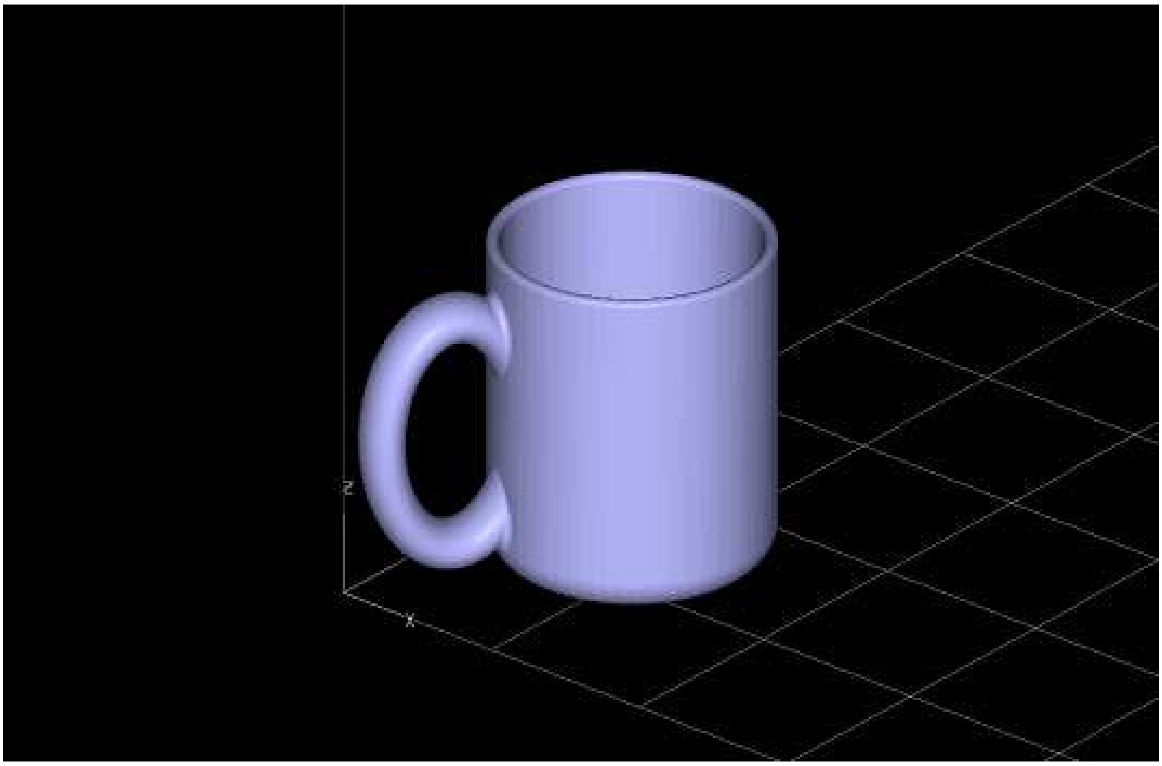

Figure 18. Part number 51.

In a figure 18, we see part number 51, with dimensions of: X=40,3; Y=53,4; Z=41,8. Models material consumption – 12,38 g, support material consumption – 3,1 g and printing time is 1:39 hour. As we see, the height of a part number 51 is even bigger than parts number 25, but the difference in printing time of part 51 is several times smaller. This comparison confirms that, part height is not crucial factor for Dimension BST 768 printing time. Therefore, any forecasting of printing time can't be based only by details height. However, this factor also can't be called as a factor causing no influence to the printing time whatsoever, because for any additive layer machine, there is important number of cross-section that machine will have to cover.

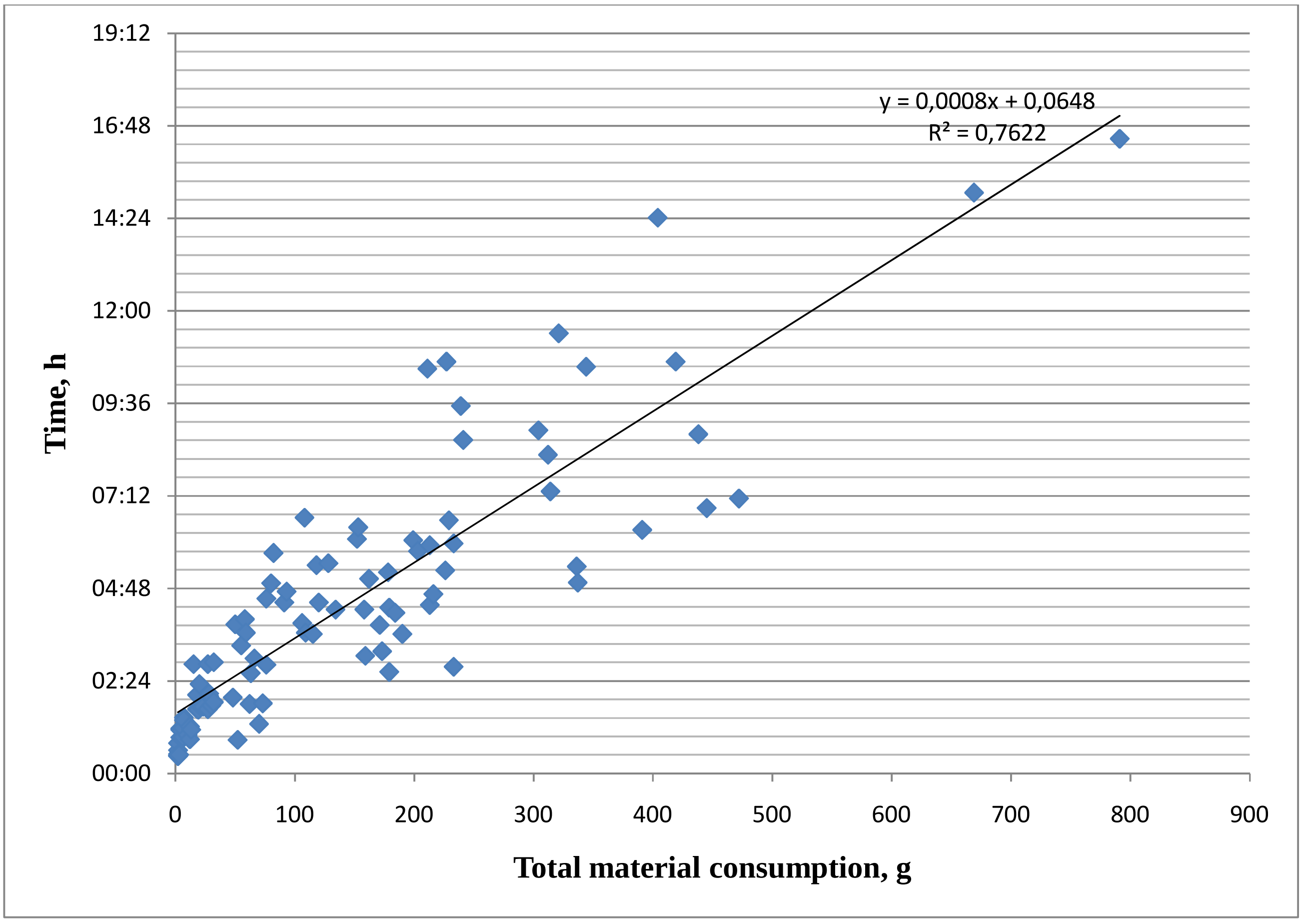

Figure 19. Dependence between details total material consumption and manufacturing time (Objet 30)

In figure 19, we see relationship between models material amount added to supports materials amount versus manufacturing time. Data were sorted as in previous cases, materials were summed and sorted from smallest to largest, choosing total material consumption as X coordinate axis and time relates Y axis. From the graph we see that, significant deviations from linearity are spotted. Points are not strictly concentrated along linearity line, determination coefficient R^2 = 0,762 show that dependency level is medium.

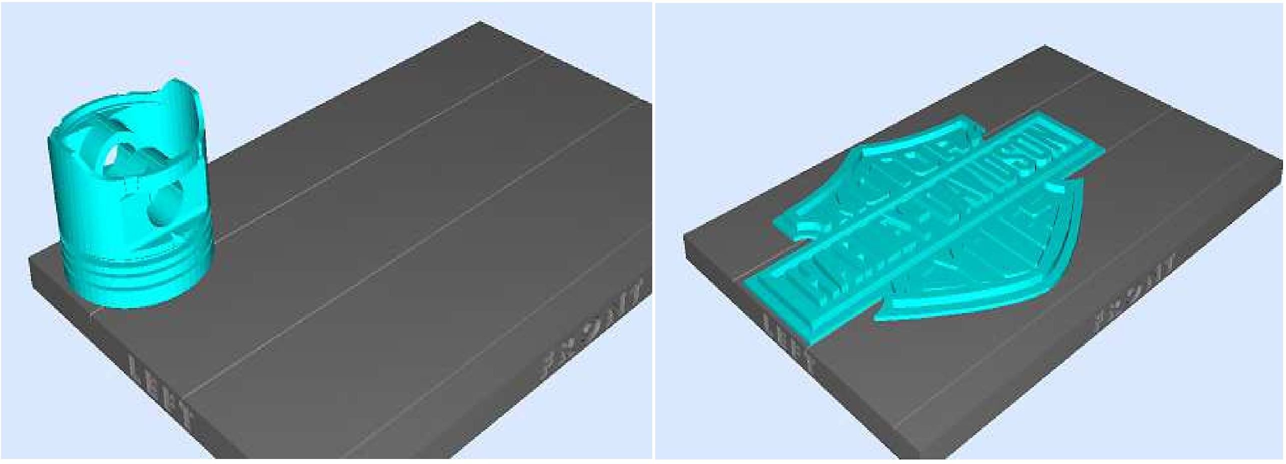

Figure 20 . Part number 75 (on the left) and part number 11 (on the right)

In a figure 20 are presented part number 75 and part number 11 that will be compared as an example. Dimensions of part number 75: X=67,52; Y=67,52; Z=56,14. Total material consumption equal to 227 g, and time consumption of 10:41 hour. Dimensions of part number 11: X=223,6; Y=169,5; Z=6,99. Total material consumption 233g and printing time 2:46 hour. As we can see, total material consumption differs just in 6 grams but printing time differs several times. The difference of printing time can be explained, that for polyjet printing technique the most important factor is height of a part and the width of a part in Y axis. In this particular example height of part number 11 is small comparing with a piston height of 56,14 mm, despite the fact that total material consumptions are almost equal, the taller part requires significantly more time. This example bring us to conclusion that, for Objet 30 3D printer cost estimation based on sum of model material and support material, do not properly relates with manufacturing time and therefore can’t be declared as only one cost estimation determining factor.

