Digital Factory, virtual reality, simulation, Digital Mock Up

Milan GREGOR, Štefan MEDVECKÝ *
Ľubomir JAHNATEK**

DIGITAL FACTORY – THEORY AND PRACTICE

Abstract

The paper focuses on the research & development of the Digital Factory solutions for industry. The developed methodology and solution of Factory Mock Up (FMU) is presented. The results of research and development cover design of assembly system, its processes, simulations model, ergonomic analysis etc. In the paper are presented the solutions developed in the framework of co-operation with industrial partners like Volkswagen Slovakia, Thyssen Krupp – PSL, Whirlpool. The advantages, restrictions and way of utilization of Digital Factory solutions are also shown in the paper.

1. INTRODUCTION

The results of recent years research conducted in the framework of international Intelligent Manufacturing Systems (IMS) research program [21] showed that the future for manufacturing lies with new forms of manufacturing strategies. The global networks of self-organizing and autonomous units will create basis for new production concepts. Modeling and simulation have became the decisive analytical tool of the 21. century [10], [19]. Global markets require short time to market, high quality products with the lowest possible price. Digital Factory seems to be a solution for above introduced demanding requirements.

Different types of software are linked in PLM solutions, which control different parts of the manufacturing cycle. Computer Aided Design (CAD) systems define what will be produced. Manufacturing Process Management (MPM) defines how it is to be built. Enterprise Resources Planning (ERP) answers when and where it is built. Manufacturing Execution System (MES) provides shop floor control and simultaneously manufacturing feedback. The storing of information digitally aids communication, but also removes human error from the design and manufacture process.

The products innovations are the topic of current discussions. There exists almost no discussion about innovations of production and assembly systems, in spite of the fact that the majority of foreign investment in Eastern Europe was focused in production and assembly [5].

The Virtual Reality can be used as by the product development as by the design of production processes, workplaces, production systems, etc. The utilization of Virtual Reality by the design and optimization of production processes and systems is often entitled as **Digital Factory** [6].

* Prof. Ing. PhD.; Prof. Ing. PhD., Central European Institute of Technology (CEIT), University of Žilina, Slovakia
** Doc. Ing., CSc., Slovak Technical University, Bratislava, Slovakia

2. DIGITAL FACTORY

Digital Factory entitles virtual picture of a real production [13]. It represents the environment integrated by computer and information technologies, in which the reality is replaced by virtual computer models. Such virtual solutions enable to verify all conflict situations before real implementation and to design optimised solutions.

Digital Factory supports planning, analysis, simulation and optimisation of complex products production and simultaneously creates conditions and requires team work [14]. Such solution enables quick feedback among designers, technologists, production systems designers and planners. Digital Factory represents integration chain between CAD systems and ERP solutions.

One of very important property of Digital Factory is the vision to realize process planning and product development with parallel utilization of common data.

Digital Factory principle is based on three parts [1]:

- **digital product**, with its static and dynamic properties,
- **digital production planning** and
- **digital production**, with the possibility of utilization of planning data for enterprise processes effectiveness growth.

It is very important to gain all required data only one time and then to manage them with the uniform data control, so that all software systems will be able to utilize it. The integration is one of the main conditions for the implementation of Digital Factory.

2.1 Digital Factory application area

Digital Factory is appropriate mainly as a support for the batch manufacturing of high sophisticated products, their planning, simulation and optimization. Its main current application area is automotive industry, Mechanical Engineering industry, aerospace and ship building industries as well as electronics and consumer goods industries [1].

3D digital model of products (DMU – Digital Mock Up) creates currently basic object for the work in digital manufacturing environment [5]. There exists possibility to optimize products, processes and production systems even by the development phase with the utilization of 3D visualization and modeling techniques. Such solution brings time to market reduction and significant cost reduction [3]. The complex 3D models are currently known as so called FMU (Factory Mock Up) [21].

The system for the design of shop floor 3D layouts and generation of 3D models of production halls is missing in current Digital Factory solutions [4]. It is possible to create the 3D model of production hall directly in CAD systems. Such solution is advantageous by new layouts or by new production systems designs.

But, production halls do exists, in majority of real cases. By such conditions, it is often more effective to create 3D model of production hall with the utilization of Reverse Engineering technologies and 3D laser scanners [7].

The material flow simulation enables to optimize the movement of material, to reduce inventories and to support value added activities in internal logistics chain [10], [19].

The subsystems for effective ergonomics analysis utilize international standards as The National Institute for Occupational Safety and Health (NIOSH), Rapid Upper Limb Assessment (RULA), etc., which enable right planning and verification of man-machine interactions on the single workplaces [2].

The highest level of analysis is represented by a computer simulation of production and robotics systems which enables optimization of material, information, value and financial flows in the factory [8].

2.2 Digital Factory Advantages

Digital Factory implementation results directly in economic as well as production indicators improvement. Any slight saving realized in a design and planning phase can bring huge cost reduction in a production operation phase. Thanks to this is payback period by investment in Digital Factory very short.

Digital Factory main advantages [6]:

- reduction of entrepreneurship risk by the introduction of a new production,
- processes verification before start of production,
- possibility of virtual "visit" of production halls,
- validation of designed production concept,
- optimization of production equipment allocation,
- reduction in required area,
- bottlenecks and collisions analysis,
- fast changes,
- better utilization of existing resources,
- machines and equipment off line programming saving time a resources,
- reduction or full elimination of prototypes,
- ergonomics analyses, etc.

Digital Factory enables to test and reveal all possible production problems and shortages before start of production.

