Methods and means of intellectual system of analysis of design solutions and training of designer

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Abstract. An intellectual system of analysis of design solutions, made in CAD KOMPAS-3D, and the training of a designer is developed. The mathematical support of the integrated system for the analysis of design solutions and the training of the designer is developed: the method of structural and parametric analysis of project solutions, the associative-oriented model of the designer's competencies, the algorithm for forming the trajectory of training in computer-aided design. The architecture of the complex system is developed; its main components are described: the block of the analysis of design solutions, the block of training of the designer. The developed system supports the functions of automatic restructuring and classification of three-dimensional engineering products, as well as the formation of recommendations to the designer and personalized trajectory of learning computer-aided design in CAD KOMPAS-3D.

1. Introduction

Ensuring the competitiveness of an industrial enterprise largely depends on the time and resources spent on designing and developing the final product. Therefore, an important condition for the effective use of CAD tools is the preservation and reuse of design solutions, which reduces the time spent on documentation, data conversion and retrieval of information about the product.

The tasks of industrial design require certain competencies for the designer, which are difficult to acquire using classical approaches to learning. Therefore, the creation of effective methods and tools for training a designer for automated design is a prerequisite for the solution and implementation of industrial tasks in the field of computer-aided design of engineering facilities. Russian and foreign scientists who made a great contribution to the development of automated training systems integrated with CAD are Norenkov I.P., Sabonnadier Zh.K., Kulon Zh.L. and etc.

In computer-aided design systems, various analysis subsystems are presented, for example: strength analysis, including static calculation, calculation of stability, calculation of natural frequencies and modes of natural oscillations, calculation of stationary thermal conductivity and thermoelasticity; the analysis of the dynamic behavior of machines and mechanisms; check for compliance with the standards of registration in the KOMPAS-Expert subsystem (the distance between dimension lines, the placement of text, the presence of intersections in the dimension line, line styles and serifs, etc.), compliance with the company's restrictive lists (permitted roughness, qualite, etc.), compliance with the rules of work in KOMPAS (manual input of dimensions, linking the position designation to the specification, the use of the object is axial, and not lines with the axial style, etc.); calculation of dimensional chains and springs; optimization of gearing; selection of electric motors, reducers and couplings.

It should be noted that in modern CAD, there is no analysis of the designer's actions in the process of designing three-dimensional solid products.

Thus, the actual task in the field of computer-aided design of engineering objects is the structural-parametric analysis of the design solution and the training of the design engineer in order to identify non-optimal sequences of design operations, automatic restructuring and classification of 3D models of engineering objects for reuse in design processes, corresponding recommendations to the designer [1].

The developed methods and algorithms should ensure the acquisition of the necessary competencies for the designer for successful project activity in the field of computer-aided design, improve the efficiency and quality of training.

The main objectives of developing an intelligent system for the analysis of design solutions and training a designer are:

1. Improving the quality of design solutions when designing 3D objects in CAD KOMPAS-3D.
2. Adaptation of the learning process of computer-aided design in CAD KOMPAS-3D.
3. Formation of the necessary competences in the design of 3D products in CAD for the trained designers.

To achieve the set goals, the following tasks were accomplished:

1. The review of systems for the analysis of design solutions for engineering products was carried out.
2. The analysis of models, methods and means of teaching automated design of machine-building objects using CAD.
3. A method for structurally-parametric analysis of design solutions is developed on the basis of a sequence of design operations performed in CAD KOMPAS-3D.
4. The models of the automated system of training (AST) are developed: the model of competences, the algorithm for forming the trajectory of training, the conceptual model of AST.

2. Review of systems for analysis of engineering solutions for engineering products

A review of the systems for analysis of design solutions and widely used in CAD production, such as: NX, CATIA V5, Creo, Autodesk Inventor, SOLIDWORKS 3D CAD, CADfix [2], CADIQ [3], 3DTransVidia [4], Heidelberg CAx Quality Manager [5], PrescientQA [6] and others.

