Method to Get Assembly Design Parameters

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Abstract. The authors propose a new method for extracting the design characteristics of products from the product lifecycle management systems (PLM) in order to control and analyze the copies of the library workflows. The method is based on the authors' temporal automatic RVTI-grammar. The method differs from analogues in presence of a conceptual mathematical apparatus like ontology, which provides the fundamental operating semantics in the complex technical systems design automatization.

1 Introduction

In CAD systems design diagram grammatical models presented in the artifacts of visual graphic languages BPMN, UML, IDEF, etc are actively used. Visual (in the form of diagrams) form of the business processes presentation is used to help designers in the design solutions development and analysis, production projects preparation, also technological preparation of production with the help of logical justification of specific complex business processes. One of the components that complicate the workflow is the time factor. This can be an operation predefined value or a timeout after which the worker thread continues to force execution. There are also situations when man need to meet with the implementation of all operations in a certain period or allocate a certain time block. Failure may result in delays or downtime, which will have a significant impact on the expected outcome.

The proposed mathematical tool allows to analyze workflows with temporal characteristics. Validating workflows for structural and semantic errors is a computational task, so different formal approaches and languages can be used. However, the approach used for validation must support the workflow language. Due to the computational complexity of the problem (polynomial, exponential), only a few approaches are able to successfully test workflows with constraints, including time, for all types of workflow graphs. The main language in which the development is carried out is the well-known BPMN. The standard business process model notation (BPMN) will provide businesses the capability of understanding their internal business procedures in a graphical notation and will give organizations the ability to communicate these procedures in a standard way [1]. BPMN specification also provides a mapping between the notation graphics and the underlying constructs of execution languages, particularly the business processes language (BPEL).

Modern production in the digital economy requires accelerating the design and technological preparation of production (TPP) processes. In real life this can be

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partially achieved by using parallel, top-down or bottom-up design. Such technologies lead to collective work on the project, reducing time to develop a large block. A significant reduction in time can be obtained using automated workflows. Such workflows are aimed at project management and to reduce the developed design documentation (DD) or technological documentation (TD) approval time in electronic form. Storage design and technological projects is the PLM system, where the electronic structure of the product attached to the projects is stored [2-4]. In the conditions of a large design and production enterprise, in which the number of nomenclatures exceeds 1.5 million positions and the number of developers (design engineers, process engineers, software engineers, etc.) more than 1,000 people, reducing the TPP time, including development and coordination of design and technological documentation (DTE) processes is more than relevant. It should also be noted that in large design and manufacturing enterprises producing complex equipment, product design is carried out in different departments, divided into areas. Thus, the design solutions modeling processes analysis, control, optimization, reengineering problems, which involve specialists from various large design and production enterprise departments and services, and the active use of CAD tools, are relevant and have great practical importance.

The authors proposed a new method for extracting products data and design characteristics from PLM PILOT system, design solutions are made in CAD KOMPAS-3D [53], in order to reduce the final product development time.

2 Related works

Workflows design process is associated with the Rational Unified Process (RUP) technology [5], the PBWD methodology, Unifeid Model Language (UML) [6] languages, extended Event Driven Process Chain (eEPC), BPMN, IDEF0, IDEF3, Amber, Promela, YAWL, the Booch Methodology [7], Hierarchical Object Oriented Requirement Analysis (HOORA) [8], Jacobson Method [9], Object Modeling Technique (OMT) [10], Planguage [11], Shlaer-Mellor Object-Oriented Analysis Method [12], Software Cost Reduction requirements method (SCR) [13], software Requirements Engineering Methodology (SREM) [14], Storyboard Proto-typing [15], Structured Analysis and Design Technique (SADT) [16], and Structured Analysis and System Specification (SASS), Volere method, WinWin approach, and Component-based methods (COTS-Aware Requirements Engineering (CARE), Off-the-Shelf Option (OTSO)) [17].

Karpov [18] uses the Model Checking approach for the business processes analysis, control, modeling and reengineering, the main drawback is the model study, but not the system itself, so the question arises about the adequacy of the model to the system, while the problems solution complexity is exponential.

Saeedloei and Gupta [19] applied a temporal machine implementing the temporal context-free grammar for the cyber-physical systems analysis with the subsequent translation of this grammar into a program for the Prolog interpreter.

