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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF AN AGENT-BASED ARCHITECTURAL AUTOMATED DESIGN SYSTEM OF FLEXIBLE PRODUCTION SYSTEMS

Specialty: 3338.01 – "System analysis, management and information processing (information technologies)"

Field of science: Technical sciences

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and degree of development.

Relevance of the dissertation work. Currently, mechanical engineering automated design systems, which are widely used in the design process, have an architecture based on classical principles, covering all areas of engineering activity. These classical principles, planned for the complex design and production of any intended types of products, do not fully meet the modern requirements for design processes and systems. This in itself does not ensure the receipt of high-quality design solutions and at the same time leads to an increase in the time spent on the design process and a decrease in productivity. It is from this point of view that the use of qualitatively new design rules necessitates a comprehensive update of the automated design system itself, changes in its architecture. The analysis and research conducted show that in order to achieve a successful solution to the above problems, it is important to apply the ideas, methods and tools of artificial intelligence to all possible stages of the design process. In other words, the capabilities of currently used automated design systems should be increased and their levels of intelligence should be raised by using and applying modern software systems and artificial intelligence elements and methods. For this, the internal and external intelligence of existing CAD should be increased by applying artificial intelligence tools.

The development of intelligent tools is currently very relevant in order to increase the efficiency and productivity of the mechanical engineering design process. At the same time, the knowledge base with a multi-level structure and knowledge representation models, which constitute the core of intellectual methods and tools, are widely used. In this regard, it is proposed to build distributed intelligent systems with a hybrid architecture that combines the properties of both agent and component architectures. Also, the methodology of a multi-agent system has been adopted to build an automated system for the conceptual modeling stage of the design process of technical systems,

which is based on knowledge and a knowledge base. The use of a knowledge-based multi-agent system and, at the same time, multi-agent system technology allows building a distributed parallel design system.

Analysis of flexible manufacturing systems and currently used examples show that the diversity, complexity and insufficient accuracy of the standard and non-standard elements and nodes that make up it make it relevant to develop an automated design system with an agent-oriented architecture that provides high-precision design and construction of flexible manufacturing systems.

The purpose of the dissertation work. It consists in the development of an intelligent automated design system with an agent-oriented architecture in order to increase the intellectuality of the design process of flexible manufacturing systems. To achieve this goal, the following tasks were defined:

- the current state of automated design systems (CAD systems) has been analyzed and the levels of their application to the design process have been determined;

- the application of multiagent technologies and multiagent systems as an element of artificial intelligence to the automated design process of flexible manufacturing systems has been studied, the possibilities of addressing the identified shortcomings have been clarified and substantiated:

- the issues of organizing an agent-oriented multicomponent automated design system of flexible manufacturing systems based on CASE technology have been considered, the functional scheme of the system has been developed and the sequence of operations has been determined;

- the architecture of the agent-oriented application development system and the technological scheme of the agent-oriented application development process have been developed; mainly for modeling and development of the designer-agent and agents of various purposes, a designer-agent template has been organized, the stages of the agent activity cycles have been determined;

- the issues of organizing the knowledge base of automated design systems based on a distributed heterogeneous database have been considered and a multiagent system has been developed for organizing the knowledge base;

- the algorithm for designing multiagent systems has been developed using a unified modeling language.

Research methods. Methods and rules for developing approaches, models, algorithms, etc. have been taken as the object of research for the purpose of developing an automated design system with an agent-oriented architecture of flexible manufacturing systems. To solve the above-mentioned problems, modern modeling devices, artificial intelligence elements and methods, the concept of a knowledge base, the theory of algorithmization, modern programming tools, software systems, etc. have been used.

✓ The main provisions put forward for defense:

✓ Identification of shortcomings of modern CAD systems and identification of issues and design procedures that are difficult to formulate in the design process of flexible manufacturing systems;

✓ Rules for substantiating the application of multiagent technologies and systems as an element of artificial intelligence to the automated design process in order to increase the intellectuality of design operations and procedures;

✓ Definition of the agent concept and the main characteristics of multiagent systems;

✓ Structural scheme of an automated design system based on agent-oriented architecture;

✓ Algorithm for organizing multiagent automated design systems of mechanical engineering parts based on CASE technology;

✓ Procedure for developing a multiagent system for organizing a knowledge base based on a distributed heterogeneous database;

✓ Development of a algorithm for agent-oriented design of non-standard elements that are part of flexible manufacturing systems;

✓ Procedure for designing a multiagent system using a unified modeling language.

✓ Scientific novelty of the research. The scientific innovations obtained as a result of the conducted research are as follows:

✓ The possibilities of applying artificial intelligence methods and tools, including agent technology and multiagent systems to CAD systems, have been studied and substantiated in order to increase the intellectuality of automated design systems;

✓ The complex formalized design operations and procedures of flexible manufacturing systems have been determined;

✓ The architecture of an agent-oriented multicomponent automated design system has been developed and its subsystems have been determined in order to increase the intellectuality of the design process of technical systems related to the mechanical engineering industry, including flexible manufacturing systems;

✓ The functional scheme of organizing a multiagent automated design system of flexible manufacturing systems based on CASE technology has been developed;

✓ An algorithm for organizing a knowledge base based on a distributed heterogeneous database has been developed;

✓ Algorithms for searching for standard elements in the composition of flexible manufacturing systems and designing non-standard elements have been developed.

Theoretical and practical significance of the research. By applying new software additions to automated design systems, the intellectualization of design procedures and operations has been increased. In order to increase the intellectualization of software packages, various software agents have been developed as an element of artificial intelligence, and the technology of using software packages has been updated. It has become possible to apply software agents applied to various application areas, especially flexible production systems, to this type of production processes.

Approbation and application of the dissertation work. The theoretical provisions and practical results of the work obtained in the work were discussed and reported at international and republican conferences: “Modern Problems of Automation and Control”

Republican Scientific and Practical Conference, AzTU, Baku, 2012, pp. 121-124; II International Scientific and Practical Conference, Krasnoyarsk, 2015, pp. 21-24; III Republican Scientific Conference on Applied Fields of Mathematics and New Information Technologies, Sumgayit, 2016, pp. 312-313; "Ufa State Petroleum Technical University" // International Scientific and Technical Conference of Postgraduate Students and Young Scientists "Science. Technology. Production", Salavat, 2017, pp. 299-301; ,pp. 299-301; Current Issues of Applied and Energy, Materials of the International Scientific Conference, Baku, 2018, pp. 381-383; Materials of the XXIII Republican Scientific Conference of Doctoral Students and Young Researchers, Azerbaijan University of Architecture and Construction, Baku, 2019, pp. 227-229; Information Systems and Technologies Achievements and Prospects II International Scientific Conference, Sumgayit, 2020, pp. 172-174; Information Systems and Technologies Achievements and Prospects II International Scientific Conference, Sumgayit, 2020, pp. 272-275; Materials of the International Eastern Conference on “Human-Computer Interaction”, II International Scientific Conference, Nakhchivan, 2022, pp. 108-110; III International Scientific Conference on Information Systems and Technologies: Achievements and Prospects, Sumgayit, 2022, pp. 347-348.

Name of the organization where the dissertation was conducted. The dissertation was carried out at the Department of Digital Technologies of Sumgayit State University.

Scope of the dissertation. The dissertation consists of an introduction, three chapters, a bibliography of 124 sources, 26 figures and tables, and comprises 230,659 characters.