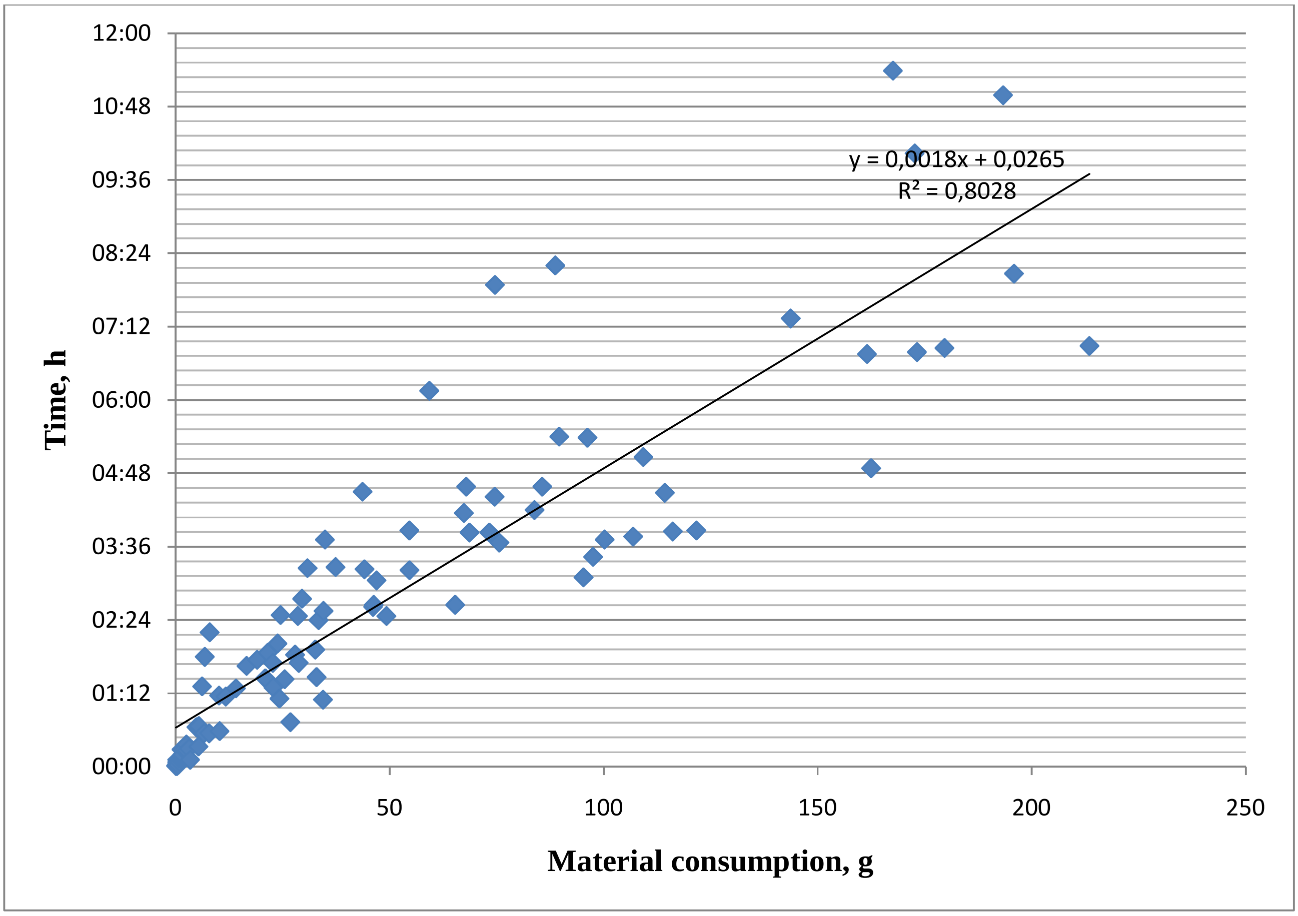

Figure 21. Dependence between details total material consumption and manufacturing time (Dimension BST 768)

In a figure 21, we are checking dependence between details model and support consumptions sum versus manufacturing time. From the concentration of points we can already notice that points are more orientated than in a figure 16, were Dimensions BST 768 printers manufacturing time dependence according details height were displayed. Linear dependence can be traced, determination coefficient R^2 = 0,802 show that dependency level is strong. To better understanding of the factors that causes points deviations from the linearity line, let's analyze highest point in the graph at 11:23 hour. This point correspond to part number 76 which dimensions are: X=93,1; Y=93,4; Z=93,2. Total material consumption – 167,58 g. Data reveals that, due to large dimensions in all directions comparing with other experiment parts that creates approximate average pattern according to which linearity dependence line is drawn, this part stand out from the average caused by height of it. I assume that, for Dimension BST 768 3D printer, main printing time characterizing factor is total material consumption, but also relates with parts height along Z axis. I checked this assumption by comparing part number 76 and part number 93.

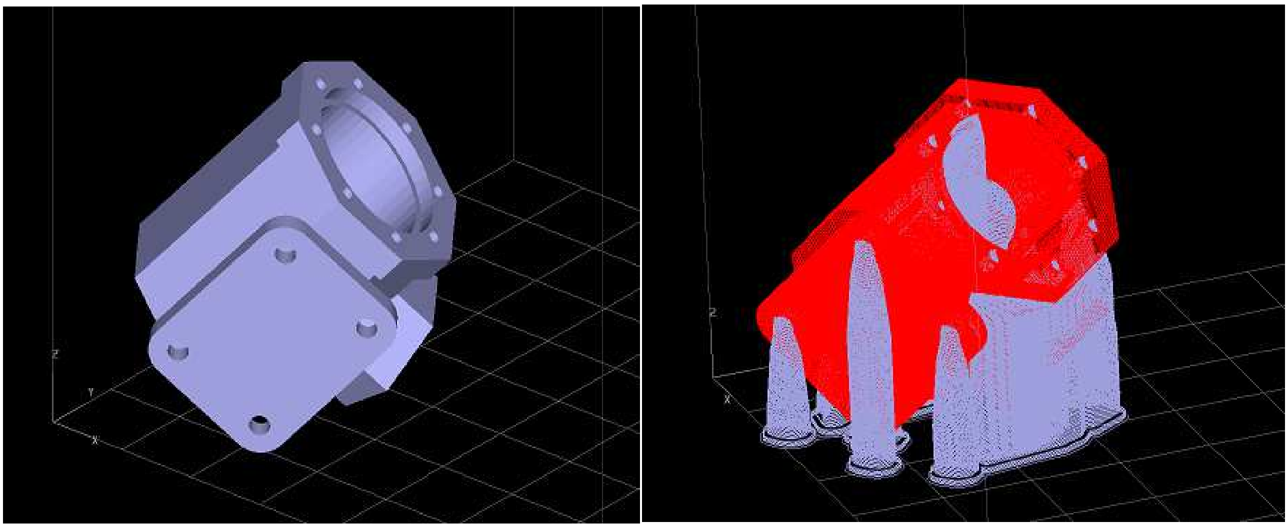

Figure 22. Part number 76 (on the left), part number 76 displayed with support material (on the right)

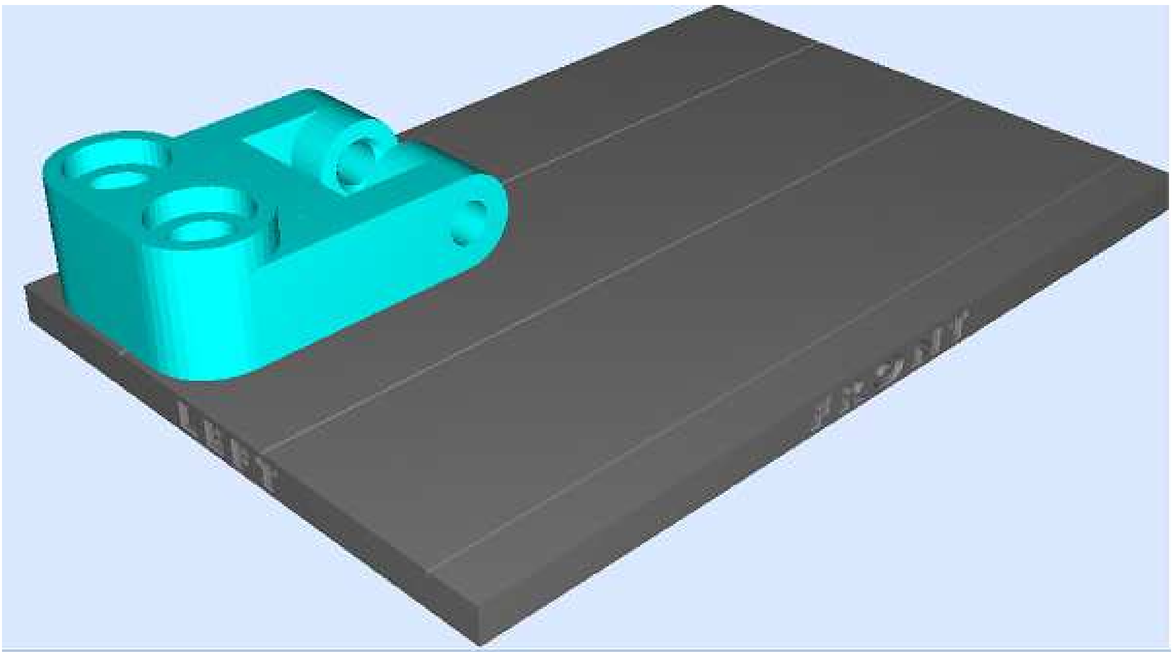

Figure 23. Part number 93.

