Research of deployment of designer tools from industrial practice in project oriented education

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Abstract**—** Use of computer tools for design, simulations, technical preparation of production and data management is the essential part of development and production processes of current industrial practice. A high efficiency of the application deployment, along with technical factors depends on a good preparation of the technical staff at schools and also during their professional experience. The text presents research results of the deployment of designer tools in project-oriented education. Research is focused on the comparison of students' and graduates' skills achieved at the concept of teaching with the demands of industrial practice on the competencies of the technical staff. A mixed approach, based on combining qualitative and quantitative approaches, is applied in the research. Results and conclusions of the research can be applied not only for planning and optimization of educational process at schools, but also for ongoing training of technical staff in practice.

Keywords**—** Data Model, Design, Engineering, Industrial Practice, Mixed Method Research, Simulation, Virtual Prototype.

I. Introduction

THE submitted text presents the issue of deployment of tools for design and simulations in project education of technical, engineering-oriented courses at secondary schools, colleges and universities. It is based on the demand of industrial practice for professional skills of graduates who get employed in engineering companies. Deployment of tools for design, simulation and data management is a specific stage in the product life cycle, in particular stages of development and technical preparation of production. At the same time, high productivity is required in these processes, based on the effective use of supporting technologies in compliance with technical, technological, environmental and ethical standards [1]. The fulfillment of these requirements can be optimized by staff training, advanced training of existing engineers or during the teaching process at technical schools [2]. A didactic system for vocational engineering subjects should include elements of project-oriented education supported by information technology [3]. The introduction of the results of the presented research is based on an analysis of selected parameters of the projects implemented at schools. The projects are compared with relevant projects that graduates of technical schools deal with in the industrial practice. Besides the concept of education and the course of the research, the examples of projects and opportunities of the used systems for educational and research purposes are presented. Linking education and industry should be beneficial for the development of a systematic approach to the education of engineering subjects. Implemented research is mixed [4], consisting of current application of qualitative and quantitative methods [5]. The sources of research data are the quantified parameters of projects of virtual prototypes.

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II. Engineering computer tools

The use of the didactic potential of information technology is based on current trends in contemporary education [6]. Computer applications for design and simulations are the basic tools used in practice for the phase of design and technical preparation of a product. The product can be a single part separately or a whole set of components of engineering equipment, or any other type of construction, such as a tool. Comprehensive use of these technologies extends beyond engineering [7]. Intensive use can be recorded for example in the construction and the deployment potential can as well reach into the field of science or medicine [8]. Digital 2D and especially 3D models of real objects created by tools for design and verified by tools for simulation are virtual prototypes. We use tools for Design - CAD (Computer Aided Design) to create models. The current industrial practice uses CAD software for the creation of 2D curved or flat models, and 3D solids. Current trend, based on development of application and performance of commercially available hardware, leads to a major use of 3D systems. The background shows the need to use 3D CAD tools at all levels of technical and information-technically oriented schools [9].

Calculations and functional verification of characteristics of the proposed designs are carried out through the simulation tools - CAE (Computer Aided Engineering). Calculations made on digital models, are based on algorithms of the finite element method - FEM (Finite Element Method). CAE simulations can be carried out in compliance with certain principles and rules, even without any deeper knowledge of the theory of FEM, using available teaching information resources that are particularly important at lower levels of education [10], [11].

The complete project implementation can include the creation of manufacturing technology, such as code generation for numerically controlled machine with the use of CAM

(Computer Aided Manufacturing). All processes are based on the original 3D or 2D model. This approach, known as master-model concept leads to an effective organization of CAx project data and enables time-independent processing of the project in a team. Individual members can implement separate calculations and simulations, generate program for machining and drawings, all derived from the original design. The schematic presentation of the philosophy of "master- model concept" is shown in Fig.1.