The introduction provides detailed information about the relevance and modernity of the topic of the presented dissertation, and the main characteristic features of the work are noted. The purpose of the dissertation work, the issues that need to be solved, and detailed information on the research methods, the main provisions put forward for defense, the scientific innovations of the research conducted, the theoretical and practical significance of the research conducted, the

approval of the dissertation work and its application areas are provided.

The first chapter of the dissertation analyzes the feasibility and current state of integrating intelligent tools—specifically artificial intelligence methods and techniques—into modern computer-aided design (CAD) systems. To this end, the architectures of widely used CAD systems were examined, their applicability across various domains was explored, and their respective strengths and limitations were identified. It is noted that the complex structure of modern CAD systems, their reliance on classical architectural principles, and various other shortcomings hinder the flexible and rapid execution of procedures within these automated design systems.

In this context, an overview is provided of the current state of applying intelligent tools to design procedures, the generation of design solutions, and automated design systems in general. Furthermore, the integration of multi-agent systems and agent technology—as elements of artificial intelligence—into design processes is justified as a means to enhance the intelligence of CAD systems. With the aim of enhancing the intelligence of design procedures, this work analyzes the development and modeling of designer-agents—each with a specific purpose—utilizing multi-agent technology. It further explores the creation of new communication links and their integration into CAD systems. Additionally, the first chapter examines the current state, application domains, potential for use in software development, and future development prospects of agent technology, multi-agent technology, and multi-agent systems.

The second chapter presents the structural scheme of an agent-oriented, multi-component automated design system—designed for the automated design of flexible manufacturing systems—and defines the communication links facilitating information exchange between its elements. Furthermore, it outlines the core characteristics and features of the agent concept (as a component within such a system) and agent-based automated design systems, while also explaining their operational principles. Furthermore, the study addresses the definition of the architecture for developing agent-based add-ons designed to

enhance the intelligence of CAD systems. By adopting an architecture grounded in knowledge-processing methods and principles, a technological framework for the development of such agent-based add-ons has been established. The stages of an agent's operational lifecycle have also been defined. It is noted that, in order to expand the intelligence and capabilities of design systems, it is advantageous to develop agent-based add-ons that utilize knowledge bases within automated design systems. This chapter identifies the goals and functions of various design agents—each with a specific purpose—that constitute the architecture of a multi-component, agent-based automated design system.

The third chapter examines the modeling of components within an automated design system based on agent-oriented technology, as well as the organization and implementation of information connectivity among these components. To this end, the key aspects of designing multi-agent systems using unified modeling languages are defined, establishing the architecture for both autonomous agents and the multi-agent system as a whole. The architecture of a reactive agent is developed using the diagrammatic notation of a unified modeling language. Given that a flexible manufacturing system is used as the application domain, the study addresses the agent-based design of non-standard elements within such a system. Furthermore, the research examines the extraction of knowledge from databases—constructed based on data and specifications frequently utilized in engineering design—as well as the development of a multi-agent system designed to organize a knowledge base derived from distributed, heterogeneous databases. An algorithm for extracting knowledge from databases has been developed.

Depending on the chosen concept for organizing multi-agent systems, three fundamental architectural classes are typically distinguished:

- architectures based on methods and principles for handling knowledge;

- architectures based on "stimulus-response" models;

- hybrid architectures. In the cases under consideration, work is carried out involving "intelligent" agents and architectures that design and implement models, methods, and tools for artificial intelligence—including intelligent automated design systems.

Many researchers believe that neither the first nor the second approach gives optimal results when developing agents and multiagent systems. Therefore, there is always an attempt to combine them, which has already led to the emergence of various forms of hybrid architectures. Currently, hybrid architecture is used in all relatively valuable projects and systems.

It should be noted that the development of multiagent systems and real intelligent agents requires special knowledge and is a complex and voluminous task. Therefore, software agents are a new class of software systems that act on the instructions of the user. If the development and implementation of software agents had not been carried out, it would probably not have been possible to master the concept of open systems and use the experience of developing them. In practice, one of the results of the application of the concept of open systems is the “client-server” architecture, which is widespread. This architecture can be successfully used when creating multiagent systems.

Currently, the following client-server interaction models are used:

- the server part only implements access to resources, the main part of the application belongs to the client;
- the client application provides the implementation of the interface, and the server connects the remaining parts of the application. This model is actively used in connection with the widespread use of Internet technology, primarily in Web browsers.

Regardless of the model used, the development and organization of distributed applications, which are considered multiagent, are based on a static and dynamic approach (providing the possibility of transferring the executed code).

The dynamic approach to a multiagent system application uses the mobile agent paradigm.

Mobile agents are programs that can be deployed on networks, for example, on the WWW, they leave the client computer, are located on remote servers to perform their work, and then return. A number of authors note that mobile agents pose a threat in terms of information confidentiality and network load.

Currently, there are no unified standards for the development of mobile agents, and a number of problems remain unresolved: the deployment of agents in networks in accordance with legal regulations, verification of agents (in particular, protection against viruses transmitted via the network), protection of private property rights by agents, confidentiality of information.

If we return to the issue of multiagent systems, then at the modern stage, software tools for their development and implementation can be divided into two large groups: multiagent system libraries and multiagent system tools.

The multiagent library is considered the basis for organizing multiagent applications. Here, models, methods and tools that assist in the process of designing agents and multiagent systems are considered. An example of this class is the Agent Builder tool.

Reticular Systems, Inc.'s tools for building multiagent systems consist of two components: development tools and an implementation environment.

The first component is aimed at analyzing the subject area of the organized multiagent system and supporting the process of designing an agent of a given nature.

The second provides an efficient environment for executing agent-oriented programs. This or that component is implemented in the Java language and runs on any computer with a Java environment. Agent programs designed within the Agent Builder framework are also Java programs and can be executed on any computer.

A general diagram of the process of designing and implementing agent-oriented applications is given in Figure 1.