Wang and Fan [20] propose to use actions temporal logic to describe workflows in a graph form, which requires a description of all routes in a graph in the action temporal logic formulas. Apply linear temporal logic to formalize the tasks route of branching AND, OR, and similarities JOIN, however, question the adequacy of building the description of the workflow in graphical form is still not settled.

Cyber-physical systems analysis and control tools database, as well as workflows are available in [21, 22]. In addition, there are CPN Tools [23], “Roméo - A tool for Time Petri Nets analysis” [24], TimesTool [25], the Tina Toolbox [26], Visual Object Net++ [27].

The traditional workflow management system includes ProBis [28]. To dynamic systems of flow control of design works according to the works [29, 30, 31], include YAWL (Yet Another Workflow Language), iPB. All these systems use diagrammatic workflows representation. This solves the structure analyzing problem (syntax) and meaning (semantics) of diagrams. Thus, in [32] color Petri nets are used for dynamic semantic workflows analysis, and in [33] PI-calculus approach formalizing workflows into algebraic statements of first-order logic is used. Currently, PI-calculus is a promising, but still very young and developing theory, it has a lot of open questions and unsolved problems. Petri nets have the following limitations:

- no universal framework for Petri nets-based project workflows modelling and analysis. In order to analyze different properties (liveliness, reachability, security), workflows are modeled in different Petri nets types, which is ad-hoc [34].
- no mechanism that would help the designer in modeling and ensuring the successful completion of the task with the necessary requirements (properties).

The model checking method has found a wide workflow analysis application in the development of error-free systems at the design stage. However, it is intended for experienced scientists and engineers, as it is difficult to understand and operate [20].

The main auxiliary tools, plug-ins which allow to receive the constructive description of the design decisions executed in CAD forming design solutions construction history and displaying it to the designer are considered.

ADEM [35] is a complex of software tools that allow to produce three-dimensional hybrid modeling of CAD objects, flat modeling and drawing, obtaining drawings from a three-dimensional model, computer processing of paper drawings, project documentation, data exchange between different CAD systems. The system implements almost all known three-dimensional bodies construction methods: moving, rotating, along sections, along the grid, merging, etc. Many types of work in the system have additional features, for example, considering the normal to the reference surface. All designs are reflected in the tree, where changes and the model rendering are featured.

Creo Flexible Modeling [36] gives engineers the ability to edit a 3D model using “direct modeling” methods while maintaining the original model build history. This makes it easier to work with data from other CAD systems and models requiring significant changes without disrupting the design intent. For example, when testing different versions of a model for durability or when developing a model for a casting tool or control program.

Geomagic Design X [37] is a 3D scanning data processing software allowing to create virtual 3D models of physical objects to perform geometry control and reverse engineering in CAD / CAM / CAE systems. It offers a full set of necessary functions, from the processing of information obtained from a 3D scanner to the construction of a parameterized solid-state or surface model for subsequent reverse engineering (obtaining technical documentation, production preparation, transfer of geometry to CAM systems, control programs creation for CNC machines, etc.).).

[38] describes a CAD system in which the process of extracting data from the CAD design solution is focused on the algorithms for searching data templates usage, which allows to achieve better results compared to traditional methods of information processing. For a complete description of process knowledge, the process information model should be based on a complete analysis of the information used in the process of developing the TD. 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 formed from an ordered combination of data and knowledge about the details, production and human resources, organization of business processes, etc. The Information model sets the Protocol for obtaining knowledge in the CAD database by standardizing the description of the process elements in the database.

In [39] the problem of data storage and extraction from design solutions in various CAD systems used in the complex technical products design and modeling in industrial enterprises is considered. Changing and adding construction operations become a very difficult task for a designer who does not have access to a direct change in the three-dimensional geometry of the design solution. There is 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 the designer in a particular situation can only choose the lesser of a trouble. “Native” design solution format is the best for using in the systems, but this is not possible if data is stored in different CAD systems. An alternative is to use a standard neutral format such as DXF [40], STEP [41-43] or IGES [44, 45]. This method is the most cost-effective and provides maximum compatibility in data exchange, but it is far from the most reliable: quite often edges, surfaces, solids and other elements disappear during the conversion.