Dimensions of part 93: X=113 mm; Y=83 mm; Z=41,28 mm. Total material consumption – 215,28 g, printing time – 9:21 hour. Remark, that picture of part 93 is taken from “Objet Studio” software, but it will not induce any inconvenience, because parts are positioned in same manner by the both 3D printers. Comparing these parts data, we see that, even total material consumption for part number 93 is bigger than for part number 76, but the printing time is smaller. To find reason for this mismatch, I am paying attention to the dimensions of parts along the axes. Only significant difference is noticed along Z axis. Dimensions of a part number 76 along Z axis is more than two times bigger comparing to a part number 93, this factor may influence printing time due to extrusion head elevation in z axis direction. Concluding figure 21, we can establish that, paying attention to parts placement on a work plane that z axis dimensions would be smallest, we could approximately estimate manufacturing time according to total material consumption.

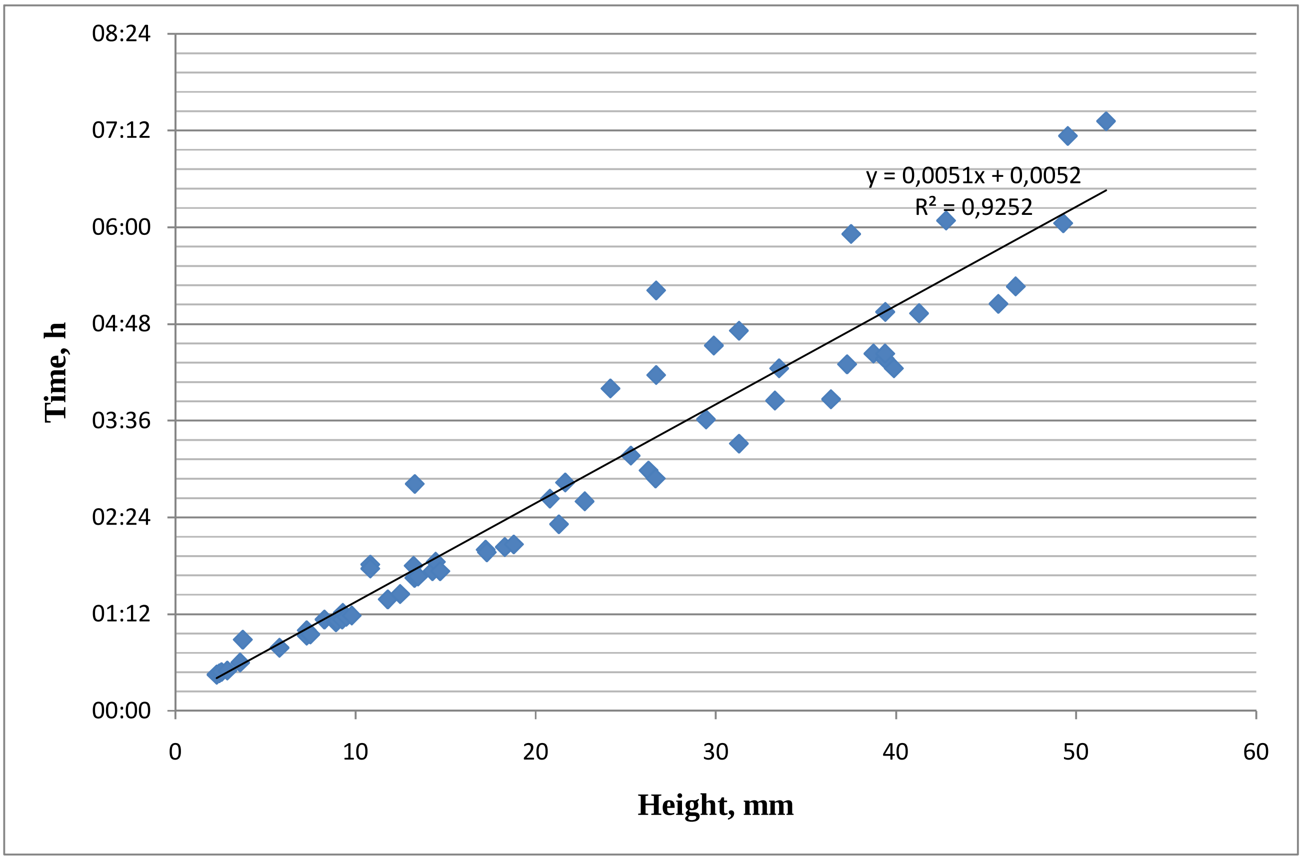

Figure 24. Dependence between part height in Z axis and manufacturing time (Objet 30, parts width less than 65 mm)

In a figure 24, results for the performed analysis can be seen. Here it is also worth mentioning, that after discarding parts whose width is over 65 mm the analysis is performed on data from 66 parts. Then again sorting data by height dimension, from smallest to largest and selecting them as independent variable on X axis with relation to Y axis manufacturing time. As we expected, from the distribution of points along the linearity line, dependence is noticeably less interrupted in comparison with figure 13 dependence. Determination coefficient R^2 = 0,925 show that dependency level between variables is very strong. It proves that, after discarding parts whose width is over 65 mm, dependence of manufacturing time is closely related to details height dimension, because no additional movement to the jetting head needs to be done in direction of Y axis, which consumes a lot of time. On the other hand there are still parts whose printing time exceeds the allowed linearity limits. For example the most distant point at 27 mm height mark.

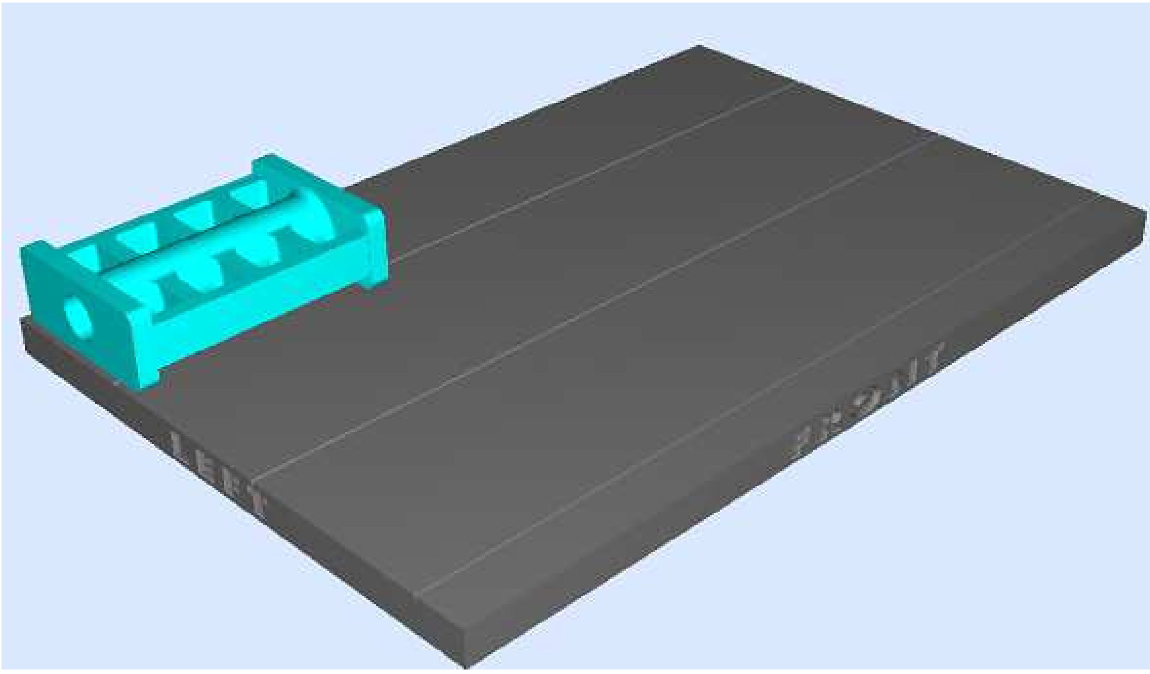

Figure 25. Part number 73.

The point corresponds to part number 73, which dimensions are X=90 mm; Y=60,79 mm; Z=26,68 mm. Total material consumption – 178 g, printing time – 5:13 hour. Printing time of a part number 73 mismatch with average printing time by 1:30 hour, such results may be due to length of the part with respect to X axis comparing with other parts set average of X axis length’s or other geometrical parameters.

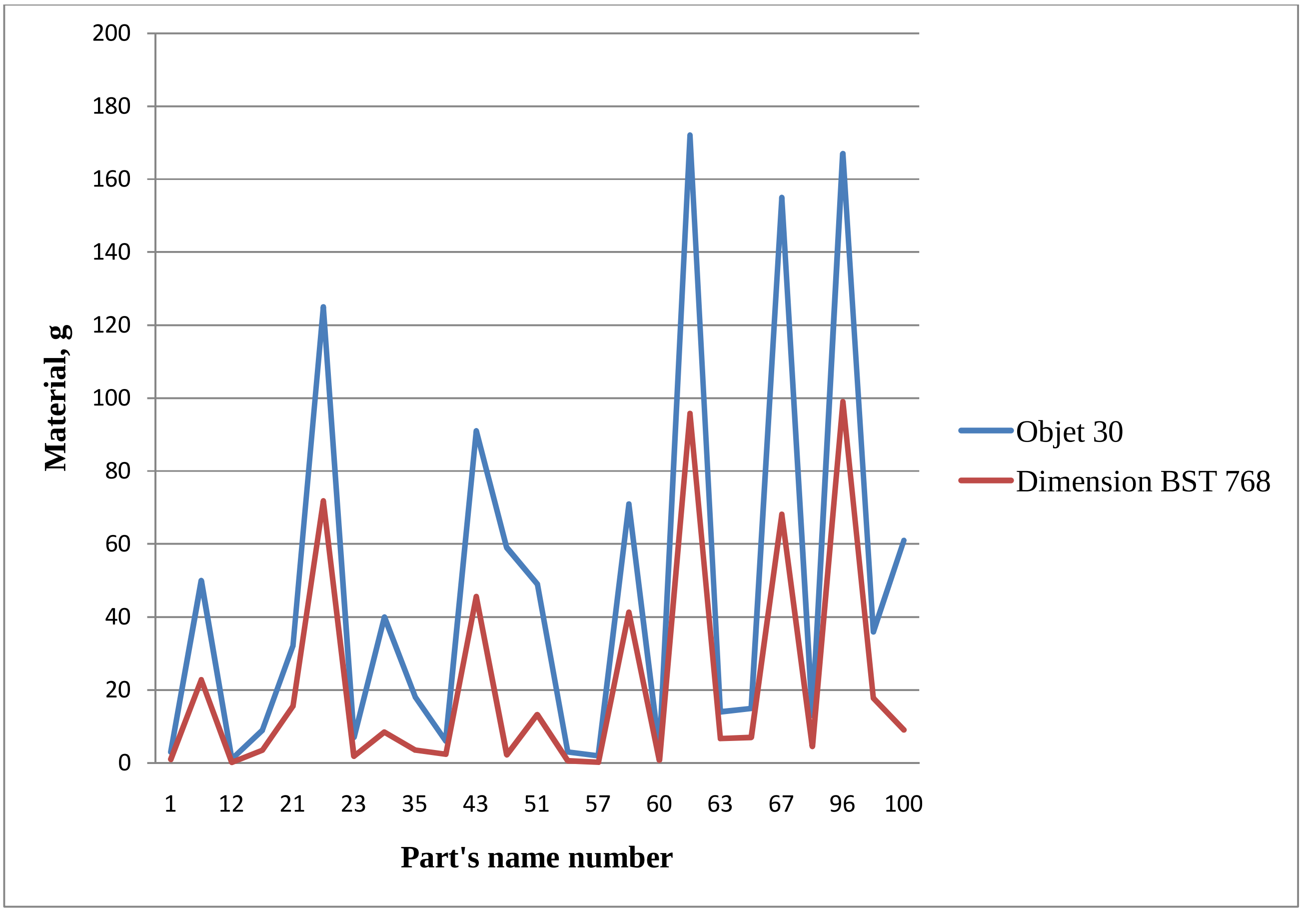

Figure 26. Comparison of model material consumption, between Objet 30 and Dimension BST 768, different positioning parts.

