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3D LASER SCANNING IN DIGITIZATION OF LARGE OBJECTS

1. INTRODUCTION

The economic significance of intense and sustainable production basis in Europe is well supported by the fact that production employed 27 million people in Europe during 2001 and it produced added value of more than 1 300 billion EUR in 230 000 enterprises with 20 (or more) employees. More than 70% of this value was produced by six main spheres: automobiles, electric and optic devices, food, chemistry, materials, semi-finished goods and mechanical engineering.

The European Union is presently launching a new project called ManuFuture [6] – the future development of technologies and of production systems. Its main goal is to create national technological platforms in member countries of EU and use them to foster the growth of EU's competitiveness in production sphere. ManuFuture has published its Strategic Research Agenda (SRA) and a strategic document, ManuFuture – a Vision for 2020, which presents a vision of the future development of production in Europe. It should particularly be oriented on the following spheres: new products and services with new added value, new enterprise models, advanced industrial engineering, new production technologies, infrastructure and education, research and development system. Its practical steps are oriented on swiftly finishing the construction of the newest progressive technologies, such as: virtual design, virtual enterprise, adaptable enterprise, digital factory, net production, knowledge-based production, rapid prototyping, new materials, intelligent systems, security, reliability, etc. In the sphere of technologies the future development will mainly focus on so-called converging technologies (nano, bio, cognitive) and miniaturisation, such as multi-material micro-engineering which enables to combine sensors, process signals and to react to them in microscale.

The ManuFuture platform defines – for the future – new manufacturing enterprises as products. These products are socio-economic systems, and are very difficult to project and to run and we must therefore pay special attention to their development. In future the competitiveness in production will be provided by such production systems in particular. Therefore it is the goal of ManuFuture to develop visionary approaches to organising and realising the production in future.

The European Union will, in the framework of EU technology platform ManuFuture, support the development of such production systems concept, which will generate the high Value Added. EU changes up to now used perception of production systems. The new

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designed, complex production systems, are uderstood as the final products, which can be sold as other products. These new concepts take off the disadvantages of Taylorism and Toyotism. The new concepts are built on the principles of Advanced Industrial Engineering, which uses as a main tool the Digital Factory concept and digitization [4].

Slovak Republic builds – as part of ManuFuture – its own National Technological Platform – ManuFuture-SK.

Underdeveloped technology is one of the most significant barriers impeding the rapid expansion of research and development in SR. Technological approaches used daily by High-Tech automotive factories are – due to being financially demanding – practically unknown to our researchers. Research and development in automotive industry, which is the most important for our national economy uses completely new approaches to designing and testing of new products and production processes. Progressive approaches utilising the most progressive technologies of rapid prototyping, digitalisation, virtual reality and simulation, are what our design teams miss. Such progressive technologies provide the ways to reduce the amount of necessary time and thus – as well – to reduce the development costs to the level of 10 to 20% of costs required by conventional technologies. One of the possible solutions would involve developing new approaches based on virtual reality (Digital Factory), which would be internationally accepted and which would push Slovak research to the level that it holds in the most developed European countries. Digital Factory currently represents the most progressive approach to complex, integrated design of products, production processes and systems in the world [3].

2. PRODUCTION SYSTEMS INNOVATIONS

The future cannot exist without innovation of production processes and production systems as it cannot exist without the innovation of products. Production systems require redesign as well, new machines and devices, transport systems, control systems, work organisation etc. Such changes are introduced by teams of specialists, designers and planners.

The production systems innovations are realised by principal, revolutionary changes (sometimes signed as stepped). In this case the production, organizational or control principles are changed. These changes are conducted in long term time periods, sometimes in decades.

Small, continuous changes are conducted in between stepped changes, sometimes signed as evolution changes. They are realised in a short term time periods, practicaly by any change of production systems or even production line or mix. These changes are comparable to known Kaizen, continuous process improvement.

Any change, even the smallest one, bring risk of unsuccess. The change has to be realised by real people who do mistakes as well. The quality and fasteness of changes can be supported by 3D production systems digital models.

In the companies running business in the HighTech sphere application of Digital Factory systems currently undergoes dynamic development. University of Žilina is the only place in central Europe where such a complex Digital Factory system is presently being built [3]. The Digital Factory system utilises 3D digital models of objects (DMU – Digital Mock Up, i.e. creation of digital models).

3D –DMU digital models have firstly begun to be used in the sphere designing and analysing products. They are starting to be used in the sphere of complex production systems as well, or even of whole factories (for instance in automotive industry). Such digital models are called **FMUs – Factory Mock Ups**, i.e. digital models of factories.