In [46], the authors analyzed the modern methods and tools for 3D-objects visualization in the web environment (JNetCAD, JSC3D, Babel3D online viewing, online viewing A360), considered engineering and computer graphics formats, converters (CADExchanger, Babel3D, online CAD file Converter), they also have developed a universal tool for text and solid model parts and assemblies from CAD KOMPAS-3D extraction and Web-oriented presentation.

3 Temoral RVTI-grammar & Method for extracting design parameters

Workflows are a powerful tool for analyzing the enterprise business processes and design tasks addressed to specific departments and performers. Such design work can be carried out simultaneously in different departments by various performers, so synchronization, blocking resources, deadlocks, bottlenecks problems etc. arise in the field of the enterprise business processes management. Design workflows can be represented on a temporary basis “before”, “during”, “after”, setting the enterprise works schedule in accordance with the parameter. Temporary RVTI grammar of the language L(G) is an ordered n-tuple of non-empty sets

$$G = (V, \Sigma, \tilde{\Sigma}, C, E, R, T, r_0)$$

where $V = \{v_e, e = \overline{1, L}\}$ is auxiliary alphabet; $\Sigma = \{a_t, t = \overline{1, T}\}$ is a terminal alphabet; $\tilde{\Sigma} = \{\tilde{a}_t, \mathrm{t} = \overline{1, T}\}$ is quasiterminal alphabet; C is a time indentifiers set; E is the set of temporal relations “Before”, “During”, “After” (initialization hours $\{c := 0\}$, relations form $\{c \sim x\}$, where x is a variable (time identifier), c is a constant, $\sim \epsilon\{=,<, \leq,>,\geq\}$); $R = \{r_i, i = \overline{0, I}\}$ is the grammar of the G schema (the set of product complex names, each r_i consists of a subset P_{ij} of products $r_i = \{P_{ij}, j = \overline{1, J}\}$); $T \,\epsilon\, \{t_1, t_2, \dots, t_n\}$ is a set of time stamps; $r_0 \,\epsilon\, R$ is RV-axiom grammar [3].

In the grammar mechanism an additional tape is introduced which contains information on the amount for the current item. When a label link is returned, the value from the ribbon associated with the current item must be retrieved. Assume that the time is spent only during performance operation. Add operation $W_1(ts^{t(5)})$, in which “ts” is the pre-calculated sum of two numbers: the sum of the current time for the element and its time characteristic. Also, when returning, $W_2(b^{1m}, b^{t(6)})$ is performed, that is, reading from the element storage and reading information from the corresponding tape about its amount of time determining the “ts”. An example of a diagram that can be analyzed using RVTI-grammar is presented in Figure 1. The timestamp for each object from the terminal alphabet is the main feature.

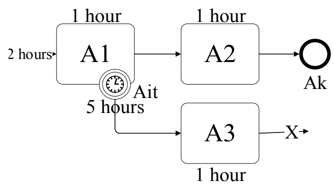

Figure 1. Temporal BPMN diagram example

RVTI-grammar is developed for the basic elements of BPMN notation. The table form is presented in Table 1.

Table 1. An example grammar for a simple BPMN diagrams

N	State	Quasiterm	Next state	Operation with memory
1	r_0	A_0	r_1	∅
2	r_1	*rel*	r_3	∅
3	r_2	$label_{EG}$	r_3	$W_2(b^{1m}, b^{t(6)})$
4		$label_{PG}$	r_3	$W_2(b^{2m}, b^{t(6)})$
5	r_3	A_i	r_1	∅
6		A_{im}	r_1	∅
7		A_{it}	r_1	$W_1(t_s{}^{t(6)})$
8		A_{kl}	r_2	$W_3(e^{1m}, e^{2m})$
9		A_k	r_4	∅
10		A	r_1	$W_1(t_s{}^{t(6)})$
11		EG_c	r_1	$W_1(t^{1m^{(n-1)}})/W_3(k = 1)$
12		EG	r_2	$W_1(1^{t(1)}, k^{t(2)})/W_3(e^{t(2)}, k != 1)$
13		$\_EG$	r_2	$W_1(inc(m^{t(1)})/W_3(m^{t(1)} < k^{t(2)})$
14		$\_EG_e$	r_1	$W_1(t^{1m^{(n-1)}})/W_3(m^{t(1)}=k^{t(2)}, p != 1)$

