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ANALYSIS OF THE QUALITY OF PRODUCTS MANUFACTURED WITH THE APPLICATION OF ADDITIVE MANUFACTURING TECHNOLOGIES WITH THE POSSIBILITY OF APPLYING THE INDUSTRY 4.0 CONCEPTION

Abstract: *With the advent of the Fourth Industrial Revolution, the manufacturing industry began to pay special attention to the introduction of solutions based on modern technologies. These include rapid prototyping techniques, which are also popularly known as 3D printing. As the 3D printing industry develops around the world, new brands of machine manufacturers, as well as companies providing services in this field, keep appearing. Thus, a need has arisen to organize and systematize processes and define certain quality standards. In line with Industry 4.0, it is also extremely important to consider modern production management solutions that use IT systems to integrate networked distributed components of manufacturing processes. In this context, a research gap has been observed in the development of a quality control procedure for 3D prints that can be implemented in an in-house cloud. For this reason, the main objective of the paper is to present the author's online platform, which presents a sample procedure for quality control of 3D models. The paper also analyzes the costs associated with the quality control of 3D models assuming that the company has its own infrastructure, manufacturing components and qualified staff.*

Keywords: *Quality control; Geometric accuracy; Additive Manufacturing; 3D Printing; Computer systems; Industry 4.0.*

1. Introduction

The dynamic development of digital technologies means that we are currently witnessing unprecedented changes within the scope of industrial development, global economy, and also communication connected with production processes.

In order to make right business choices in terms of production and outlet, enterprises have to, first and foremost, follow innovations which will render it possible to meet market demand, frequently shaped by customers having specific and constantly changing requirements, effectively (Fonseca & Domingues, 2017; Lysenko-Ryba & Zimon, 2021). The profile of production

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evolves all the time, and mass production is replaced by short-series and single-piece production, simultaneously taking into account product tailoring (Muñoz et al., 2021; Pilat & Criscuolo, 2018). Therefore, the scientific and research centres of the global economy's greatest players have commenced independent work, the principal goal of which was to apply the new tools of technology serving the purpose of customising a product, and, *ipso facto*, attaining competitive advantage (Santos et al., 2021; Schwab, 2016; Zhong et al., 2017). Streamlining solutions are sought, among others, in the field of cost reduction, quality improvement and shortening required production time, minimising stock, increasing production flexibility, and also innovativeness, based upon the application of dispersed tools implementing cyber-physical systems (Hamrol, 2020; Paszkiewicz et al., 2020; Oleksy et al., 2019; Singla et al., 2018).

The Fourth Industrial Revolution, referred to as well as the Industry 4.0, has given us many innovative technologies, to mention, but one, among others, rapid prototyping techniques. Additive manufacturing is frequently referred to as 3D printing. This fact results from similarities in the functioning of certain machines applying additive methods to 2D and 2.5D printers. To mention, but one instance, the method of printing known as 3D Jetting System (JS), e.g. with the application of PolyJet, with heads and spreading a liquid resin on a working plane relying on piezoelectric heads, whose principle of operation is identical to that in 2D printers, can be referred to. The application of the term 'a*dditive manufacturing'* as the synonym of '3D printing' has already become a permanent practice in many scientific and industrial publications, and, for that very reason, regardless of certain differences, these terms are treated as identical in terms of meaning in this dissertation (Redwood et al., 2017).

Analysing the literature of the subject, and also available reports, it is possible to ascertain that that the contemporary 3D printing industry is in the growth phase (Wohlers Report, 2015, 2018; SIEMENS, 2020). The recent years show that the number of studies in the field of additive technologies is increasing annually. Changes are visible as well in the quality and diversity of printing materials, increasing productivity, and also in improving the quality of manufactured elements (Ngo et al., 2018). In addition to that, new standards are being drawn up within an entire value chain (ISO/ASTM 52900:2017-06; ISO/ASTM 52901:2019-01; ISO 17296-2:2016-10; ISO 17296-3:2016-10; ISO 17296-4:2016-10; ISO/ASTM 52902:2019; ISO/ASTM TR 52912:2020; ISO/ASTM 52911-1:2019; ISO/ASTM 52911-2:2019; ISO/ASTM 52902:2021). This fact signals a growing demand for systematising processes taking place in this industry.

Regardless of observing a significant progress in the 3D printing industry, it seems that it has not yet reached the phase of maturity (widespread implementing). In the course of industrial meetings, attention is drawn to the fact that 3D printing methods are constantly developing, and are becoming a serious alternative to production methods hitherto applied (or a solution that complements them) (Patalas-Maliszewska & Topczak, 2021). By means of the application of additive technologies in finished products manufacturing, it has as well become required to determine certain quality control standards applicable to 3D prints (Pisula, 2019).

Therefore, it seems reasonable to review the existing methods of quality control of finished models/products manufactured using incremental technologies, taking into account economic aspects of their application. Nowadays, it is also necessary to formulate and implement strategies for the development of manufacturing enterprises, in accordance with the assumptions of the concept of Industry 4.0. It is particularly important to take into account modern solutions for production management, in which IT systems are used that integrate networked distributed components of manufacturing processes. In this context, a research gap has been observed in the development of quality control procedures for 3D prints that can be implemented in an in-house cloud. For this reason, the main objective of this paper is to present the author's online platform, which presents an example procedure for quality control of incrementally manufactured products. The SMART CLOUD QUALITIES platform is an IT solution that will significantly facilitate the functioning of the quality control unit and improve the flow of information within the entire enterprise. In quality control processes it is extremely important to refer to the economic aspects of the application of specific solutions. For this reason, the paper presents an analysis of costs associated with the quality control of 3D models, assuming that the company has its own infrastructure, production elements and qualified staff.

2. Characteristics of additive manufacturing

Additive manufacturing consists in creating a physical (tangible) shape of a detail upon the basis of virtual geometry. This process is commenced by modelling the virtual geometry of an item in any CAD system. Next, a lattice geometry ought to be prepared, and that means saving an item to a file, e.g. in the STL format. The next stage is that of setting the parameters of the printer, and also of dividing the geometry into layers (pre-processing). After these activities, programming the momevents spreading a material, binder or a laser beam is commenced, to be followed by commencing process and manufacturing a real item (processing). The final stage of production is post-processing, which may be performed manually or with the application of devices (post-processing). (Badiru et al., 2017).