To design whole factories is an extremely complex and difficult problem. Quality of the project determines the future long-term effectiveness of the factory. FMU make it possible to greatly enhance the communication among the design teams, to lower the risks evoked by making wrong decisions and to speed up innovation and increase the efficiency of the innovation process by improving the performance.

Only classical approaches are being used for digitalisation and geometric analyses of the existing production systems in Slovakia. Information about the real state of the production system is in case of complex production systems obtained using the measuring tape, or laser measurers. Using such approach makes digitalisation of the whole enterprise extremely time-demanding and expensive. It is also a potential source of vast inaccuracies and errors.

It is much faster, much more effective and qualitatively better to create the 3D models of the existing production systems using the newest 3D laser scanners. These make transforming the existing, real 3D word into its exact 3D digital copy, which correctly reproduces the exact geometry of the recorded space and can simply be used for any computer analyses, a matter of a few moments.

Thus obtained 3D digital model (so-called master model) can be used in all designer professions; it can be used by analysts as well as by the factory's management. Using the internet it is possible to share such model from anywhere worldwide. Its accessibility makes it easier to eliminate errors. Designers from all over the world can simultaneously work on new projects without any need to travel on to the spot and manually do all the measurements required before they start to design.

Extensive research is currently underway – all over the world – in the sphere of utilising the digital methods for digitization, modelling, analysing, simulation, recording and presenting real objects [2].

3. 3D digitization of large objects

The sphere of creating, modelling and storing 3D digitalised virtual models of real objects is one of the most significant spheres, which are able to radically influence the effectiveness of producers in Slovakia. Research and development in this High-Tech sphere is technically and financially demanding, which is why it is currently mainly supported by industrially mature, ergo rich countries.

The most important sphere related to the development of national economy is – from Slovakia's point of view – automotive industry, which determines the tempo for other branches of industry. The most significant automotive companies are well aware of the constant need to innovate their products, which is why they release a new model every 2-3 months [5]. Innovation can only be successful if it is swiftly put on the market. To fulfil the requirement to shorten the whole production cycle of a product from its design to delivering it to the customer keeping the costs as low as possible is the most important prerequisite of success of every enterprise. The launch of a new product is always connected with the initial chaos, which increases the realisation costs behindhand.

This is why the University of Žilina in co-operation with the Slovak Productivity Center build their own concept of Digital Factory, which will make it possible to do integrated modelling of all the important process on the computer – from the original idea, through the design of products, production system, production planning and control, on to actually assembling the product. A system for the creation of 3D production layouts and generating 3D models of production halls of FMU is what Digital Factory solutions miss today. It is principally possible to design the model of production halls and production layouts using the direct CAD system approach. Such solution is convenient when designing new production systems. However, the more frequent case is, that the production halls already exist. That is the reason why it is often more efficient to create a 3D model of the hall using the Reverse Engineering technologies. Reverse Engineering is the step we need to take to achieve high efficiency and accuracy of digitization – not only considering the existing equipment, but also when the production layout themselves come into question. It opens up new opportunities to realize virtual designing. Creation of 3D-DMU of large objects using the 3D scanning is – at the moment – the joining link between virtual reality and real virtuality.

3.1 The main problems by the digitization of large objects

Based on experience of authors as well as conducted analysis, they can be summarized as follows:

- current approaches prioritize 3D digital models of halls, they are not focused into creation of machines or equipment DMUs,
- DMU machines and equipment obtained from their designers (e.g. from Catia) have to be simplified, being possible to use them in DMU of production halls,
- many DMU of existing large objects were created by increase of 2D models (pulling of 2D model in CAD system). These solutions do not assure required precision (deviation higher than 10 centimeters) on the contrary to laser scanning where the deviation is in milimeters,
- there does not exist any methodology and no approaches were described to the integration of DMU machines with DMU of production halls and following creation of FMU (Factory Mock Up),
- up till now, no procedure has been developed for cyclical actualisation of existing DMU (cyclical scanning and automatic identification and comaprison of changes),
- there exist no standards for FMU creation,
- there exist no obligatory regulations, which can instruct the designers of new objects to create simultaneously DMU with the real constrution and after realization of project to compare the level of unity of real objects with its DMU, through the scanning,
- up till now was not developed any approach for integration of production halls DMUs, obtained through laser scanning with the production systems DMUs obtained from digital factory solutions (Delmia).