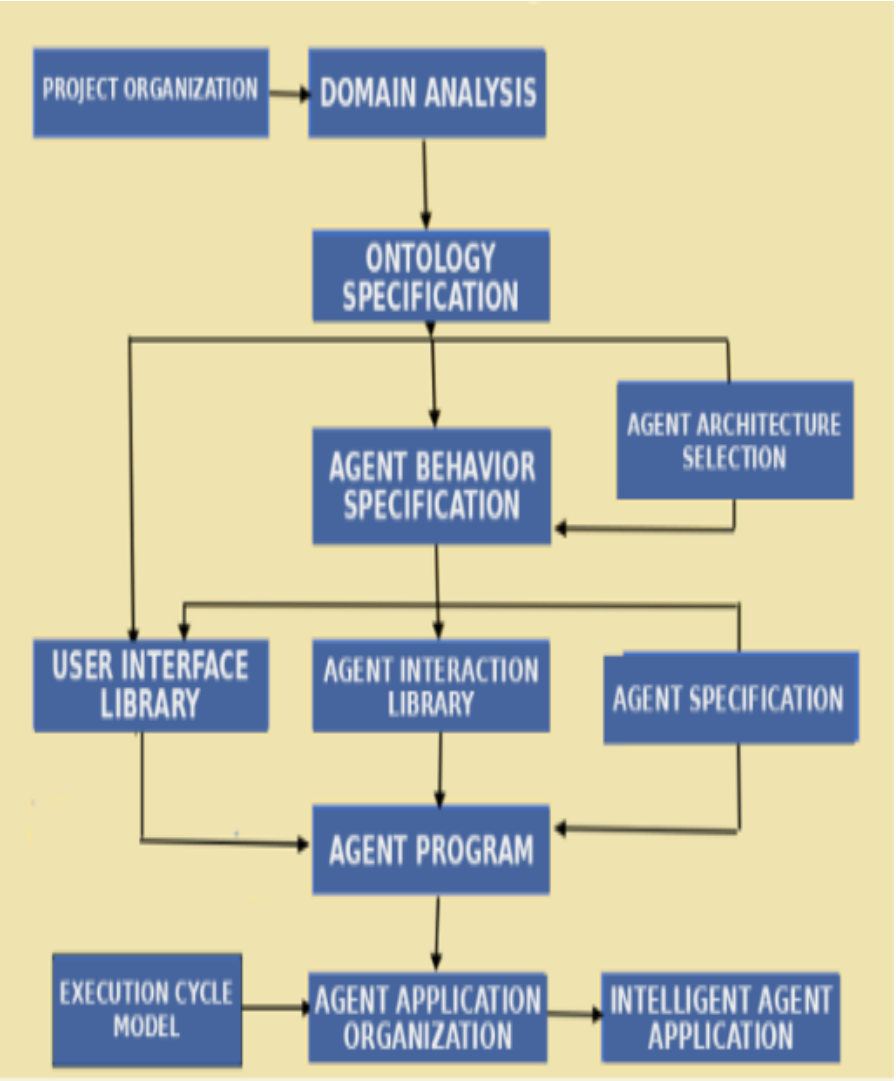


Figure 1. Technological scheme of the agent-oriented additive development process.

These tools provide facilities for organizing a multi-agent system, specifying its architecture and agent behavior, configuring agent extensions, and monitoring the activities of the agents.[9].

The model of the “activity cycle” of agents developed within the Agent Builder framework is depicted in Figure 2. From the given scheme, it follows that the standard “activity cycle” of an agent includes the following main steps:

- processing new information;
- determining the application of the behavior rule in the current situation;
- performing the actions specified by these rules;
- updating mental models in accordance with the given rules;
- planning.

In the Agent Builder system, special object-oriented languages are used for the specification of agent behavior. In this language, the behavior rule can be viewed as a WHEN – IF – THEN construction.

WHEN – is the part of the rule that addresses new events that arise around the agent and includes new information received from other agents.

IF – the part of the comparison of the current mental model with the condition for applying the rule.

THEN – the part that determines the effect on the current event and the state of the mental model, the response to the environment.

A specific file is created regarding the agents' behavior and their mental models; this file is utilized—along with an interface library—by employing classes and methods from the agent's action library.

In light of the above, it can be noted that the use of tools and methods aimed at substantiating the design process for artificial

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[9] M.R.Səlimova, P.Ə.İbrahimova. Avtomatlaşdirilmiş layihələndirmədə agent yönümlü əlavənin işlənmə texnologiyası. İnformasiya sistemləri və texnologiyalar nailiyyətlər və perspektivlər beynəlxalq elmi konfransin materiallari,Sumqayıt. 2018. S.381-383

intelligence software agents and multi-agent systems is highly relevant in current efforts regarding the organization of such tools.

Consequently, the development of new-generation technologies for organizing multi-agent systems can be addressed by drawing upon both the research experience in multi-agent systems and the methodology for knowledge processing within artificial intelligence. In this context, it is primarily necessary to adapt the methods and tools used for designing and implementing applied intelligent systems to the new subject domain (i.e., the development of new-generation multi-agent systems).

Clearly, the specification of the development process for multi-agent systems—based on methods for designing knowledge bases—entails the following for such technologies:

- a description of the multi-agent system's architecture (as it is being designed) within the knowledge base; - explicit specification of the architectures for various types of agents within the multi-agent system being designed;

- representation of the knowledge model—necessary for achieving the goals assigned to each agent—in the form of a specific knowledge base.

The analysis and research conducted indicate that enhancing the intelligence and capabilities of modern automated design systems is a highly significant issue, one that inevitably commands the attention of researchers.

To address this challenge, it is advisable to develop agent-oriented extensions—incorporating knowledge bases—when creating automated design systems[1]

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[1]Hüseynov A.H., Məmmədova M.R. Avtomatlaşdırılmış layihələndirmədə agentyönümlü əlavələrin işlənmə sistemlərin arxitekturasının təyini. SDU Elmi xəbərlər Təbiət və texniki elmlər bölməsi, Sumqayıt, 2011, №3

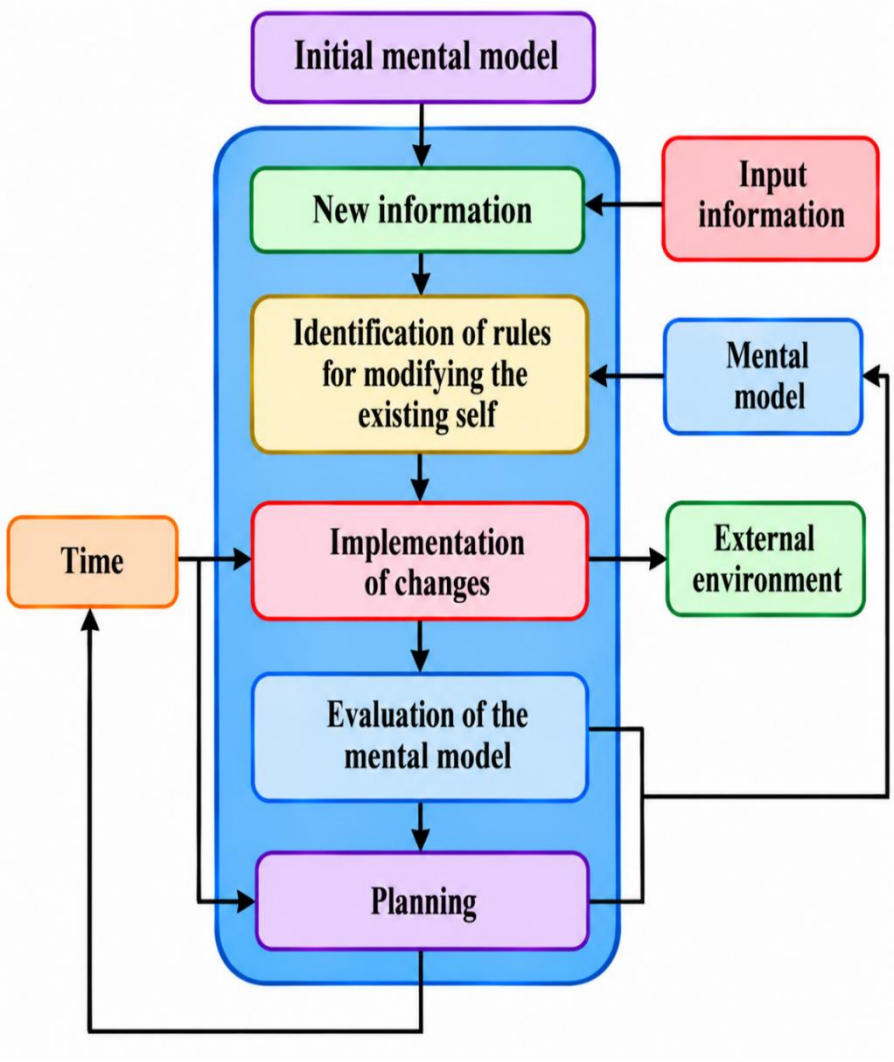


Figure 2. Model of the “activity cycle” of agents developed within the Agent Builder framework

An agent template with a three-level structure is proposed for the organization and programming of design agents (Figure 3). This structure encompasses the agent's initial and current states, its

behavior, and its coordination mechanisms. At the level of the agent's mental state, the base class "Intelligent Agent" provides mechanisms for knowledge management, commitment rules, capabilities, representations, and solution generation. At the behavioral level, the "Reactive Agent" class handles the calculation of commitment rules and the identification of solutions based on a model that satisfies specific constraints. The "Communication Agent" class level contains the means for the agent to interact with other components of the system.

