8. Hickerson, A. I. Experimental study of the behaviour of a valveless impedance pump [Text] / A. I. Hickerson, D. Rinderknecht, M. Gharib // Experiment in Fluids. – 2005. – Vol. 38, Issue 4. – P. 534–540. doi: 10.1007/s00348-005-0946-z
9. Lee, V. C.-C. Valveless pumping using a two-stage impedance pump [Text] / V. C.-C. Lee, Y. A. Abakr, K.-C. Woo // Frontiers of Mechanical Engineering. – 2013. – Vol. 8, Issue 3. – P. 311–318. doi: 10.1007/s11465-013-0270-x
10. Popov, S. V. The designing of crank mechanism of piston pump [Text] / S. V. Popov, A. V. Vasilyev, S. V. Rymar // Eastern-European Journal of Enterprise Technologies. – 2013. – Vol. 1, Issue 7 (61). – P. 30–32. – Available at: http://journals.uran.ua/eejet/article/view/9321/8092

Представлено опис компонентів інформаційної системи для автоматизації застосування елементів САПР. Проведено системний аналіз процесу проектування як предмету автоматизації. Визначено необхідні інформаційні потоки для організації процесу проектування технічних об'єктів. Наведено діаграми взаємодії проектантів із системою проектування та елементів самої системи між собою у процесі виконання проектних робіт. Запропоновано концептуальний устрій системи для комп'ютеризації процесів проектування та управління ними

Ключові слова: система автоматизації проектних робіт, інформаційна модель, архітектура системи

Представлено описание компонентов информационной системы для автоматизации применения элементов САПР. Проведен системный анализ процесса проектирования как предмета автоматизации. Определены необходимые информационные потоки для организации процесса проектирования технических объектов. Приведены диаграммы взаимодействия проектировщиков с системой проектирования и элементов самой системы между собой в процессе выполнения проектных работ. Предложено концептуальное устройство системы для компьютеризации процессов проектирования и управления ими

Ключевые слова: система автоматизации проектных работ, информационная модель, архитектура системы

UDC 004.09
DOI: 10.15587/1729-4061.2016.76928

DEVELOPMENT OF THE SYSTEM ARCHITECTURE FOR DESIGN WORKS AUTOMATION

V. Zakharchenko
Assistant*
E-mail: victorialT@ukr.net
V. Nenia
PhD, Associate Professor*
E-mail: nenja_vg@mail.ru
*Department of computer science
Sumy State University
Rymskogo-Korsakova str., 2,
Sumy, Ukraine, 40007

1. Introduction

Today design automation of technical objects is an important factor for the increase of the designers' labor productivity. However, it isn't developed enough. Nowadays achievements in this area are rather insignificant in comparison with achievements in mechanical engineering in general. In the work [1] Petrenko observed that in the twentieth century the labor productivity in mechanical engineering increased much more, than the labor productivity of developers, who designed new equipment.

It is noted that complexity and volumes of projects tend to double every 10 years. Developers use rather old and well-known design methods for the automation of only separate design operations, which doesn't significantly contribute to the increase of their labor productivity. The latter depends on the use of traditional design methods, which aren't optimized, and the job management, which isn't controlled enough and doesn't provide the optimization of non-manufacturing actions. All these are reasons of the designers' lagging behind the general increase of the industrial manufacturing.

Therefore, there is an urgent need to solve this complex problem and to develop the full-function system for design works automation. Further, under the system for design works automation (CAD system) we will consider the set of programming and information means, which help to exclude the expert from a contour of the design process management. According to requirements of an integrated approach, not only separate components of the system, but also their interaction have to be the subject of improvement. Based on this provision it is necessary to automate the whole design process from the development of Terms of Reference to the formation of the completed project and its transferring to the client, but not only separate design operations, as it takes place nowadays. Such full-function CAD system would provide both the design automation of technical objects and the job management of the whole design process. In consequence, it will increase the designers' labor productivity. This determines the topicality of the CAD system development for the management of the performance of all kinds of works at design organizations and design subdivisions of industrial enterprises.

2. Literature review and problem statement

Nowadays there are many available sources concerning CAD systems. First of all, we analysed the works where the authors were focused on the development and the creation of systems for design works automation.