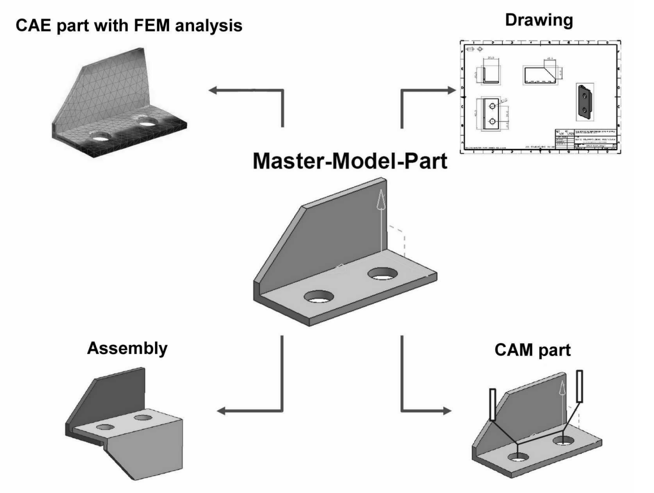


Fig. 1 Master model concept schema

These modules may be available separately, but it is advantageous to have a comprehensive application which contains most of the tools needed for the majority of stages of development and technical preparation of the product [12].

Benefits of project oriented education, based on attempts to solve complex problems of variable difficulty, are shown to give an idea of the environment of industrial practice. For example, following types of projects can be solved according to the current learning objectives and the time allotment for a particular thematic unit:

1) Detailed design of one component, including the development of drawings and manufacturing or assembly process.
2) A conceptual proposal of an assembly for the functional assessment of individual parts and the whole.
3) A detailed proposal of an assembly of any extent with the detailed development of parts, including the strength analysis and drawings.

An example of a project meeting these criteria is shown in Fig.2 with construction of a mold cavity for pressure casting as a result.

In all cases, the projects should be designed and entered with the requirement of representation of all steps and activities, based on previous theoretical foundations of the field of study. An example of a project fulfilling the assumptions is in Fig. 2. The research is focused on the consolidation of interdisciplinary relations and strengthening of knowledge structures, caused by the deployment of these teaching methods and the use of sophisticated design tools [13].

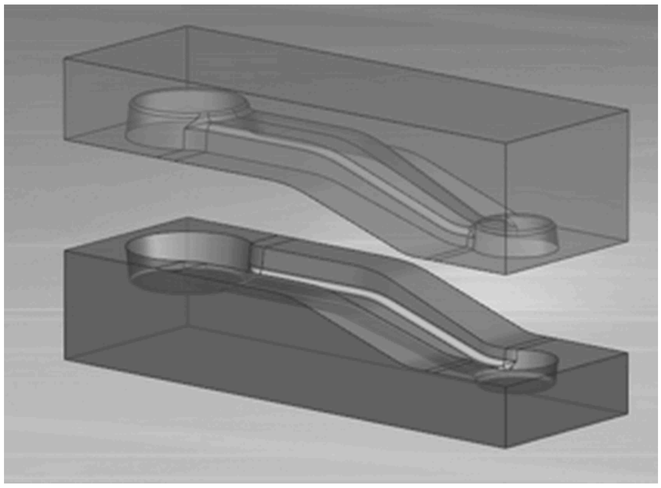


Fig. 2 CAD data of a mold cavity for pressure casting

The main objective is the assessment of benefits of increase and consolidation of knowledge of engineering issues in relation to the skills of using CAD and CAE tools for problem solving [14]. For the major part it concerns knowledge gained in the following courses:

1) Engineering.
2) Manufacturing technology.
3) Creation of technical documentation.
4) Technical mechanics, elasticity, strength.
5) Technology specialization field.
6) Working with CAD.
7) Mathematical and physical principles, relevant to the requirements of the solved problems.

The key to the qualitative assessment of a student´s final project is also designed with regard to the desired structure of knowledge based on the same foundations.

III. Target of the Research

The aim of this research is to increase knowledge and skills of technical staff by the use of CAx applications in the education of technical, engineering-oriented subjects at secondary schools and colleges. The research is conducted at the secondary school and college of the information - engineering focus. For purposes of comparison with industrial practice, the selection of data originating from designers in the development departments of industrial enterprises and design offices was made.

The main research problem can be expressed by the following question:

„*Does the project oriented education, supported by the deployment of tools for design and simulations, increase knowledge and skills of graduates?*"

and related research sub-problem:

„*Will the deployment of CAx technologies for the education of vocational technical engineering oriented subjects increase skills of graduates for solving the tasks of industrial practice?*“

Based on the piloting and pre-research survey, the research hypothesis was formulated:

H1: The deployment of tools for design and simulations in project oriented education of engineering fields will increase the skills of graduates to solve problems of industrial practice.