The continuous evolution of information technology, combined with the complexity and frequent modifications inherent in the technical systems being designed, necessitates that the architecture of an Automated Design System (ADS) allow for the addition of new properties and components. Currently, the use of distributed object technology has become a practical necessity. However, existing conditions for component reuse are often insufficient. Therefore, adopting an agent-oriented architecture for the framework of an ADS is considered an appropriate approach. The advantage of a design system with an agent-oriented architecture is explained by the following characteristics:

- a structure based on agent technology that facilitates the integration of distributed objects and components;
- the use of information semantics at the knowledge level when organizing interactions based on specifications;
- the utilization of unique agent name registries and the services provided by agents within the system's functional specification;
- the capability to develop and extend agents based on a functional foundation.

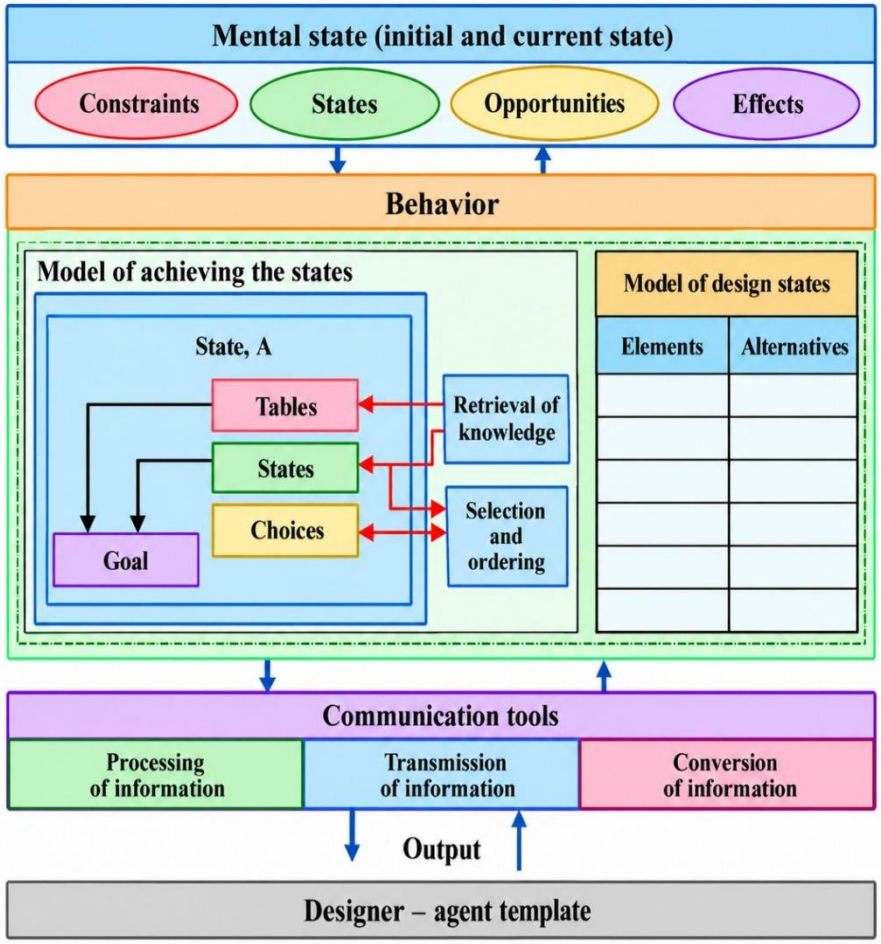
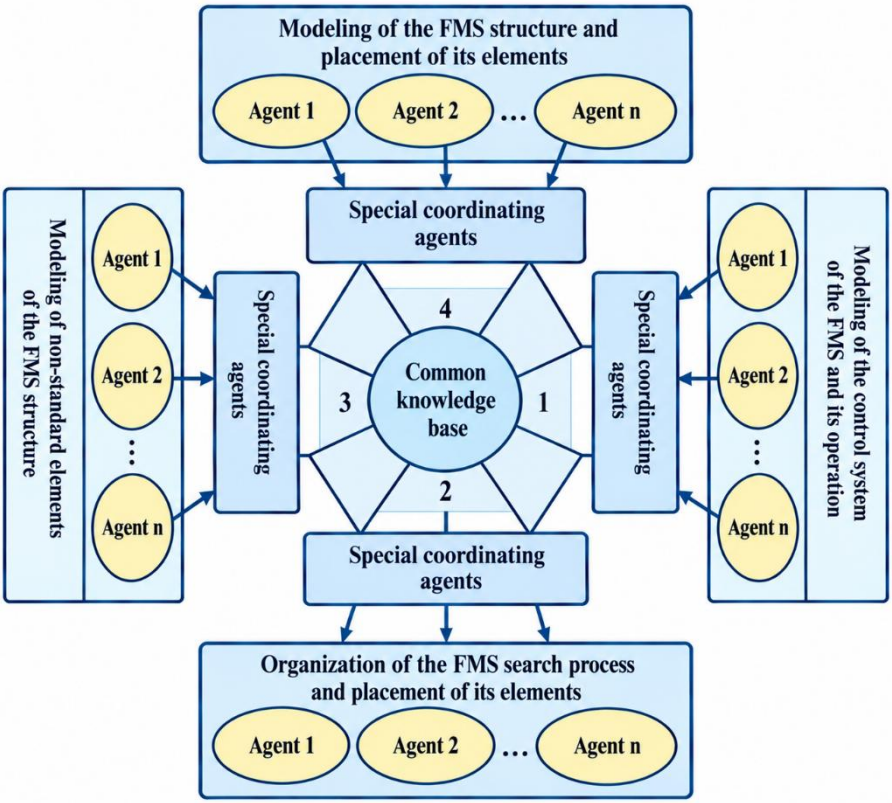


Figure 3. Project agent template

The interaction of agents at the knowledge level for the design of Intelligent Information Systems (IIS) offers significant advantages in the development of complex, multi-component, programmable Automated Information Systems (AIS). The agent-oriented architecture for multi-component AIS within IIS is presented in Figure 4.

As indicated by the architecture, specialized communication agents can be employed to organize the processing of data context among the aforementioned subsystems. These agents analyze the nature of the data and route it to other agents based on their specific knowledge or areas of interest.



1 – Specialized knowledge base for organizing the management system

2 – Specialized knowledge base for organizing the search process

3 – Knowledge base for automated design;

4 – Knowledge base for modeling and the placement of elements.