Since the mid-1980, a dozen or so various additive methods have been developed, and the most popular of them include: FDM (Fused Deposition Modeling), SLM (Selective Laser Melting), SLS (Selective Laser Sintering), PolyJet, SLA (Stereolitography), 3DP (Three Dimensional Printing), and also MJF (Multi Jet Fusion) (Cunico, 2019; Bitonti, 2019).

Until recently, 3D printing has principally been applied as a complementing technology in production process (Rapid Modeling and Rapid Prototyping). Prototypes made with the application of additive manufacturing were applied to visualise products, verify their functionality, conducting preliminary tests, or as demonstrators. Phasing mass production out has caused, however, the dynamic development of additive technologies. Rapid prototyping methods are no longer applied solely at the stage of design and construction, and they are currently applied as well to produce fully-valuable finished products and tools (Rapid Manufacturing and Rapid Tooling) (Budzik et al., 2019; Ngo et al., 2018; Rayna & Striukova, 2016; Wong & Hernandez, 2012).

In accordance with the report of the international consulting company, Wohlers Associates, the principal areas of the application of 3D printing were: the production of functional elements (33%), adjusting and assembling (17%), and also educational and research work (11%).) (Wohlers Report, 2018). The results and share in per cent are graphically presented expressed in Figure 1.

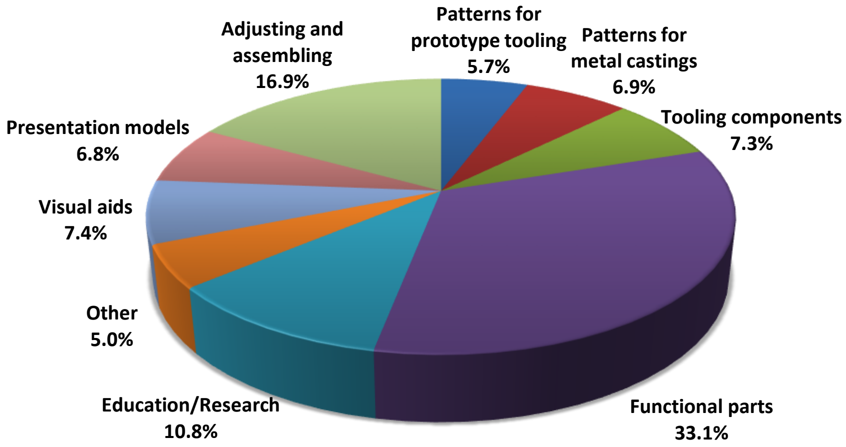


Figure 1. The scope of the applications of additive methods and their share in per cent (Wohlers Report 2018)

Additive technologies are applied, among others, in the automotive, aviation, space, medical, military, construction, founding, and food industries (Horst, 2018; Lim et al., 2016; Marchment & Sanjayan 2021; Turek et al., 2020; Salmi, 2021). In addition to that, this technique is applied within the scope of medicine and bioengineering. Applying it, it is possible to manufacture, to mention, but a few instances, prostheses, implants, vascular tissues, and also bones (Berman, 2012; Fudali, 2018; Horst, 2018). 3D printing techniques are applied in ever more areas.

3. Review of quality control methods for 3D models

The ISO 9000 standard defines quality control as measuring, testing, estimating or checking one or several properties of an item, and also comparing results with requirements in order to ascertain, whether each and every one of them is compliant with the standard (ISO 9000:2015).

Depending upon their intended application, models manufactured with the application of 3D printing may undergo various quality control processes. In the case of developing prototypes, their intended application usually consists in visualising a given product, therefore, their functional traits are not so important. In turn, taking under consideration printing finished parts, a very important role is that of accuracy, and also an appropriate strength. quality control course in the case of 3D prints may, therefore, be different and highly tailored on a case-by-case basis.

The selected qualitative assessment methods applicable to prints are, first and foremost (Budzik et al., 2018; Dziubek & Oleksy, 2017; Gapiński et al., 2017; Morek, 2012):

- print visual control,
- model dimension control with the application of measurement tools,
- model/finished product control with the application of gauges,
- control with the application of tracer measurement methods (i.e. coordinate measurement systems)
- control with the application of non-tracer measurement methods (i.e. laser scanning, optical scanning and computer tomography).

At this point, it is worth noting that when selecting quality assessment methods, it is important to consider several aspects each time, namely mianowicie (Khosravani & Reinicke, 2020):

- the cost of conducting the quality check,
- the time taken to carry out the quality control,
- the available apparatus and tools,
- the expertise required to carry out certain processes and interpret the results,
- customer requirements.

For example, testing of products with the use of computer tomography allows to obtain comprehensive results that determine both the geometric accuracy of the product of external and internal surfaces, as well as the structure of the product material. However, this type of testing is expensive, time-consuming and requires specialized equipment and knowledge of the inspector, which is why it is used for a specific group of products, e.g. aircraft engine blades (Budzik et al., 2021). Therefore, while choosing the methods of quality control of incrementally manufactured products, it is worth conducting target costing, which allows to analyse and limit the costs, taking into account the whole chain of creating added value for the customer.

3.1 Visual control

Visual control constitutes the most cost-effective qualitative assessment method. It does not require the application of costly equipment, nor does it result in destroying an assessed item. Because of its simplicity and minimal cost, visual inspection is the most commonly used non-destructive technique that can be performed quickly. Regardless of its numerous assets, visual control is not flawless, being the result, principally, of it being impossible to present the obtained results in the SI units. In addition, the conclusions of the visual inspection also depend on the predisposition and knowledge of the individual employee, so it does not guarantee a correct assessment.

If an obtained print is complex and/or constitutes a finished product, visual control constitutes the first stage of verifying the model qualitative compliance, and determines further activities. If a model is damaged in a way visible with a 'naked eye', it is usually treated as a non-compliant product; then, errors are analysed and printing process must be re-commenced. If there is no such damage, print may be checked in terms of geometric accuracy, and also strength.

3.2 Control with the application of tools

Control with the application of tools allows to verify model dimensions. Among popular tools, there are (Mitutoyo, 2013):

- slide caliper – it is one of the basic workshop measurement devices, applied for the quick measurement of manufactured elements. Applying it, one may measure external and internal dimensions, and also depth. The measuring scopes of slide calipers are between 0 and 150 mm, or even reach 3,000 mm,
- micrometer – the intended application is that in measuring external and internal dimensions, hole width and depth (with the accuracy of 0.001 mm),
- workshop microscope – an optical measurement device, which is applied for non-tracer item length measurement in cartesian coordinates system, and also angles.