Today the tendency of the transition from the computerization of separate manufacturing operations to the computerized integrated manufacturing (Computer Integrated Manufacturing – CIM) is conventional [2]. It is a modern approach to manufacturing: by computer means to control the whole design process and the product (object) lifecycle from its design to its operation by the final consumer. At the same time, the important place is taken by the computer-oriented design (Computer-aided design – CAD) – CAM.

Commercial software solutions of CAD/CAM systems for the industry can be purchased easily. These solutions or systems, however, can't be connected together in a smooth way, in other words, they can't be included to the integrated environment [3]. To combine different CAD/CAM solutions, the additional applied software is required to support data exchange in information systems at industrial enterprises. The authors of the work [4] make a conclusion about the impossibility of the majority of the modern architectures to support data integration; they can't connect different applications of the CAD/CAM software for data exchange on the basis of the STEP standard (ISO 10303) and can't include the applied software for collaborative work of users. It is offered to develop additional «layers» of the software with temporal data storage in databases. The process of information exchange includes multistep overwriting of data and the validation performance. This process is difficult to computerize.

Another way out of this situation is to use CAD means of the software with open architecture for needs [5]. The following concept of different CAD means as a basis for the implementation of industrial requirements according to these systems and for the cooperation with developers and suppliers of systems is offered. Interfaces of access of various system cores are implemented for the interaction of a CAD systems network. The authors of the work [6] support the idea of an open architecture, offer to standardize information in databases, insist on the publication of program interfaces. They also advocate for support of a heterogeneous network of the program components functioning on hardware of different vendors by the modern CAD systems.

Web technologies continue to grow quickly. The Internet is becoming available everywhere. The ability to interact with online information is provided. The integration of Web applications and services into the software of CAD means is essential. The idea of Web-oriented development of CAD systems is developed in the work [7].

Results of the work [8] confirm the following two provisions. Web technologies allow to expand the functional possibilities of program CAD means and provide the participants of the design process with convenient means of communications for the discussion of design results.

Researchers pay considerable attention to development of the CAD systems architecture on the basis of a common information space by the use of software products of various vendors. Solutions on the basis of the STEP standard (ISO 10303) [9] and the use of additional system for product data management (PDM systems) are most often proposed. The nontrivial processing of diverse data formats, the availability of specific documented instructions, but not the general guidelines, and the mandatory user intervention to the process of data processing are noted. All of them aren't conducive to proper computerization.

Currently, basic processes of technical objects design aren't supported by technologies which are based on knowledge. The CAD software supports only pre-selected algorithms [10]. The FfCAD system is considered. It processes the processes of document-oriented engineering design in the environment, based on knowledge which integrates CAD files with technical requirements. All documents are semantically annotated and connected among themselves with the help of the structured ontology background. The FfCAD system allows to receive semantic services. This approach allows to organize general management of technical object design and can't serve as a basis for influence on the performance of specific design procedures. Each of propositions concerns a specific design object and offers a pre-selected design algorithm. Such situation doesn't allow to use gained achievements for design of other objects by replication or to use as completed templates.

The insufficient attention is paid to the automation of the design processes management in the available publications. Work of designers isn't tracked systematically. Statistical data for the reasonable planning of design works aren't generalized and there are difficulties according to the adoption of reasonable decisions about it and the planning of design works.

3. The Aim and Research Tasks

The aim of this paper is to develop the architecture of CAD system for design works automation on the basis of computerized methods of the technical objects design.

To achieve this aim it is necessary to solve the following research tasks:

– to carry out the system analysis of the design process performance;

– to offer such order of the design process, which would be appropriate for its implementation using the means of CAD system and for its management;

– to develop the information model of the design process as the conceptual basis for development of the CAD system project.

4. Investigation of the Design Process and Its Realization by the Means of CAD System

Considering the design process [11–14] as the process of information transformation from the Terms of Reference (ToR) into information, which describes the completed design solution, CAD systems belong to the class of information systems. The design of information systems of various purposes has been investigated for many years. Thus, the substantial experience is gained in this area [15–17]. Its main provision is the carrying out of the predesign research, during which the subject area description is formed, typical elements and relations between them are defined.

It is quite clear that the rationally performed analysis of the CAD system functioning, in time determined features of system components and their functioning substantially predetermine the successful realization of the information system and its maintenance.