3.2 Practical procedure for large objects digitization

The practical and simulataneously effective procedure for scanning, digitization, modeling, analysis and storing of digital models of large objects does not currently exist. Any workplace which works with 3D laser scanning uses its own approach.

These approaches are characterised mainly by following:

- procedure of an efficient way of realising 3D laser scanning of large objects,
- procedure of creating 3D digital models using the obtained 3D scanned data

- postupom tvorby 3D digitálnych modelov pomocou získaných 3D skenovaných dát, fulfilling the standards of Slovak legislative – STN (e.g. technical standards of buildings, construction drawing, etc.),
- the way of storing, handling and change management of created 3D digital models using a structured database system,
- procedure of integrating DMUs of real objects with DMUs of production systems created in Digital Factory environment (Delmia),
- system of digital models presentation,
- the way of internet support for using the 3D models.

The procedure used at the University of Žilina [2]:

- Obtaining of data about digitized object through Reverse Engineering. It is based on computer model of the object (DMU – Digital Mock Up), which is obtained through 3D scanning (digitization) of real, existing objects. We will use it for obtaining of the computer model of the real object, to which no drawings do exist. The Computer Tomography could be used for purpose of Reverse Engineering, it means 2D cuts, which are integrated into complex 3D model of the object, during next phase.
- 3D laser scanning is used for the building of 3D digital model of existing layout or by the analysis of static constructions (production halls), etc. Tha basis of scanning is creation of reference raster, with the support of reference points, software (e.g. Faro Clouds) is used for this step. It enables the integration of 3D scans for the specification of the future virtual model. We obtaing the 3D object from 3D scanns through modeling in CAD systems environment (e.g. Autocad, Microstation, Catia, ...). The software systems (e.g. iQscene), supplied by laser scanner producers, are used for data export from gained scanns.
- Created 3D digital model of production hall is be saved into DMU models database.
- Complex, digital model of production system (PPR – Product, Process, Resource) is created in Digital Factory (DF) environment (Delmia).
- 3D digital model of production system, created in DF environment (Delmia), is integrated into created 3D digital model of production hall.
- Such integrated 3D digital model is used for the detailed analysis of the complex production system (e.g. production processes analysis, ergonomics analysis, etc.).
- The computer simulation, supported by virtual reality (Quest simulation system), is used for the dynamic analyses.
- Obtained 3D digital model of object is further used for the identification of potencial collisions, for example in system environment of Navis Works, or Walk Inside.

Complex and in depth tested solution will fullfil all assumptions for the long term, effective operation.

4. THE MEANS FOR 3D LASER SCANNING AND DIGITIZATION

A Reverse Engineering laboratory, which already runs a workplace for acquiring 3D scanned data, utilises more equipment and software systems for scanning of real objects.

The mobile measuring arm FARO with laser head (which provides contact or contact-less scanning using 3D scanned data processing software PolyWorks) is used for measurement and scanning of shape complicated objects. The accuracy of scanning when doing contact measurement is 0,05 mm, in contact-less laser measurement 0,03 mm.

3D measuring device MORA MS 10 is used for CNC digitizaton (which provides contact measurement and contact-less scanning, using the software for 3D scanned data INCA 3D, the accuracy is 1,8 µm).

Minolta Vivid 900 is used to scan small objects of, say, 1 metre at distance of about 1,5 metre. Processing of the scanned 3D data is carried out in Geomagic Studio 8.

The new 3D laser scanner FARO LS880 which has a reach of about 100 metres with accuracy of 1 mm on 30 metres is used to scann large objects (e-g- buildings, large machines and equipment, etc.).

Both – the University of Žilina and the Slovak Productivity Center have purchased licenses to various innovative, modelling, simulative and optimization programs, are going to be used in the investigation. Program bundles from Invention Machine (Goldfire Innovator), MSC (Nastran, Patran, Marc, ADAMS, ...), PTC (PRO/Engineer, PRO/Mechanica, ...), Dassault Inc. (Catia, Delmia, Quest,...), Ansys, Witness, Mantra 4D, Virtual Reality, AutoCad and other, are available.

The University of Žilina invested into equipment and software for 3D laser scanning about 20 mil. SKK. Further means, in about 6 mil. SKK were invested into Digital Factory sytem (SW+HW).