In addition to the hypothesis H1 the null hypothesis is formulated for the purposes of statistical evaluation:

H0: The use of tools for design and simulations in project oriented education has no effect on the increase of skills of graduates to solve practical problems.

and alternative hypothesis:

HA: The use of tools for design and simulations in project oriented education has an impact on the increase of skills of graduates to solve practical problems.

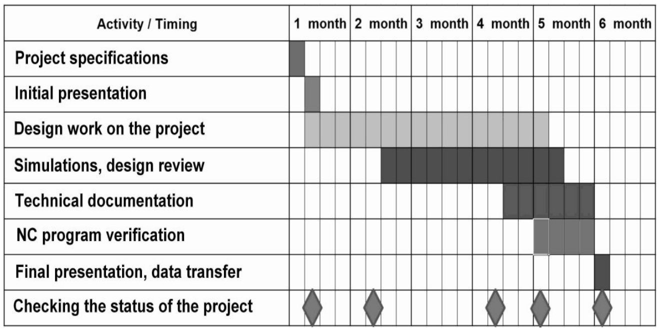
The acceptance of the HA hypothesis leads to the current acceptance of the hypothesis H1. The total contribution of the presented teaching methods, however, will be assessed in addition to test the hypothesis by observing students' work on projects and testing the knowledge of engineering issues. Pupils' attitudes to information technology and education on project also play a certain role.

IV. Collecting of Research Data

The research data come from teaching projects of virtual prototypes, processed within the subjects of CAD, CAE and Information technology in mechanical engineering at a college. Data were obtained in a total of three educational cycles. A semester of teaching, or a half of the school year, according to the time allocation for teaching was considered as one cycle. Table I presents an example of a term plan of a project indicating sections of activities and key points.

Time schedule for a project can be modified as needed but it should contain the indicated activities. While obtaining research data, emphasis was put on the requirement of the same conditions of the research. Above all, it was important to check the initial knowledge and skills of students before the start of the project [8]. A pretest of knowledge was prepared and in the pre-research phase piloted for this purpose and simultaneously an analysis of an input CAD task took place.

Table I An example of a term plan of a project



CAx (CAD, CAE) data of project outputs were subjected to an in-depth analysis of the structure, taking into account factors observed in the education. The following aspects were assessed, some of them were compared with the parameters of projects of a comparable scale, processed by engineers in industrial practice:

1) Compliance of procedures with the specifications and the term plan.
2) Compliance with the naming conventions and data organization.
3) Application of rules for creating of 2D sketches.
4) Application of rules for creating of 3D design elements and procedures.
5) Compliance of the topology of model making up elements with the strategy of using of components.
6) Incorporating of technological requirements into the design of a 3D model.
7) The accuracy of design of drawings in accordance with the intent of the model and technical standards.
8) Relevance and accuracy of the applications of a CAE simulation in connection with the function of the proposed component.

Some parameters of educational projects cannot be compared with the parameters of the "live" industrial projects. For example, compliance with the assignment of projects must be always in industry, or in exceptional cases a justified deviation. The same view is also consistent with the case of an assessment of compliance with the term plan.

In total, 25 factors of the quality of the project development were assessed. 15 factors from this group were used to compare experimental (students) and control (designers) groups. Each of the evaluated parameters was evaluated according to the points scale:

0 - Does not meet.
1 - Meets partially.
2 - Meets fully.

Overall, it was possible to get 0-50 points in the assessment of skills within the experimental group and 0-30 points for comparison of quality of students' and designers' projects.

Students' projects were developed through the school applications in the education and were transmitted within the classification of the subject. Projects by designers from practice were collected directly in the design office, or from multiple remote locations through a PLM (Product Lifecycle Management). This ensures the collection of relevant projects with sufficient relevant information important for evaluation. Projects analyzed in this group come mainly from the designers of the Czech Republic, Belgium, Holland and USA.

Overall, the survey research included 41 students' projects and the same number of designers' projects.

V. Process of virtual prototyping data analysis

Next paragraph aims to introduce the process of qualitative analysis of digital data of virtual prototypes. The analysis is focused on monitoring the factors mentioned in the previous chapter. We concentrate above all on following parameters of virtual prototypes. The parameters are evaluated in chronological order according to their origin, as indicated in the term plan of Table I.