In figure 26, we analyze model material consumption between two given 3D printers. As I earlier mentioned, some of the parts were positioned differently by “CatalystEX” and “Objet Studio” software. Having in mind that, graph was drawn using 27 details of different positioning manner given data. To compare how different positioning effect material consumption between these two 3D printers we start comparing just models material consumption. At first sight results are confusing, because theoretically speaking, same size models material consumption should be equal on both printers, no matter how they are positioned. The difference is caused be different printing technique and different printing materials. Objet 30 3D printer for model uses rigid opaque material which has density value of 1,19 g/cm^3 comparing to Dimensions BST 768 ABS material, which has density of 1,06 g/cm^3. The difference in density had cause deviations in weight, expressed in grams. The difference in weight is up to 12%, because of different densities. Other factor that adds up to the gap between these printers printing time, is the printing technique. As we see, Objet 30 printer uses more model material, it can be explained:

when jetting head is jetting model material onto cross-section of a printed part, some of the modeling material is jetted into support material, to increase its strength and improve other support material properties.

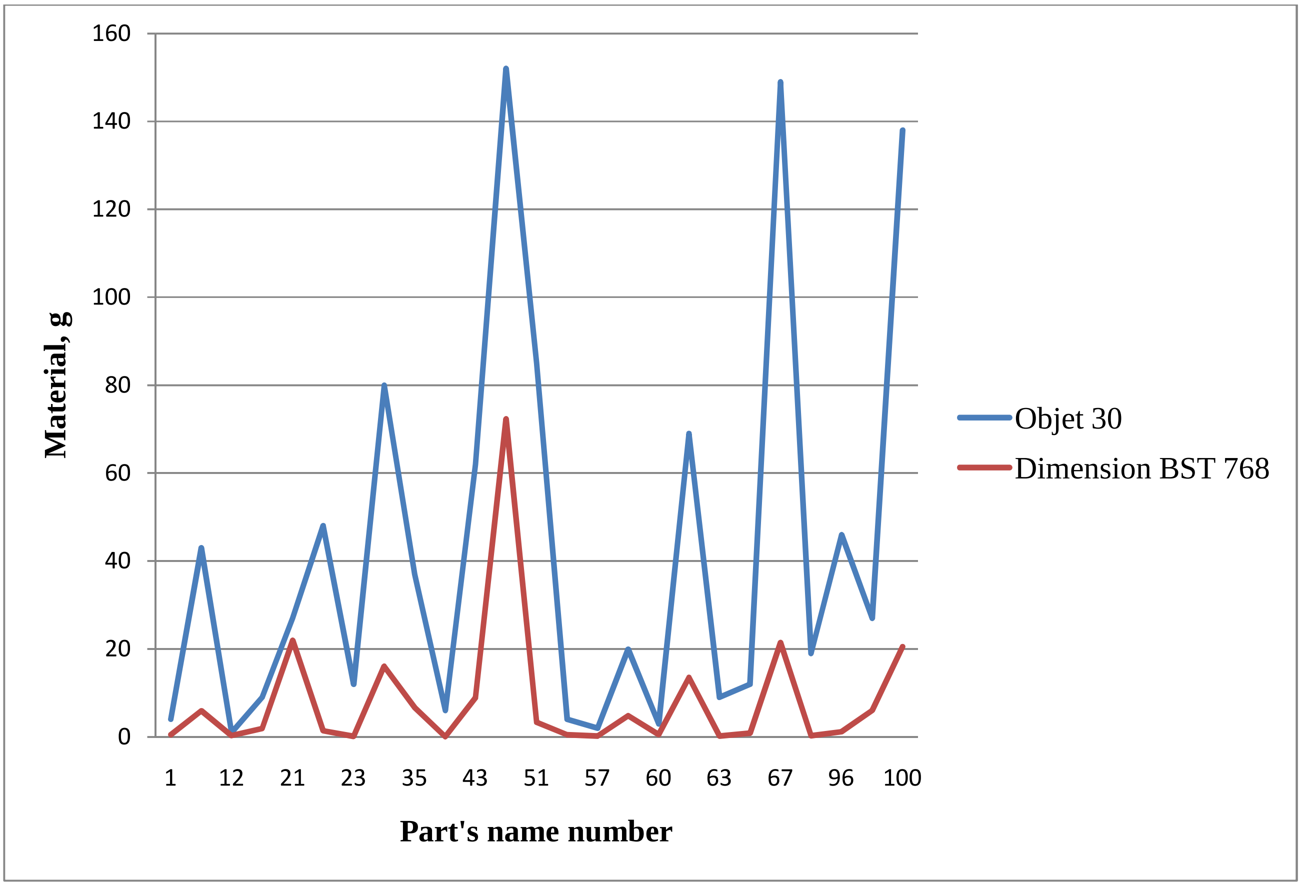

Figure 27. Comparison of support material consumption, between Objet 30 and Dimension BST 768, different positioning parts.

Figure 27 presents the comparison between the given two 3D printers support material consumption in different positioning of the 27 details on a work plane. As we clearly see, curves do not coincide. There was expectation that, support material consumption will differ, because positioning is important not only for time consumption, but also for support material consumption, which effects total parts cost. If, part is positioned for example, at an angle, on the edge or vertically there is necessary bigger support platform that increases material consumption. In figure 28, we see an example of inefficient positioning of part number 21, large quantity of support material is required when part is positioned vertically.

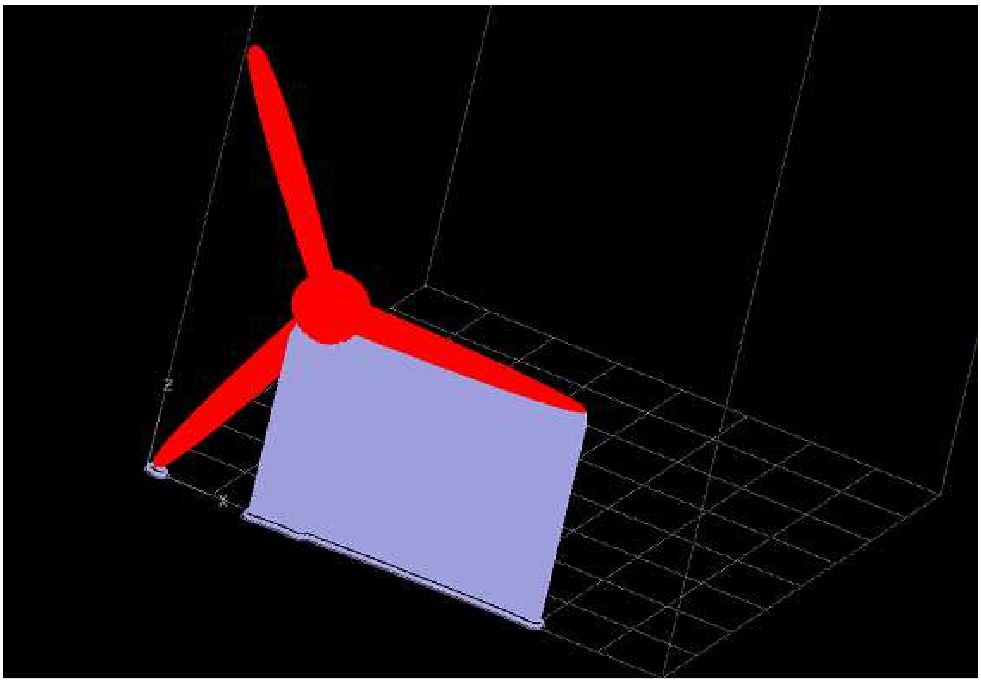

Figure 28. Part number 21.

Let's take another example, a ring shape part, horizontally it consume small amount of support material, because the parts structure tend to withstand its own weight when its placed horizontally, and do not deform. On the other hand, when ring shape part is placed on the work plane vertically then, wide base area is necessary and filament for all vertical cavities, to support models weight. Also difference between the consumption curves is affected by other factors. One of them is the technique of printing. In one way in which the Objet 30 3D printer technology differs from other ALM technologies is the mixing of support and model materials. Model material is mixed in with intent to improve support material and its mechanical characteristics. That brings us to the difference of density of the materials. As in model material consumption case and in this case, materials are different, so the densities also differ. For Objet 30 printer is used FullCure 705 non-toxic gel – like photopolymer, which density is 1,22 g/cm^3 and for Dimension BST 768 breakaway support cartridge is same ABS material, but with worse properties of it. Hence, Objet 30 uses heavier material and technique of materials extrusion that, consumes more of it, than Dimension BST 768 3D printer.