3.3 Control with the application of gauge

Control with the application of gauges renders it possible to verify 3D prints without destroying assessed items. The use of gauges offers the possibility of significantly speeding up the quality control process. It is most frequently applied in the case of series production, for verifying models with specific holes.

3.4 Control with the application of tracer measurement methods

The 3D geometry of contemporarily manufactured items is very complex. Traditional measurement tools relied on a single dimension direct measurement, which caused difficulties in measuring models with complex shapes, and also significantly extended the time of quality control process. This fact provided an impulse to develop the new field of coordinate measurement technique.

A coordinate measuring machine is a device in which measuring sets move according to determined coordinates, whilst at least one of them is travelling. The travel directions are determined by the axes of cartesian coordinates system (x,y,z), and define the machine spatial coordinate system. Movements along the axis are indicated by length specimen, and sent to a computer and electronic control systems. Regardless of its assets, there are, however, many limits of applying a coordinate measuring machine, among others: high purchase price of the device, extended measurement time, the lack of possibility, or significant difficulty, of measuring items with complex shapes (especially, the internal ones) or very small, the necessity of adjusting the measuring tips to measured shapes, and also the risk of damaging them, as well as that of damaging the surface of measured item (Ratajczyk & Woźniak, 2016).

3.5 Control with the application of non-tracer measurement methods

Measurements with the application of non-tracer methods, first and foremost, exclude a direct contact of measurement devices (measurement system and head) and the analysed surface, which eliminates the risk of destroying an assessed item.

The main assets of non-tracer measurement include the possibility of conducting the analysis of items regardless of their dimensions and shapes, whilst keeping the measurement time relatively short. 3D scanners are very mobile as well, which is owed to their small weight. Their drawback, in turn, is the fact that they remain slightly less accurate than that of tracer methods.

Non-tracer measurement methods include: laser scanning, optical scanning, and also computer tomography (Dziubek & Oleksy, 2017; Morek, 2012).

4. Development of a research model

The research model which was applied for the quality control of products manufactured with the application of additive technologies is a car mirror holder. It was the intention of the authors that the element chosen in the paper should be general enough to be used by automotiv companies.

The process of element manufacturing was commenced by modelling the virtual geometry of an item in the 3D – CAD system, and also saving it to a file in the STL format. For that purpose, the Autodesk Inventor Professional 2019 program was applied (Figure 2).

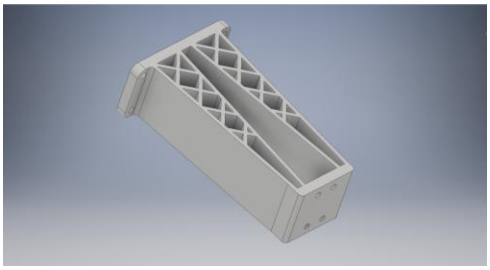


Figure 2. 3D CAD model of a car mirror holder

The research model was developed in the Laboratory of the Machine Engineering Department of the Rzeszow University of Technology. In manufacturing process, an 3D Object Eden 260V printer, applying the PolyJet method, was applied. A ready model is presented in Figure 3 and Figure 4.

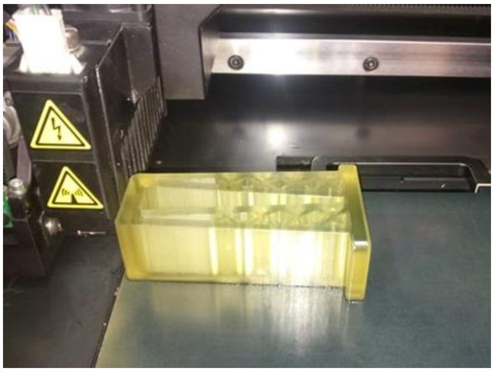


Figure 3. Ready research model in printer working space

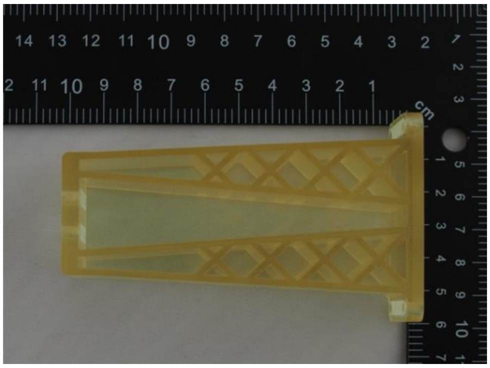


Figure 4. Ready research model in top-down view

5. Quality control cost analysis for 3D models

Geometric measurements are one of the basic elements of product quality control. Technological devices including 3D printers are characterized by a specific accuracy of execution. However, it should be remembered that the technological accuracy is not the same as the accuracy of the product. Therefore, the design of each product also defines the tolerance of its performance. An important element is the control and measurement apparatus used in this process. The data presented here are a shortened analysis of the measurement process depending on the applied measurement method. It should be remembered, however, that the inspection process itself is related to the given product, hence the presented generalization refers generally to the product with shape and dimensions of the car mirror holder presented in the article.

The summary presented in the Table 1 refers to the size of the measurement costs related, among others, to the purchase costs of measuring equipment and its depreciation over a period of five years converted into monthly depreciation for five years. In addition, costs per hour have been entered, referring to the cost of instruments, the cost of infrastructure maintenance, and the cost of hourly employee salaries. The Table 1 does not include institutional mark-ups, which are an individual matter for the company or the scientific and research institution. In the case of measuring workshop equipment, depreciation costs were not entered, since this type of tool is not depreciable and represents the unit cost of purchase. These costs were included hourly in the infrastructure maintenance costs.

The Table 1 presented in the last column shows the total cost per hour of measurement using a specific measurement device. It should be added here that the time per hour devoted to the measurement of an element will depend on the dimensions of the element, the complexity of the shape of the material from which it is made, the accuracy of the results and the preparation and completion times for the measurement process.

For computed tomography (CT) measurements, depreciation of the CT scanner, infrastructure maintenance, and the cost of a highly skilled operator are significant cost elements. Therefore, the cost of measurement is the highest.