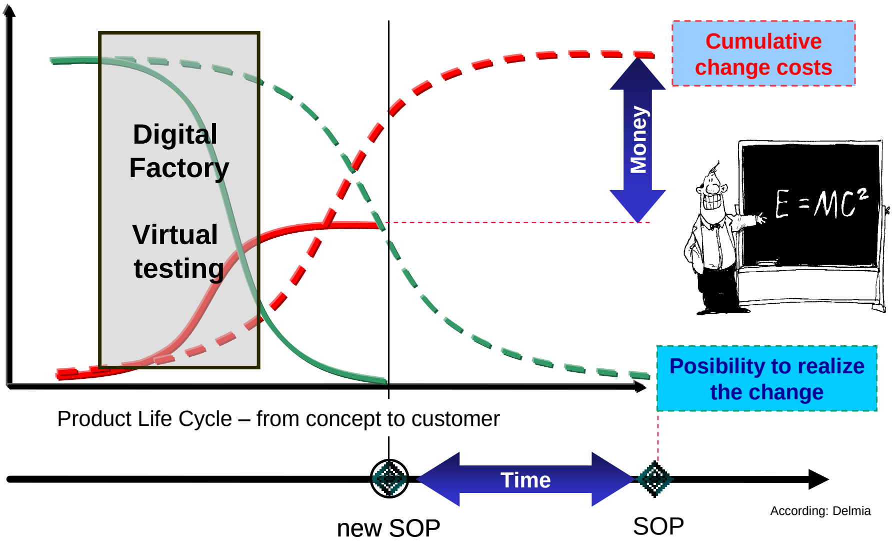

Fig. 1. The Digital Factory Advantages

The highest potentials for high quality and low costs of products are in product development and production planning phases. The statistics show that product design and production planning influence about 80 % of production costs [6].

Digital Factory enables product launching time reduction up to 25 - 50 %. Estimated cost savings are supposed from 15 to 25 %. According to some studies done in industry, using digital manufacturing techniques, twice the amount of design iterations can be processed in 25 percent of the time.

The current production equipment is often inflexible by quick changes [18]. That is why the designers of such equipment are looking for new solutions (automatic reconfiguration of production machines) with fully automated control systems, which will be able to find optimized production process and parameters after production task definition [14].

According to CIMdata report (March 2003), Digital Factory enables to achieve following financial savings:

- *Cost savings by assets reduction about 10 %,*
- *Area savings by layout optimization about 25 %,*
- *Cost savings by better utilization of resources about 30 %,*
- *Cost savings by material flows optimization about 35 %,*
- *Reduction in number of machines, tools, workplaces about 40 %,*
- *Total cost reduction about 13 %,*
- *Production volumes growth about 15 %,*
- *Time to market reduction about 30 %.*

3. DIGITAL FACTORY IMPLEMENTATION METHODOLOGY

Rough procedure of Digital Factory implementation is as follows [7]:

- definition of total standards and production principles for entire planning operations, creation of primitives and customer databases,
- first data collection and organization with the utilization of data management system. All responsible persons have direct access to the date, their addition, inspection and changes,
- in this phase, Digital Factory system improves co-ordination and synchronization of individual processes throughout their “networking” supported by workflow management system,
- in the fourth phase, Digital Factory system takes automatically some routine and checking activities, which are very time consuming in common systems. Implemented system insures high quality of all outputs.

4. DIGITAL FACTORY IN A RESEARCH

The University of Žilina belongs among the universities using software solutions for Digital Factory in education and research [11]. The University of Žilina in co-operation with the Central European Institute of Technology started to build their own Digital Factory concept whose structure is shown in Fig. 2.

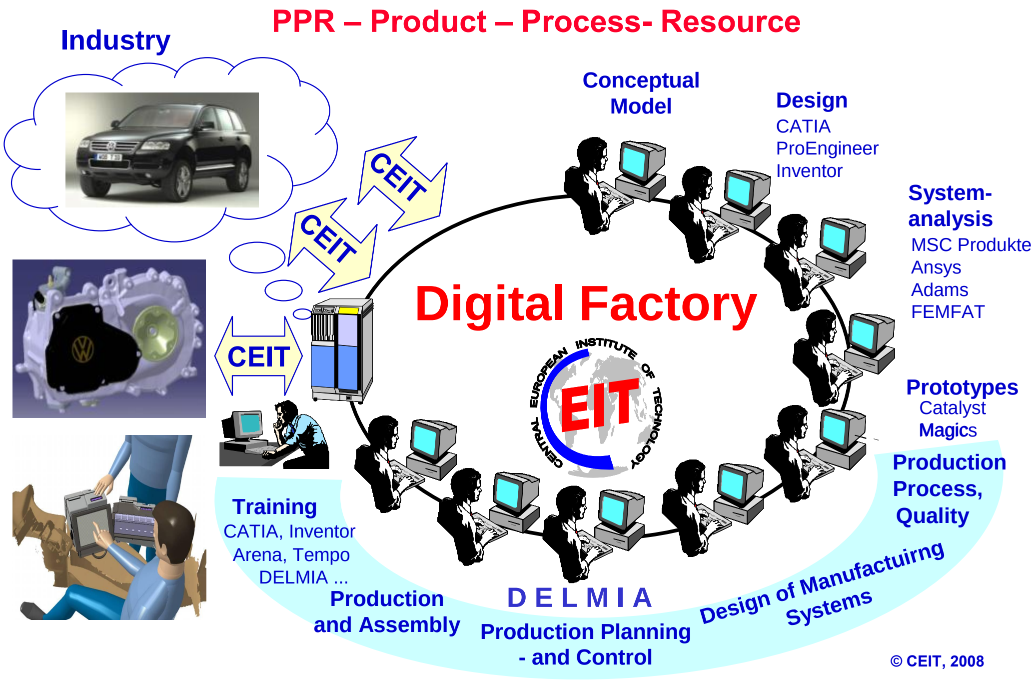

Fig. 2. Digital Factory Concept Built at the University of Žilina [11]

This concept increases the borders of current Digital Factory solutions. It endeavors to integrate activities conducted by designers, technologists, designers of manufacturing systems, planners. It simultaneously tries to increase the offer of individual existing modules. The concept design goes from theoretical studies as well as practical experience gained in industry in Slovakia (VW Slovakia, Whirlpool Slovakia, Thyssen Krupp - PSL, etc.).

5. RAPID PROTOTYPING AND VACUUM CASTING TECHNOLOGIES

The following part presents the chosen results of the research studies conducted in co-operation with the industrial producers of Electrical Engineering and automotive OEM producers.

The first example shows the results from research done at the University of Žilina and company Scheidt & Bachmann. The developed buss terminal is shown in the Figure 3.

