Method for extracting product design characteristics from life cycle management systems of complex technical objects

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***Abstract*— This paper reviewed and investigated the main approaches, methods and means of extracting design documentation from PLM systems widely used in production. The authors proposed a new method for extracting data from design solutions of CAD, which allows extracting data and parameters as a result of analyzing design solutions, highlighting the history of building a three-dimensional model of a complex technical product, describes the main models and algorithms. The authors proposed a theoretical assessment of the effectiveness of the designer's activities using the system for extracting design characteristics from PLM.**

Keywords*— *PLM systems; CAD; project documentation; process documentation

I. Introduction

Modern production in the digital economy requires the acceleration of the design process and technological preparation of production (KTPP). In modern reality, this can be partially achieved through a parallel, descending or ascending design. Such technologies lead to collective work on the project, reducing the time to develop a large block. Significant reduction in time can be achieved through automated workflows. Such workflows are aimed at managing the project and reducing the time required to approve the developed project documentation (KD) or process documentation (TD) in electronic form.

PLM-systems are intended for storage of design and technological projects in which projects with output documents are attached to the electronic structure of the product [1-3]. In the conditions of a large design and production enterprise in which the number of nomenclature exceeds 1.5 million positions and the number of developers (design engineers, process engineers, programmers engineers, etc.) is more than 1,000 people, the shortening of the time of the KTPP, which is to develop and coordination of design and technological documentation (KTD) is more than relevant. It should also be noted that in large design and production enterprises producing complex equipment, product design is carried out in different divisions, divided into areas. Thus, the problem of analyzing, controlling, optimizing and reengineering the processes of modeling design solutions, which involve specialists from various departments and services of a large design and production enterprise, and active use of CAD tools, is relevant and of great practical importance.

The authors propose a new method for extracting data and design characteristics of products from PLM systems [4] LOTSMAN [5], SAP AG [6], BAAN [7], TeamCenter Engineering [8], ENOVIA [9], SmarTeam [10], design solutions which are made using CAD tools to reduce the development time of the final product.

The article consists of an introduction representing the relevance of the topic, Related Work - a comparison of the author's method with the existing ones, a description of the method itself is given in section III. DEVELOPMENT OF A METHOD FOR EXTRACTING PROJECT CHARACTERISTICS.

II. Related Work

We considered the main auxiliary tools, plug-ins, which allow to obtain a constructive description of the design solutions made in CAD, forming the history of the construction of design solutions and displaying it to the designer.

ADEM [11]. The system is a set of software tools that allow for the production of three-dimensional hybrid modeling of CAD objects, flat modeling and drafting, receiving drawings from a three-dimensional model, computer processing of paper drawings, design documentation, data exchange between different CAD systems. Almost all known methods for constructing volumetric bodies are implemented in the system: displacement, motion, rotation, along sections, along a grid, merging, etc. Many types of construction in the system have additional features, for example, taking into account the normal to the reference surface. All constructions are reflected in the tree, in which you can make changes with the subsequent regeneration of the model.

Creo Flexible Modeling Extension [12]. Creo FMX (Flexible Modeling Extension) gives engineers the ability to edit a 3D model using "direct modeling" techniques while maintaining the original model building history. This simplifies working with data from other CAD systems and with models in which significant changes need to be made without disrupting the design intent. For example, when checking various versions of a model for strength or when developing a model for a casting tool or a control program.

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Geomagic Design X [13]. The software for processing 3D scanning data allows you to create virtual three-dimensional models of physical objects in order to perform geometry control and reverse engineering in CAD / CAM / CAE systems. This software product offers a complete set of necessary functions - starting from processing the information obtained from the 3D scanner to building a parameterized solid-state or surface model for subsequent reverse engineering (obtaining technical documentation, preparing production, transferring geometry to CAM systems to create control programs for CNC machines, etc.).