Table 1. Pricing of basic components needed in the measurement process

Cost (€) / **Position**	**Purchase Cost**	**Annual Costs (Depreciation)**	**Monthly Costs (Depreciation)**	**Labor hour cost of laboratory employee**	**Hourly depreciati on cost**	**Cost per hour of infrastructure maintenance**	**Total per hour**
CT	600 000	120 000	10 000	30	63	30	123
CMM	150 000	30 000	2 500	25	16	20	61
GOM	120 000	24 000	2 000	22	13	10	45
Handyscan	20 000	4 000	334	20	2	10	32
Gauges	120			10		3	12
Micrometer	100			10		3	12
Slide caliper	50			10		3	12

A coordinate measuring machine (CMM) is an expensive device whose price increases significantly with its size. For the purpose of this analysis a medium sized machine dedicated to the measurement of machine elements not exceeding the dimensions of a cube of 1000 mm side was considered. CMM measurement costs depend on the detail of the measurement, including the number of measurement points for a given feature. For larger numbers of measurements on the same feature, software automation can be introduced which can result in unit cost reductions.

Structured light scanning measurements allow for relatively quick geometric analysis of the product, especially with software and hardware automation. The table includes the cost of performing a measurement with a basic version of the scanner (using the GOM system as an example) without automation and robotization systems.

Hand-held scanners allow measurements in diverse conditions, which makes them mobile measurement systems. It should be noted, however, that in some cases their accuracy does not allow their use to measure machine parts with high geometric requirements. The price of this type of equipment is at a level lower than the previously mentioned measuring equipment.
In the workshop practice very often there are used such measuring tools like micrometer or caliper, which are perfect for quick verification of accuracy of the products manufactured with the use of incremental methods. The price of such devices is relatively low and their accuracy is sufficient for most measurements of 3D prints.

In mass production it is worth to use gauges, which price depends on the complexity of the shape and accuracy of the workmanship. The table shows the cost of a typical shop gauge, for example for checking threads. However, it may not be cost-effective to make gauges with complex shapes to analyze the geometry of incrementally manufactured products.

Taking into account the mirror holder type element presented in the article, it is possible to estimate the costs of its measurement, e.g. with respect to the number of measurements. By adopting the use of a remote application for the geometric analysis of the product, it is possible to transfer the measurement process to the manufacturer, who enters the measurement data into appropriate protocols established jointly with the customer ordering the product. This way, the ordering party does not have to invest in expensive measurement equipment, thus reducing its operating costs. Figure 5 presents a graph of the cost of measuring a car mirror mount.

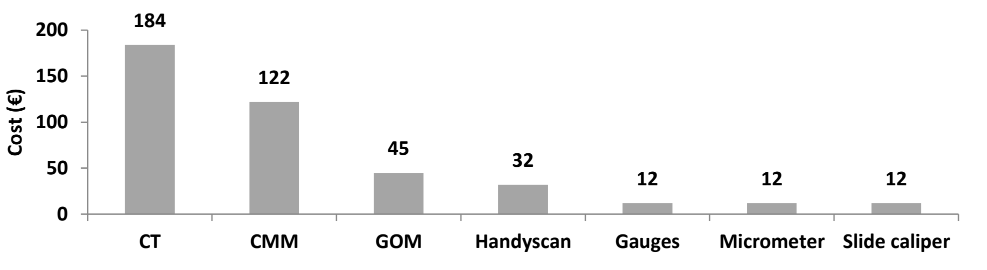


Figure 5. Car mirror holder measurement cost chart

For the analysis of the costs of measurement of one piece of the holder of the car mirror, the data from the table in the Annex were used. Also, the time required to perform the measurement was assumed for CT measurement - 1.5h, for CMM measurement - 2h, for GOM and Handnyscan measurement - 1h, for gauge, caliper and micrometer measurement - 5 minutes.

6. Instance of applying the on-line platform SMART CLOUD QUALITIES (AM-SCQ)

The authors prepared a platform for the quality control of products manufactured with the application of additive technologies, www.amquality.prz.edu.pl/en, which is presented in Figure 6.

Figure 6. View of the platform AM-SCQ

It matters that the platform is sufficiently general to be applied by enterprises in the rapid prototyping industry.

The platform renders it possible as well to preview a model saved in the STL format, which is presented in Figure 7.