Fig. 3. The Developed Buss Terminal

The chosen technologies of the Digital Factory have been tested in the framework of the long term scientific co-operation between the University of Žilina and company VW Slovakia [9]. Following example shows the application of Rapid Prototyping and Vacuum Casting technologies by the development and production of gear boxes.

Fig. 4. The Real VW Gearbox

The DMU model of given gearbox was created through Reverse Engineering technologies (Minolta 3D Laser Scanner VI 900).

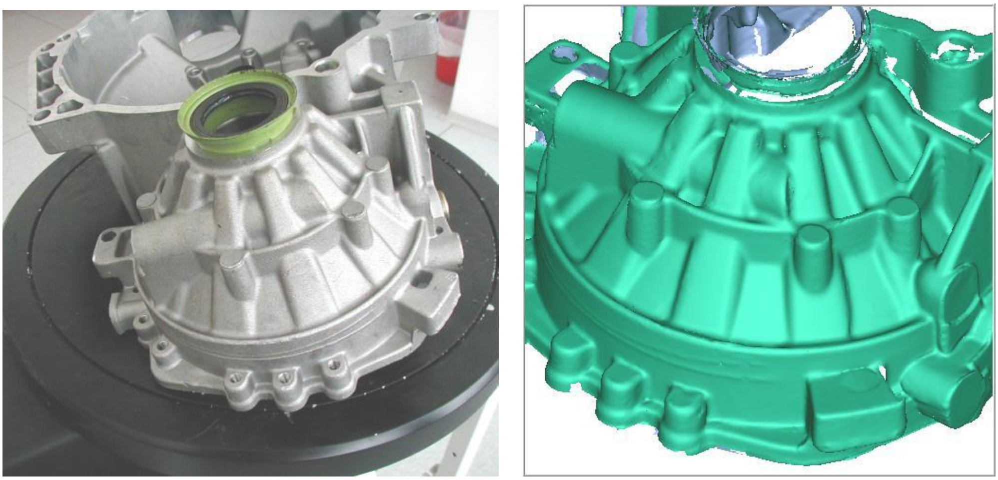

Fig. 5. The Real VW Gearbox and Its Scanned Clouds of Points Model [16]

In the following the 3D digital model of single parts of gearbox was developed based on clouds of points model (see Figure 6). The Rapid Prototyping technologies were tested by the development of the gearbox prototype. The chosen examples are presented in the following part of this paper.

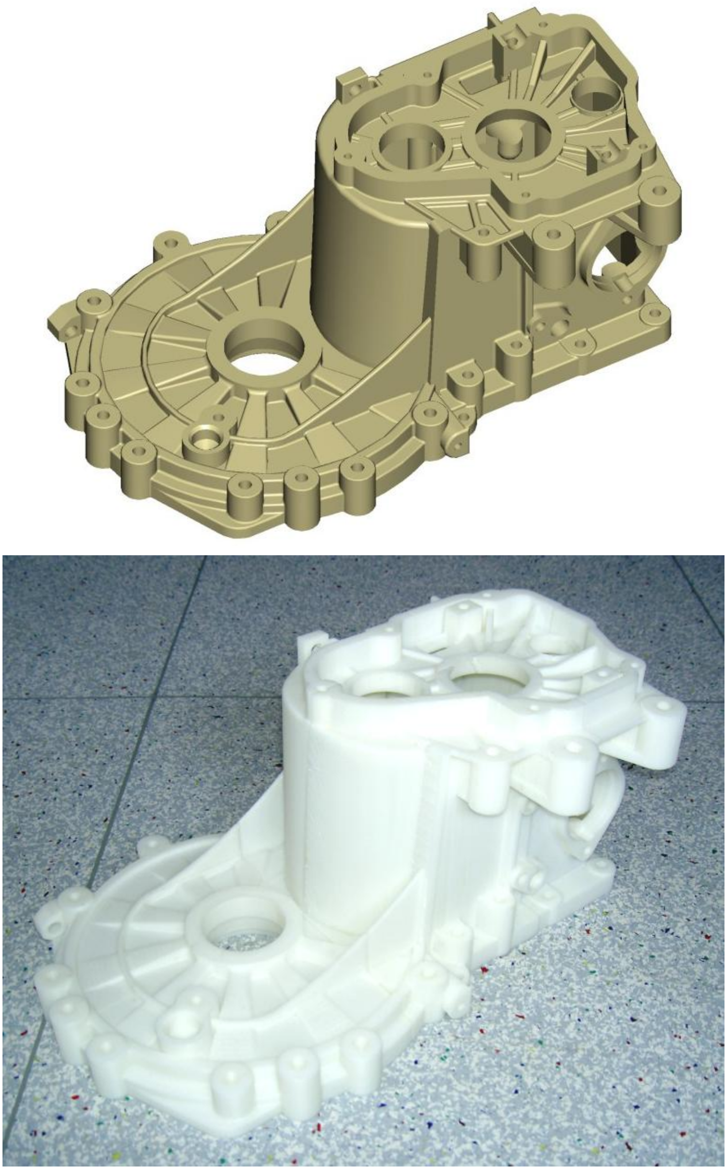

Fig. 6. The 3D Model in Catia and FDM Prototype [16]

The following Figures show the results of optimization of chosen gearbox parts and the production of prototypes through Fused Deposition Modeling (FDM) method and Vacuum Casting technologies.

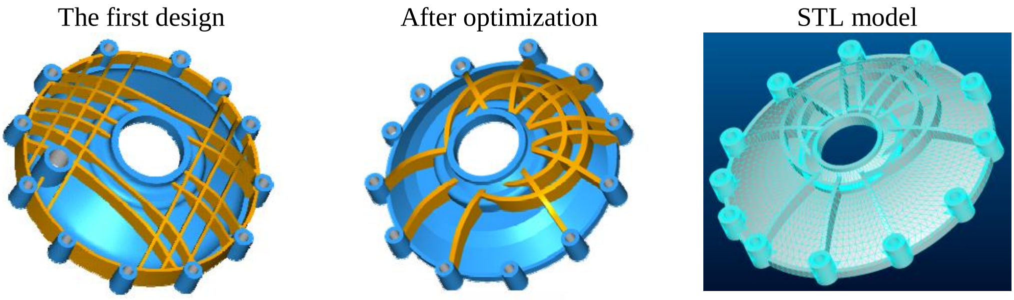

Fig. 7. The Development of the Prototype [15]