Figure 4. Architecture of an agent-oriented multi-component automated design system (ADS)

It is impossible to conceive of the development of modern, problem-oriented intelligent systems without appropriate CASE (Computer-Aided Software Engineering) technology[20]. In a broad sense, CASE technology encompasses the methodology for analysis, design, software development and maintenance, as well as a comprehensive suite of automation tools.

CASE technology, as described here, constitutes a system based on the science of systems—studying relationships, interlinking system elements, and analyzing the properties of these relationships that are critical to the system as a whole; the aforementioned components form its methodological foundation.

It should be noted that, in the process of systematization, the hierarchical classification of a system is based on hierarchical levels of knowledge. At the lowest level of this hierarchy, the characteristics of the system under design—and the interrelationships between its properties (variables)—are examined.

Subsequently, data is incorporated into the system; this is addressed at the next level, which is referred to as the "data system." Depending on the specific requirements regarding the data, it becomes possible to achieve the desired state for the system being designed. Higher levels encompass knowledge that defines the relationships between variables, facilitating the generation of data in accordance with initial and boundary conditions.

In the context of automated design, the subsequent level incorporates a knowledge base that generates the structure and properties of the information, as well as the values of variables defining the technological process—where the generation of properties corresponds to the realization of the process itself. Here, the state of the primary variables emerges from a set of parameters determined by various initial and boundary conditions.

[20] A.G. Guseynov, M.R. Salimova. An Agent-Oriented Approach to the Design of Flexible Manufacturing Systems. *Bulletin of the Astrakhan State Technical University. Series: Management, Computer Engineering, and Informatics*. 2022, No. 4.

This level is referred to as the "newly generated system level." At this subsequent stage, the generated system is defined by the preceding systems; sharing a set of common variables—or combinations thereof—it is designated as a subsystem of the overall system. Systems at this level are also known as "structured systems."

Systems of the fourth and higher levels consist of a set of lower-level systems. At the same time, they include metacharacteristics of lower-level systems (rules, relationships, procedures).

In a broad sense, technology is aimed at obtaining the necessary results, which include the work performed, and their implementation with the help of appropriate tools. For the implementation of each step, one or more methods are applied, which are also used to describe the results.

Figure 5 presents a functional diagram of the sequence of work performed, aimed at generating a methodological program complex of an applied multi-agent system.

The diagram indicates the names of the instrumental software tools used using the corresponding functional block axes.

At the initial stage of technology, issues of developing a metasystem project, which includes a set of all the details intended to be developed using a multi-agent automated design system, are considered and analyzed. The development of the metasystem is carried out with the help of a functional structural analysis of the applied area. This analysis is performed using a combination of methods based on IDEFO and IDEF1X standards.

Here, the functional decomposition of the assemblies constituting the object is presented. Each sub-function has its own specific implementation mechanism. For example, the transmission of mechanical energy is accomplished via shafts supported by bearing assemblies.

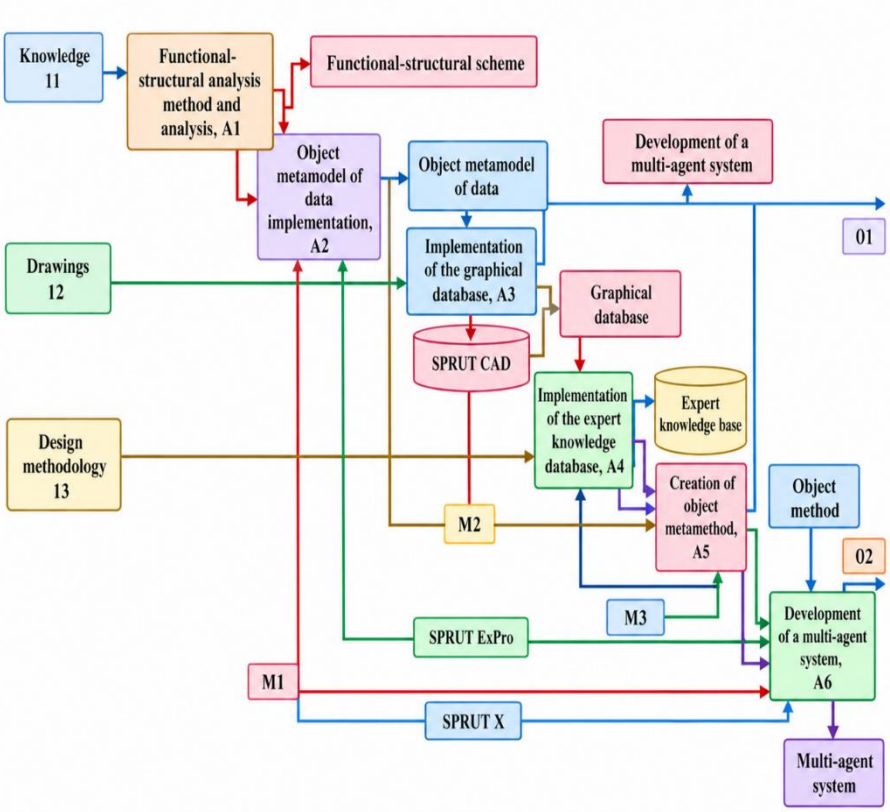


Figure 5. Functional diagram of the organization of a multi-agent automated design system using CASE technology.

Each structural element, in turn, has several implementation variants and consists of a collection of various structural components. The decomposition of a part's metamodel leads to the identification of its geometric form elements, which links the design of the technological process to a knowledge base. Through functional structural analysis, hierarchical structures and/or graphs are formed; these integrate all the input systems necessary for constructing a complex, multi-agent automated design system.

Parameters for standard parts (such as bearings, bolts, etc.) are stored in a database. Archives of previously designed products are also maintained within the database.

The next operation in the CASE methodology involves processing the metamodel data of the object.

When constructing metamodels, classes of objects are utilized as elements. A hierarchy of objects—based on a "whole-part" relationship—is defined by the inclusion of assemblies and individual parts within the product structure. The "whole-part" relationship defines the connection between specific object types. If the value of the "group" parameter is non-zero, the relationship between the object classes is of an "OR" type. Once the hierarchical structure of the data's object model has been developed, the next step involves defining the components, as well as the properties of the objects and their interrelationships. A comprehensive set of properties is both necessary and sufficient to address all design, technological, and management issues related to the production of items within the class under study. These properties include designations, mass, the material grade of a part, surface finish class, types of structural elements, and dimensions indicating the precision required for their fabrication, among others.

The established data metamodels define all elements contained within the interface component of the object classes. Consequently, this interface component allows for the tracking of the state of the design process.

The Sprut CAD system serves as the toolkit for developing the geometric and graphical foundations for the creation of technical drawings. It functions as an open design environment, designed to automate the work of engineers and researchers within the design system. A key feature of parameterization in the Sprut CAD system is that all geometric objects possess a dual representation: graphical and textual. As a result of the user's hierarchical actions, the program text in the Sprut language is automatically generated within the graphical window. The system ensures synchronization between the graphical and textual representations of each element.

The SprutExPro system serves as a tool for developing expert knowledge bases. It enables expert programming, allowing non-programmer specialists to create intelligent design and manufacturing systems; this increases productivity by a factor of 7 to 10 compared to that of a professional specialist. Expert programming is based on representing knowledge in the form of functional blocks, which can be termed "object-functions." Graphically, such an object-function can be depicted as a rectangle, where each of the four sides has a specific purpose: the left side represents the input, the right side the output, the top side the control, and the bottom side the mechanism.