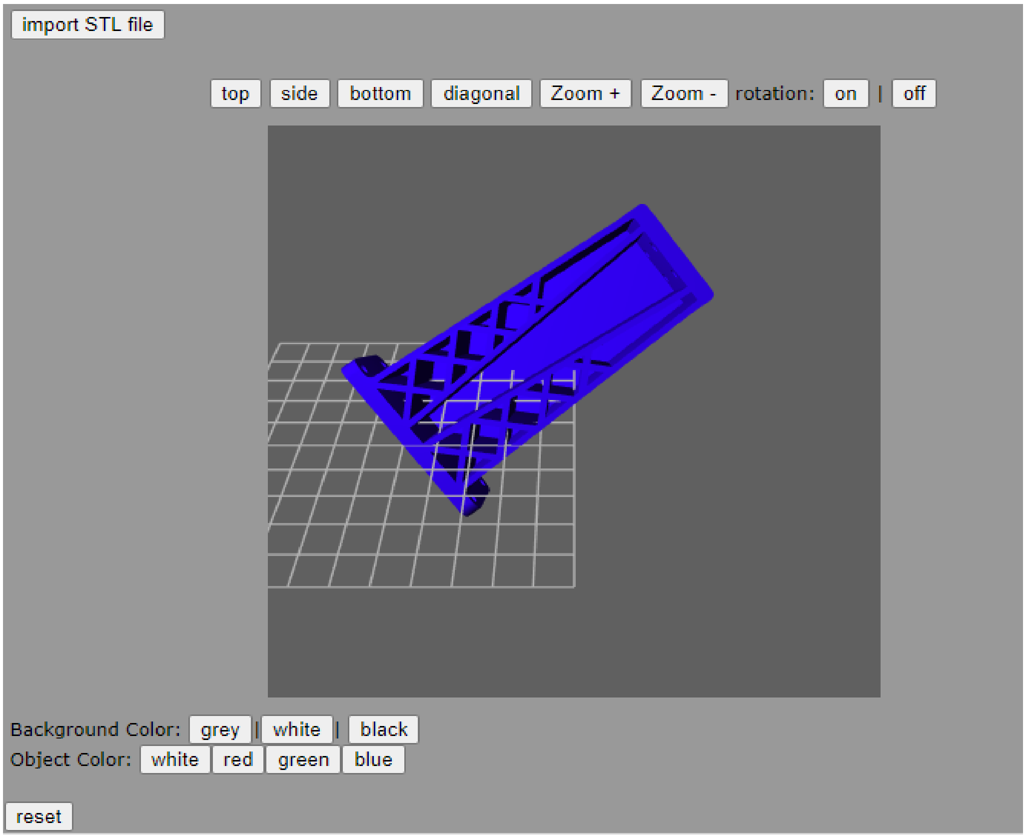
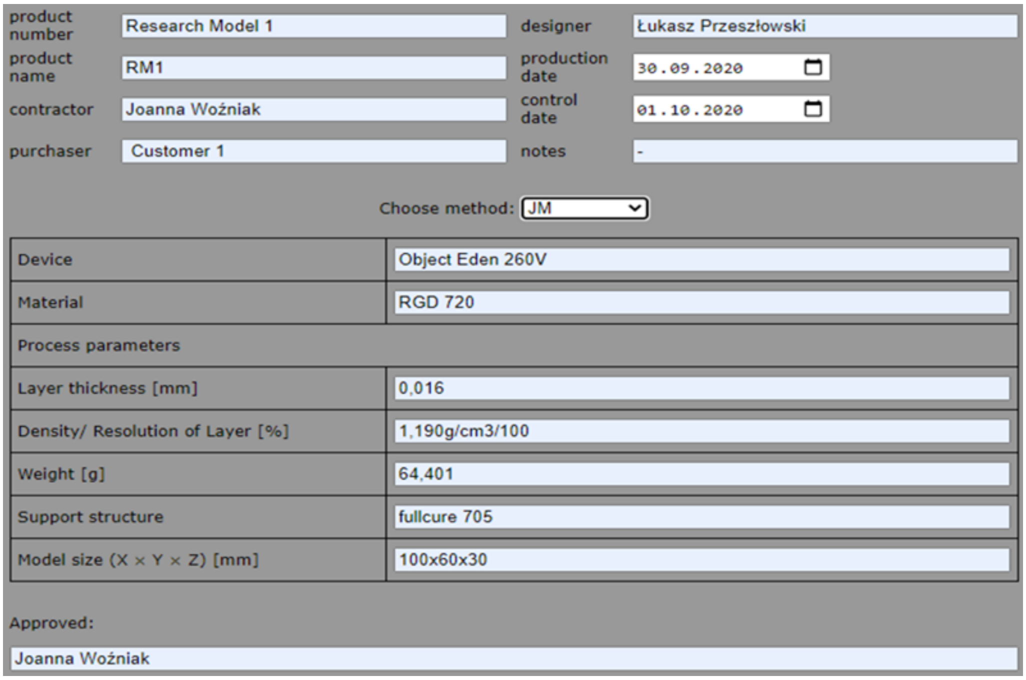


Figure 7. Preview of a STL model with the application of the AM-SCQ platform

Commencing filling in a quality control report, first of all, the following basic information ought to be provided in detail:

- orders (i.e. product no. and name, contractor, contracting party, designer, production and control date, and also comments if there are any),
- printing methods (FFF/FDM, SLM/DMLS, SLS, DLP, JM, SLA, 3DP, LOM, MJF, other), and also devices and material applied in printing process,
- process parameters (i.e. layer thicknes, layer density/resolution, weight, supporting structure and a model size).

A filled research model sheet is presented in Figure 8.



product number	Research Model 1	designer	Łukasz Przeszłowski
product name	RM1	production date	30.09.2020
contractor	Joanna Woźniak	control date	01.10.2020
purchaser	Customer 1	notes	-

Choose method: JM

Device	Object Eden 260V
Material	RGD 720
Process parameters	
Layer thickness [mm]	0,016
Density/ Resolution of Layer [%]	1,190g/cm3/100
Weight [g]	64,401
Support structure	fullcure 705
Model size (X × Y × Z) [mm]	100x60x30

Approved:

Joanna Woźniak

Figure 8. Filling in a preliminary report sheet

Next, a user may fill in a quality control sheet, which is divided into 7 principal parts:

- a preliminary visual assessment,
- photographic documentation,
- control with the application of tools,
- control with the application of a manual scanner,
- control with the application of an automated scanner,
- control with the application of a tomograph,
- control with the application of coordinate measuring machines.

For each and every stage, a separate sheet with information on a given process, and also recommended OSH protective means, has been prepared. It matters that a user selects quality control methods on their own and bearing own needs in mind, therefore, it is not necessary to fill in all the sheets. After filling in each and every sheet, a model ought as well to be qualified (as a compliant/non-compliant model), and the surname of the person who approved a given stage ought to be provided.

The authors, taking under consideration the intended application of a model, and also economic aspects, decided to conduct the following activities in quality control process: a preliminary visual assessment, photographic documentation, control with the application of tools, and also control with the application of an automated scanner, whereas they did not include tomography, a manual scanner and coordinate measurement methods.

A preliminary visual assessment consists in determining, whether an item is damaged in a visible manner and in a way that would render it classified as a non-compliant product with customer's expectations. A controller can enter their own comments, observations and conclusions as well.

Preliminary visual research model assessment demonstrated the lack of visible damage that would disqualify an item (Figure 9).

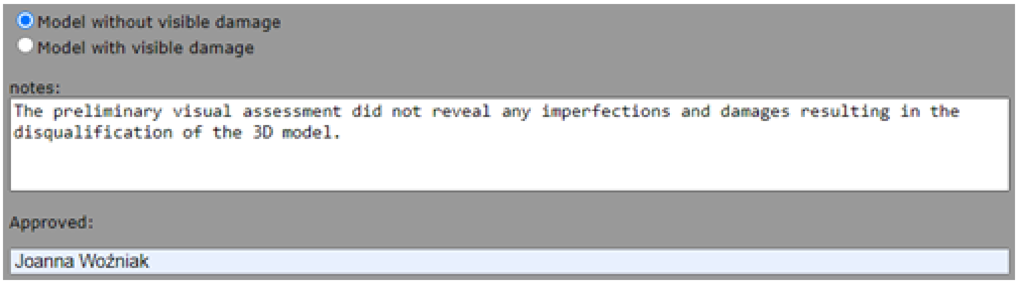


Figure 9. Conducting a preliminary visual assessment

Entering photographic documentation allows to present a model in the systems of 6 projections. In order to facilitate this process, the authors made a rectangular projection model, which provides hints relevant to arraying a model and an item (Figure 10), available. In the course of this process, a controller determines the number of taken pictures according to their own needs. In Figure 10, an instance of entering a picture for a research model in side projection 1 (A) is presented.