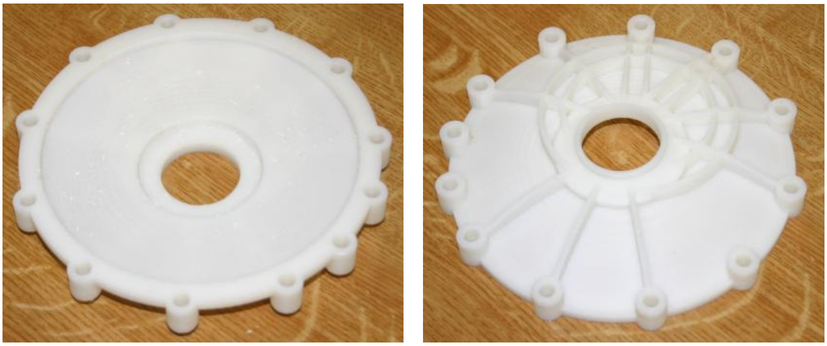

Fig. 8. The Production of FDM Prototype [15]

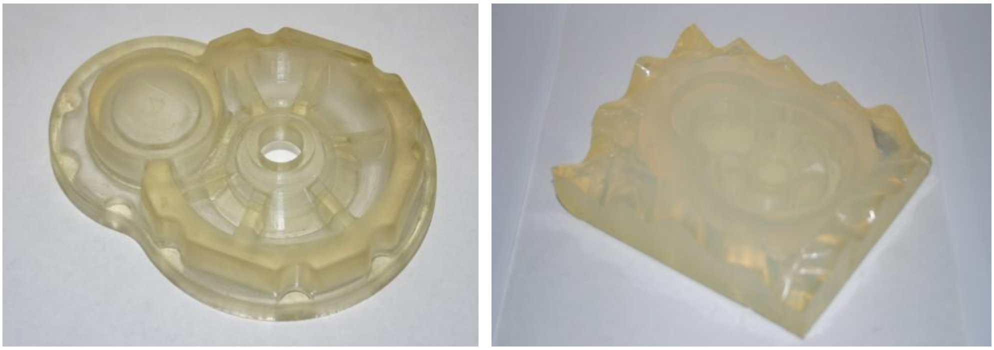

Fig. 9. The SLA Prototype and Its Silicon Form [15]

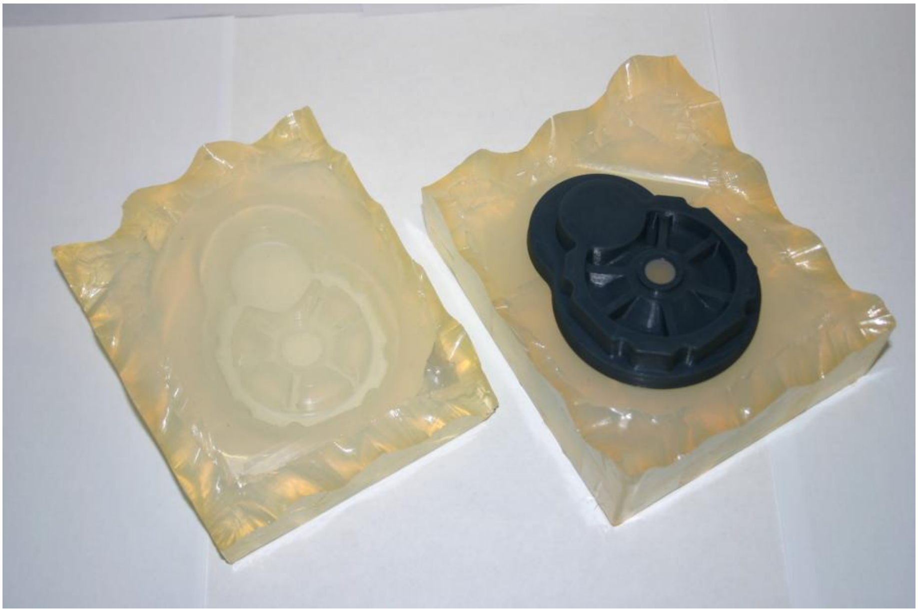

Fig. 10. The Result of Prototype Casting of Plastics [15]

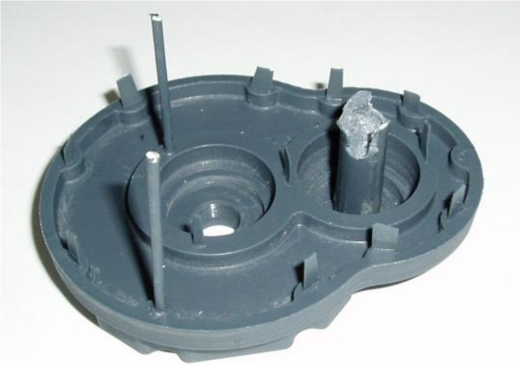

Fig. 11. The Real Prototype After Vacuum Casting [15]

6. DIGITAL FACTORY IN THE INDUSTRY

The further development and prosperity of any country depends on quality of its engineers responsible for innovations. Investment into education brings almost 8 times higher increase of productivity than investment in capital assets.

The University of Zilina has conducted several research studies in industry focused in Digital Factory solutions.

The DMU model of a real gearbox was developed using Reverse Engineering technology (3D laser scanning), in the framework of co-operation with VW Slovakia.

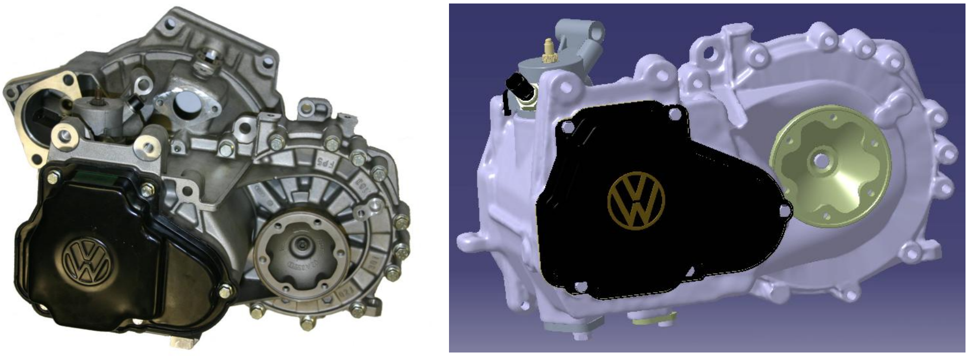

Fig. 12. Real Versus Virtual VW Gearbox [9]

Following the Gearbox DMU a set of DMUs of VW production workplaces and transportation equipments was developed.