A. Model analysis

The correct application of modeling and auxiliary elements and setting their characteristics in conformity with the strategy of subsequent modeling and also placement in the assembly is observed in the model analysis. The basis for efficient modeling is the correct orientation of the coordinate system to the main body geometry of the proposed component.

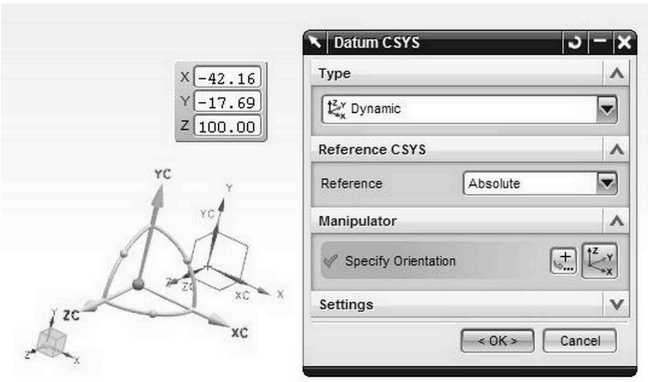


Fig. 3 Coordinate system and Datum geometry

Methods of orientation of coordinate systems depend on the used software. The orientation of the principal axes may be based on predetermined rules, considering the resulting virtual prototype assembly, or we can apply the general conventions and recommendations. If these requirements are not defined, or are not relevant, the orientation of the coordinate system is set by the user and can affect the efficiency of modeling, composing assembly and implementation of simulation in subsequent steps.

The location of the coordinate system is followed by the insertion of the reference geometry for the initial modeling procedures. The reference geometry at the beginning of the tree structure of the modeling elements enables to control the model topology. Correct topology allows to carry out subsequent changes in the main parameters with possibility of proceeding of connection with other modeling elements and objects. The practical importance is for example for the implementation of development studies in the context of assemblies, by optimizing the model after the performed simulation, or by implementation of change processes based on feedback of operation of the component. The position and orientation of the reference geometry can be controlled by parameters, which is, in more advanced stages of modeling, important for the control of the properties of model by external tools of mathematical bases, as shown on Fig.3. This factor will be mentioned also by next modeling objects. Another important qualitative feature of the model is making a major design geometry. According to the complexity and nature of the resulting body, it is important at this stage to choose, whether the default shape will be implemented by means of predefined basic form offered by the application, or whether it will be advantageous to create a 2D contour through the sketch, which will then pulled in a straight line, rotated around a selected axis or driven by a general curve. Both approaches can be combined. Selection of the process affects subsequent modeling and editing processes. Sketch is shown in Fig.4.

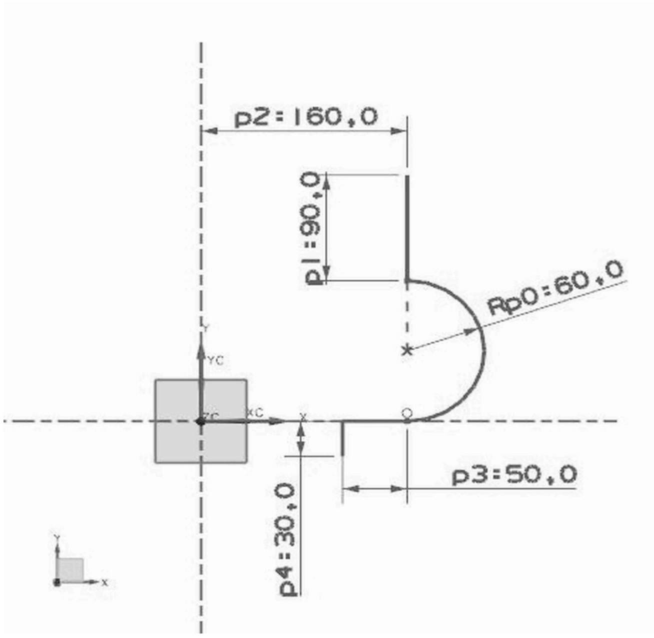


Fig. 4 Sketch geometry with dimension and constraints

The possibility of future orientation in the structure of the model can be greatly affected already at this stage. This factor may be particularly important for model transparency and teamwork. The next step, after the implementation and verification of these objects, is the analysis of using of designer engineering predefined elements, shown in Fig.5.