4. 1. Working principles of the proposed CAD System

According to the national standard 22487-77 «Proektuvannia Avtomatizovane. Terminy ta vyznachennia» computer-aided design systems are defined as a set of the computer-aided design means, which are interconnected with necessary subdivisions of the design organization or group of experts (users of the system, who carry out the computer aided design). Thus, the following model of the CAD system architecture is proposed (Fig. 1).

A CAD system is composed of the certain set of the computing machinery means. This set is aimed at supporting the solution of such tasks, on which the system is configured.

This provision we can consider as a fact because each CAD system has its own branch specifics (the construction of automobiles, planes, steamships, machines, weapon objects, furniture etc.), taking into account the development perspectives. It is also assumed that the technical means of the CAD system include the material media for the storage and the use of the other various supports for the CAD system functioning.

The CAD system, as the system that implements information technologies of design, is composed of the staff (Fig. 1). It provides services, which support the work of the proposed CAD system. The staff includes the following:

– a supervisor, who organizes and provides the working capacity of the whole system in general;

– several subdivisions, which implement the complex of works for the support of the working capacity of the CAD system and its development in the certain directions.

The CAD system interacts with the environment mainly in two directions.

Firstly, the CAD system constantly has to be improved, be adjusted to all new requirements, i. e. to develop itself [17]. In this case, CAD system developers receive the ToR for the creation of new design procedures or for the modernization of existing ones etc. through the supervisor or the authorized employee (right unit in Fig. 1). These developers also perform the development of corresponding software, methodical and information support and transfer it for testing and further use.

Secondly, the CAD system interacts with the organizations of designers (left unit in Fig. 1), each of which has certain powers. The chief manager stands at the high level of such organization. This person is responsible for the whole project, establishes deadlines of its performance, accomplishes the strategic planning and external communications and distributes resources. The chief designer of the project is also at the high level of the management, but he has other responsibilities. This person performs the conceptual design (makes system decisions), defines the search directions of design decisions for components (subsystems) of the designed object, and controls the most responsible design procedures. Supervisors of groups, which are specialized in the design of separate objects and subsystems, which are the part of the designed object, form the medium level of the design organization. They make decisions according to the design process within their competences, form the ToR for design of subsystems of medium-low level in the structure of the design object and can also perform the design procedures. Designers, who are at the low level of the hierarchy of the design organization, perform separate design and engineering operations.

One person within implementation of one project can also have several levels of powers. For example, if the organization has enough financial resources, it can hire two employees as the chief manager and the chief designer of the project. In another case, the organization hires one employee, who combines responsibilities of both positions. The organization of works performance within the design organization as separate activities has a wide dissemination and provides the possibility of the participation of one person in various activities at the same time.

The ToR (Fig. 1, Terms of Reference – ToR) is the input for the proposed CAD system. When the last one gets new ToR, it is the sign of the formation of a new design process. All authorized employees of the organization, who are registered in the CAD system and received certain powers, interact with this design process. Designers use all available resources of both the organization and the CAD system in order to satisfy their needs (performance of functional responsibilities, design works, tasks, etc.).

The ToR is subject to the system analysis. The conformity of the technical object, which is designed according to this ToR, to that technical system, in which it will operate, is established during this system analysis. Only with the conformity of ToR conditions to the functioning conditions of the mentioned system, project will be developed. Otherwise, the ToR is amended. The described procedure is called external design and performed once as a separate action.

It is expedient to perform all the subsequent design steps by the principle of gradual detailing of the description of the designed technical object [14]. This description is decomposed from top to down into simpler parts. At each step the designed technical object is presented as a set of defined components. They can be both simple elements and complex subsystems. In turn, these complex subsystems again are decomposed into simpler parts etc. This process continues until all complex subsystems will be represented by the set of simple elements.