In the systems considered, there is no function for classifying solid-state 3D machine-building objects in CAD. The mechanism for rebuilding the design solution as a result of the analysis is implemented in semi-automatic mode only in such systems as CADfix (ITI), 3DTransVidia and PrescientQA. The function to formulate appropriate recommendations for changing the design solution is implemented in Cax Quality Manager systems (suggestions for correcting designer errors) and ModelCHECK [7] (improvement of changes in the form of a dynamic HTML report).

Thus, to improve the quality of design solutions implemented in CAD, it is necessary to develop a method of structural-parametric analysis that allows you to analyze the actions of the designer (design operation), the tree of the design model (construction history) with the goal of restructuring, classifying and reusing design solutions, executed in engineering CAD.

3. Analysis of the features of the process of teaching computer-aided design

A major contribution to the development of adaptive automated learning systems was made by G. Weber, A. Möllenberg, K. Warendorf, K. Kabassi, M. Virvou, C. Tan, J. Vassileva, E.R. Panteleev, L.V. Zaitseva, G.V. Rybin and others.

Adaptive methods allow to increase the efficiency and quality of training, as well as to shorten the time of the learning process by tracing the learning trajectory of the trainee, changing the sequence of providing theoretical training material and practical assignments. The following adaptation mechanisms are used: rule-based, adaptive annotation and reference sorting, expert system based on instructions and templates, adaptive hypermedia, advisory systems, author's algorithm.

The analysis of adaptive automated learning systems, allowing personalization of the learning process, such as: ELM-ART, Web F-SMILE, ADIS, author's system of Vasilieva, Protus, author's AST of Kanev D.S. [8] and others.

The analysis of these systems showed that in the considered AST there are no mechanisms of integration with the competence model of the design engineer. The recommended part is implemented only in the systems Web F-SMILE, Protus, as well as in the author's AST Kanev D.S.

As a result of the analysis, the requirements for the development of an automated system for training the designer of project activities in CAD were singled out:

- integration with the designer's competencies model;
- forming an alternative script for the training of the designer;
- evaluation of the effectiveness and quality of the training of the designer;
- forming recommendations to the designer in the learning process.

Various existing professional standards, training programs for engineers related to the designer's competencies and project activities are considered. A list of the designer's competencies has been created, including knowledge, skills and computer-aided design skills in the CAD-3D environment. The list of competences is described in more detail in [9].

4. Development of mathematical support for an intelligent system for analyzing design solutions and training a designer

A new method for structurally-parametric analysis of design solutions is developed on the basis of a sequence of design operations.

The essence of the method lies in the search for non-optimal project operations performed by the designer on the basis of the analysis of the tree model of the design solution and analysis of operations of 3D modeling objects built in the CAD-3D CAD environment. The method allows you to rebuild the tree model of the design solution and classify the products of engineering objects for the reuse of three-dimensional models in the design of solid-state products in CAD KOMPAS-3D.

The tree of the design solution consists of the following components: design planes, assembly units, parts and design operations for constructing a three-dimensional solid model of an engineering product. Each element of the model tree has certain properties and parameters: external parameters, coverage, material of manufacture, etc.

A number of models have been developed that form the scientific basis for the method of structural and parametric analysis of design solutions: the model of the sequence of design operations, the operation model, the model of the initial data for reconstructing the design decision tree, the model of the part parameters, the rule for analysis, the model of the initial data for the classification of engineering products. Algorithms for the formation of a sequence of optimal design operations and the classification of products of machine-building objects are also developed. The method of structural-parametric analysis is described in more detail in [1].

An associative-oriented model of the designer's competencies is offered, which is distinguished by the establishment of interrelations between knowledge, skills and skills related to the subject area of computer-aided design of engineering facilities, and allows forming a sequence of mastering competences and adapting the learning process to computer-aided design in CAD KOMPAS-3D.

The competency model is represented as a graph

$$G(V, D),$$

in which V is the set of vertices, D is the set of arcs.

The set V consists of sets of vertices V^F assignment, V^R of parallelization and V^L of connection. The set D consists of sets of arcs D^P of branching, D^R of parallelization and D^L connection, that is, $D=D^P \cup D^R \cup D^L$.