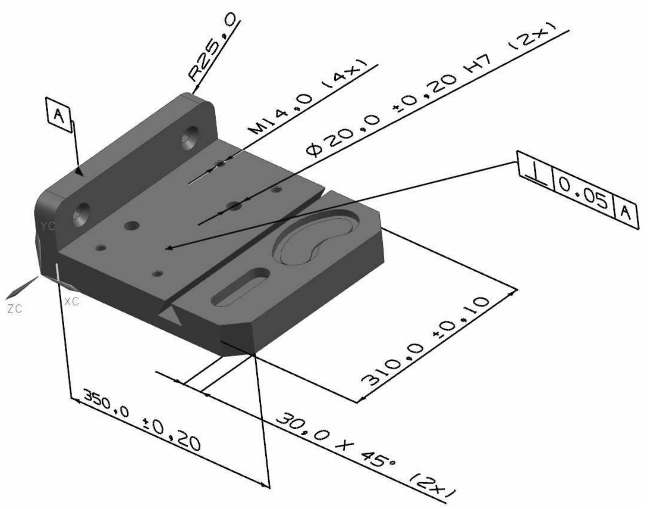


Fig. 5 Data model with pre-defined features

These objects have already a direct link to application of technical knowledge and skills acquired by studying the basic theoretical subjects. These elements can be for example different types of holes, grooves, threads, fillets and chamfers, and other more or less typical objects. It is important, at this stage, to evaluate following criteria:

Relevance of insertion and settings of the element parameters:

1) Location of the element in relation to the main body.
2) Link to the previous objects in connection with potential subsequent implementation of changes.
3) Estimated relationship of elements to the assembly.

It is important, in all these cases also in the continuous phase of the model, to consider the available production technology and the related selection and placement of components. Although the data model allows us a wide range of shapes and placement of objects, there is no check of the available production technology, and this factor is left to the skills and knowledge engineer. It is also possible in more advanced stages of construction, already by the creation of the data model, to consider the potential cost of the complex technological operations and in connection with them to optimize the model while keeping the main purpose and function in the operation. Optimization example may lie in the choice of inner radii of curvature with respect to the used instruments, or ensuring freedom of space for clamping during machining. In a particularly advanced design procedures, such as the design of shaped tools or complex shape designs, we can still analyze the procedures and implementation of free-formed surfaces.

One of the generally considered factors is the associativity of factor-related design components and the use and the interconnection of parameters in case of parametric modeling techniques.

B. Assembly analysis

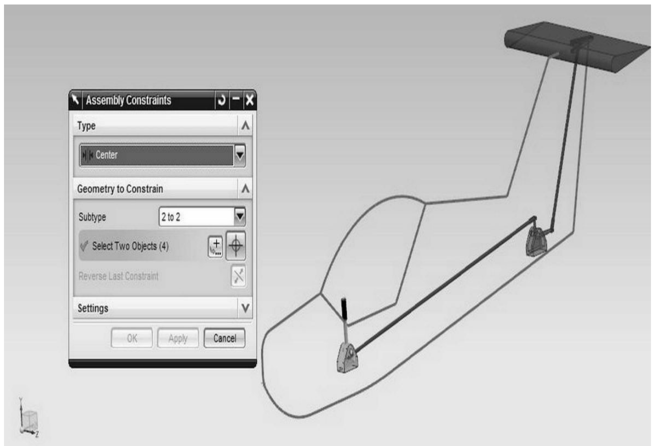


Fig. 6 Sketch geometry with dimension and constraints

In case that the proposed model is a part of an assembly of a device, another important factor is its position in the virtual prototype assembly. The reference factor may be primarily the choice of constraint conditions, which determine and ensure the position of the component due to other related components. A key parameter is the definition of component interconnections and defining the degrees of freedom, which may be particularly important for elementary kinematic analysis and screening of potential conflicts of mechanisms. A key factor for more complex assemblies is the overall structure of individual levels. Split into subassemblies is of relevance to the real assembly process, but it also affects inventories of items, which is especially important in terms of logistics processes related to production. Example of an assembly is shown in Fig.6.