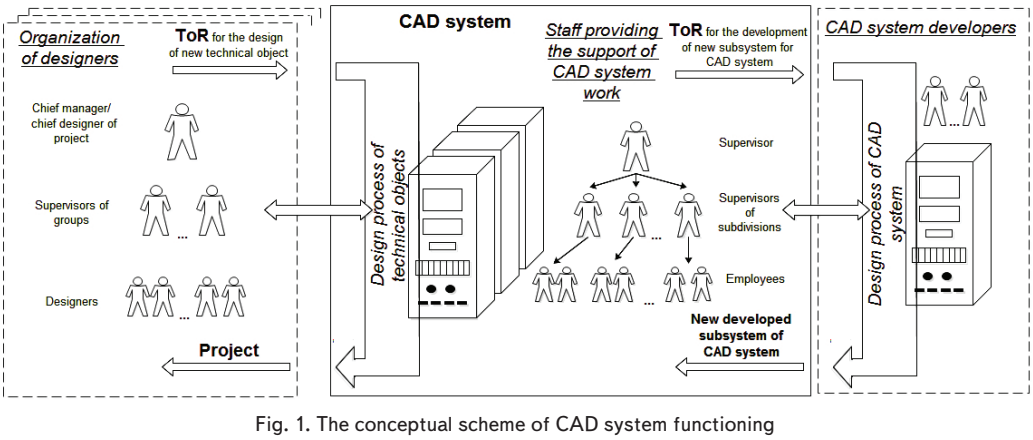

Fig. 1. The conceptual scheme of CAD system functioning

Components descriptions with both known and unknown parameters can be at any step of the decomposition. If the components descriptions contain defined parameters, they are completed design results. Unknown parameters of the components descriptions are defined from a mathematical model of the designed component by the parametric synthesis. Thus, by the results of each step of the decomposition of the designed object description, we have specific values of all parameters, which are used. At this stage the following three variants are possible:

1) the formed component description corresponds to an available product (a detail, a node, a mechanism, a unit etc.); the development process stops and the project gets the link on it;

2) the formed component description corresponds to a certain detail; the design process comes to the end and the ToR for the constructive processing of the detail is formed;

3) the formed component description corresponds to a subsystem, the structure of which meanwhile is unknown; the ToR for its design is formed; the parameters of this ToR have already passed the system verification of the conformity of the designed component to its suprasystem.

Each design solution that implements the specified ToR and includes chosen components and their parameters, is recorded in one or more design documents of the same or different types, the quantity of which is limited (drawings, text documents, electronic models etc.). The design solution is checked, evaluated and approved through the documents.

Manufacturing task is formed for the development of each document. Corresponding employee is assigned to perform each manufacturing task. The latter is implemented during the manufacturing operation. Each manufacturing operation, which includes the performance of design works, has its own deadline. Some of them can be finished in a few hours; others can last for several working shifts etc. Each manufacturing operation is formed by the corresponding manager in the proposed system with the possibility of its editing.

Other components of CAD system (software, hardware, methodological and other types of support), as well as involved staff, do not create complications for the formation of their information descriptions. They are generally presented by the examples in works on databases [18, 19].

On the basis of the performed design process analysis, the following model of information support of this process was made (Fig. 2).

Archive (Fig. 2, Archive) is a place of access to project information for the purpose of support of all subsequent stages of a technical object life cycle. The ToR (Fig. 2, ToR) is recorded in the system and reduced to the form, which is acceptable in the selected information technology of design. By the design results the complete description of the designed object is formed with the use of a package of applied design programs (Fig. 2, unit A) and is transferred to a current status of the project (Fig. 2, CPrS). This process is controlled and managed. Then the design documentation of the completed project (Fig. 2, IPr) is formed. According to the ToR requirements the description of the designed object is transformed to the form, which the customer requires and is transferred to him as the design documentation (Fig. 2, DD).

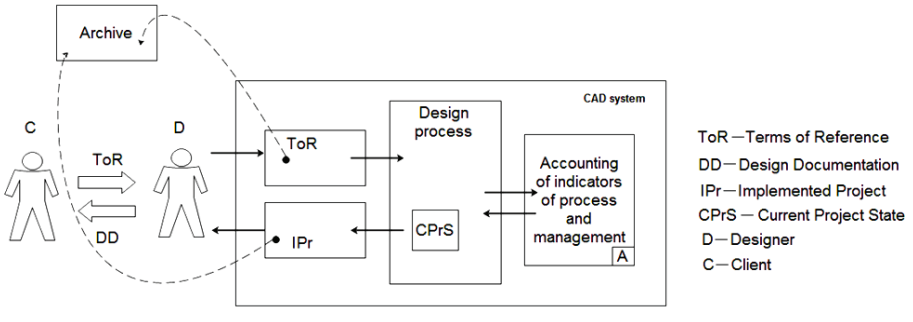

Fig. 2. Conceptual model of information flows during the design using CAD system

4. 2. Organization of Interaction between Users and System

Each user logs in the CAD system using the client program (ClP). Users have their own status in the CAD system. According to this, the system provides them with various powers and the certain opportunities.