In [14], a CAD system was described in which the process of extracting data from a design solution of a CAD system focuses on the use of data template search algorithms, which allows to achieve better results compared to traditional information processing methods. For a complete description of knowledge about the process, the information model of the process should be based on a complete analysis of the information used in the process of developing the TP. The information model includes all the main objects of the process (product, parts, production resources, route, etc.). The information model is a composite structure and is formed from an orderly combination of data and knowledge about details, production and human resources, organization of business processes, etc. The information model sets the protocol for acquiring knowledge in the CAD database of the TP by standardizing the description of the process elements in the database.

In [15], the problem of storing and retrieving data from design solutions in various CAD systems used in the design and modeling processes of complex technical products in industrial enterprises was considered. Making changes and adding building operations becomes a very difficult task for a designer who does not have access to directly change the 3D geometry of a design solution. There are a number of ways to import data created in other CAD systems and presented in different formats, but they all have certain limitations, as a result of which the designer in a particular situation only has to choose the lesser of evils. Of course, the best is, of course, the design solution in the "native" format of the system used, but this is not possible if you have to use data created in different CAD systems. The alternative is to apply a standard neutral format, for example DXF [16], STEP [17-19] or IGES [20, 21]. This method is the most economical and provides maximum compatibility when exchanging data, but it is far from the most reliable: quite often edges, surfaces, solids and other elements disappear during the conversion.

In [22], the authors analyzed the modern visualization tools for 3D objects in a web environment (JNetCAD, JSC3D, Babel3D Online Viewer, A360 Online Viewer), reviewed engineering and computer graphics formats, format converters (CADExchanger, Babel3D, Online CAD File Converter), the author developed a universal tool for extracting textual and solid model descriptions of any part and assembly from CAD KOMPAS-3D and presenting it in the web environment.

III. Development Of A Method For Extracting Progect Characteristics

The essence of the method lies in the construction of a semantic model of a design solution of engineering products made in CAD, or objects created in PLM-systems as a result of the work of the designer with specialized plug-ins. The method allows to extract data and parameters as a result of the analysis of design decisions, highlighting the history of building a three-dimensional model of a complex technical product, as well as numerical characteristics of the parameters of design operations of solid-state modeling in CAD.

The history of the construction of a design solution is understood as a sequence of design operations performed by a designer in CAD, forming as a result a three-dimensional solid model. The history of construction, as a rule, is displayed in the form of a tree consisting of a set of initial and derived modeling objects. It is worth noting that each element included in the tree of the model of the design decision has a unique name or identifier. In modern CADs, the construction history of a design solution is necessary to limit and establish the relationship between the elements of the three-dimensional model tree, allowing you to control the designer's changes made by him while editing the design solution, and monitor all stages of the final technical product change.

We have developed a number of models that constitute the scientific basis of the method for extracting data using the template for determining the characteristics and parameters of a design solution. The initial data for the attribute analysis of the design solution of a PDM system are the technical requirements (TT) for a specific part or assembly unit (DSU) obtained from the technical requirements of the customer or technical specifications for the design of the SCH. Model TT has the following form:

$$TT = (Reg, Value, Mes, F\_pReg), \qquad (1)$$

where Reg is the set of requirements of products; Value is the set of values of requirements; Mes is the set of unit values; F_pReg - the function of forming a list of the requirements to the product as a whole defined in the TT and to the design solution in particular, the description of which is given by the expression

$$F\_pReg = Reg \times Value \times Mes \rightarrow L\_RegParams.$$

On the basis of the proposed model, the technical requirements of the design solution form the ontological concept of "TT" in the form of values of the ontological database, which generates a list of necessary requirements and their values in the form of an interrelated relationship, as well as the characteristics of the CAD design solution and parameter values in the corresponding units of measurement. The formed list of parameters and characteristics of the DSE is used in the verification of the design solution made in engineering CAD.

We have developed an algorithm for the formation or addition of technical requirements for the product, which is presented in Fig. 1 and consists of the following steps:

1. Getting started on the formation of the technical requirements of the product.

2. Consideration of the technical requirements of the customer.

3. Check for the presence of a product in the PDM-system project tree. If the product does not take into account all the characteristics, then go to step 5. If the values of the characteristics have changed, then go to step 6.