Conditions define the input and control parameters, as well as the domain of the function implemented by the module.

Methods for handling unstructured knowledge within a given application domain—analogous to production-based knowledge bases in artificial intelligence—constitute the knowledge base for that domain, which is then utilized within the expert system. The knowledge module mechanism must ensure the implementation of all functions that may be required during the organization of a knowledge base.

A subsequent operation in organizing the object metamodel involves linking (associating) a method with an object, a task performed using Sprut X. During this linking process, the input and output variables of the method are associated with the corresponding object. Methods facilitate the following: performing necessary engineering calculations; selecting standard or procured components; generating 3D models and technical drawings (where required); and designing the manufacturing processes for parts and assembly units.

The final operation in the CASE-technology-based organization of a multi-agent automated design system (ADS) is the generation of the system's application interface. This generation is carried out in a semi-automatic mode, based on the development of the product's object metamodel. The interface is simulation-based and consists of a minimal set of control elements. The resulting application system differs from other design technologies in terms of productivity and is capable of operating in a fully automatic mode. As an example,

it can be noted that the external description of a module whose data is stored in a knowledge base is presented as follows:

Module: M1.

Designer: Salimova M.R.

Name: Calculation of the diameter of the shaft.

Source of information: Anurev V.I. Handbook designer, T2, ctr.9.

If this knowledge module is interpreted as a production rule, it can be represented by the following statement:

"**If the shaft has a solid cross-section, the bending moment (BM) is greater than 0 and less than 95,000 N·mm, and the allowable bending stress satisfies the condition 0.6 MPa < [σ] ≤ 0.95 MPa, then the shaft diameter is determined using the formula d0=BM/(0.1[σ])3d_0 = \sqrt[3]{BM/(0.1[\sigma])}."**

Once the modules of the expert knowledge base have been developed, the methods that utilize these modules are generated. It should be noted that in SprutExPro, the generation of methods is performed automatically. It is sufficient to simply select the module required to solve the problem; the system itself determines the necessary set of input data and generates the program for the method. The set of output parameters is selected from the variables defined within the generated method.

Multi-criteria evaluation mechanism for a design agent. Analysis indicates that a key aspect of a design agent's activity is the multi-criteria evaluation of design solutions obtained through a search process. In accordance with the design task, the design agent conducts a search for design solutions based on several parameters and evaluates the results of this search. Design solutions corresponding to varying numbers of parameters may be generated; however, the mere existence of these solutions does not imply that they are all equally suitable. Therefore, it is necessary to implement an automated evaluation mechanism to compare design solutions and select the most appropriate options.

The evaluation process is based on the significance of each parameter, expressed through a pre-determined weighting coefficient.

This coefficient indicates the relative importance of a specific parameter within the overall assessment of a design solution. Since the parameters may have different levels of significance, their respective contributions to the final outcome also vary. Thus, instead of considering all criteria as having equal weight, the project evaluator incorporates the relative importance of each parameter—based on the requirements of the project brief—into the evaluation process.

It is necessary to distinguish between two concepts here: the *weight coefficient* of a parameter, which represents its importance, and the *final project score*, which reflects the overall evaluation result for a specific project across all considered parameters. This final score is used to compare the project against other alternatives and enables the ranking of projects.

The Weighted Sum Model (WSM) can be employed for project evaluation. In this method, the score of each project for an individual parameter is multiplied by its corresponding weight coefficient, and these results are then summed. This yields the overall evaluation score for the project.

To formally express the evaluation model, let us adopt the following notation:

(m) — the number of projects obtained as a result of the search;

(n) — the number of parameters used in the evaluation;

X_{ij} — the score of the i-th project for the j-th parameter; Wj — the weight coefficient of the j-th parameter;

S_i — the final score of the i-th project.

When weight coefficients are defined in a normalized form, their sum must equal one:

$$\sum_{j-1}^{n} W_j = 1$$

$$X_{ij} = \begin{cases} 1, \text{if the j} - \text{th value of the i} - \text{th project is known} \\ 0, if\ the\ j - th\ value\ of\ the\ i - th\ project\ is\ unknown \end{cases}$$

This condition allows for the expression of the relative importance of the weight coefficients within the overall evaluation. The specific values of the weight coefficients are determined based on

the characteristics of the project assignment, technical requirements, and the significance of the evaluation criteria.

Once the indicators for project solutions across various parameters have been presented as comparable values, the final score for the i-th project can be calculated using the following formula:

$$S_i=\sum_{j-1}^{n} W_j X_{ij}$$

where (X_{ij}) is the normalized value of the i-th project for the j-th parameter.

Search algorithm for the database of existing design solutions. The process of searching and evaluating within the database of existing design solutions consists of interconnected stages. The primary objective of this process is to identify alternatives that meet the requirements of the design task, evaluate them, and present the results to the design agent to facilitate decision-making.

The main stages of the algorithm are as follows:

1.Defining search parameters based on the design task and providing them to the search agent.

2. Inputting the weighting coefficients for the parameters to be used in the evaluation.

3. Conducting a search within the database of design solutions based on the specified parameters.

4. Separation of the design solutions found during the search for further processing and evaluation, and their transfer to the appropriate results database, if necessary.

5. Derivation of indicators for the design solutions based on specific parameters and preparation for comparison.

6. Normalization of parameter values and application of weighting coefficients, where necessary.

7. Calculation of the final score for each design solution.

8. Displaying the graphical representations of the identified design solutions on the screen to facilitate visual comparison.

9. Ranking the design solutions based on their final scores and identifying the alternatives with the highest evaluation metrics.

10. Presenting all relevant parameters of the selected design solutions to the user or the design agent.

11. Assessing the selected alternative for compliance with technical requirements and its feasibility for implementation.

12. Formulation of a decision by the design agent based on the evaluation results.

In this algorithm, the search and evaluation phases are functionally distinct. The search phase identifies alternatives that meet the requirements, while the evaluation phase assesses the relative advantages of these alternatives. The presentation of visual representations facilitates the designer's selection process. In the final stage, the implementation possibilities for the chosen design are determined, and its compliance with the requirements of the design brief is reviewed.

The Search Agent is a software application developed using modern information technologies and implemented on the basis of a relational database architecture. Detailed information regarding the Search Agent software developed within the framework of this dissertation is presented in the following sections.