Fig. 3 shows the general scheme of the organization of interaction between users and the CAD system by displaying the basic information flows. Hereinafter numbers of information flows are presented in the parentheses.

Each user's request (1) to the system is recorded in a log-book LB.

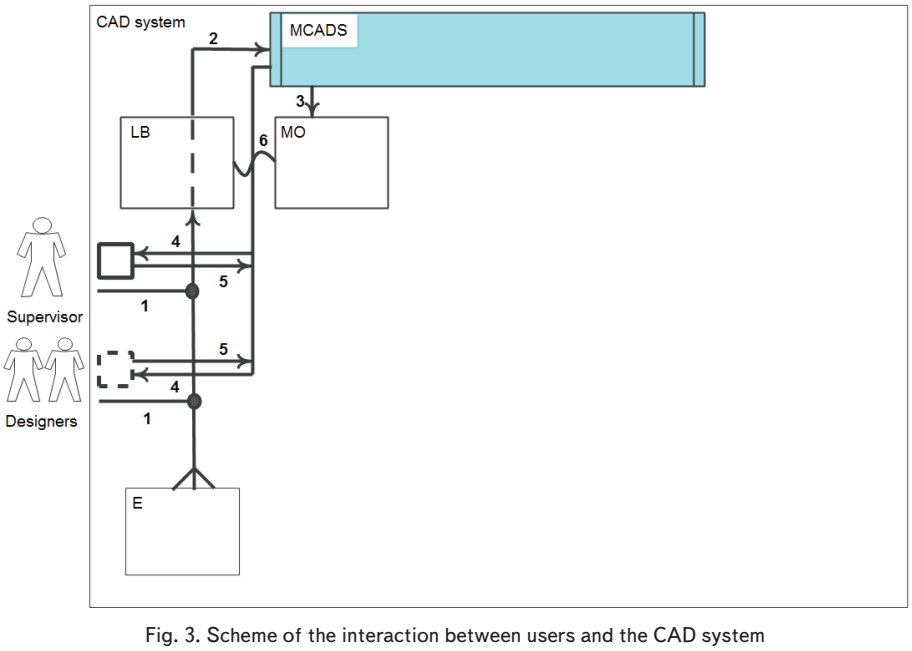

Fig. 3. Scheme of the interaction between users and the CAD system

The user can only declare about his manufacturing activity (that he is available and ready for work) or can immediately make a request for receiving his established tasks for performance or can report about the continuation of the performance of the postponed earlier design procedure.

This system receives the message from the user (2), analyzes the current tasks MO (3) and sends the interactive message (4) to the user through its control program MCADS.

In response to the result of the user's accepted decision (5), the CAD system provides the user with the opportunity to carry out the planned tasks. This decision is also recorded in a log-book LB (6).

It is quite clear that each of the user's new requests to the CAD system is accompanied by the process of his identification in the system, which happens in coordination with the information about performers of this design organization E.

4. 3. Organization of the Typical Design Operations Performance

Components of the CAD system, which are involved in the design operations performance, are shown in Fig. 4.