4. Creating concepts of DSE and Technical Requirements.

5. Highlighting requirements for the product.

6. Filling requirements with values.

7. Completion of work.

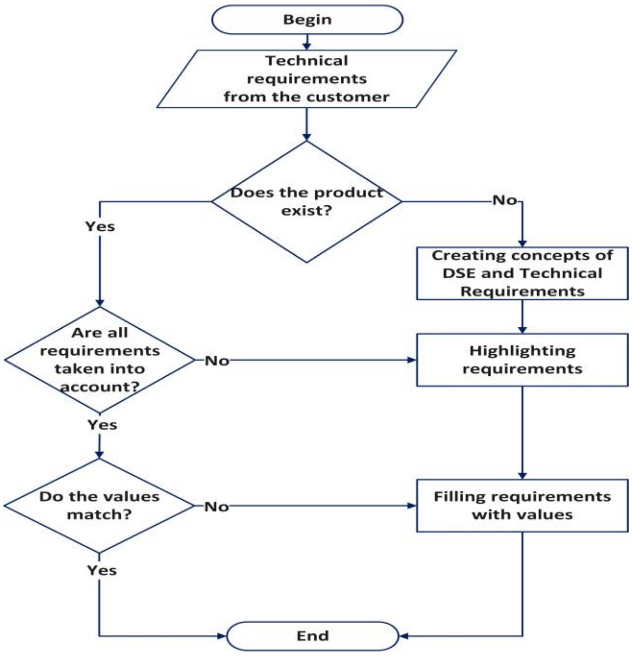

Fig. 1. Algorithm for the formation of requirements for the product

The technical assignment model (TZ) represents the attribute part of the corresponding PDM-system object related to the terms of performing the tasks and their performers, and also includes the technical requirements model. Model TZ has the form:

$$TZ = (Task, State, TTs, Controls, Person, DT\_Start, DT\_Finish, DT\_plan, Customer, F\_tList), \quad (2)$$

where Task is the set of job descriptions for design; State - a set of admissible states characterizing the life cycle of a technical task; TTs - many technical requirements; Controls - a set of rules and conditions checks; DT_Start - the actual start date of work; DT_Finish - the actual end date of the work; DT_Plan - planned completion date; Customer - many development customers; Person - many developers; F_tList - the function of forming a list of the requirements for a design solution defined in the TZ when the designer works in CAD, the description of which is given by the expression

$$F\_tList = Tast \times TTs \times Controls \rightarrow L\_RegParams.$$

On the basis of the proposed model for the specification of a design solution, the concept of "TZ" is formed in the form of ontological database values, in which a list of necessary requirements is generated with the values of the CAD design solution in the form of an interconnected relationship, and deadlines are generated.

The generated data on TZ are used to control the timing of the implementation of the design solution, made in engineering CAD.

We have developed an algorithm for the formation or addition of technical specifications for the product, which is presented in Fig. 2 and consists of the following steps:

1. Getting started on the formation of technical specifications for DSE.

2. Consideration of the technical requirements of the customer.

3. Consideration of product requirements.

4. Description of the list of works.

5. Determination of technical requirements for the component part of the product (SCH).

6. Check for the presence of a product in the PDM-system project tree. If the product does not take into account all the requirements, then go to step 8. If the requirements have changed, then go to step 9.