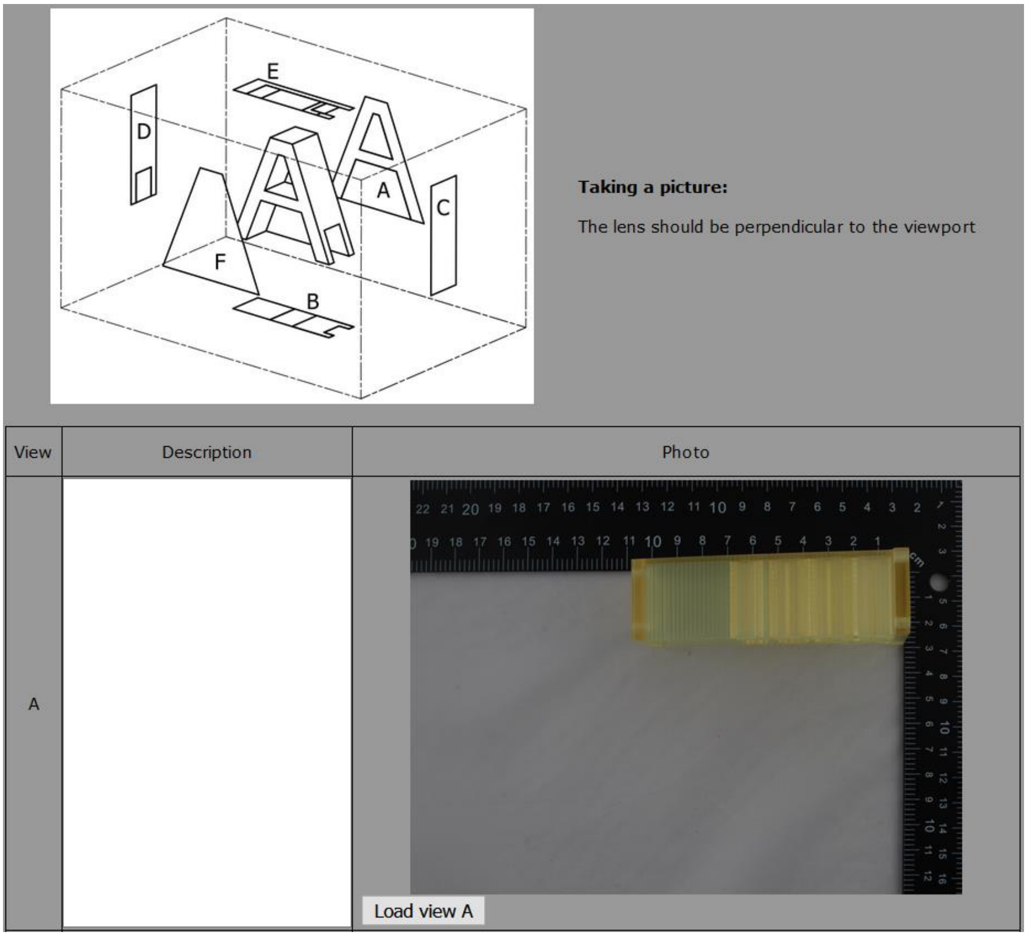


Figure 10. Introduction of photographic documentation

The next stage is filling in a control sheet with the application of measurement tools. It is suggested to apply a slide caliper, micrometer, workshop microscope or gauge. A controller can apply a different device as well, and then the answer 'other' is marked. To verify model compliance, it is recommended to enter a figure with technical dimensions.

The authors applied a slide caliper as a measurement tool. In order to determine model dimensional compliance, 4 typical dimensions were chosen, and the degree of tolerance was simultaneously determined (Figure 11).

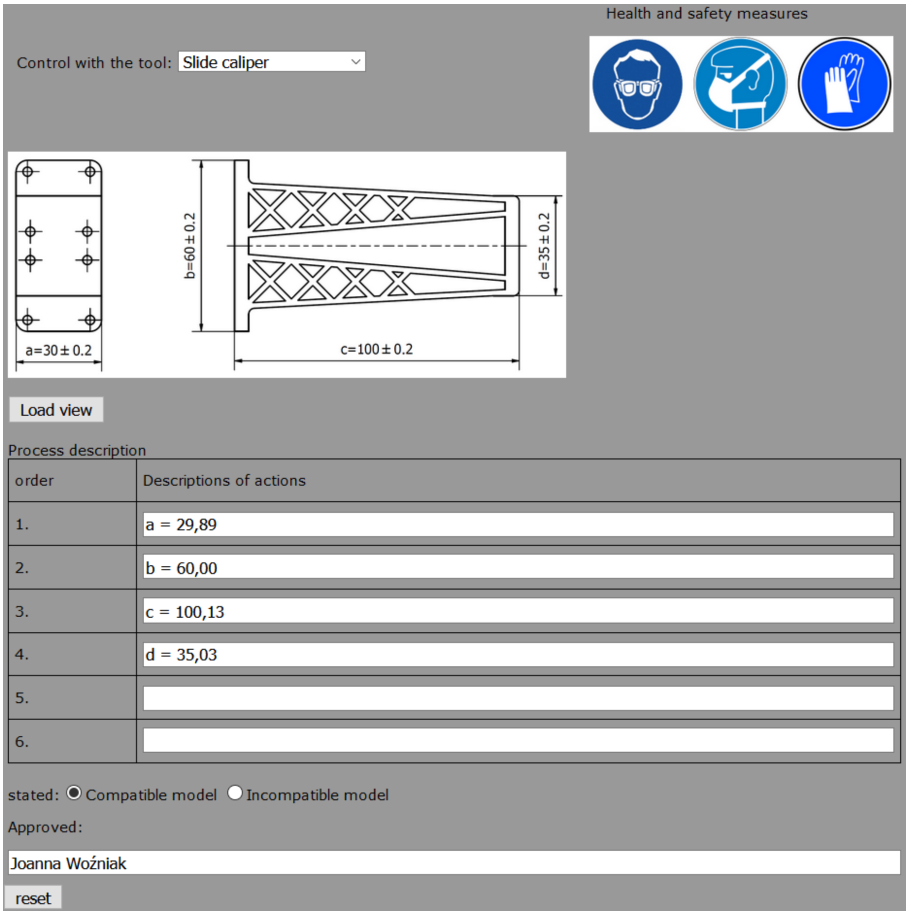


Figure 11. Conducting control with the application of slide caliper

The next stage was constituted by control with the application of an automated scanner. At this stage, it is possible to enter 3D maps – 3 isometric views, simultaneously with deviations, and also to enter 2D maps – views in the system of 6 projections: A, B, C, D, E and F. A controller can as well enter additional information on the process, and also formulated conclusions.