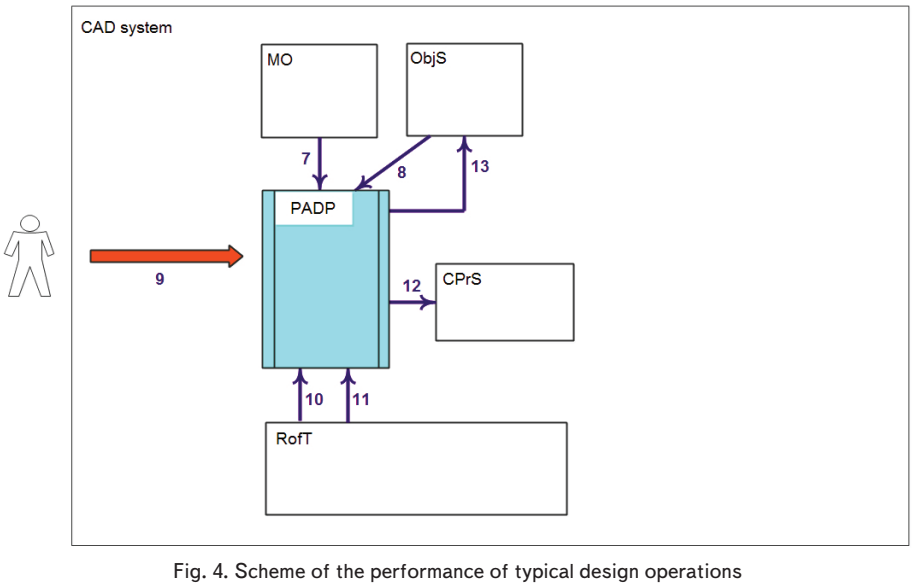

Fig. 4. Scheme of the performance of typical design operations

The user takes design operation for the performance, which is provided to him by the CAD system from the current tasks MO (7). He chooses the detailed description of a design assignment from the current state of the information description of the structure of the designed technical object (8). The user has the opportunity to influence the design process (9).

For the ToR implementation, the performer uses templates of the already processed typical design solutions (10), and templates of design documents (11), which are corresponding to them. All of them are available to the performer from the repository of templates RofT, where templates of design solutions models and templates of documents are stored. Parameters of the chosen variant of the design solution are brought into conformity to the ToR requirements by the impact (9), using one program from the package of applied design programs PADP, which is needed for the performance of the defined design operation. As a result, specific values of parameters are formed and transmitted (12) into the current project state repository CPrS also by the impact (9).

The CAD system automatically forms tasks for checking and approving of the design solution after receiving the user's message about its readiness.

Design operation receives the status «done» after making the decision about its approval. In case of existence of completed design components descriptions with defined parameters, they are replaced in the information description of the designed object structure ObjS (13). The updated current state of this structural description allows the chief designer of the project to analyze the progress of the design process performance.

4. 4. Organization of the Atypical Design Operations Performance

4. 4. 1. Formation of the ToR

Processes of the main atypical design operations performance are presented in Fig. 5.

The new ToR is formed according to the conditions of the CAD system or, otherwise, the available ToR can be converted to the form, which is corresponding to the requirements of the accepted design technology and to the information description. In this case, the designer (9) uses all needed templates (10), (11) from the repository of templates RofT for the ToR formation.

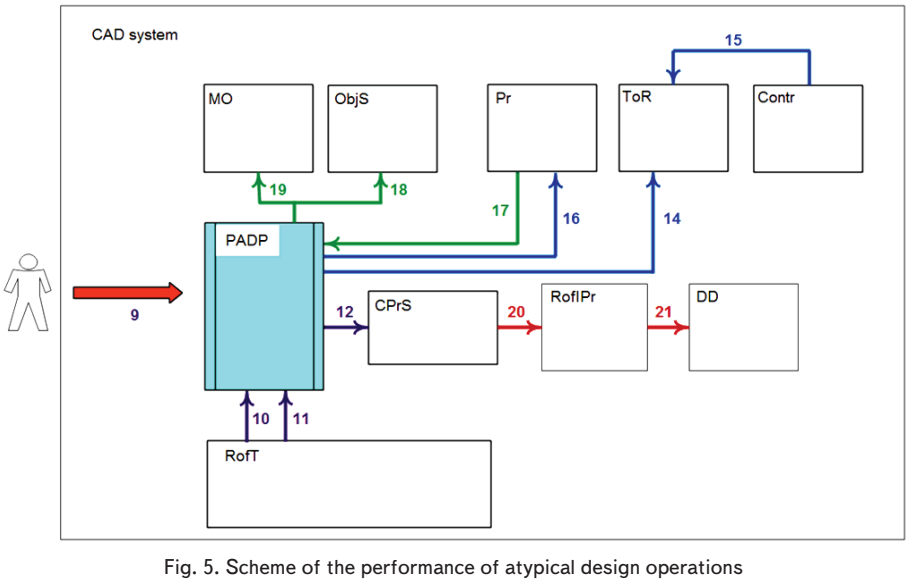

Fig. 5. Scheme of the performance of atypical design operations

And after the corresponding actions (editing, negotiations with the client etc.), he fills in the ToR templates and transmits (12) into the current project state repository CPrS. After the corresponding concordances and approval, and after its conversion to the accepted form, the ToR becomes the normative document and is transferred (20) to the repository of documents of implemented projects RofIPr for storing and, if necessary, is added to a package of the design documentation DD.

In case of a contract acceptance for the implementation, the requirements of the designed technical object are transferred to the Terms of Reference structure ToR (14) along with the main contract requirements (15) to the contract structure Contr and the new project is initiated and described (16) in the project structure Pr.