C. Analysis of drawings

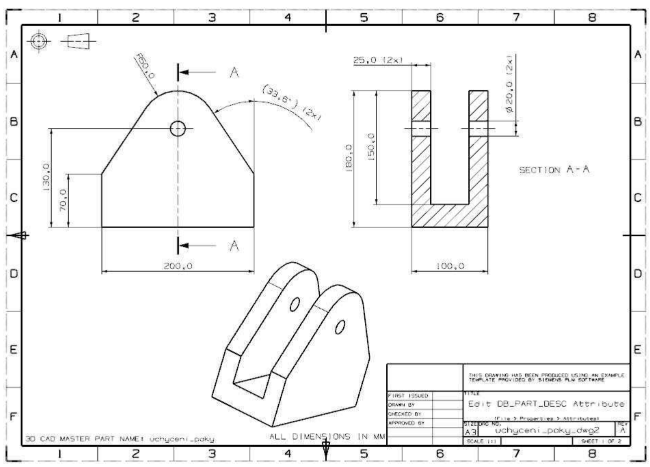


Fig. 7 Drawing of component

2D drawing documentation, example in Fig.7, is still the main source of technological information. Current systems already allow inclusion of geometric, shape and technological information directly into the 3D model, this procedure is, however, rarely used in practice. The main medium for transmission of production information and the material for archiving is currently, even in the environment of full deployment of CAx tools, a 2D drawing in a transportable format. Factors related to exact transmission of relevant information are particularly analyzed and evaluated in technical drawing. It applies mostly to the following factors:

Implementation according to the principles and recommendations for the creation of technical documentation.

1) Application of general, professional, or internal standards for the registration of geometrical and technological information.
2) Selection of entered main and derived views.
3) Proper placement of sections and detail views.
4) Adequacy or redundancy of information.

These factors cover most of the range of control activities carried out in the drawings in the approval phase for the needs of the assignment phase for production and archiving.

D. Results of CAE simulations

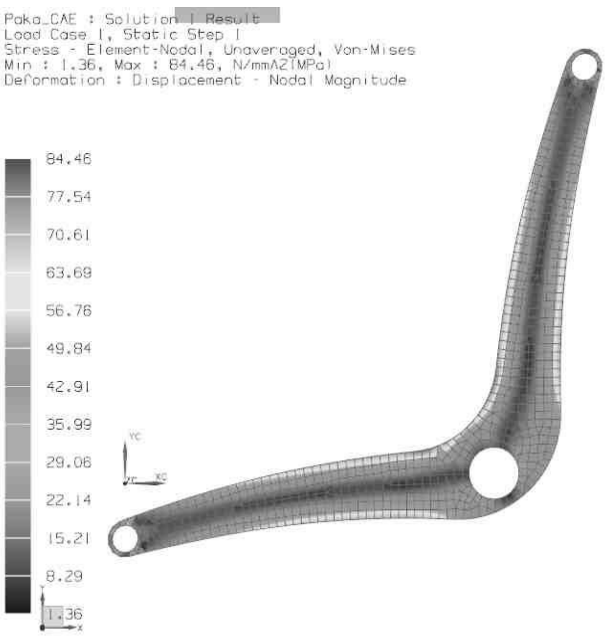


Fig. 8 CAE strength and deformation analysis of component

Implementation of CAE simulations in a virtual prototype phase is a key activity to verify the characteristics of a model, or an assembly in the draft stage. The following factors are examined in particular by the CAE data of virtual prototypes:

1) Selection of the relevant reference parameter.
2) Proper adjustment of the data model to perform simulations taking into account the properties of the used computational methods.
3) Proper setting of contact elements in assemblies.
4) The relevant choice of the type and density of the network to perform finite element calculation.
5) Proper adjustment of boundary conditions, load and placement of objects.
6) The correct interpretation of the results.
7) Possibility to use also external computer tools as well as integrated CAE module in an application such as Excel [15].

When analyzing CAE data it is important to proceed from the theoretical foundations that can be expected from students of the certain degree of the educational establishment. Example of simulation of component is shown in Fig.8.