5. THE EXAMPLES OF UTILISED TECHNOLOGIES

Hardware

No.	Name	Description
1	MORA	stabile, contact and contact-less CNC digitization
2	FARO LS 880	mobile, contact and contact-less, manual digitization using laser scanning up to 100 meters
3	Minolta ViV 900	3D laser scanner up to 2.5 m
4	FARO	mobile, flexible arm for measurement and digitization of objects (small objects)

Software

No.	Name	Descritpion
1	FARO Clouds	collection of data from 3D laser scanning
2	FARO Scene	design of virtual sceneries
3	PolyWorks	polygonization of 3D digital models obtained by laser scanning
4	Delmia	comprehensive sytem for Digital Factory
5	Quest	simulation system with the support of virtual reality, with the direct integration to Delmia system

6. TECHNICAL SOLUTION

Current digitization technologies enable 3D scanning of large objects with precision of some milimeters (creation of clouds of points, its identification and working out of 3D digital model). These technologies enable, as well, very precise measurement of object dimensions, snap shot the colors, spatial shapes, scanning type and its transformation into digital form, etc.

The digitization technologies enable, from obtained data, to create digital documentation of complex digital models which can be later used for objects analysis, study, design, protection, maintenance, etc. These technologies enable integrated working out of data and using of existing data (e.g. 2D scanns, photos, paintings, machines pasports, construction projects, etc.).

It will be needed to save and archivate all obtained information in databases of digital objects. Such databases have to able to save alphanumerical as well as graphical information (2D, 3D, pixel and vector).

The created digital models of objects enable utilisation of modeling and simlation methods for testing of objects properties, level of their damage, firmness and fatigue characteristics, important for objects safty (e.g. large buildings, halls, machines, equipment, etc.).

Technical solutions for 2D data collection and digitization

The today already common means are used for 2D scanning and digitization (2D scanners, digitization tablet, digital camera, etc.)

Technical solutions for manual 3D digitization

Institute of Competitveness and Innovations of the University of Žilina, owns and utilizes flexible arm for maual 3D digitization. It enables contact and contact-less digitization of spatial objects.

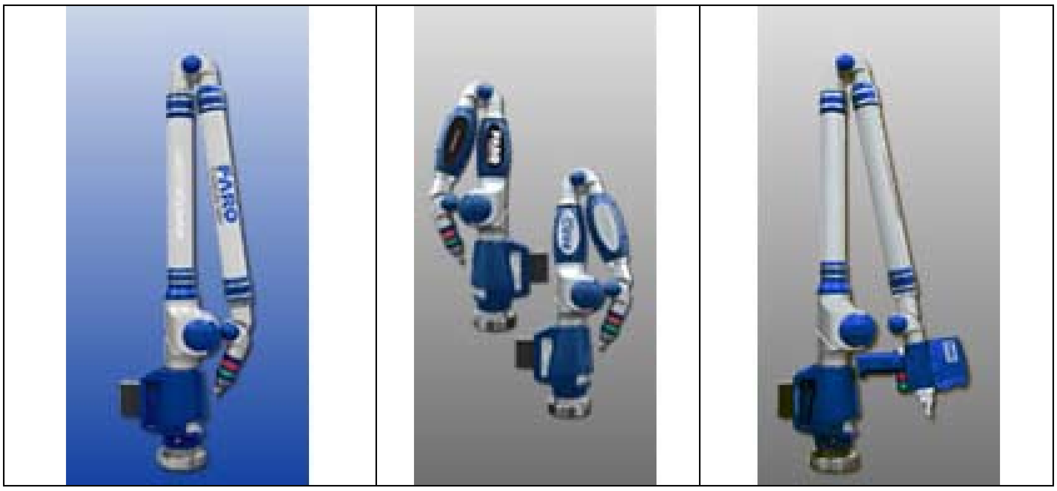

Fig.1. The Flex Arm FARO

The examples of utilization of flex arm for digitization of objects in technical practise are shown in the following figures.

Fig. 2. Utilization Of The Flex Arm FARO

Technical solutions for automatic 3D CNC digitization

The University of Žilina uses MORA system for digitization of complex objects. It enables automatic contact and contact-less digitization of spatial objects.

Fig. 3. MORA – CNC Measurement and Digitization Machine

Technical solutions for 3D scanning and digitization of small objects

The 3D scanner Minolta Vivid 900 is used for small objects scanning (up to 1 meter with distance to 1.5 meters) equiped with software for working out of scanned data and 3D modeling.