The following types of links are distinguished:

$\longrightarrow$ - consistent mastering of the designer's competences;

- mastering a new level of competence.

The following types of vertices are distinguished: parallelization, connection, assignment.

Parallelization vertices allow the learner to master several competences at the same time. Mastering competencies occurs independently of each other with different time intervals. Connection vertices allow the new designer to master the new competency only when all previous competencies have been mastered. Assignment vertices allow the trained designer to progressively master the competencies one by one.

Figure 1 shows the developed competency model, as a theoretical basis the apparatus of parallel network schemes of algorithms was used [10]. From this model it is clear that certain competences can be mastered in parallel or the mastering of competencies occurs consistently one after another. Certain competences contain the possibility of mastering a new level of competence. Each vertex of the model contains 4 levels of competence development.

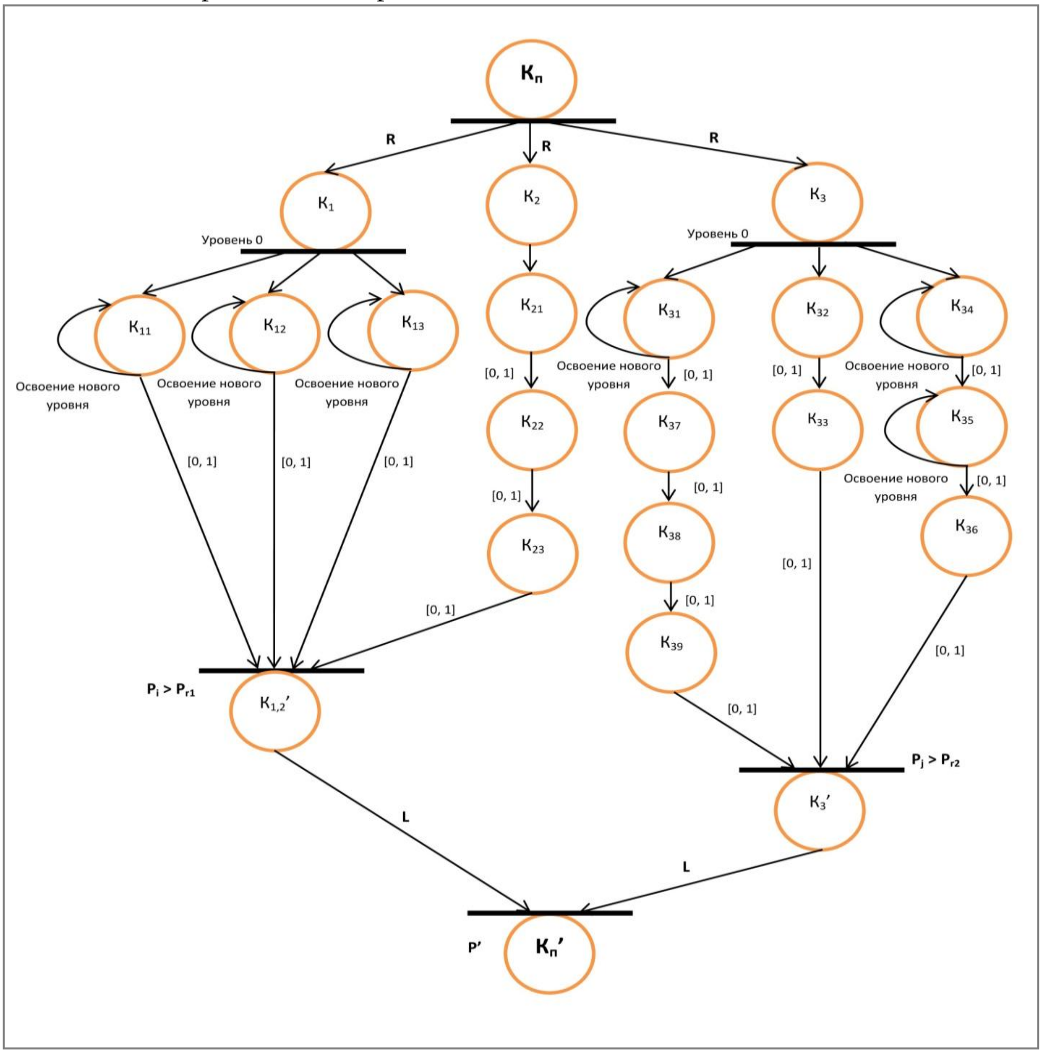

Figure 1. Competency model.