E. Verification of machining program for a CNC machine

The phase of creation of a digital model, simulation and calculations for model optimization and the subsequent creation of technical drawing precedes technological activities related to production. Initial data can be used, in connection with the chosen production technology, for generation, debugging and performance of simulation of a machining process. These processes can be applied on the machining and the preparation of a tools in the case of product design produced by casting, injection or shaping. Example of tools for die casting is shown in Figure No. 2 In the analysis of CAM data, we primarily focus on the following factors:

1) Appropriate adjustment of data 3D or 2D model for the creation of machining technology.
2) Selection of machining operations and their sequence.
3) Selection of appropriate tools with the planned technological progress.
4) Setting of machining process conditions.
5) Implementation of the machining process simulation.

This procedure can be implemented based on the comprehensive use of a model and production drawing. Given that it is already a production phase, it is possible to initiate a virtual change management to optimize the initial design based on the experience with the process of machining simulation. Example of CAM process in virtual environment is shown in Fig.9.

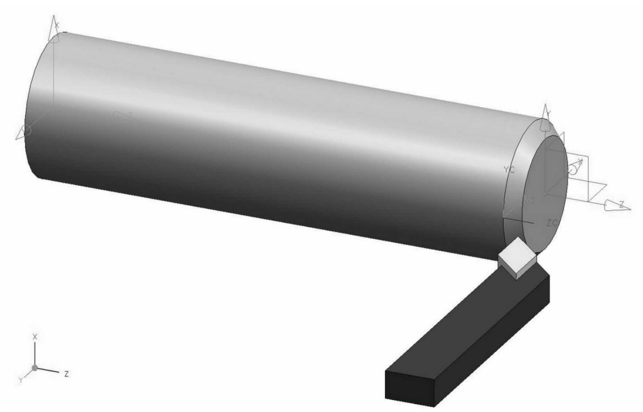


Fig. 9 CAM process on part

F. Analysis of the data structure and compliance with the term plan

A comprehensive set of virtual prototype data includes CAD, CAE and CAM data. Where possible, the individual processes are interrelated and associative. This way designed data package can be considered as a complete digital documentation for the project. Using the availability of activities performed in the history, data can be analyzed with regard of key steps and derive feedback for planning subsequent projects of similar scope. Compliance with the term plan, designed by a project researcher, is an important source of experience for use in professional practice. By analyzing the history of the development of data, we can approximately determine, whether the path to achieve the result was straightforward or which events were identified as deviations from the plan in the form of a bad practice and caused the need to return to a certain point for implementation of an optimized procedure.

A part of complex data of educational and industrial virtual prototype project is the input and the final presentation. The initial presentation introduces intention of a project, the intended method of processing, expectations associated with the project work and a term plan. The final presentation contains the performance of results of the project, description of processing and also the comparison of the actual timing of the activities with the assumption at the beginning of the project. Economic evaluation of the project can be simulated in advanced stages of education and implementation of projects. Example of data and a process control system is shown in Fig.10.

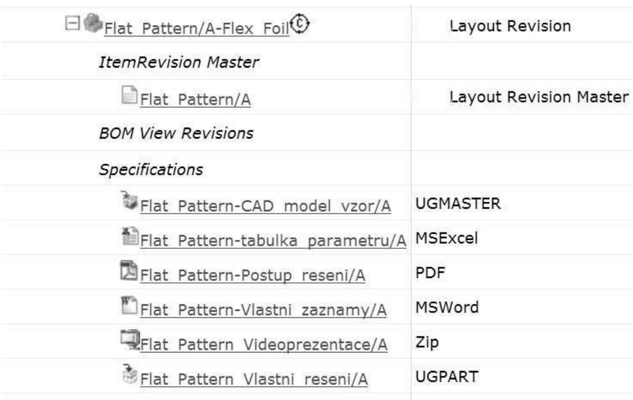


Fig. 10 Data control structure of design and related data

VI. Evaluation of Research Data

The data obtained according to the methodology of the previous chapter were quantified [16]. The add-on application "Data Analysis" of the spreadsheet MS Excel was used for their processing [17]. Graphical outputs were realized through the „Statistica“ tool and guidance, or supervisory calculations were carried out in the field of statistical functions through a graphical calculator Casio. The processed results of evaluation the students´ input skills at the beginning of the project are presented in the left part of Fig. 11.