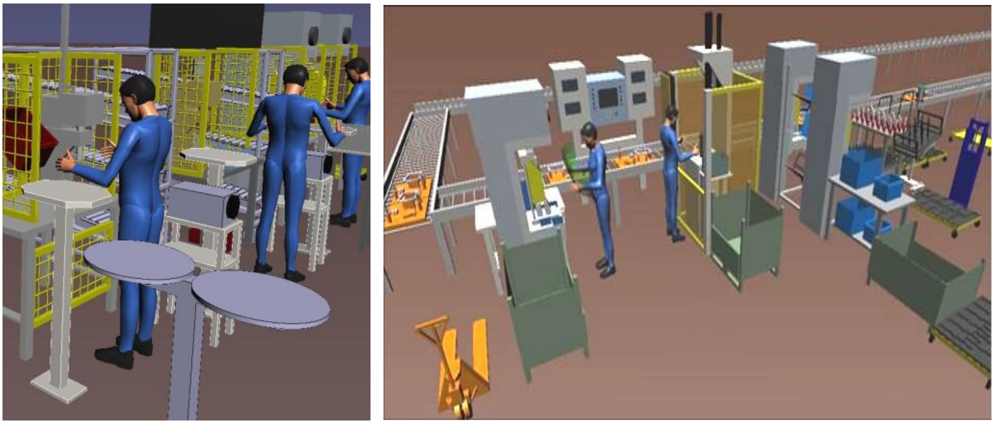

Fig. 13. DMUs of Assembly Workplaces [9]

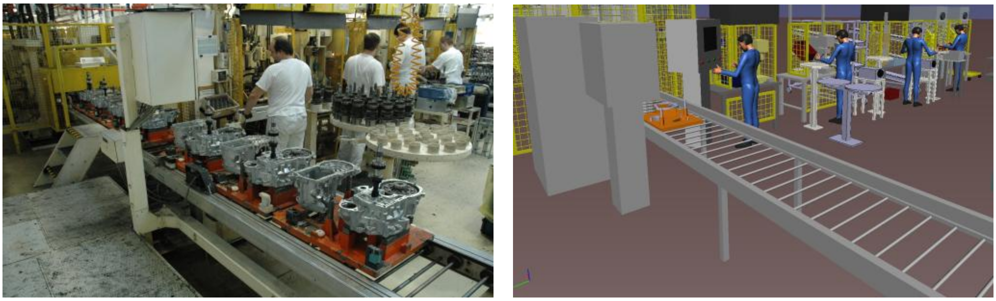

Fig. 14. VW Slovakia – Real Versus - 3D Digital Model [9]

The design of workplaces was especially checked by an ergonomics analysis whereas manikin concept of Delmia V5 Human was used (see Figure 15).

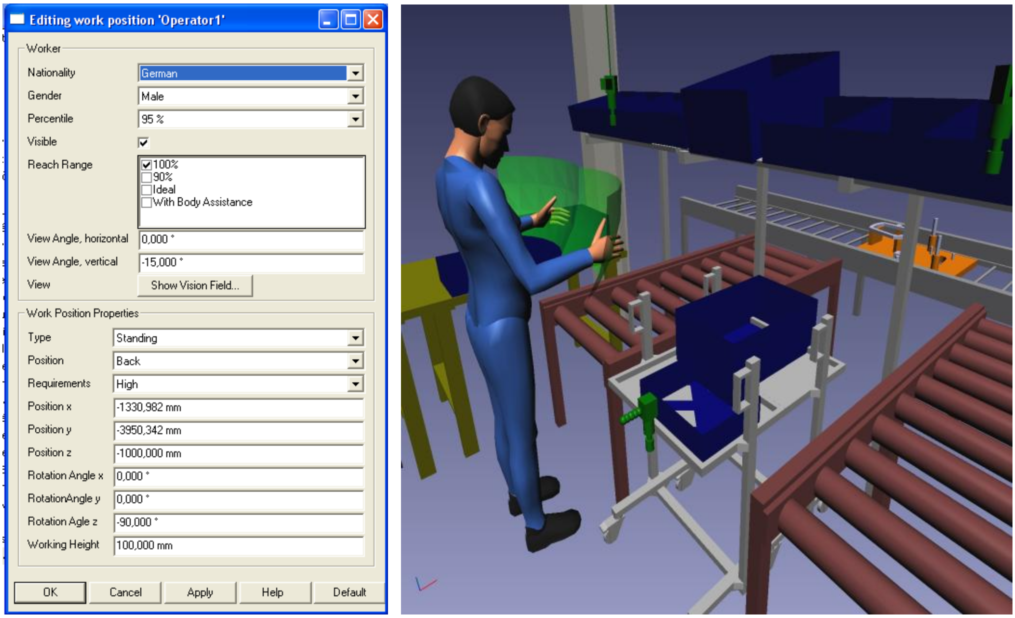

Fig. 15. Ergonomics Analysis of a Manual Workplace [9]

The static virtual model of a given gearbox assembly line was developed through integration of individual DMUs into manufacturing system scene as it is shown in Figure 16.