7. Creating concepts of DSE and Technical Requirements.

8. Highlighting requirements on SCH.

9. Filling requirements with values.

10. Completion of work.

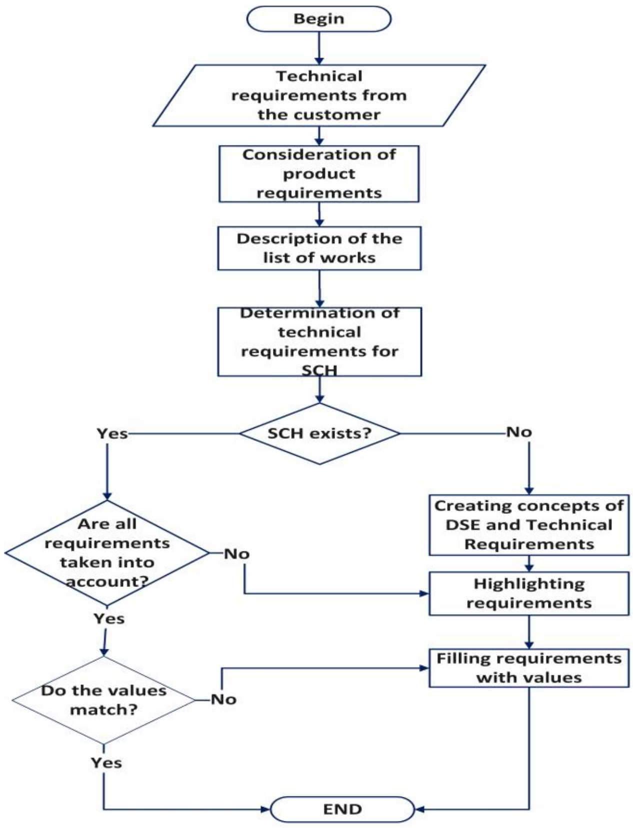

Fig. 2. Algorithm of formation of requirements on SCH

The initial data for the analysis of the history of building design solutions for CAD [23-25] are three-dimensional models of parts and assembly units (DSE) of engineering products, the model of which is as follows:

$$DSE = (PrOperations, Type, Class, State, Designtion, Name, F\_history) \quad (3)$$

where PrOperations is a set of design operations of CAD, which make up the history of building a three-dimensional model of an engineering product; Type - many types of DSEs that are possible to perform in CAD; Class - many classes of DSEs in CAD; State is the set of possible states of the DSU that characterize its life cycle; Designation - many designations DSE; Name - many DSU names; F_history - the function of forming the history of building a design solution when the designer works in CAD, the description of which is given by the expression

$$F\_history = PrOperations \times Type \times Class \rightarrow L\_history.$$

The model of design operations of solid-state three-dimensional modeling in CAD has the following form:

$$PrOperations = (Id, Pr\_type, Pr\_params, F\_list\_prO), \quad (4)$$

where Id is the set of identifiers of project operations in the history of building a three-dimensional model of the DSE in CAD; Pr_type - type of project operation; Pr_params - a set of parameters for design operations of CAD; F_list_prO - the function of forming the sequence of the design operations performed by the designer for three-dimensional solid modeling in CAD, the description of which is given by the expression

$$F\_list\_prO = Pr\_type \times Pr\_params \times L\_history \rightarrow L\_list.$$

Based on the proposed design operations model, a description of the construction history of the design decision is generated in the form of an XML file, which displays the DSE structure as an interconnected sequence of design modeling solid-state modeling operations in CAD, as well as parameter values, attributes and characteristics of the design decisions. In the future, according to the XML file, the ontological model of the design decision is formed in the description of the concept of "DSE".

The model of initial data for the classification of design solutions in CAD is as follows:

$$ClassPrO = (PrO, L\_list, Templates, F\_PrO\_class), (5)$$

where PrO is a set of design solutions made in CAD; L_list is a sequence of project operations performed by the designer; Templates - a set of templates for constructing a design solution in CAD for determining the class of an engineering product; F_PrO_class - the function of defining and assigning to a design solution a class of engineering products, the description of which is given by the expression

$$F\_PrO\_class = PrO \times L\_list \times Templates \rightarrow Pro\_class.$$

The proposed model allows to classify the design solution made in CAD, based on the set of templates for constructing the DSE and the sequence of design CAD operations.

The model of parameters and characteristics of DSE is as follows:

$$Params = (Symbol, Description, Value, Mes, F\_pList), \quad (6)$$

where Symbol is the set of designations of characteristics of DSE; Description - many descriptions of the characteristics of the DSE; Value - the set of values of parameters and characteristics of the DSE; Mes is the set of units of measurement for the numerical characteristics of DSE; F_pList - the function of forming the list of characteristics of the DSE performed in CAD, the description of which is given by the expression

$$F\_pList = PrO \times Symbol \times Description \times Value \rightarrow L\_params.$$

Based on the proposed model, a list of characteristics of the design solution of the CAD system is generated [26, 27]. The formed list of parameters and characteristics of DSE is used when implementing a search system for similar design solutions made in engineering CAD.