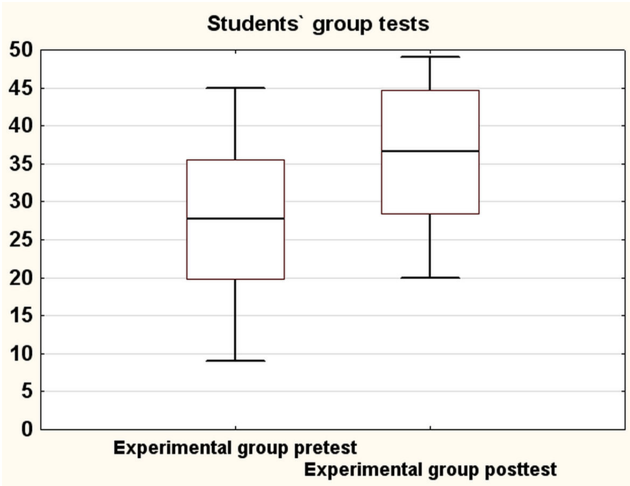


Fig. 11 Comparison of pupils' skills in the analysis of virtual prototyping projects

The paired t-test was used for the acceptance respectively the rejection of the hypotheses about the difference of mean values of the success of students in the pretest of baseline skills and in the posttest of increased skills. The evaluation and the processing of parameters of final projects are shown graphically in the right part of Fig.3 and comparison of the level of skills at the beginning of processing and after project completion is presented in Table II.

Table II Statistic evaluation of the CAx skills of a group of students

	Pretest	Posttest
Mean	27.707	36.561
Variance	60.158	64.051
Maximum	45	49
Minimum	9	20
Number of samples	41	41
Degree of freedom	40	
|t - stat|	5.624	
t - krit (0.05)	2.021	
t - krit (0.01)	2.704	

By the visual assessment of the chart, you can observe an increase of skills of students after completing an educational project. The results show that the average success rate achieved in the posttest is higher than by the pretest. Given that | t-stat | > t - Critical at significance levels 0.05 and 0.01, we refuse H0 and accept HA.

Considering the above criteria we can at the same time reliably accept the hypothesis H1. Considering related circumstances and the nature of mixed research, the adoption of hypothesis is supported by other factors, involving a high motivation of students to realize educational projects with the support of tools for design and simulations and their success and adaptability in subsequent employment.

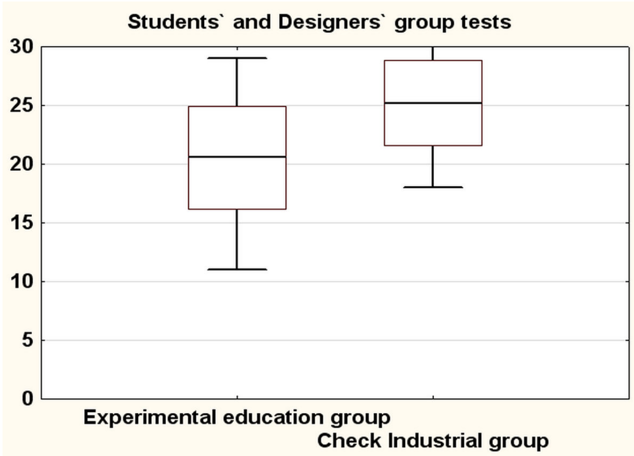


Fig. 12 Comparison of the projects solved by students and projects solved by designers.

Comparison of selected parameters of students' projects with the projects implemented in industrial practice by designers is shown in Fig. 12. In this case, no statistical hypothesis testing due to significantly different conditions for the development of the analyzed problems was carried out.

Nevertheless, the assessment of data is an important basis for the realization of students' projects and subsequent optimization of didactic engineering subjects to comply with the requirements of industrial practice. Together with the research carried out on topic of skill increasing in relation to work on a long term project and this information is important for the overall assessment of the benefits of deployment of tools for design and simulations in education.

VII. Conclusion

Based on the submitted concept of education and on the results of research that was carried out by the described method, the benefits of project oriented education supported by tools for design and simulation in industrial practice can be expected. Didactic and research potential of utilities of engineering computer applications can be used in the preparation and planning of educational projects at technical, engineering and information technology oriented engineering schools of all levels. The use of these tools is not only beneficial in terms of improving skills of graduates, but also positively affects their motivation for learning and self development in the area of the selected field. Work on challenging projects in a virtual environment of tools for design and simulations supports creativity with the possibility of implementation and assessment of their own, often non-standard procedures and solutions.

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