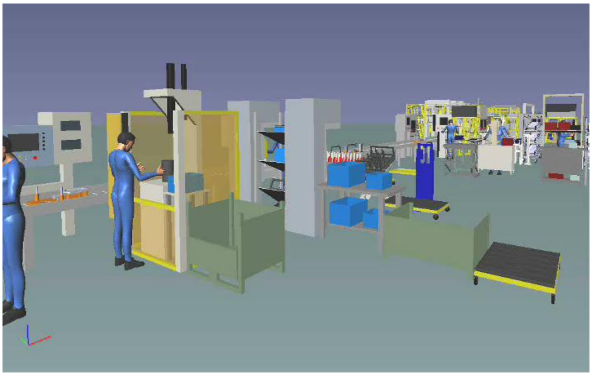

Fig. 16. Static Digital Model of Assembly Line [9]

The dynamics of production system was added in the 3D simulation environment Quest (see Figure 17). The set of simulation experiments was conducted with the developed simulation model which showed bottlenecks stations and the possibilities for performance growth of gearbox assembly line.

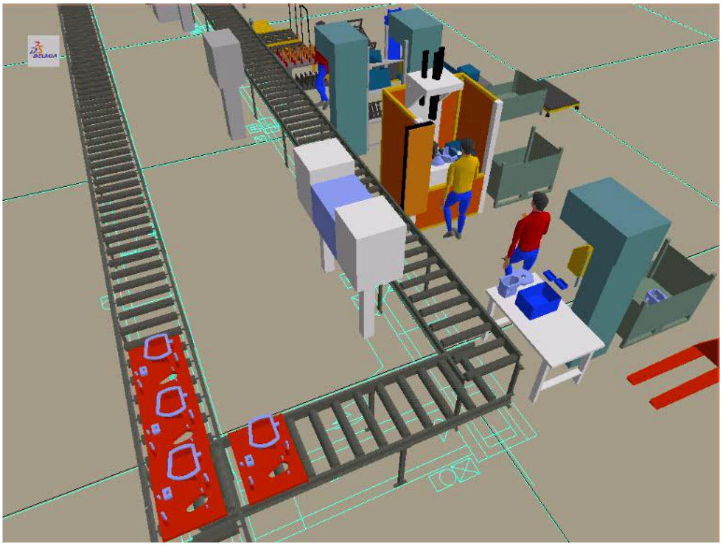

Fig. 17. 3D Simulation Model of Gearbox Assembly Line [9]

Afterwards an FMU of the whole assembly line for gearboxes assembly in VW Slovakia was developed. This FMU represents the complex digital model of the entire assembly line. The final solution is shown in Figure 18.

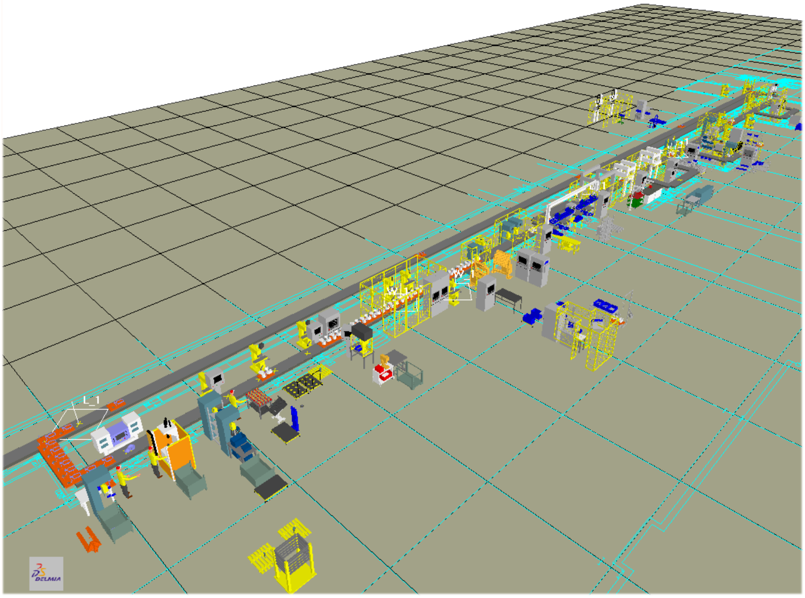

Fig. 18. VW Slovakia – FMU of Gearbox Assembly Line [9]

7. 3D LASER SCANNING SUPPORTS DIGITAL FACTORY

The 3D laser scanning (3D-LS) is one of the Reverse Engineering technologies which is usually used for the digitization of real objects [17]. The digitization through 3D laser scanning represents one of the most productive and effective ways of how to get the high quality 3D digital models of current production systems. Those technologies enable simultaneously the transformation of current real worlds into their 3D clouds of points copies which represents their spatial geometry. Such 3D models are very useful by the analysis of current production systems [12].

The 3D-LS technologies became a part of The Digital Factory technologies. Their advantage lies in the simplicity und a huge potential of cost and time savings by the development of 3D models of current objects.

Following statistics are known in a project practice of big project companies:
€ 100 mil. investment requested
€ 10 mil. increased costs because of lower transparency and about
€ 1 mil. additional costs and time because of lower transparency, clashes, organization problems and mistakes in suggestions.

Based on a research by 3D laser scanners users were achieved following costs savings [7]:

- € 3-4 millions 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.

		
Clouds of point model	Transfer in CAD	3D Digital model

Fig. 19. The DMU Model of Handling Device [7]

The chosen Reverse Engineering technologies were tested in the framework of co-operation of the University of Žilina and Thyssen Krupp – PSL and Whirlpool companies. The following example shows the development of DMU model of handling device.

The DMU of the large machine tools were developed through 3D laser scanning (Faro LS 880 HE) and modeling (Catia).

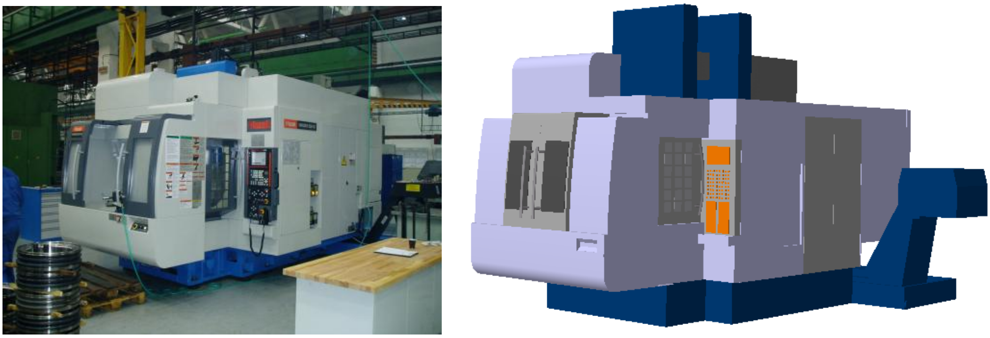

Fig. 20. The Machine tool and its DMU model [4]

In the following the 3D virtual models of production halls were developed through 3D laser scanning (Faro LS 880 HE) and modeling (HLS).