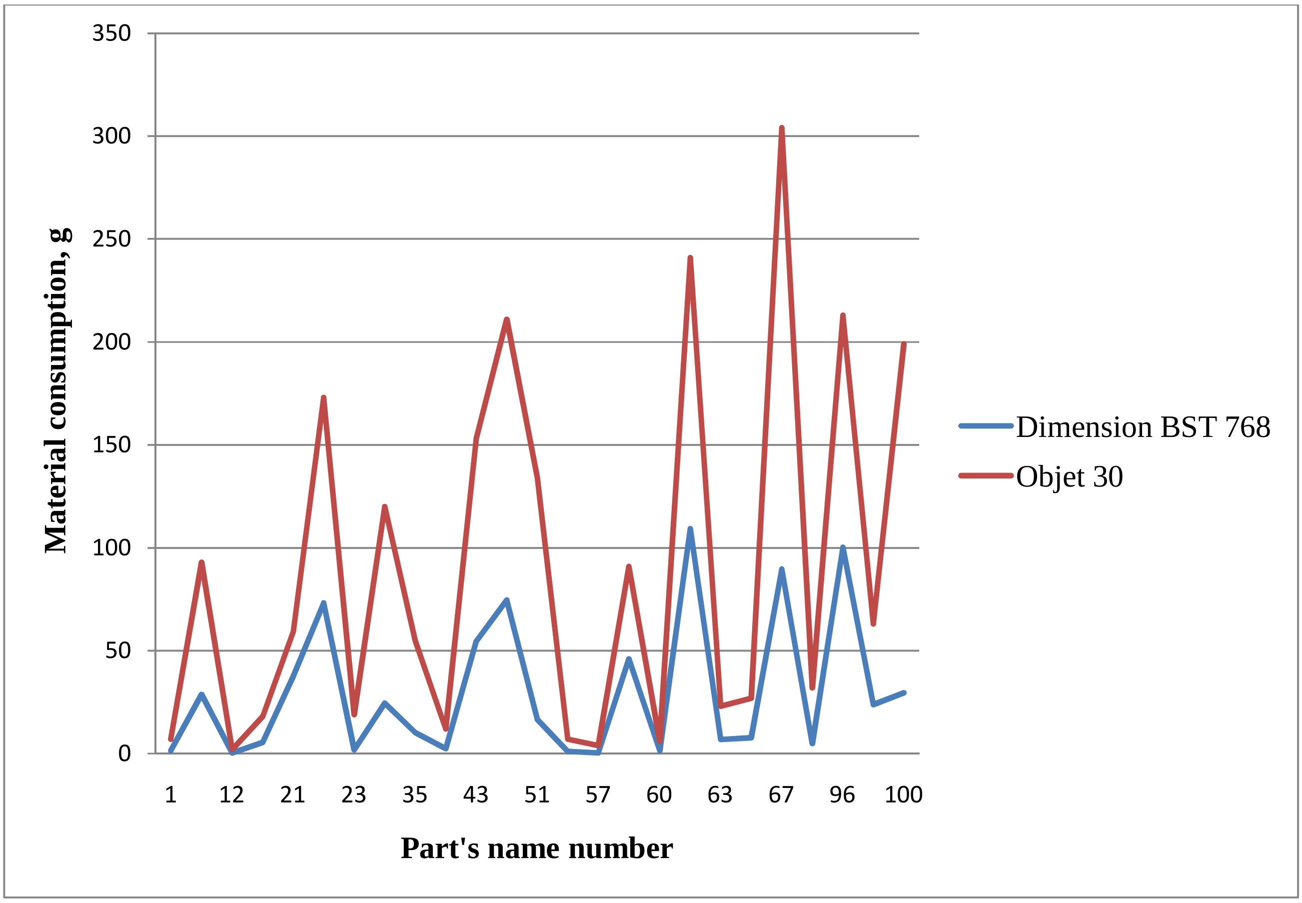

Figure 29. Comparison of total material consumption, between Objet 30 and Dimension BST 768, different positioning details.

Figure 29 display the comparison curves of the sum between support material and model material. Same 27 details material consumptions were added together and graph was drawn. As in previous graphs results are similar to this graph. Dimension BST 768 3D printer has a clear advantage against Objet 30 comparing which uses less material in printing process, even considering 12% error, caused by difference of material densities. It is difficult to determine what quantities of model material are jetted into support material by polyjet technology in Objet 30 3D printer. When materials are added, the gap between Dimension BST 768 and Objet 30 total material consumption, comparing with model and support material consumption gets bigger. That wide gap can be explained as a reason of one polyjet technologies feature. That feature is the marginally closer relation between model material consumption and support material consumption for Objet 30 3D printer comparing to Dimension BST 3D printer. The relation difference is graphically displayed in a figure 30 and figure 31.

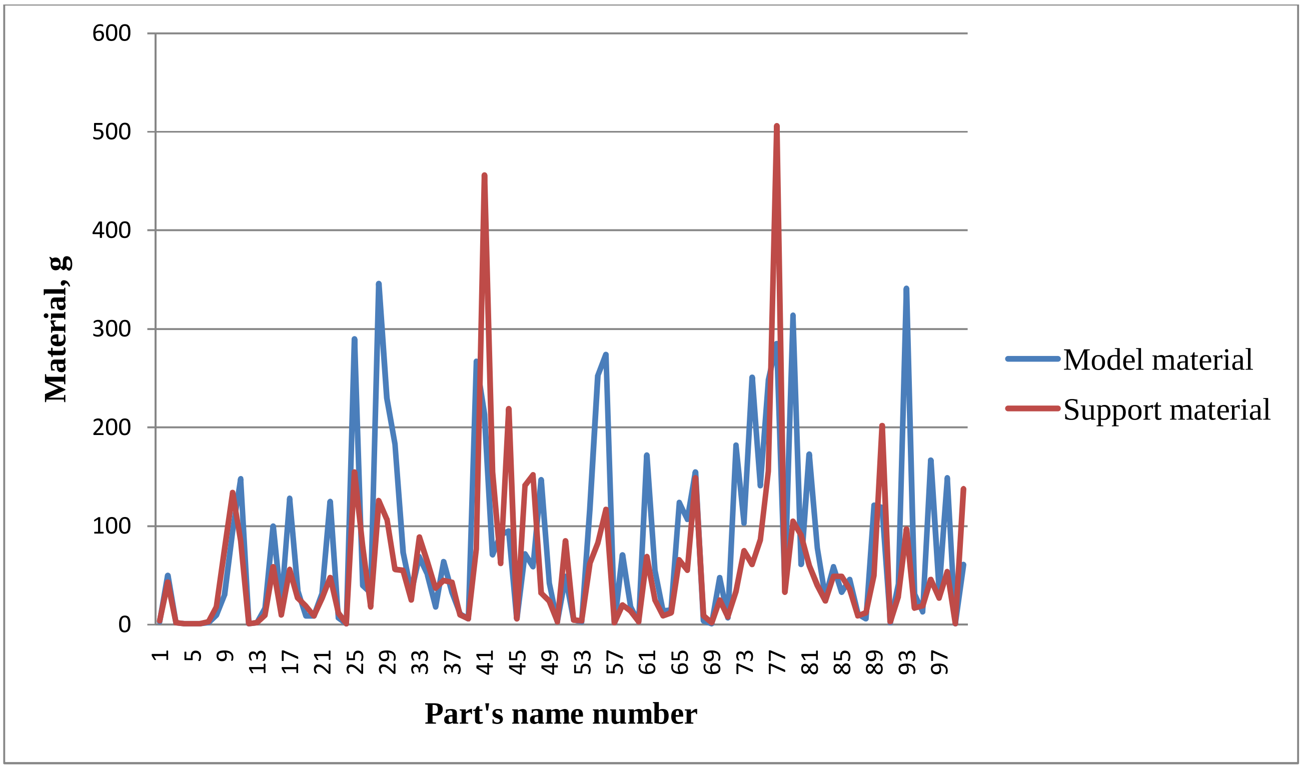

Figure 30. Models and support material comparison (Objet 30)

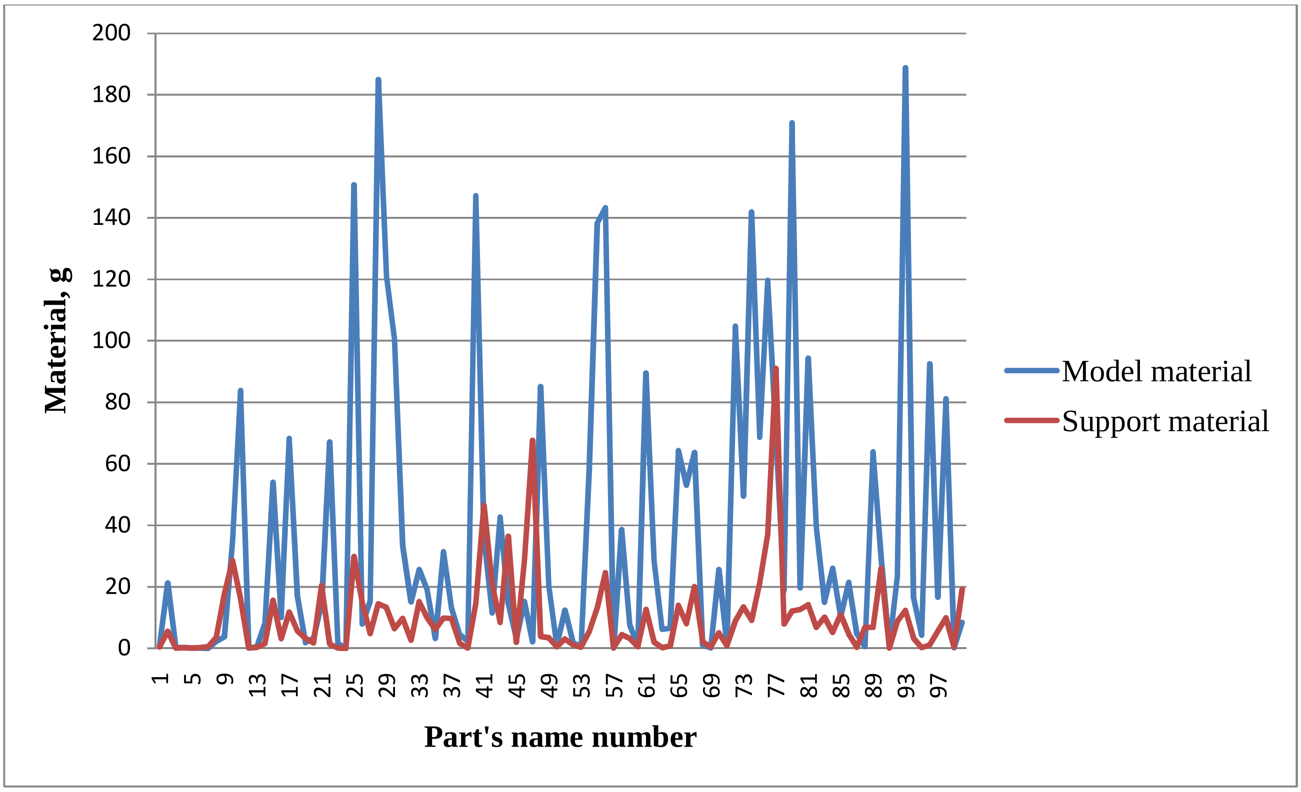

Figure 31. Models and support material comparison (Dimension BST 768)

In a figure 30 we see that, as models material amount is growing so does the support material amount. They are related due to polyjet technology working principle, to cover all parts surfaces with improved support material. Also, support material amount depends from complexity of a part and positioning. Comparing Objet 30 to Dimension BST 768 graphs, we notice clear difference between model material and support material amounts relation. For Dimension BST 768 same rule can't be applied, because model material amount do not correspond to support material amount as much as Objet 30 3D printer. The reason, why Dimension BST 768 uses a lot of less support material and amount of it is not related to model material amount is because of FDM technology working principle, which was explained in theoretical part. Concluding figure 29, the difference of total consumption of material in comparison between these two printers, mainly is caused by the different printing technologies as figure 30 and figure 31 revealed.