The authors decided to enter 1 isometric view (Figure 12), and also 4 projections – A, B, E and F (Figure 13). They provided as well information on the applied device, and also conclusions formulated after conducting geometric analysis (Figure 14).

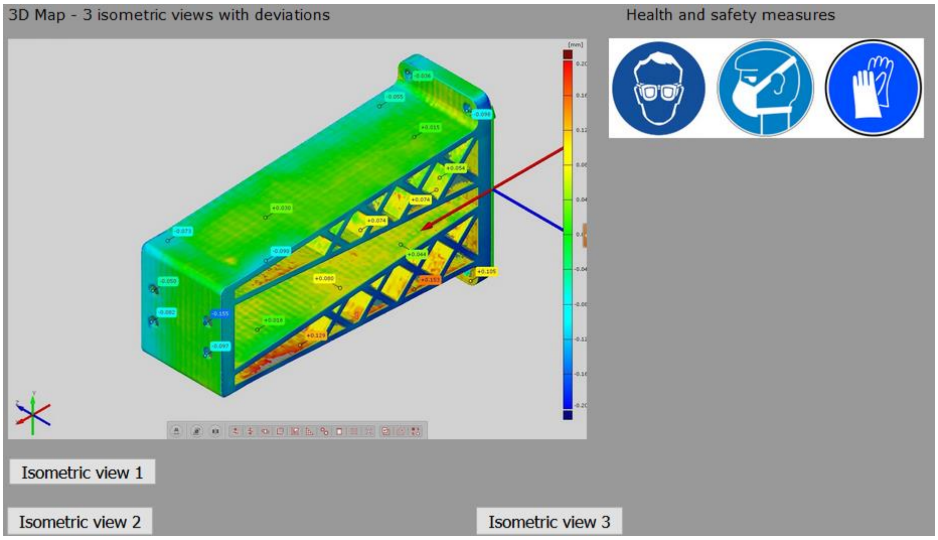


Figure 12. Entering isometric view

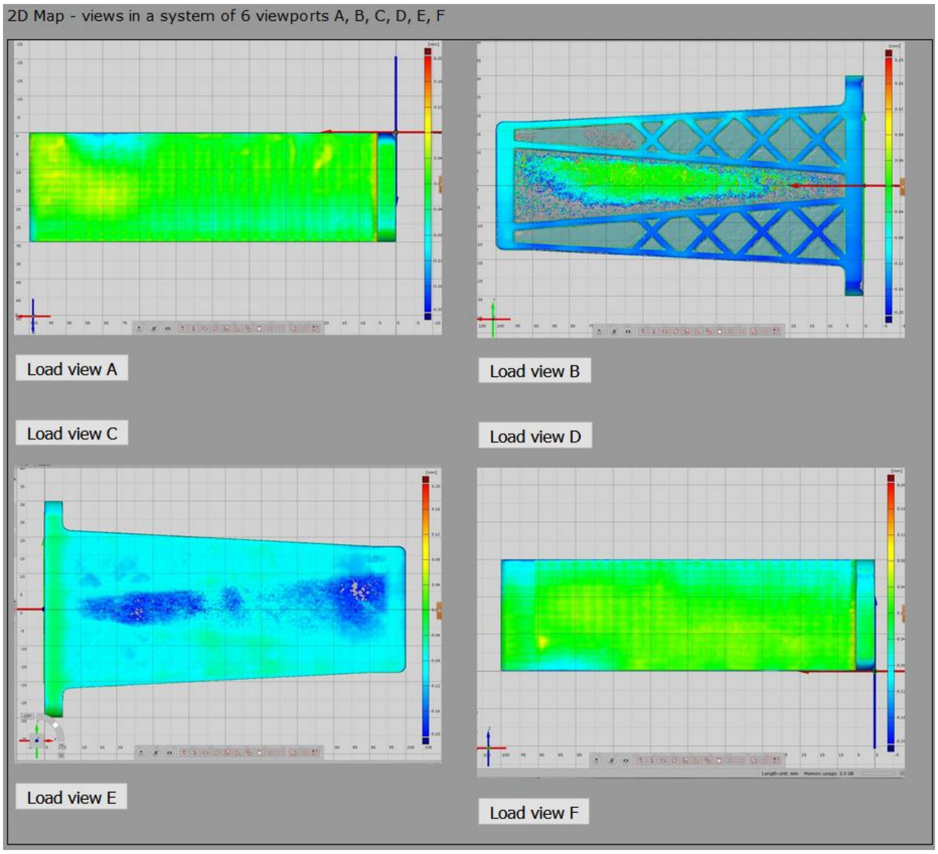
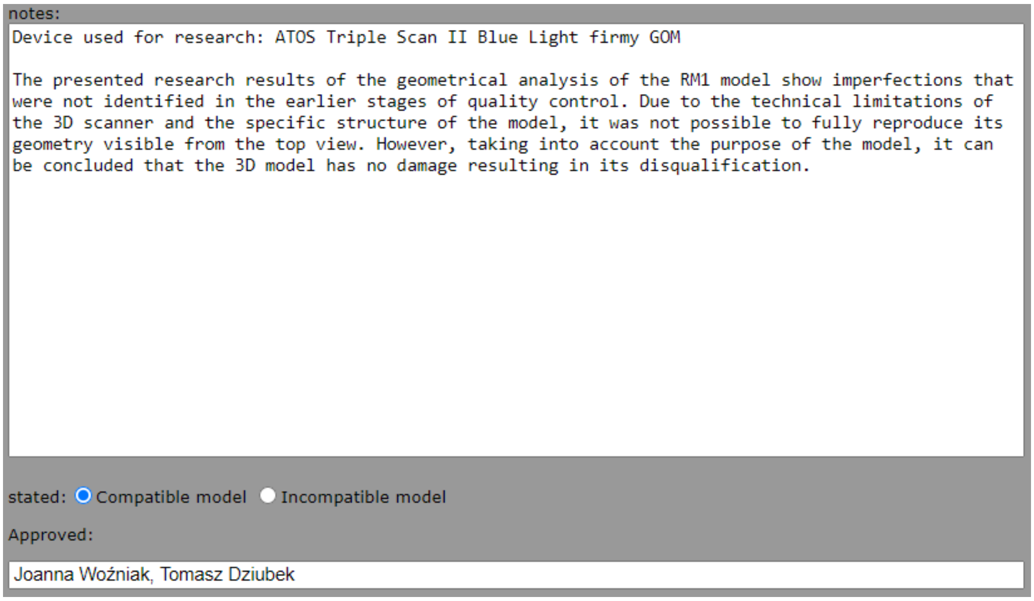