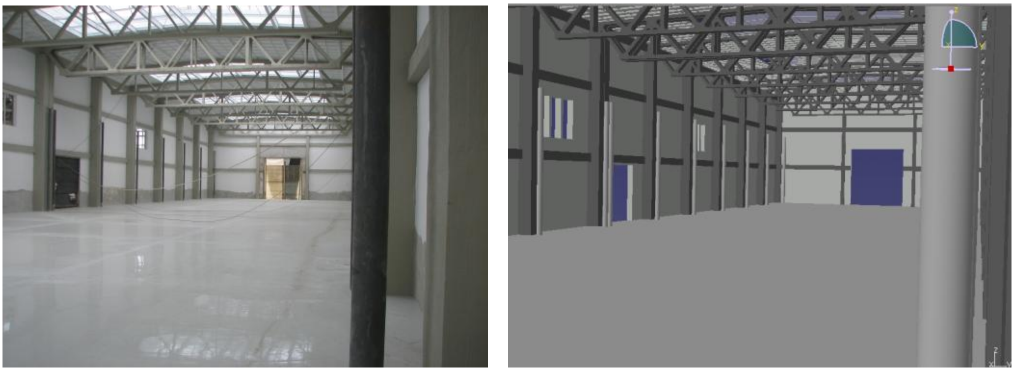

Fig. 21. The real production hall and its DMU model [7]

Then the new assembly concept and the material flow were developed in the framework of research. The solution represents an comprehensive model and the development further continues.

The new designed production halls were directly in Bentley HLS system developed. All objects (eg. production halls, machine tools, handling devices, etc.) were as follows in Delmia V5 integrated and through this was an comprehensives FMU developed. Then as the next step was an 3D simulation model of this complex production system developed. The simulation helped to find optimal way of operation of the designed production system.

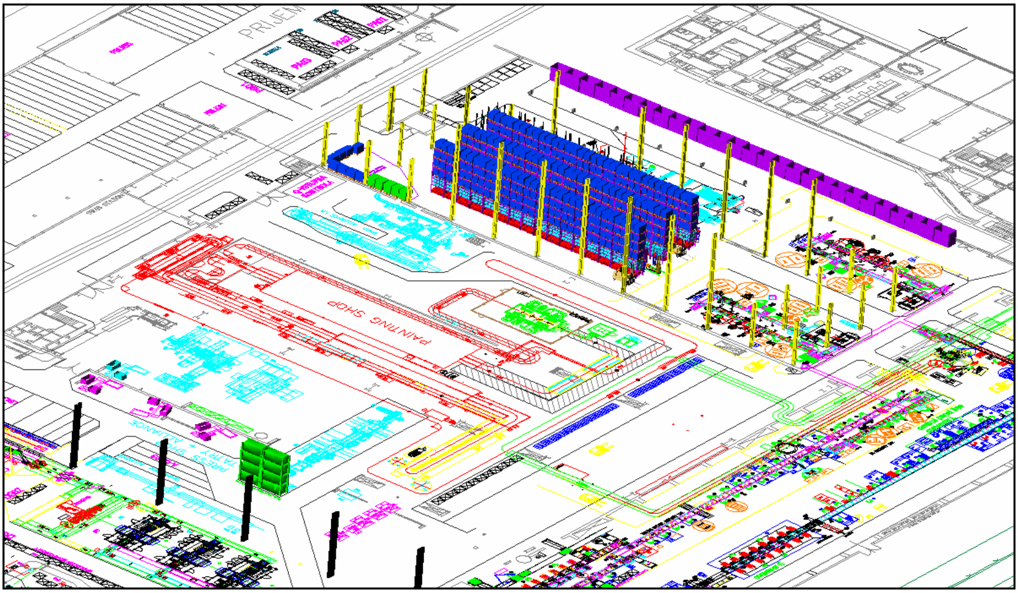

Fig. 22. The DMU of Material Flow System in a Projected Manufacturing [4]

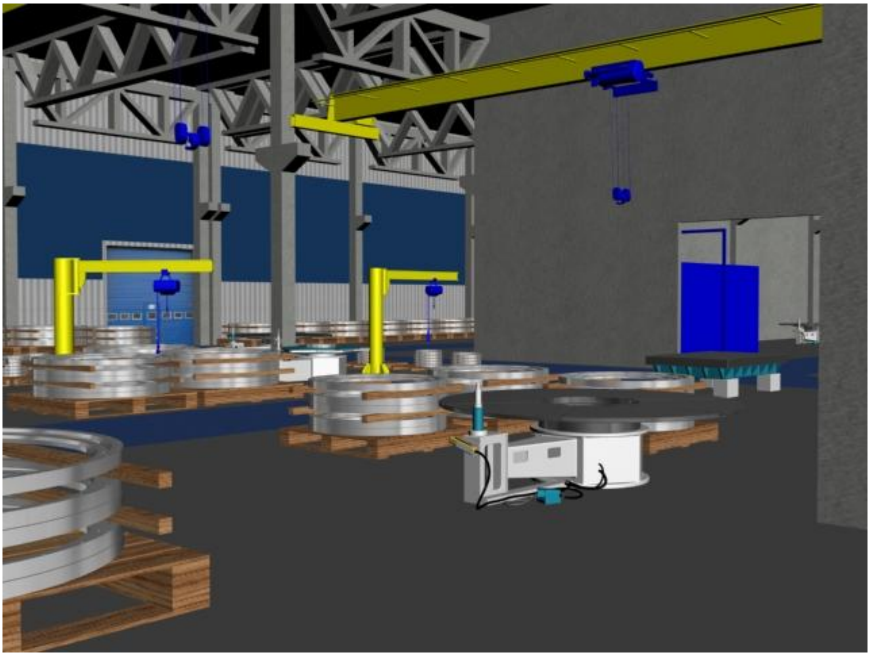

Fig. 23. The FMU Model of a Projected Manufacturing [7]