15		$\_EG_{me}$	r_1	$o/W_3(m^{t(1)}=k^{t(2)}, p = 1)$
16		PG_f	r_1	$W_1(t^{2m^{(n-1)}})/W_3(k = 1)$
17		PG	r_2	$W_1(1^{t(3)}, k^{t(4)})/W_3(e^{t(3)}, k \,!= 1)$
18		$\_PG$	r_2	$W_1(inc(m^{t(3)})/W_3(m^{t(3)} < k^{t(4)})$
19		$\_PG_e$	r_1	$W_1(t^{2m^{(n-1)}})/W_3(m^{t(3)}=k^{t(4)}, p \,!= 1)$
20		$\_PG_{je}$	r_1	$W_1(t^{2m^{(n-1)}})/W_3(m^{t(3)}=k^{t(4)}, p = 1)$
21	r_4	*no_label*	r_5	*
22	r_5			

The essence of the method lies in the engineering product design solution semantic model construction 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 design solutions analysis, 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 design solution construction history presents 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 tree form consisting of an initial and derived modeling objects set. It is worth pointing out that each element included in the design solution tree has a unique name, or identifier. In modern CADs, the design solution construction history is necessary to limit and establish the relationship between the three-dimensional model tree elements, so as to control the designer's changes made by him while editing design solution, and monitor all stages of the final technical product change.

Set of models that constitute the scientific basis of the data extraction method using the template for determining the design solution characteristics and parameters is enabled. The initial data for the design solution attribute analysis by a PDM system is the technical requirements (TR) for a component or assembly unit (CAU) obtained from the the customer or technical specifications TR for the CAU design. TR model has the following view:

$$TR = (Reg, Value, Mes, F_{pReg}), \tag{1}$$

where Reg is the product requirements set; $Value$ is the requirements values set; Mes is the unit values set; $F_{pReg} = Reg \times Value \times Mes \rightarrow l_{RegParams}$ is the function forming a requirements list to the product as a whole defined in the TR and to the design solution in particular, the description of which is given by the expression.

Based on the proposed model, the design solution TR forms the "TR" ontological concept designed as the ontological database values, which generates a list of necessary requirements and their values in the form of an interrelated relationship, as well as the CAD design solution characteristics and parameter values in the corresponding measurement units. Formed CAU parameters and characteristics list is used in the of the CAD design solution verification.

An algorithm for the product technical requirements formation or addition is developed and presented in Figure 2. It consists of the following steps:

1. Formation of the product technical requirement.

2. Review of the customer's technical requirements.

3. Seraching the product in the PDM system project tree. If the product does not take into account all characteristics, then go to step 5. If the characteristics values have changed, then go to step 6.

4. Creating the CAU and TR concepts.

5. Highlighting product requirements.

6. Filling requirements with values.

7. Completing the work.

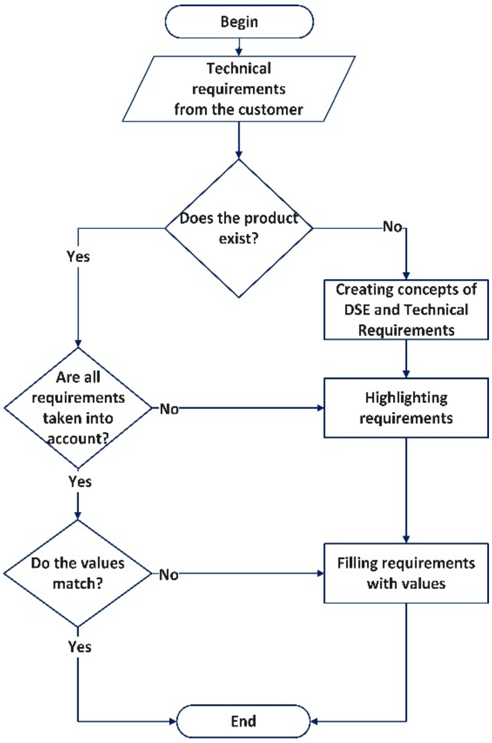

Figure 2. The product requirements formation algorithm

The technical task model (TT) 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. TT model has the following view:

$$TT = (Task, State, TRs, Controls, Person, DT_{Start}, DT_{Finish}, DT_{plan}, Customer, F_{tList}), \quad (2)$$

where $Task$ is the design job descriptions set; $State$ is admissible states set characterizing the TT lifecycle; TRs is technical requirements set; $Controls$ is the rules and conditions checks set; DT_{Start} is the actual start date of work; DT_{Finish} is the actual work end date; DT_{Plan} is planned completion date; $Customer$ is development customers set; $Person$ is developers set; $F_{tList} = Task \times TRs \times Controls \rightarrow l_{RegParams}$ is the function forming a requirements list for a design solution defined in the TT when the designer works in CAD.