1. First of all, how to use the software visually and get acquainted

2. Information about the technologies used in the development of the software

3. Basic structure of the software

How to use the software visually and get acquainted. Each part has separate search and data entry, editing and deletion functionalities. The main screen is as follows:

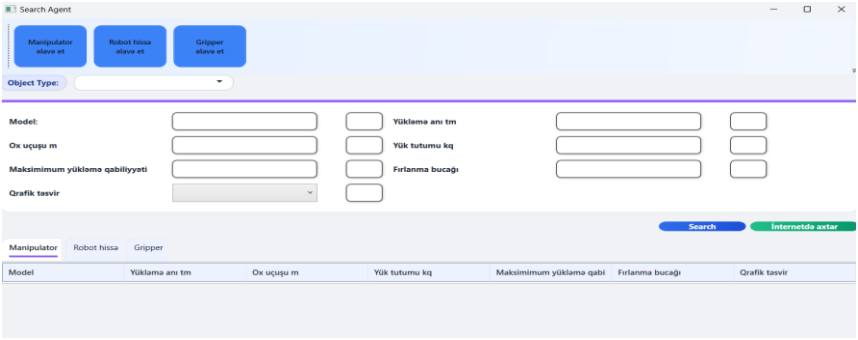
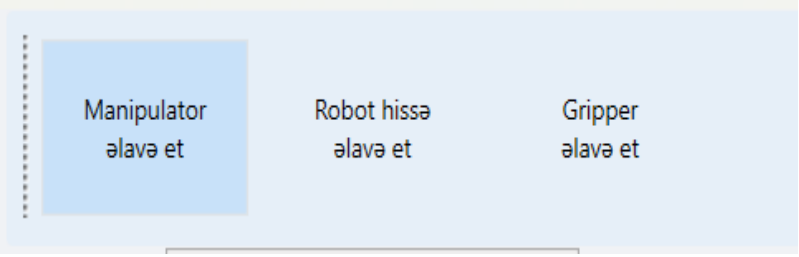


Figure 6. Visual representation of the main screen.

The main screen consists of several parts.

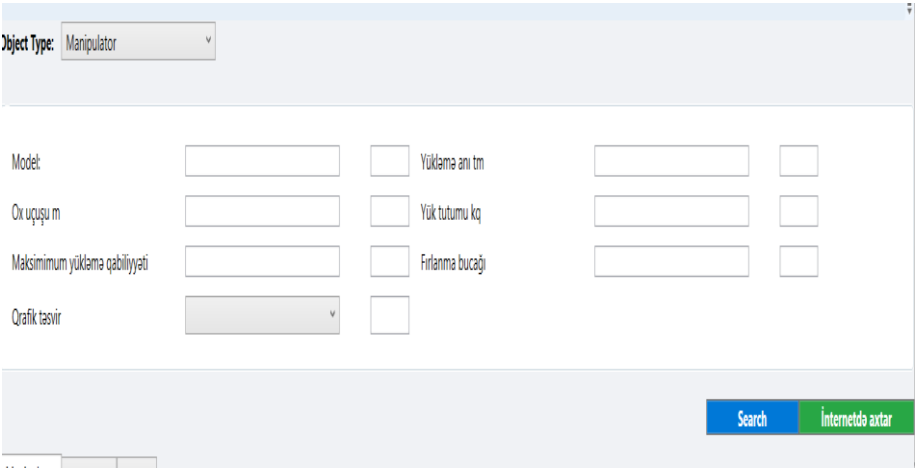
First, the buttons we saw above:



The corresponding operations are performed on each button. The corresponding screen created for entering new data into the system opens:

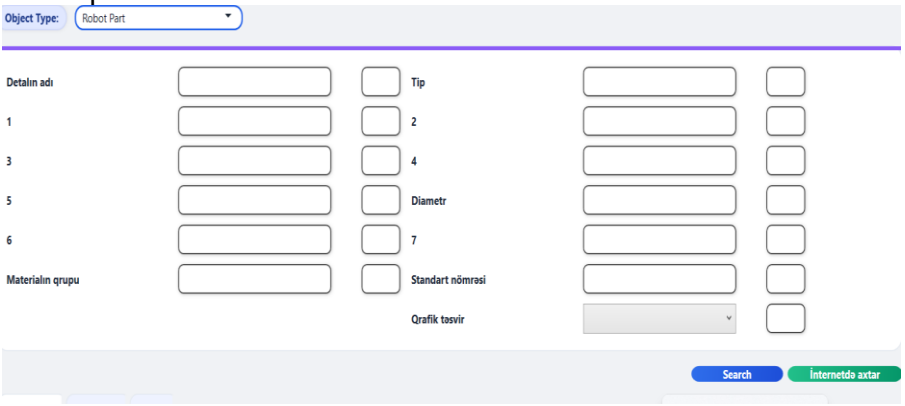
- Add Manipulator
- Add Robot Part
- Add Gripper

The next section is the section for filtering.

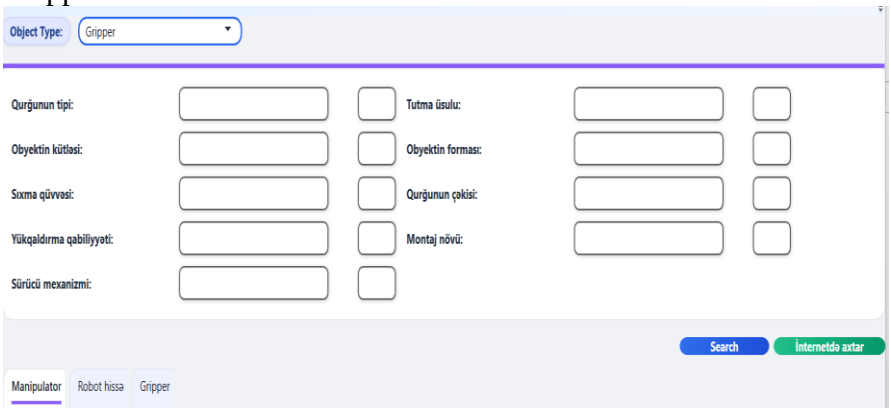


The image above shows the manipulator search filter.

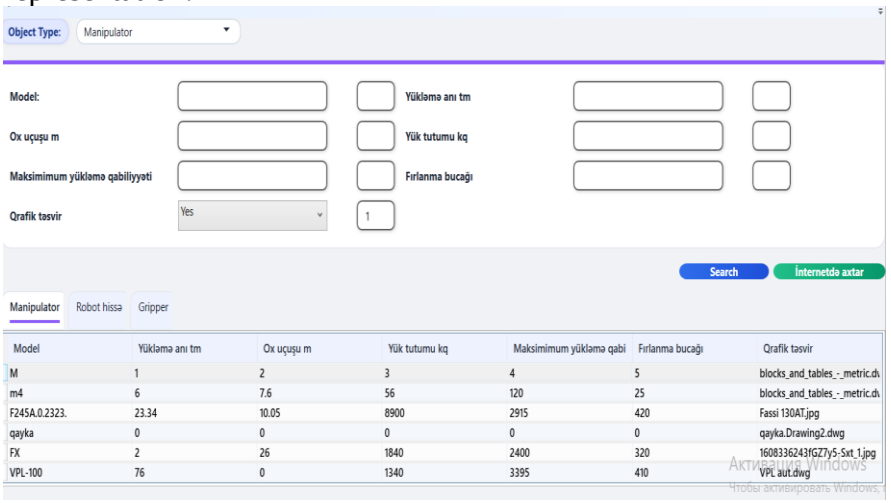
Robot parts filter:



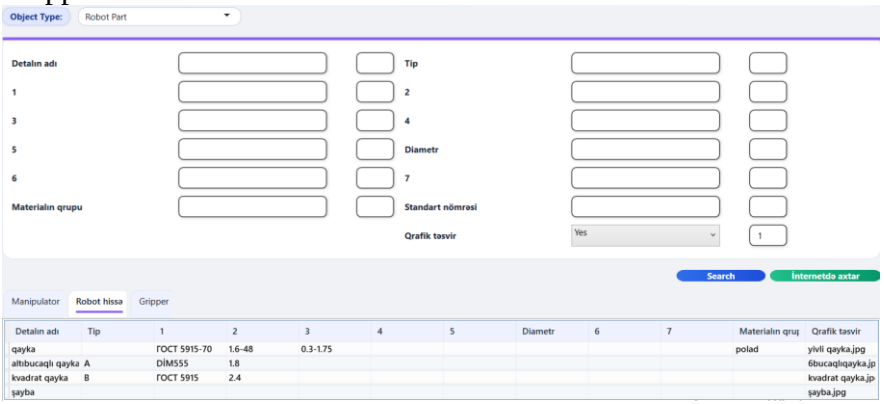
Gripper Search Filter



According to the information entered in the filters, the data is searched and displayed on the screen in a table format. As an example, the following filter shows a list of manipulators with a graphical representation:



The data is displayed in the same tabular format in the Robot part and Grippers.