In the developed model, three blocks (classes) of basic competences in the field of automated design of three-dimensional objects (the designer's competence) were allocated: K1 - knowledge of the theory, K2 - designer skills in CAD, and K3 - designer skills in CAD.

An algorithm is developed for the formation of an adaptive learning path for automated design, which has the following form.

1. Formation of input control tasks (CT): theoretical test, practical tasks.

2. Execution of input CT by the designer.
3. Analysis of the current level of mastering by the trained competency designer (group of competences).
4. Formation of the goal of training.
5. Formation of educational material (EM).
6. EM study by the designer.
7. Formation of output CT.
8. Execution by the designer of a practical task.
9. Analysis of the degree of mastering the proposed UM by the designer. If the learning goal is achieved, go to step 15.
10. The choice of didactic units, necessary for further study.
11. Formation of ancillary EM and final CT.
12. Study the designer of an auxiliary EM.
13. Implementation of the final CT by the designer.
14. Analysis of the final CT. If the competences of the designer do not satisfy the learning objectives, go to step 10.
15. Completion of the training of the designer. Adjustment of the purpose of training.

5. Development of the architecture of an intelligent system for analyzing design solutions and training a designer

The generalized diagram of the complex system for analysis of design solutions and training of the designer is presented in figure 2. The basis of the mathematical support is based on the methods, models and algorithms of analysis and adaptive learning outlined above.

The system consists of two main components: a block of analysis of design solutions and a training unit for the designer.

The block of the analysis of design decisions - is intended for management of the analysis of the design decision executed in CAD KOMPAS-3D, with drawing up of recommendations and updating of model of the trained designer in view of the generated recommendations. Provides re-engineering of the design solution based on the optimal sequence of design operations.

The block of analysis of design solutions contains the mechanism for the formation of the optimal sequence of design operations with the goal of rebuilding the tree of the design model and the formation of appropriate recommendations to the trained designer.

The block of the analysis of design decisions also allows to classify three-dimensional models of machine-building products using various analysis modules for certain classes of objects, such as: "Ring", "Flange", "Rivet", "Nut", "Washer", etc.

For each class of products, the main parameters and variables of the three-dimensional model, as well as tree patterns and sketches for building a solid-state 3D model in CAD KOMPAS-3D are highlighted. Next, consider the basic variables and parameters of the three-dimensional model for classes of engineering products such as "Ring", "Puck", "Rivet".

The following basic parameters and variables are distinguished for the "Ring" product class:
- internal diameter;
- outer diameter;
- the width of the ring;
- cutting angle;
- material of manufacture.

The following basic parameters and variables are distinguished for the product class "Washer":
- internal diameter;
- outer diameter;
- washer thickness;
- material of manufacture.

The following basic parameters and variables are distinguished for the "rivet" product class:

- the diameter of the rivet body;
- diameter of the rivet head;
- thickness of the rivet;
- the length of the original rivet;
- material of manufacture.