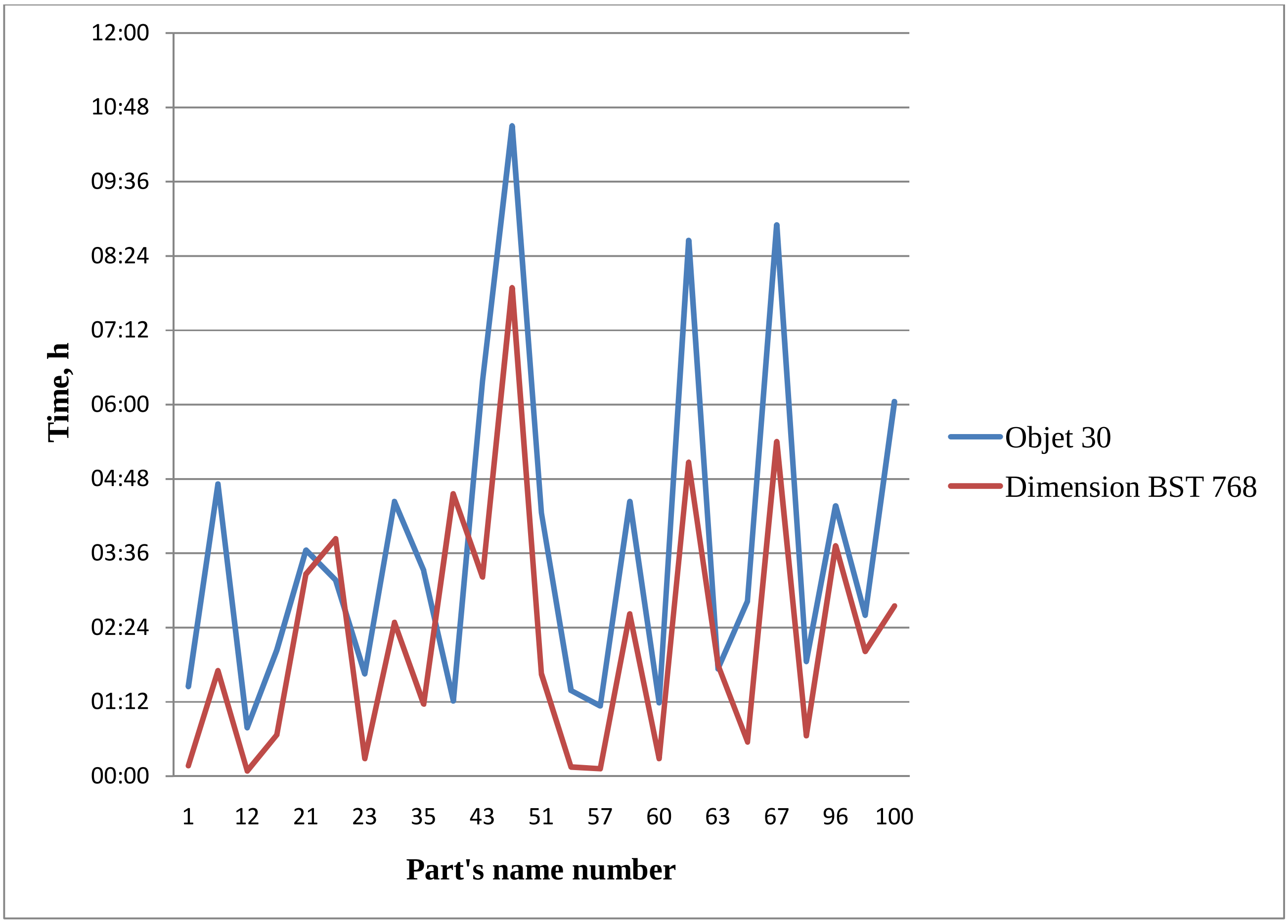

Figure 32. Comparison of printing time, between Objet 30 and Dimension BST 768, different positioning parts.

In figure 32 we see comparison of printing time consumption between given printers, of different positioning 27 details. Again, Dimension BST 768 is ahead in this area too, it consumes less time to print same part, but positioned differently with respect to Objet 30 3D printer. However, considering that Dimensions BST 768 one printed layer thickness is 0.254 mm comparing to Objet 30 0.028 mm. The difference of layer thickness is more than 9 times. So the question is, how Objet 30 3D printer keeps such small difference between printing times, comparing to Dimension BST 768. The answer is due to printing technology difference. Dimension BST 768 using fused deposition modeling technology would consume more time, because the printing process actually is slower due to technique in which layers of material are laid. Extrusion head have to directly follow every single cross-sections geometrical path in order to lay one layer. On the other hand polyjet technology lays 65 mm width continuous layer of material, despite any geometrical shapes of a part. Considering that layer is 9 times thinner than FDM's printer, even the technique principle is faster, but that is not enough offset 9 times thicker layer.

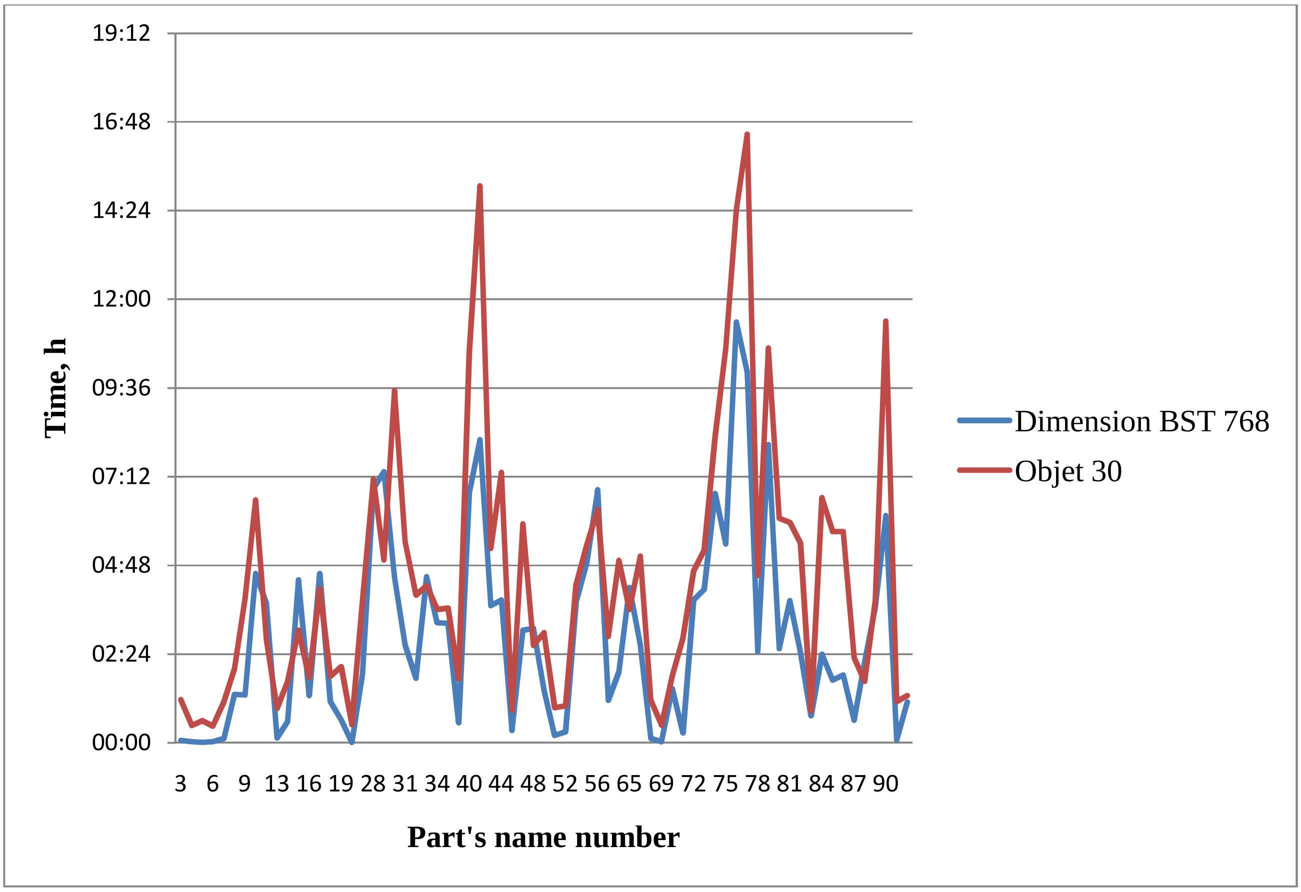

Figure 33. Comparison of printing time, between Objet 30 and Dimension BST 768, same positioning parts.