4. 4. 2. Formation of an Initial Project State

If the project is approved for development or an additional element is added to its structure, using this information (Fig. 5) (17) from the project structure Pr, the manager with certain powers adds (18) new elements to the information description of the designed technical object structure Objs and forms the corresponding manufacturing operations (19) in the current tasks MO for the planning of their implementation.

4. 4. 3. Formation of tasks for performance of simple design operations

Simple design operations are considered as those that don't lead to structural changes in the designed technical object and don't require modeling performance.

The new document is added to the project structure Pr (16), and the corresponding additional manufacturing operation is added (19) to the current tasks MO.

If all design solutions of the project are approved and the ToR for performance is absent, the project is considered as implemented and all its contents are transferred (20) into the repository of documents of implemented projects RofIPr, where all approved models and documents of projects are stored. For external use necessary documents are selected and the set of design documentation DD of the certain project is prepared (21).

5. Information models of main types of CAD system supports

The software of the proposed system consists of the programs set, seen in Eq. (1), which are necessary for its functioning:

$$SW = ClP \cup MCADS \cup PADPS, \quad (1)$$

where SW – description of the CAD system software; ClP – client program; MCADS – control program «Monitoring of CAD system»; PADP – package of applied design programs.

The information support (IS) of this CAD system consists of a set of system and applied IS, shown in Eq. (2):

$$IS = sIS \cup aIS, \quad (2)$$

where IS – description of the CAD system information support; sIS – system information support; aIS – applied information support.

As the applied information support aIS concerns the description of particular designed objects, it has individual and specific character and in this paper isn't considered. Fig. 3–5 show the application of information support and connections between its components. It is involved during the performance, maintenance and management of each of the projects. This information support makes the system information support of the system for design works automation. It provides the efficiency of the system, which architecture is offered. In general, the complete description of this system information support is given by the Eq. (3):

$$sIS = ToR \cup Contr \cup Pr \cup ObjS \cup MO \cup \cup CPrS \cup RofT \cup RofIPr \cup E \cup LB, \quad (3)$$

where ToR – Terms of Reference; Contr – contracts; Pr – projects; ObjS – structural description of the designed technical object; MO – manufacturing operations; CPrS – current project state; RofT – repository of templates; RofIPr – repository of documents of implemented projects; E – users (experts); LB – log-book.

6. Discussion of the proposed architectural solution of CAD system

The mutually agreed solution that provides the automation of the main types of works of the design documentation development by CAD system means is received. At the same time the implementation of monitoring of the progress of each manufacturing operation performance, for the purpose of reasonable management of this process as the manufacturing process is provided. These functions aren't inherent to the existing design systems yet, and are implemented by means of separate systems. Thus, such situation doesn't provide the declared unity of information space even within one stage of the technical object lifecycle – design.

The proposed solution involves the use existing or better specialized software and information support for the automation of specific design operations. From the point of view of the design process management it is provided to perform the functions of the project management (Project Management), the project data management (Project Data Management) and works flows (Work Flow) using a single platform.

This organization of the CAD system functioning as the organizational system can be used for implementation of the system for automation of the technological documents development.

7. Conclusions

As a result of the performed researches it is found that little attention is paid to the issues of management of the design works computerization. To implement the possibilities of the design process management the following tasks were solved.

1. System analysis of the design process of technical objects for the purpose of development of the system for the design works automation is carried out. The connections of the system for the design works automation with the external environment that allow both to perform the design and to improve and develop the system itself are offered. The need of existence of three software types for the system functioning is set: the client program for interaction between a designer and

the system, the monitoring program for tracking of a system status and the package of applied design programs, which implement the process of the design works computerization.

2. The reasonable performance of design works using the «top-down» scheme is presented. According to it each object is designed as a system. Each subsystem involved in a project must consist of the ToR for its design.

3. The information model for the design process support is composed. This model supports the structure of the technical objects projects and provides the formalization of the design process description.

Thus, at the conceptual level the architectural solution of the system for design works automation at organizations is received.