Based on the proposed design solution specification model, the “TT” concept is designed as ontological database values, in which a list of necessary requirements is generated with the CAD design solution values in the form of an interconnected relationships, and deadlines are generated.

The generated TT data is used to control the design solution parts implementation timings made by CAD.

Product technical specifications formation or addition algorithm is developed, which is presented in Figure 3 and consists of the following steps:

1. CAU technical task forming starting.

2. Review of the customer’s technical requirements.

3. Product requirements review.

4. Works list description.

5. Specification of technical requirements for the complex product unit (CPU).

6. Searching the 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 CAU and TR.

8. Highlighting CPU requirements.

9. Filling requirements with values.

10. Completing of work.

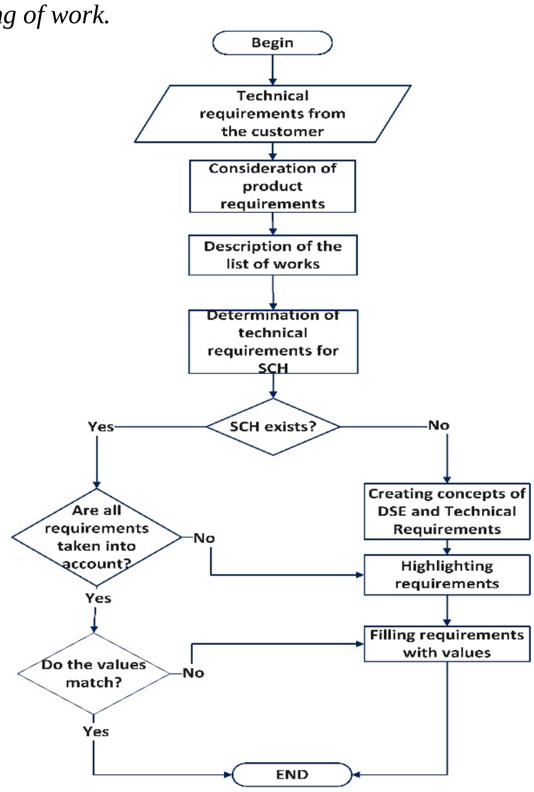

Figure 3. Complex product unit requirements formation algorithm

The initial data for the CAD design solutions building history analysis [48-50] is three-dimensional models of engineering products components or assembly units (CAU), the model of which is as follows:

$$CAU = (PrOperations, Type, Class, State, Designation, Name, F_{history}), \quad (3)$$

where $PrOperations$ is a set of CAD design operations, which make up the engineering product three-dimensional model building history; $Type$ is CAUs types set that are possible to perform in CAD; $Class$ is CAUs classes set in CAD; $State$ is the set of CAU possible states characterizing its lifecycle; $Designation$ is CAU designations set; $Name$ is DSU names set; $F_{history} = PrOperations \times Type \times Class \rightarrow l_{history}$ is the function forming design solution building history made by designer in CAD.

The CAD solid-state three-dimensional modeling design operations model has the following view:

$$PrOperations = (id, pr\_type, pr\_params, F\_list\_prO), \quad (4)$$

where id is the set of project operations identifiers in the CAU three-dimensional model building history; pr_type is project operation type; pr_params is a set of parameters for design operations of CAD; $F\_list\_prO = pr\_type \times pr\_params \times l\_history \rightarrow l\_list$ is the design operations sequence forming function. These operations are performed by the three-dimensional modeling designer in CAD.

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

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

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

where PrO is a set of design solutions made in CAD; l_list is a project operations sequence performed by the designer; $Templates$ is a set of templates for constructing a design solution in CAD for determining the engineering product class; $F\_PrO\_class = PrO \times l\_list \times Templates \rightarrow pro\_class$ is the engineering products class design solution definition and assignment function.