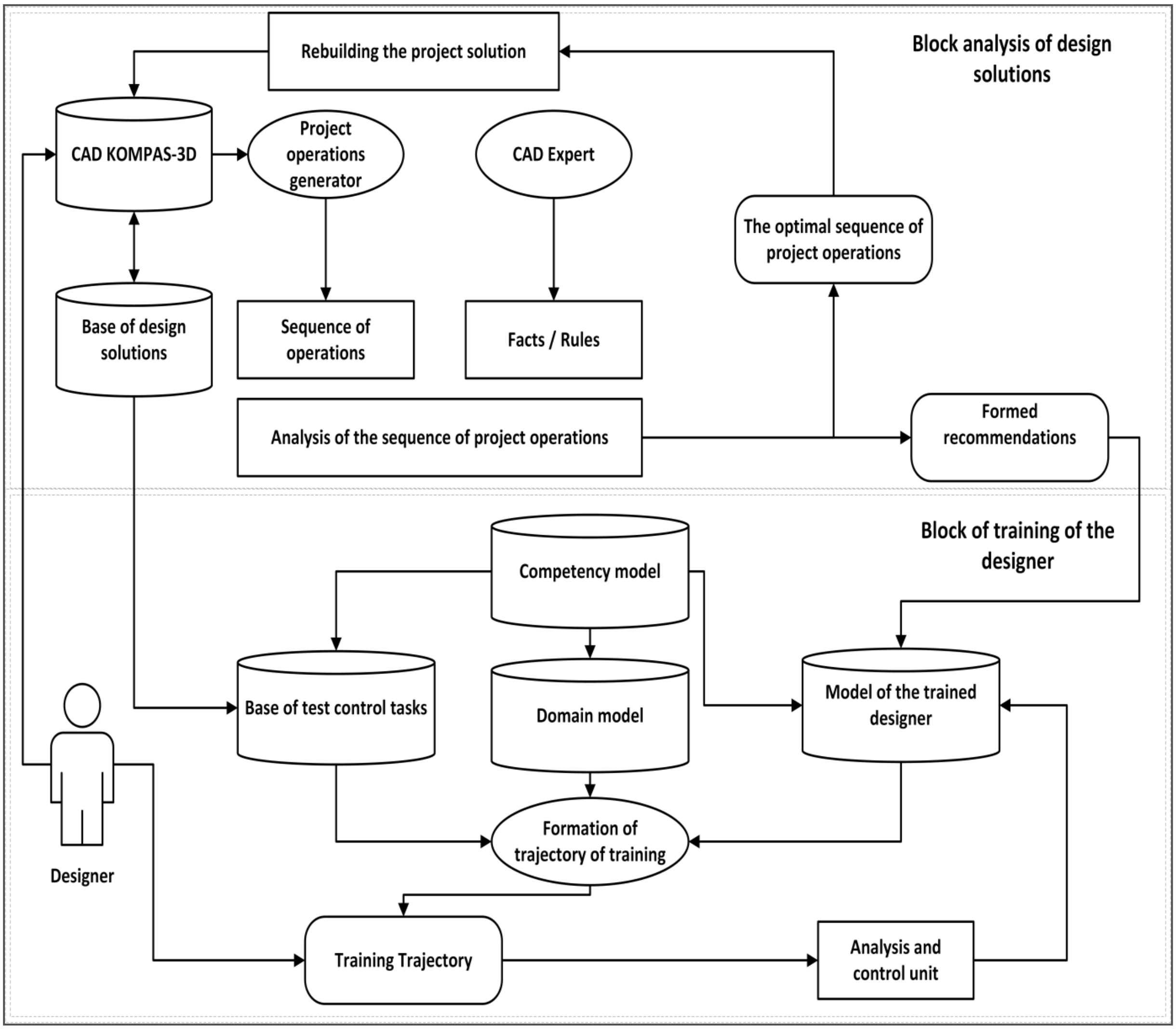

Figure 2. Structural diagram of the developed complex system.

The block of training of the designer is intended for training the designer of computer-aided design of machine-building objects executed in the environment of CAD KOMPAS-3D (formation of educational material, control tasks, trajectory of training).

The process of training the designer for computer-aided design in CAD KOMPAS-3D is carried out on the basis of an analysis of the implementation of practical and test tasks, as well as on the basis of the recommendations made. Recommendations are a list of design operations and a sequence of actions to eliminate errors in the design decision. In the block of analysis and control, the degree of mastering by the trained competency designer is checked, the model of the trainee is adjusted.