References

1. Petrenko, A. I. Osnovi porstroenija sistem avtomatizirovannogo proektirovanija [Text] / A. I. Petrenko, O. I. Semenkov. – Kyiv: Vishha shkola, 1985. – 294 p.
2. Pedagopu, V. M. Integration of CAD/CAPP/CAM/CNC to Augment the Efficiency of CIM [Text] / V. M. Pedagopu, M. Kumar Adejuyigbe // International Review of Applied Engineering Research. – 2014. – Vol. 4. – P. 171–176.
3. Miyazaki, T. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience [Text] / T. Miyazaki, Y. Hotta, J. Kunii, S. Kuriyama, Y. Tamaki // Dental materials journal. – 2009. – Vol. 28, Issue 1. – P. 44–56. doi: 10.4012/dmj.28.44
4. Kim, J. Standardized data exchange of CAD models with design intent [Text] / J. Kim, M. Pratt, R. G. Iyer, R. D. Sriram // Computer-Aided Design. – 2008. – Vol. 40, Issue 7. – P. 760–777. doi: 10.1016/j.cad.2007.06.014
5. Mao, X. Construction process reengineering by integrating lean principles and computer simulation techniques [Text] / X. Mao, X. Zhang // Journal of Construction Engineering and Management. – 2008. – Vol. 134, Issue 5. – P. 371–381. doi: 10.1061/(asce)0733-9364(2008)134:5(371)
6. Park, Y. Product architecture, organizational capabilities and IT integration for competitive advantage [Text] / Y. Park, T. Fujimoto, P. Hong // International Journal of Information Management. – 2012. – Vol. 32, Issue 5. – P. 479–488. doi: 10.1016/j.ijinfomgt.2011.12.002
7. Korpyljov, D. The structure of web-oriented cad system for microelectronic devices of designing [Text] / D. Korpyljov, S. Tkachenko // Visnyk Natsional'noho universytetu «L'vivs'ka politekhnika». Komp»yuterni systemy proektuvannya. Teoriya i praktyka. – 2013. – Vol. 777. – P. 61–65.
8. Cheng, J. C. WEB-ENABLED MODEL-BASED CAD for the architecture, engineering and construction industry [Text] / J. C. Cheng, K. Law, Y. Zhang, C. S. Han // Proceedings of the first international conference on sustainable urbanization (ICSU 2010), 2010. – P. 1199–1208.
9. Waldenmeyer, K. M. Multiple CAD Formats in a Single Product Data Management System: A Case Study [Text] / K. M. Waldenmeyer // Journal of Industrial Technology. – 2009. – Vol. 25. – P. 1–7.
10. Kohlhase, M. Knowledge management for systematic engineering design in CAD systems [Text] / M. Kohlhase // Professionelles Wissenmanagement. – 2013. – Vol. 7. – P. 202–217.
11. Encarnacao, J. Computer Aided Design: Fundamentals and System Architectures [Text] / J. Encarnacao, R. Lindner, E. G. Schlechtendahl. – Springer Science & Business Media, 1990. doi: 10.1007/978-3-642-84054-8
12. Norenkov, I. P. Osnovyi teorii i postroeniya SAPR [Text] / I. P. Norenkov, V. B. Manichev. – Moscow: Vyisshaya shkola, 1990.
13. Kunwoo, L. Principles of CAD/CAM/CAE Systems [Text] / L. Kunwoo. – Assison Wesley Longman Inc., 1999. – 640 p.
14. Norenkov, I. P. Osnovy avtomatizirovannogo proektirovanija [Text] / I. P. Norenkov. – Moscow: Izd-vo MGTU im. N. E. Baumana, 2002.
15. Gunasekaran, A. Techniques and Tools for the Design and Implementation of Enterprise Information Systems. Vol. 2 [Text] / A. Gunasekaran. – IGI Global, 2008. – 408 p.
16. Bauer, E. Design for Reliability. Information and Computer-Based Systems [Text] / E. Bauer. – IEEE Press, 2010. – 348 p.
17. Zhuk, K. D. Postroenie sovremennyh sistem avtomatizirovannogo proektirovanija [Text] / K. D. Zhuk, A. A. Timchenko, A. A. Rodionov. – Kyiv: Tehnika, 1983. – 250 p.
18. Coronel, C. Database systems: design, implementation, & management [Text] / C. Coronel, S. Morris, – Cengage Learning, 2008. – 832 p.
19. Teorey, T. Database Modeling and Design: Logical Design [Text] / T. Teorey, S. Lightstone, T. Nadeau, H. V. Jagadish. – Elsevier, 2011. – 352 p.