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

The CAU parameters and characteristics model is as follows:

$$Params = (symbol, description, value, mes, F\_pList), \quad (6)$$

where $symbol$ is the CAU characteristics designations set; $description$ is the CAU characteristics descriptions set; $value$ is the CAU parameters and characteristics values set; mes is the CAU numerical characteristics measurement units set; $F\_pList = PrO \times symbol \times description \times value \rightarrow l\_params$ is the CAD performed CAU characteristics list forming function.

Based on the proposed model, the design solution characteristics list is generated [51, 52]. It is used in implementation of a system searching the similar design solutions made in engineering CAD systems.

An algorithm for CAD design solution semantic model constructing is developed (Figure 4), which consists of the following steps.

1. Beginning of designer work in the design solution data extraction system.

2. Opening the engineering product three-dimensional model in CAD.

3. Beginning of the XML engineering product three-dimensional model design operations description formation.

4. Extraction of the CAD design solution three-dimensional model type.

5. Formation of a list of active CAUs included in the final product assembly.

6. Obtaining a set of structures (model tree elements) and parameters of a given type for the CAU.

7. Forming the design solution history based on the three-dimensional model.

8. Forming the the design solution active elements array.

9. Retrieving the CAD design solution object parameters.

10. Establishing connection between the model tree elements.

11. Determination of the CAD design solution building history type.

12. Extraction of the design opeariotns parameters and characteristics for each building history element.

13. If there are no more active CAUs in the design solution, then the generated project operations sequence is written into an XML file. Otherwise, go to step 6.

14. Uploading the project solution to the PDM-system file storage.

15. Filling in the CAU parameters and characteristics in the PDM system.

16. Closing a design solution in CAD.

17. End of the designer work.

Theoretical assessment of the designer's activities effectiveness during PLM-based design characteristics system extraction usage is developed. On the average, the time of a designer activity in a CAD system using the proposed system based on a new data extraction method, is reduced on 11% and depends on the search accuracy in the system and the coverage level of the enterprise engineering products electronic catalog [53]. The experiment results are shown in Table 2.

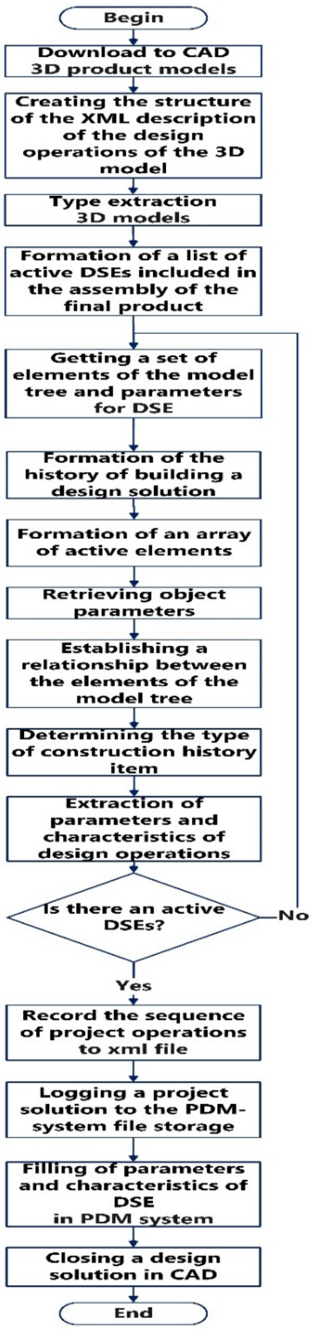

Figure 4. Design solution semantic model construction algorithm

Table 2. The design activities time reduction after the data and product design characteristics extraction system implementation

N	Accuracy search	Coverage degree	The probability of finding a 3D-model	The probability of a 3D model manual construction	Design time reduction
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%*

7 Conclusion

The software for an automated data extraction system and design characteristics of PLM-systems using CAD has been researched and developed. The new method allows to create a three-dimensional product building history, get a list of product's assembly units, extract the design operations and three-dimensional objects parameters, upload 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 developed.

The RVTI temporal grammar proposed by the authors has a linear characteristic of the of working processes analysis time. It considers the language of the process description and can be applied to any diagram and allows time parameters to be considered. This will help to identify logical errors in the CAD systems development and design. *The proposed method of neutralization applied to this grammar allows to identify several errors during the passage*. Further work is the semantic analysis diagram patterns possibilities extension with the point of view of matching text attributes diagrams to the project documentation.

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