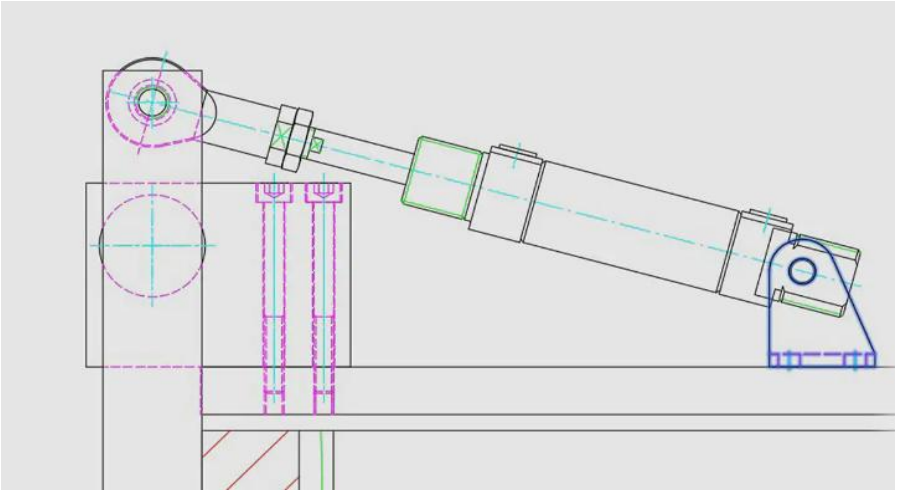


Other advantages of the search agent:

1- Availability of graphical representation;

Another advantage of the search agent program is that it not only provides a representation of data in tabular form, but also allows y outo add visual graphical images and view those graphical images.

2. Operations on AutoCAD files



AutoCAD files allow you to directly load the program, then open and edit or view those files in AutoCAD.

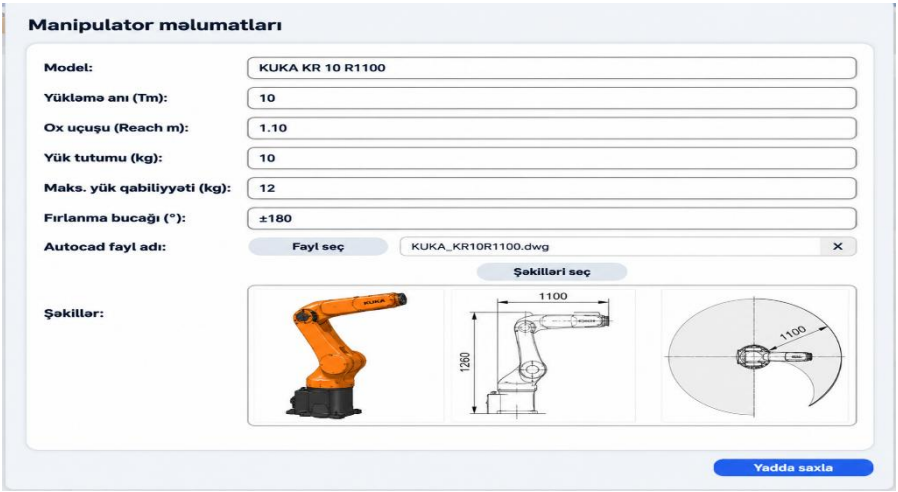
3. Search capability on the Internet

There is the ability to search for information directly on the Internet.

The search system is based on the data entered in the filter screens. Each data has its own priority level. Data corresponding to the parameter with a higher priority level is displayed first, and then sorted according to their priority levels.

Briefly, information about the new data entry screens is as follows:

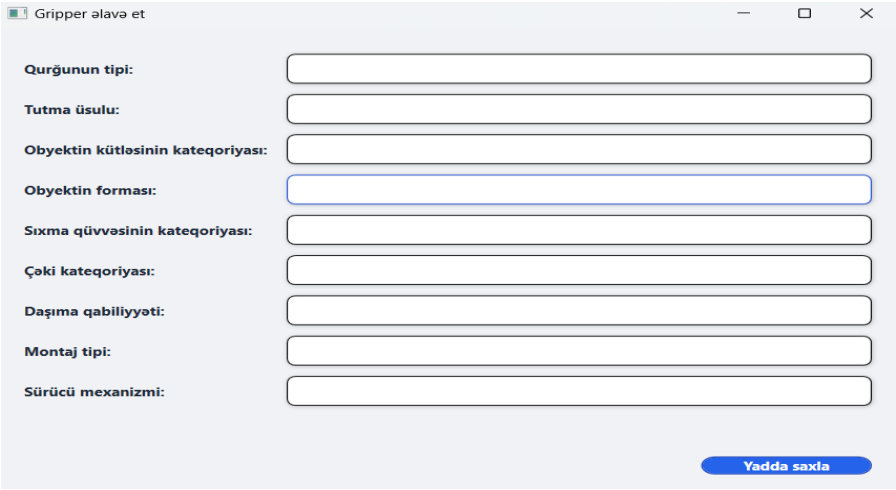
New data entry screens. New manipulator:



New Robot part:



New grippers



The following technologies were used in the software:
Visual Studio 2022 Enterprise was chosen as the main project environment for writing the software. The project was built on the C# programming language and the .NET platform, and the user interface was developed using WPF (Windows Presentation Foundation) technology. A Microsoft SQL Server database was applied for data storage and management, and communication with it was provided through Entity Framework Core ORM technology. XAML was used to design visual elements in the user interface, as well as the ability to add graphic images and integrate AutoCAD in the future.
Microsoft SQL Server Management Studio (SSMS) is used to monitor and manage the data stored in the database.
As a result of the dissertation work, the results of the research conducted in accordance with the topic were interpreted.

RESULTS OF THE DISSERTATION

As a result of the scientific research work carried out in the dissertation, the following general results were obtained:

1. Analysis and study of modern computer-aided design systems (CAD systems) show that there are shortcomings in their application to various subject areas, and at the same time, a generalized perfect theory of the creation of such systems has not been developed.

2. The conducted studies show that there are shortcomings in the application of artificial intelligence elements, as well as other intellectual tools, to automated design processes. In this regard, the possibilities of applying agent technology and multiagent systems to the design process have been studied and solutions have been explored.

3. In order to ensure automated design of flexible production systems, which are taken as the application area, the architecture of an agent-oriented multicomponent automated design system has been developed.

4. The structure of the distributed knowledge base for agent-based design systems has been determined and the issues of organizing the knowledge base have been considered.

5. An algorithm for designing non-standard elements and structures that are part of the agile production system using a multiagent system has been developed.

6. A designer-agent that performs design operations and design procedures, and in general, automated design of a technical object, has been developed.

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