In a figure 33, we see parts which were positioned in same manner, compared with respect to printing time. From this graph we can precisely determine which printers printing technique is faster, because parts were positioned in the same way. Dimension BST 768 3D printer is in front, for the same reasons that I explained for the figure 32, due to technology and layer thickness difference. As I earlier revealed that, support materials quantity significantly differs even in the same positioned parts, because of technology difference, so comparing figure 32 and figure 33 gap's width between printing times as a cause of supports material quantities difference is meaningless.

2.5. CONCLUSION OF ANALYSIS

After analysis of the given data was done, manufacturing cost estimating factors for each 3D printer was determined.

Objet 30: dimension of a part, placement on the work plane, height in Z axis direction, width in Y axis direction.

Dimension BST 768: dimensions of a part, volume/mass of a part, placement of a part.

3. ECONOMICAL PART

3.1. REVIEW OF 3D PRINTING ECONOMICAL FIELD

The use of 3D printing technology has potential effects on the global economy, if adopted worldwide. The shift of production and distribution from the current model to a localized production based on-demand, on site, customized production model could potentially reduce the imbalance between export and import countries.[29] 3D printing would have the potential to create new industries and completely new professions, such as those related to the production of 3D printers. There is an opportunity for professional services around 3D printing, ranging from new forms of product designers, printer operators, material suppliers all the way to intellectual property legal disputes and settlements.

The effect of 3D printing on the developing world is a double-edged sword. One example of the positive effect is lowered manufacturing cost through recycled and other local materials, but the loss of manufacturing jobs could hit many developing countries severely, which would take time to overcome. The developed world, would benefit perhaps the most from 3D printing, where the growing aged society and shift of age demographics has been a concern related to production and work force. Also the health benefits of the medical use of 3D printing would cater well for an aging western society.[29]

Additive Manufacturing or 3D printing could transform the manufacturing process in many critical ways, some of which are likely to happen sooner than others and all of which will likely apply to different end products at different paces. But overall, AM will bring production closer to the consumer and thus production at any given point will likely be required in smaller numbers.[34]

Supply Chain Structure:

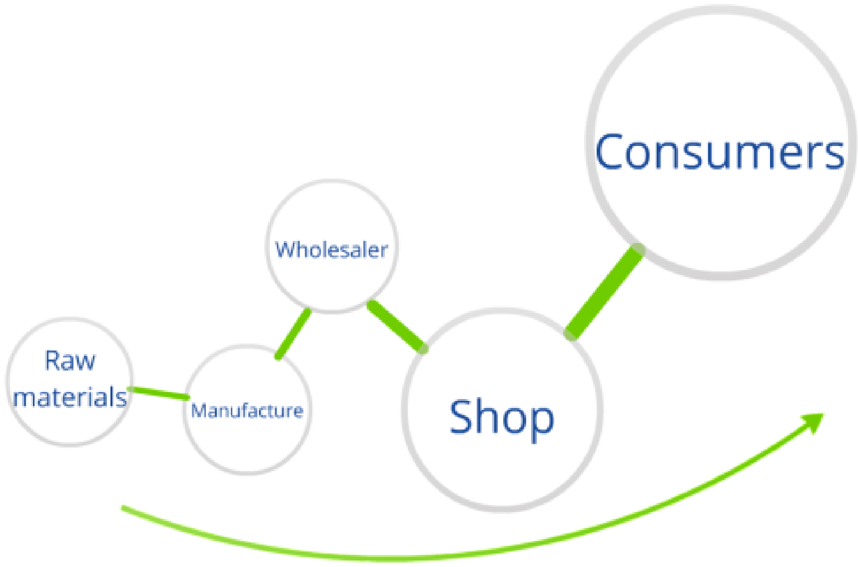

Figure 34. The Traditional Supply Chain for Consumables.[31]

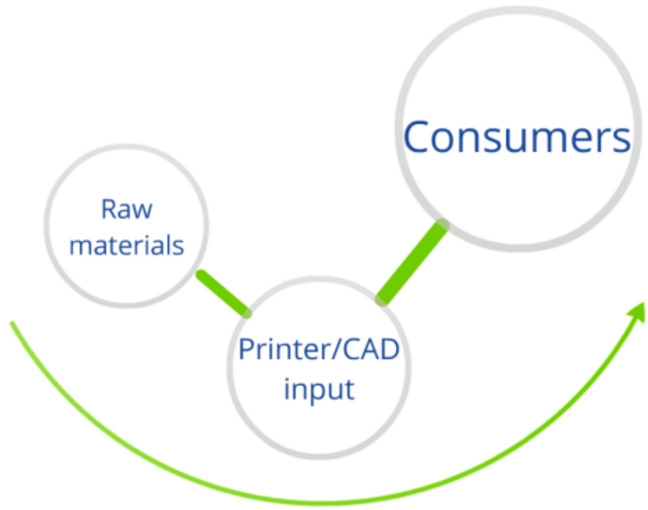

Figure 35. New (3D Printer diffused) Supply Chain.[31]

The removal of part of the supply chain and human economic activity in producing goods could potentially lead to the destruction of manufacturing industry. This affects not just the direct participants in this industry but also the service sectors that support it.

Economic benefits:

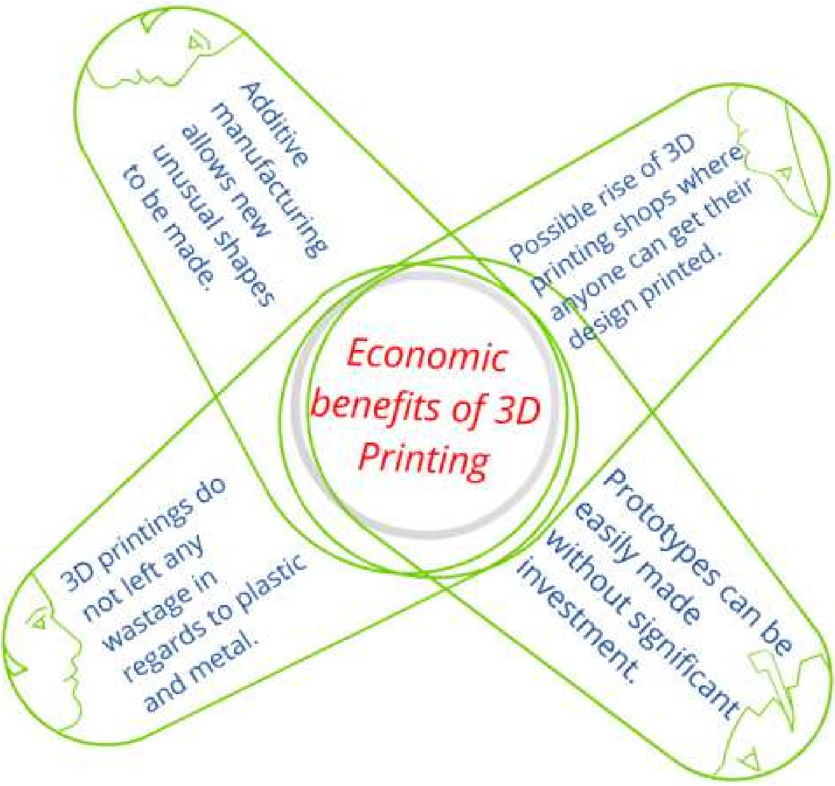

Figure 36. Economic Benefits.[31]

Furthermore, 3D printing is showing great promise in terms of fulfilling a local manufacturing model, whereby products are produced on demand in the place where they are needed — eliminating huge inventories and unsustainable logistics for shipping high volumes of products around the world.[29]

The value of the global market for 3D printers and services is up to $2.2 Billion. The market size is growing at a significant rate, with a 30 percent increase between 2011 and 2012. That's an impressive jump for a manufacturing industry recovering from recession, and it's a sign that manufacturers think 3D printing capabilities are worth the investment concern related to 3D printing for many IP holders.[26]

An outsourced prototype can cost anything from several hundred dollars for simple design, up to thousands of dollars for a more complex model. Creating the same prototype on an in-house 3D Printer can convey a significant cost saving. It's not unheard of for an outsourced part to cost as much as 3-5 times that of a part printed in-house. Even if printing only two models per month on average, using an onsite 3D printer can produce major cost savings over the costs of sending designs out. In addition to the lower out-of-pocket expenses, there are the savings resulting from designers and developers not having to wait for prototypes to return, time to market savings, and savings on reduced manufacturing errors due to the ability to print many prototypes. Cost is based on material used, so big things are expensive, and small things are cheap.

There is given an example. Filament typically costs around $45 / £30 / €35 for a 1kg reel. This means – very roughly – that 1 meter of 3mm filament will cost around 45¢ / 30p / 35c. So the complex pair of nut crackers, which uses 4m of filament to print, will cost you about $1.80 / £1.20 / €1.40; this thimble (right) costs about 15¢ / 10p / 12c. Most printers use standard reels of filament, manufacturers of 3D printers can't control the cartridge price the way inkjet printers do, and it's up to the open market to set the cost of filament. A notable exception is 3D Systems, maker of the Cube and CubeXmachines, whose printers only use their own brand compatible cartridges, and which consequently cost significantly more.

Most printers work with only one type of material—plastic, metal, ceramic, wood, or a biological material. To create more useful products and expand the market, 3-D printers will need to process multiple material types within a single build cycle. Various factors, mostly related to materials themselves, make this requirement challenging.

It is needed to evaluate and costs related with prototyping reduces manufacturing errors and saves costs by enabling design details to be fine-tuned before costly molds and die casts are made. This is true whether the prototypes are outsourced or created by an in-house 3D Printer. However, when prototyping is readily available and can be done inexpensively in multiple iterations, the potential for errors is significantly reduced. Designers can test out different ideas to find the optimal design; and small variations can be modeled and checked for functionality.

Despite growing enthusiasm for the use of 3-D printing in medical training, cost is a significant obstacle. Additive manufacturing can offer time, energy and cost savings over traditional manufacturing techniques in certain applications, but most 3-D polymer printers on the market today can only fabricate small prototype parts.

Inkjet printing for 2-D printers has been around since the 1970s, but was adopted for 3-D printing only about seven years ago by Objet (now part of Stratasys) in a process the company calls PolyJet. By jetting two or more base materials in varying combinations, this technology allows the creation of new material properties that span from rigid plastic to rubber-like and from opaque to transparent. More recently, the technology also allows the printing of multiple colors.[28]

The cost of the Material - Volume of material used.

Wasted material - in Supports and/or tests for the printed model.