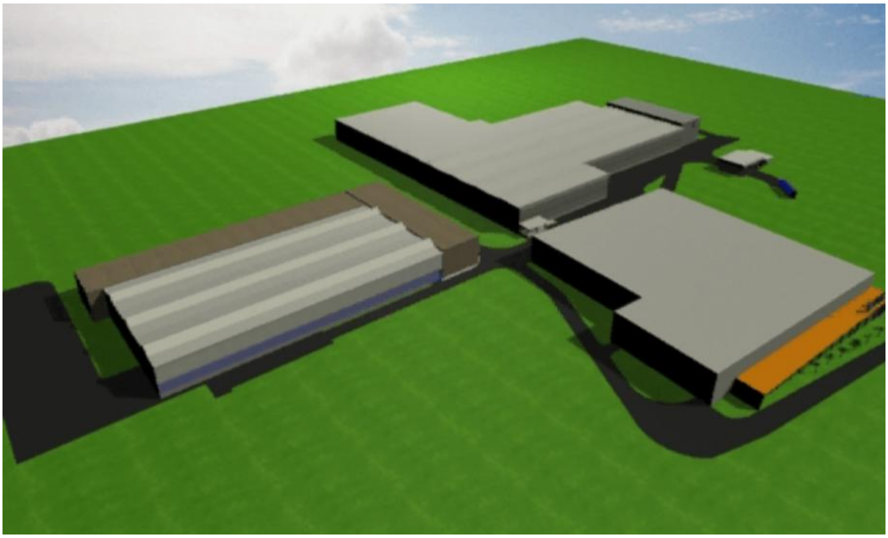

Fig. 24. The FMU Model of the Whole Factory [7]

8. CONCLUSION

The future outlook shows that next generation products can benefit from digital manufacturing. Any type of process elements are stored so that as modifications are made at any stage of product development, they are made to the entire design and manufacturing process.

Every university is obliged to educate students who will be able to design competitive products and production systems with the help of advanced information technologies. The common intention of the University of Zilina is to establish a fully integrated system for the design of sophisticated production systems with its main focus on automotive and electronics industries. Such a system should enable to bring new technologies into industry as well as into education and simultaneously to support the education of future designers, designers of manufacturing systems, technologists and managers.

This paper was supported by the Agency for Support of Research and Development, based on agreement No. APVV-0597-07.

References

[1] DELMIA – DPE. DELMIA. Paris, 2008.
[2] DELMIA – Human. DELMIA. Paris, 2008.

[3] DELMIA Quest. DELMIA. Paris, 2006.
[4] FURMANN R.: *The design of an Algorithm for the layout creation in Virtual Reality*. Dissertation Thesis. University of Žilina, Faculty of Mechanical Engineering, 2007, 135 pp.
[5] GREGOR M. et.all.: *Virtual reality technologies for the support of competitiveness and productivity*. Research project, Contract No.: APVT-20-026304.
[6] GREGOR M. et.all.: *The research of possible use of Digital Factory in the Slovak industry*. Research project, No.: AV 4/0021/05.
[7] GREGOR M. at al: *3D Laser Scanning. The methodology of large production halls scanning*. Research project CEIT-V001-11-2007, CEIT, Žilina, 2007, 82 pp.
[8] GREGOR M. et.all.: *Digital Factory*. Slovak Ministry of Economy, Bratislava, 2006, 346 pp. Research project No. 245/2006-3100-3210.
[9] GREGOR M. at all: *Factory Mock Up*. VW Assembly System. Research Study. CEIT-S002-12-2007, 27pp.
[10] GREGOR M., MATUSZEK J.: *Simulation in Factory Optimization*. Applied Computer Science and Production Management. Vol.1,No.1,2005, pp. 61-74.
[11] GREGOR M., MEDVECKÝ Š., MATUSZEK J.: *Digital Factory*. Productivity and Innovation. Vol.2, 2006, N.1, pp.38-42.
[12] GREGOR M., MEDVECKÝ Š., ŠTEFÁNIK A.: *3D Laser Scanning in Digitization of Large Objects*. Applied Computer Science and Production Management. Vol.3 ,No.1,2007,pp.95-109 .
[13] GREGOR M., MEDVECKÝ Š., MIČIETA B., MATUSZEK J., HRČEKOVÁ A.: *Digital Factory*. SLCP Žilina. KRUPA print 2007. ISBN 80-969391-5-7. 148 pp. (In Slovak).
[14] HAAS W.: *AK-Digitale Fabrik*. Bericht Roadmap. Juni, 2004, Audi Ingolstadt.
[15] HRČEK S.: *The design of an automotive gearbox supported by sophistic methods of 3D modeling, Rapid Prototyping, Rapid Tooling and Reverse Engineering*. Dissertation thesis, University of Žilina, Faculty of Mechanical Engineering, March, 2005, 140 pp.
[16] HRČEK S., MEDVECKÝ Š., KOHÁR R., MAČÚŠ P.: *The production of and gearbox prototype supported by Rapid Prototyping technologies*. Research project, No. 002-UKaI-06. University of Žilina, May 2006, 64pp.
[17] MAČÚŠ P., ĎURAJOVÁ M.: *3D Laser Scanning*. Research project No. 006-UKaI-06. University of Žilina, July 2006, 86 pp.
[18] STEFFAN R., SCHULL U., KUHLAN T.: *Integration of Virtual Reality Based Assembly Simulation into CAD/CAM environments*. Aachen University of Technology. 2005.
[19] ŠTEFÁNIK A., GREGOR M.: *Rapid development of the new production system with the support of computer simulation*. In: Rapid technologies. Wroclaw, CAMT, October 2004, pp.234-242.
[20] TAISCH M., THOBEN K.D., MONTORIO M. Ed.: *Advanced Manufacturing. An ICT and Systems Perspective*. Taylor & Francis, London, 2007, 319pp.
[21] ZIMMERMANN P.: *Virtual reality – Forschung und Anwendung Bei Volkswagen*. VR-Labor der Konzern-Forschung, Wolfsburg, 2005.