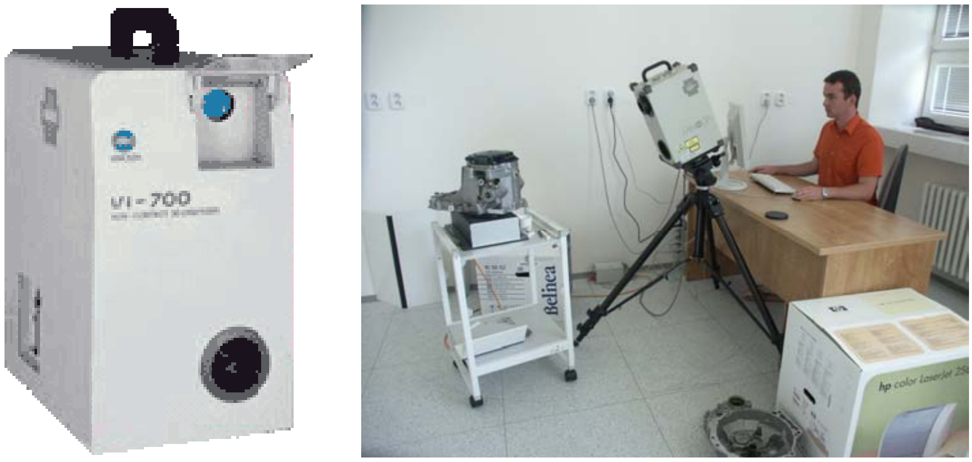

Fig. 4. 3D Laser Scanner Minolta Vivid 900

Technical solutions for 3D scanning and digitization of large objects

The special, high powerfull 3D scanners are used for digitization of large objects and creation of virtual scenes. They enable spatial scanning into distance of 100 to 150 meters.

Institute of Competitveness and Innovations of the University of Žilina, owns and utilizes for large objects scanning – 3D scanner Faro LS 880 (IQVOLUTION) equiped with software FARO Clouds and FARO Scene.

Fig. 5. 3D Laser Scanner FARO LS 880

7. DIGITAL TECHNOLOGIES – THE MAIN PRODUCTIVITY DRIVERS IN 21. CENTURY

The productivity and competitiveness improvement in the world was achieved, in years of 1900 till 1990, mainly through mechanization and automation. The growth during 1990 till 2000 was achieved through IT applications. According to the world leaders in technology development will be the digital technologies the main driver of productivity and competitiveness improvement in 21. Century.

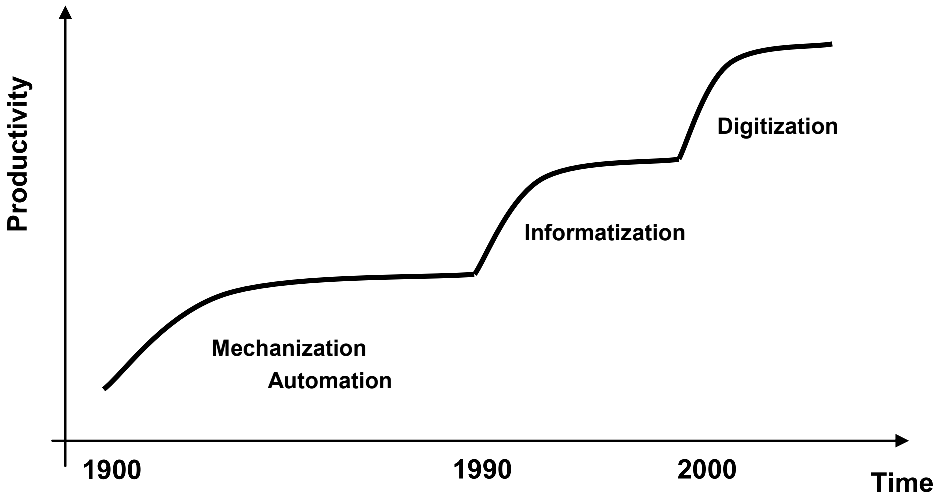

Fig.:6 Technological Progres From The Productivity Point Of View

The digitization brought new phenomena, principal fastenning of time to market. This was possible thanks the fact that digitization enables to create and test virtual prototypes through which it reduces ol totaly eliminates the need to create physical prototypes.

7.1 Economic benefits from digital technologies

3D laser scanning is basis for application of Digital Factory solutions [8], [9]. The authors of this paper estimate, that only during the first phase of transition to the digital solutions (HighTech companies undertaking in the SR) will be required in SR to scann about 5 mil. m^2 of industrial area. The scanning can be realised by the Slovak subjects (work will remain at home) or this job will be contracted in abroad. The direct costs of the scanning of surfaces written above (first phase) will, according the nowadays price relations, create the sum min. cca. 400 mil. SK. These can be markedly reduced by application of suggested approach and a fact, that they will be realized by native organizations.