Electricity bill

If you have to Design the object - Cost for Design.

Your own Added Value - Quality of your object, if it has post processing painting or just a raw 3D print in one color.

Kyle Stevens, of Macy Moo Studios, has developed a 3D Printing Price Calculator plug-in for Word Press that will make it easy for anyone to figure out approximately how much it would cost, in terms of material price, to print a solid 3D object.[29]

A single reel contains 1.5 lbs (.7kg) of filament. The amount you print per lb/kg varies with the amount of raft and support material required, but it averages out to $0.02-$0.05 per cubic centimeter, or $0.33-0.82 per cubic inch. The easiest way to calculate the cost of the material that will be used for your model is to use the print preview option under the 3D Print menu. This will calculate the total weight of material used, including the raft and any support material. Then, use this formula: Cost to Print = Weight of Model x (Cost of Spool / Full Spool Weight)

And Finally your time, calculate how much of your time will require the preparation, printing and finishing the object itself, and put a price on it, like if you are working in a firm, $Dollars/Hour.

3.2. CALCULATION OF A PRICE

Below, there is calculation of the exact price of one produced experimental 101 part. The first version – printer “Objet 30” which uses Poly jet technology. The second one – “Dimension BST 768” which use FDM technology.

Objet 30

The Objet30 combines the accuracy and versatility of a high-end rapid prototyping machine with the small footprint of a desktop 3D printer, making it great for prototyping consumer products within limited space and budget. Powered by PolyJet technology, it offers five 3D printing materials and features PolyJet's signature smooth surfaces, small moving parts and thin walls. With a roomy tray size of 300 × 200 × 150 mm, Objet30 gives you the power to create realistic models in-house – quickly and easily The Objet 30 features four Rigid Opaque materials and one material that mimics polypropylene. The Vero family of materials all feature dimensional stability and high-detail visualization, and are designed to simulate plastics that closely resemble the end product.

Based on PolyJet 3D Printing technology, Precision 3D Printers give you the best surface quality, finest details and widest range of material properties available. Produce color and multi-material models that look and feel just like your future products. 3D printers using PolyJet technology work with a vast array of materials, including Rigid Opaque and Rubber-like materials in hundreds of vibrant colors, clear and tinted translucent shades, Simulated Polypropylene, and specialized photopolymers for 3D printing in the dental and medical industries.

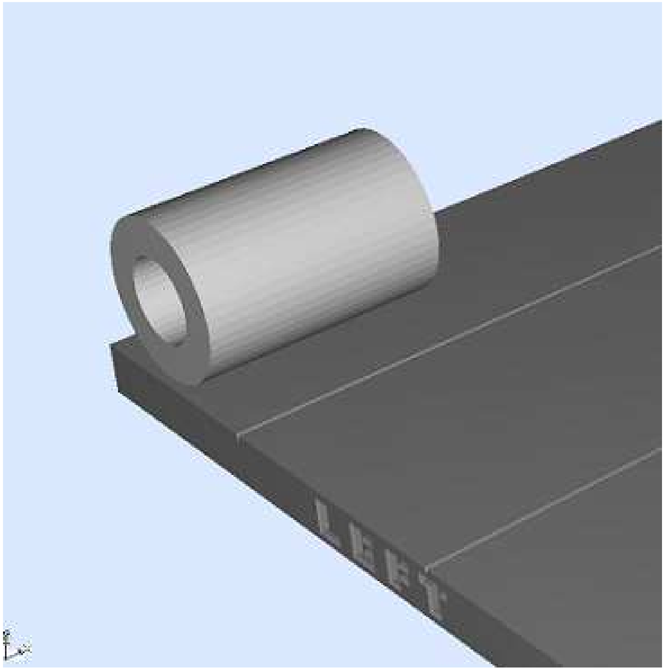

Figure 37. Part number 101 (Objet 30)

There is given dimensions of detail and related costs.

Model material 97 g

Support material 53 g

Printing time 4:13

X=59,7 mm; Y=40,78 mm; Z=39,08 mm

OBJ-04020 Pack of 2 FullCure 705 Support Resin 1 kg - 228.8 €

OBJ-04054 Pack of 2 FullCure 835 VeroWhitePlus 1 kg Model Resin - 549.15 €

OBJ-04016 Pack of 2 Support Cleaning Fluid - 45.76 €

OBJ-04018 Pack of 2 Model Cleaning Fluid - 45.76 €

Calculation:

Model material price/detail:

$$\frac{97 * 549{,}15}{1000} = 53{,}27\ €$$

Support material price/detail:

$$\frac{53 \ * \ 228,8}{1000} = 12,12 \text{ €}$$

The total price of printing is 65.39 €.

Even for simple products, 3-D printing still takes too long—usually hours and sometimes days. Incremental improvements as well as new methods that have the potential for an order of magnitude change will help printers meet the challenge for greater speed. There are lots of ways to improve speed by using higher-quality components and by optimizing the designs and movement of the lasers.

Dimension BST 768

The Dimension BST 768 3D Printer features the finest resolution of any Stratasys Design Series Performance 3D Printer. Driven by Fused Deposition Modeling (FDM) Technology, it prints in nine colors of real ABS plus thermoplastic. For times when you don’t need the finest Dimension resolution of 0,178 this 3D printer lets you speed up printing with a layer thickness of 0,254 mm.[32].

Dimension 3D printers use ABS plus thermoplastic to build your models. Model and soluble support materials come in convenient enclosed cartridges that are a snap to load. Inside the 3D printer, plastic filament travels through a tube to the print head, where it’s heated to a semi-liquid state and extruded in thin, accurate layers.[32]

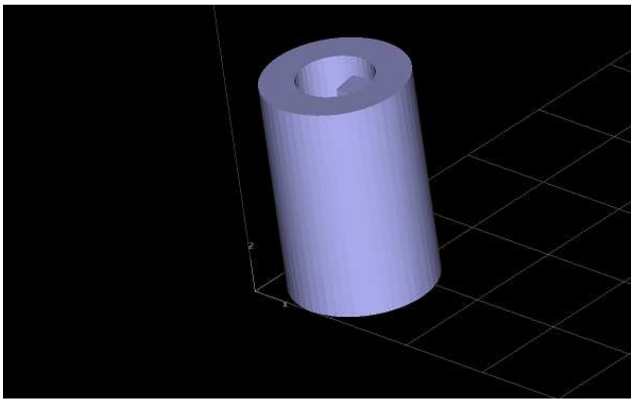

Figure 38. Part number 101 (Dimension BST 768)

There is given dimensions of a part and related costs.

Model material - 50,8 g

Support material - 2,05 g

Printing time - 4:08

X=37.8 mm; Y=37.8 mm; Z =56.7 mm

ABS Breakaway Support Material Cartridge - 238 €

ABS White Model Cartridge - 238 €

Modeling base (case of 10) foam foundation - 114.40 €

Calculation:

Model material price/detail:

$$\frac{50,85 \ * \ 238}{1000} = 12,10 \text{ €}$$

Support material price/detail:

$$\frac{2,05 \ * \ 238}{1000} = 0,49 \text{ €}$$

Modeling base:

$$\frac{114,40}{10} = 11,44 \text{ €}$$

The total price of printing is 24,03 €.

What our approach has shown is that FDM 3D Printers can be used to realize key production goals in industries such as the packaging sector where deep drawing processes are primarily applied. Comparing two different printers and technologies, estimate the costs of it there are the results.

Objet 30			Dimension BST 768	
	65,39 €	Price	24,03 €	
	4:13	Time	4:08	

Table 3. Comparison of final parts price between Objet 30 and Dimension BST 768

That depends, of course, on size. The choice of resolution, support material, and raft influence speed greatly. The included print software provides a time estimate before you begin printing. From the table above one can easily see that Objet 30 3D printer would take 4:13 min and Dimension BST 768 would take 4:08 min. to print a chosen part. Thus, printing time is similar for both printers, Objet 30 taking a slight edge over its competitor. But when one takes a look at price comparison, things are getting more interesting as the Dimension BST 768 would make the same part more than twice cheaper than Objet 30. Such difference in price is mainly due to the price of model material which is a lot more expensive for the first 3D printer.

The technology for 3-D printing, also known as additive manufacturing, has existed in some form since the 1980s. However, the technology has not been capable enough or cost-effective for most end-product or high-volume commercial manufacturing.

Return on investment in an in-house 3D printer is typically fast, even when outsourced modeling is low-volume. The short-term economic return expands to long-term advantage through enhanced innovation, increased confidentiality, more productive design cycles, higher-quality designs, and faster time to market are about to change. Previously impossible shapes and geometries can be created with a 3D printer, but the journey has really only just begun. 3D printing is believed by many to have very great potential to inject growth into innovation and bring back local manufacturing.

CONCLUSIONS

Performed research enables to make following conclusions:

1. During the work, the advantages and disadvantages of polyjet and FDM technology was revealed. FDM technology: uses significantly smaller amount of support material, is less dependent to precise placement in work area, consumes less time to print same part, comparing to polyjet technology, replacements of support material is noticeably cheaper, has a wider material color choice. Polyjet technology: is more accurate, produces excellent surface finish, printed model has better strength properties, expensive replacement materials, consumes more time to print same part, is highly dependent to the positioning of a part.

2. Analysis was performed using 101 random parts. 27 parts were positioned on the work plane differently by the different software's. 5 graphs were drawn in a search of linear dependence between chosen variables. Graphs variables, with the highest determination coefficient values were chosen as crucial factors to the manufacturing cost estimation. 7 graphs were drawn to compare polyjet and FDM technology manufacturing cost influencing factors.

3. During the investigation of polyjet technology, was determined crucial factors which influence manufacturing cost is: dimensions of a parts and positioning of them in work area.
   Also, there was determined that, part's height in direction of Z axis is critical factor for printing time.
   Significant influence to the manufacturing time has the width of a part in direction of Y axis, if parts width exceeds 65 mm than manufacturing time massively increase.
   After FDM technology was investigated, there was determined manufacturing cost estimating factors: dimensions of a part and placement of a part in a work area.
   Manufacturing time depends from: mass/volume of a part, a minor influence is caused by height of a part in Z axis direction.
4. For the economical part of a work, were calculated exact price for the same part using different technologies. Results showed that: FDM technologies price per part is nearly three times cheaper comparing with polyjet technology, due to smaller amount of support material consumption and cheaper material itself.

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