6. Results of the computational experiment

The calculation of the time of designing three-dimensional products in CAD KOMPAS-3D is made. The following values and assumptions of the variables are accepted: the average time of search for design solutions in the product database is 3 seconds; the average time for the designer to insert and edit the finished 3D model into the design solution is 30 seconds; average time of conjugation of parts - 120 min; the average time for the designer to open a 3D model in CAD KOMPAS-3D is 5 seconds; the average time for the designer to close the window with a three-dimensional model in CAD KOMPAS-3D - 3 seconds, the average time to select a product class for searching and enter parameters - 5 seconds; the number of parts for viewing by the designer after the work of the designer with the system of classification of engineering products is reduced by an average of 20 times; The accuracy of the search varies from 0.5 to 1; degree of coverage by the classification system of machine-building products of the electronic products catalog of the enterprise - from 0,7 to 1; the average probability of the designer finding a 3D part in the product catalog is 0.8; the average time for the designer to build a 3D model in CAD KOMPAS-3D is 300 minutes.

The results of the calculation are given in table 1.

Table 1. Reduction of the time of the designer's design activity when using the product classification system.

№	Search accuracy	Degree of coverage	The probability of finding a 3D model	The probability of manually building a 3D model	Reduce design time
1	0,5	0,7	0,35	0,65	-39,1%
2	0,5	0,8	0,4	0,6	-30,4%
3	0,5	0,9	0,45	0,55	-21,6%
4	0,5	1	0,5	0,5	-12,9%
5	0,6	0,7	0,42	0,58	-26,9%
6	0,6	0,8	0,48	0,52	-16,4%
7	0,6	0,9	0,54	0,46	-6,0%
8	0,6	1	0,6	0,4	4,5%
9	0,7	0,7	0,49	0,51	-14,7%
10	0,7	0,8	0,56	0,44	-2,5%
11	0,7	0,9	0,63	0,37	9,7%
12	0,7	1	0,7	0,3	21,9%
13	0,8	0,7	0,56	0,44	-2,5%
14	0,8	0,8	0,64	0,36	11,4%
15	0,8	0,9	0,72	0,28	25,4%
16	0,8	1	0,8	0,2	39,3%
17	0,9	0,7	0,63	0,37	9,7%
18	0,9	0,8	0,72	0,28	25,4%
19	0,9	0,9	0,81	0,19	41,0%
20	0,9	1	0,9	0,1	56,7%
21	1	0,7	0,7	0,3	21,9%
22	1	0,8	0,8	0,2	39,3%
23	1	0,9	0,9	0,1	56,7%
24	1	1	1	0	74,1%

On average, the reduction in the time of the designer's design activity in CAD COMPASS-3D CAD using the system of classification of engineering products is 11%.

7. Conclusion

The models and algorithms that make up the scientific basis of the method of structural-parametric analysis and the process of shaping the trajectory of the designer's training are developed. An associative-oriented model of the designer's competencies is offered, which is distinguished by the establishment of interrelations between knowledge, skills and skills related to the subject area of computer-aided design of engineering facilities, and allows forming a sequence of mastering competences and adapting the learning process to computer-aided design in CAD KOMPAS-3D.

Based on the proposed models and algorithms, the architecture of a complex system for analyzing design solutions and training a designer using the CAD COMPASS-3D example is developed, and its main blocks and components are described.

The software package being developed consists of a system for analyzing project solutions, a product classification system, an automated training system for the designer. The implementation of the software and information support was carried out with the help of the Web server Apache HTTP Server, MySQL, NoSQL LiteDB, Java Platform, Microsoft.NET and Ruby.

The developed complex system supports the personified training of the designer for practical tasks, mastering the competences of the designer, and also allows optimizing and classifying the design solutions for the purpose of conservation and reusing in the engineering processes of engineering products.

A theoretical evaluation of the designer's performance in the use of the system of classification of machine-building objects was made. On average, the reduction in the project designer's time in CAD COMPASS-3D CAD using the product classification system is 11% and depends on the accuracy of the search in the system and the degree of coverage of the electronic catalog of the machine-building products of the enterprise.

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