Figure 13. Entering model manufacturing accuracy maps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Device used for research: ATOS Triple Scan II Blue Light firmy GOM

The presented research results of the geometrical analysis of the RM1 model show imperfections that were not identified in the earlier stages of quality control. Due to the technical limitations of the 3D scanner and the specific structure of the model, it was not possible to fully reproduce its geometry visible from the top view. However, taking into account the purpose of the model, it can be concluded that the 3D model has no damage resulting in its disqualification.

stated: Compatible model Incompatible model

Approved:

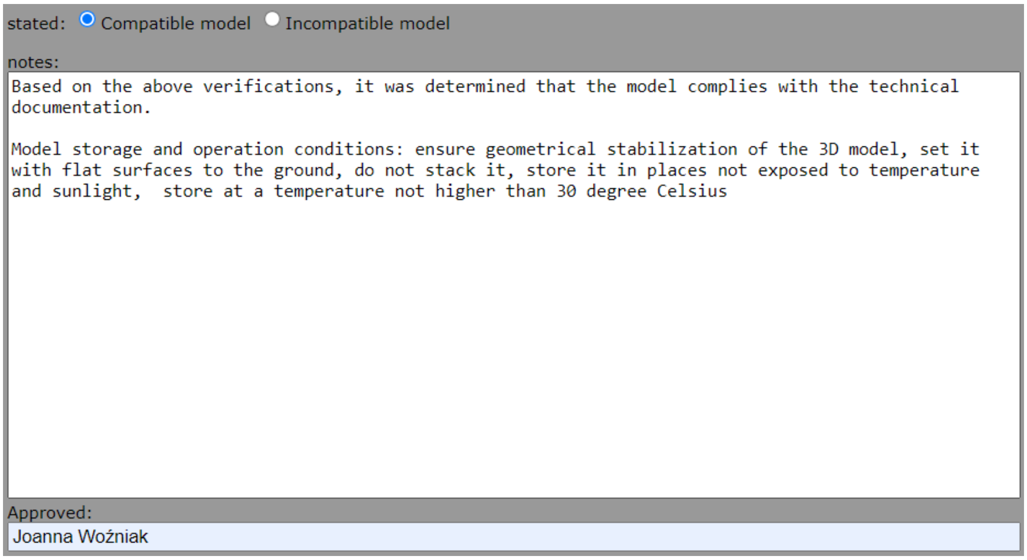
Joanna Woźniak, Tomasz Dziubek

Figure 14. Entering conclusions after conducting geometric analysis

The last stage of model quality control is its final qualification, and also providing comments for customer if there are any.

Based on the verification procedures described above, the model was found to conform to the technical documentation. The authors developed as well a recommendation on model transport and storage method. Conveying such information may significantly improve customer's satisfaction and loyalty towards the company (Figure 15).

After filling in infomation on the required parameters, a report ought to be generated to a PDF file (Figure 16).


stated: Compatible model Incompatible model

notes:

Based on the above verifications, it was determined that the model complies with the technical documentation.

Model storage and operation conditions: ensure geometrical stabilization of the 3D model, set it with flat surfaces to the ground, do not stack it, store it in places not exposed to temperature and sunlight, store at a temperature not higher than 30 degree Celsius

Approved:

Joanna Woźniak

Figure 15. Final qualification of a research model

Figure 16. Generating a report to a PDF file

7. Limitations and further directions of research

The on-line platform for quality control products manufactured with the application of additive technologies is dedicated to 3D printing industry enterprises, and currently made available to the staff of Rzeszow University of Technology. It is accessible without limitations, however, without some of the functionalities. After perfecting by means of adding further features, it is planned that it will be made available to other users (as a paid product).

The authors hope that the presented research outcomes will be found useful by production companies having additive technology machines.

Upon the basis of performed work, the following directions of further research were proposed:

- further development of the on-line platform for 3D print model quality control,
- designing solutions to minimise human labour input at the quality control stage,
- studies aiming at the verification of the impact of external factors on prototypes made with the application of additive manufacturing, and also developing recomendations for customer on conditions of their storage and transport.

8. Conclusion

Models produced by 3D printing can go through various quality control processes. Regardless of its imperfection, which results, principally, from the high risk of defects remaining undetected, or formulating the erroneous assessment by an employee, visual control is the most frequently applied quality control method. In the case of complex models, and also finished products, it is, however, recommendable to take additional steps connected with verifying their quality, by means of, e.g. the application of measurement tools, gauges, automated scanning, manual scanners, tomography or coordinate measurement methods. When selecting specific methods of quality control of incrementally manufactured products, each time the costs of conducting quality control, the time of conducting quality control, the available apparatus and tools, the expertise necessary to carry out specific processes and interpret the results, as well as customer requirements, should be taken into account. The cost analysis conducted by the authors allows to draw conclusions that comprehensive quality control of 3D models is a large financial expense. Therefore, in order to increase customer satisfaction, companies offering 3D printing services should introduce additional services related to quality control of the produced models.

In the times of the Fourth Industrial Revolution, it is extremely important as well to apply modern IT systems, which allow to integrate production processes. The application of the SMART CLOUD QUALITIES (AM-SCQ) platform provides controllers with hints relevant to particular processes, and also renders it possible for them to enjoy certain freedom.

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