We have developed an algorithm for constructing a semantic model of a CAD design solution, which consists of the following steps.

1. Start of work of the designer with the system of data extraction from the design solution, made by means of CAD.
2. Discovery in CAD of a three-dimensional model of an engineering product.
3. Beginning of the formation of an XML description of the design operations of a three-dimensional model of an engineering product.
4. The type of the three-dimensional model of the CAD design solution is extracted.
5. Formation of a list of active DSEs included in the assembly of the final product.
6. For DSE, we obtain a set of structures (elements of the model tree) and parameters of a given type.
7. Based on the three-dimensional model of the design decision, the history of the design decision is formed.
8. An array of active elements in the design solution is formed.
9. Retrieve the parameters of the object design decision CAD.
10. A connection is established between the elements of the model tree.
11. Determine the type of the element of the history of building a design solution for CAD.
12. The parameters and characteristics of design operations for each element of the construction history are extracted.
13. If in the design decision there are no more active DSEs, then the generated sequence of project operations is written into an XML file. Otherwise, go to step 6.
14. Entry of the project solution to the PDM-system file storage.
15. Filling in the parameters and characteristics of the DSE in the PDM system.
16. Closing a design solution in CAD.
17. Shutting down the designer with the system.

We have proposed a theoretical assessment of the effectiveness of the designer's activities when using a system for extracting design characteristics from PLM. On average, reducing the time of a designer's design activity in a CAD system using the proposed system, which is based on a new data extraction method, is 11% and depends on the search accuracy in the system and the coverage level of the enterprise's electronic catalog of engineering products [3]. Reducing the time of the design activity of the designer is calculated according to the following formula:

$$\Delta T = 1 - \left(\frac{A * T_{sc} + D * T_{db} + \sum_{i=0}^{n} (T_{pst,i} * S'_{i,n})}{[\sum_{i=1}^{N} (p_i * TK_i) + (1 - p_i) * T_i] + T_{link}} + R_{i,N} \right). \quad (7)$$

A more detailed derivation of the formula and calculation of the experimental results are given in [28].

By "Accuracy search" *(A)* we mean the probability of finding the necessary three-dimensional model of a machine-building object, made in CAD, in the product classification system. "Degree of coverage" *(D)* means the degree of coverage of the catalog of electronic products of the enterprise with the classification system of engineering products. We introduce the probability p - the probability of the designer finding the necessary three-dimensional part in the catalog. Suppose that if a part is not found, the designer spends time both manually searching the catalog and designing a three-dimensional model from scratch, then *(1 - p)* is the probability of a designer creating a three-dimensional part manually from scratch. The results of the calculation are shown in Table I.

TABLE I. REDUCING THE TIME OF THE DESIGN ACTIVITIES OF THE DESIGNER USING THE DATA EXTRACTION SYSTEM AND THE DESIGN CHARACTERISTICS OF THE PRODUCT

N	Accuracy search	Degree of coverage	The probability of finding a 3D-model	The probability of manual construction of 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%*
…	…	…	…	…	…
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%*

CONCLUSION

We researched and developed the software for an automated data extraction system and design characteristics of PLM-systems using CAD. The new method allows you to create a history of building a three-dimensional product, get a list of assembly units of the product, extract the parameters of design operations and three-dimensional objects, enter the analyzed design solution into the PDM / PLM file storage system, form technical requirements as a result of analysis. The technical requirements in the PLM-system are presented as a requirements tree, which contains the main characteristics, parameters and description of the product. Based on the requirements, a project is being worked out and a product division scheme is being formed, according to which design schedules and technical tasks are already being developed.

The use of the developed system for extracting design characteristics from PLM systems, which is based on the models and algorithms proposed given in section III. DEVELOPMENT OF A METHOD FOR EXTRACTING PROJECT CHARACTERISTICS, allows us to reduce the design time of a designer by an average of 11%.

Future research is focused on the development of an ontological model of a design solution and an ontological database of design decisions made by CAD tools. The database will contain concepts of design decisions, taxonomy and personal experience of the designer. The method of extracting design characteristics proposed in this work will be used to accumulate this database.

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