The economic benefit can be documented on the next example. At the innovation of products and production systems it can`t be done without PC high-tech. In company Asea Brown Boveri (ABB) were many of orders analyzed. Out of the analyze resulted, that about **20 data** from customer in a simple order leads average to:

- **200 data** till optimization,
- **2000 data** in structure and documentation of product, includes results, calculations,
- **20000 data** in geometrical description,
- **200000 data** in documentation for production, material, planning, NC-control, scheduling,..

If we consider, that in the company is in the course of year executed for example 100 orders, we receive data capacity cca**.** $\mathbf{2\cdot10^7}$.

If we consider next, that in a car industry is every car an individual order, so than for example in case of VW Slovakia, which produces cca. 300 000 cars per year, it represents data capacity of cca**.** $\mathbf{6\cdot10^{12}}$

In a project practise of big project companies are known following statistics:

- **100 mil. €** investment requested
- **10 mil. €** increased costs because of lower transparency and cca.
- **1 mil. €** additional costs and time because of lower transparency, clashes, organization problems and mistakes in suggestions.

Based on research by 3D laser scan users were achieved following costs savings:

- 3-4 mil. € apport trough the virtual reality. According to the research by customers consistent application of 3D factory can save 30-40 % additional costs and time in projects.
- Complex 3D data are basis for detection and elimination of clash causes. It can be saved up to 2 % of investment costs by investment in to factories by using detection and elimination clash causes.
- Created and complex 3D DMU allows us accurate, quick, easy and effective change management. Time in this case is featured, so these planning and management systems are also marked as 3D-CAD-Planning tools (also marked 4D). The utilization of automatic scanning based on ahead set plan allows quicker obtain of new and real 3D DMU. The planning system on the other side allows with one click to realize changes in integrated form, which were in past solved by groups of specialists for months.

Amomg the other benefits of digitization of large objects belong:

- direct access of researchers and industrialist in digital models of large objects,
- the growth of quality and disponibility of information about preserved objects,
- cost reduction of documentaion, analysis, precision of working out and preserving of information about objects,

- simplification of documents and archivation of information about objects,
- the growth of degree of objects protection,
- precise monitoring of objects movement (e.g. machines, equipment, etc.),
- support of the development of new scientific methods for the maintenance of objects,
- the growth of productivity and precision of created digital models of spatial objects,
- cost reduction and growth of effectiveness by creation of databases of digital models of different objects,
- support of development of knowledge about 3D laser scanning, digitization, modeling and simulation supportde by virtual reality means and through comprehensive databases of digital models.

8. CONCLUSION

The implementation area of 3D scanning is very wide. The systems of 3D scanning can be used from manufacturing applications by designing production systems (3D model creation of production machines and lines, production halls, buildings and big production devices), in building industry (orientation of real building state, difficult technological complexes and constructions, bridges, underbridges or for obtention of records for building by orientation terrain profile), by measuring hardly accessible places for example stone pits, caves, dumping ground, mining tunnels and tube systems. 3D scanning can be useful by cultural heritage saving or by restoration, reconstruction and documentation of historical buildings, churches, statues, castles and manor houses. Nowadays can be 3D scanning of huge objects used by creation 3D models of Slovak cities for tourist traffic support (possibility of virtual city walk, get information on parking possibilities, access roads and so on).

The Slovak Republic did not built the workpalces for 3D laser scanning technologies of large objects and Digital Factory technologies. The whole technical world has been recently focusing its effort into development and application of these technologies. The dynamic development on this area brought the firts practical solution, which are tremendously expensive.

The University of Žilina, in co-operation with the Slovak Productivity Center, have long been investing their human and financial resources into obtaining and developing progressive technologies. The Institute of Competitiveness and Innovations of the University of Žilina currently possesses workplaces focused on 3D scanning of both – small and large objects. In recent years the University of Žilina has – as the only one in Slovakia – gained extensive experience in application of such technologies as: digitalization, reverse engineering, 3D scanning, visual data processing [1], creation of 3D digital models of objects, modeling and simulation of real objects' properties, creating copies of real object using additive technologies and Vacuum Casting.

The further research on the area of digital technologies moves the whole scientific and technological basis of the SR and opens the possibilities for co-operation in the framework of the European Research Area and international research. The authors of this paper co-operate already with the following organisations: Fraunhofer Institute (Germany), Polish Academy of Science and with research groups of Audi and VW.

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