Agile Design Tool Architecture and Its Application in Logistics Systems

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Abstract. The article proposes the architecture of an Adaptive Design Tool (ADT) featuring a modular and open structure. The proposed model integrates a working data and knowledge base, an accumulation subsystem that collects reusable mathematical and graphical models, and a dynamically formed block of standard tools. In addition to internal databases, the architecture provides real-time access to global Internet resources and enables flexible configuration of tools within the design process.

The developed architecture enhances the flexibility, scalability, and integration potential of the automated design system (ADS) environment, creating a methodological foundation for the development of distributed and knowledge-based electronic design systems.

The proposed adaptive design tool architecture offers significant advantages not only from a technological perspective but also in economic terms. By reducing time and resource consumption in the design process, the system contributes to the optimization of production costs and the improvement of productivity. Real-time data integration and dynamic configuration capabilities accelerate decision-making processes, thereby increasing the competitiveness of enterprises.

Furthermore, the application of the ADT architecture in logistics systems enables more efficient management of transportation and cargo flows. This approach ensures optimal allocation of resources, reduces transportation costs, and positively impacts the expansion of economic linkages. Thus, the proposed model can be considered a comprehensive approach that promotes both technological innovation and increased economic efficiency.

Keywords: automated design systems, adaptive architecture, management mechanisms, logistics systems, information integration, economic efficiency, green transformation.

1. Introduction

The increasing level of complexity of electronic systems and the shortening of product life cycles necessitate the development of adaptive and highly integrated automated design systems (ADS). Although existing ADS platforms possess extensive functional capabilities, their rigid architecture limits the dynamic integration of distributed design resources and user-oriented tool configurations. In this regard, the development of flexible and adaptive design tools based on the CAD framework concept emerges as one of the current scientific research issues. The design of electronic devices in modern industry is characterized by a high level of integration, multiparametric optimization, and short innovation cycles. Particularly in microelectronics, industrial automation, and mechatronic systems, the complexity of projects has increased not only at the functional level but also at the structural and informational levels. Under these conditions, the design process has evolved from merely a schematic development stage into a multi-level system process requiring the interaction of various software environments, databases, and modeling platforms.

Although existing automated design systems (ADS) have a wide range of functional tools, their architecture is mostly based on a fixed modular structure. This makes it difficult to form flexible combinations of tools that correspond to the specific features of a given design task. At the same time, some of the data used in the design process is located in local databases, while others are distributed over network resources, which makes the problem of cross-system integration relevant.

Although integration issues in the ADS environment are mainly solved at the functional level, the possibility of reconfiguration at the adaptive structural level remains limited. Especially in the design of special-purpose electronic interfaces, the user often has to create additional tool configurations within the existing system and form an individual working environment. This negatively affects the efficiency and efficiency of the design process.

Modern CAD approaches provide for the construction of systems based on the principle of open architecture and the integration of various software modules within a unified environment. However, in practical implementations, dynamic tool selection, structured accumulation of knowledge, and mechanisms for reuse across projects are not sufficiently organized in a systematic manner. Therefore, there is a need for new architectural approaches that ensure flexible configuration and real-time resource integration in the design process.

In the modern global economic environment, the efficiency of production and logistics systems is determined not only by technological capabilities but also by the level of integration of these technologies and the flexibility of management. The acceleration of digitalization and automation processes requires enterprises to implement more flexible, adaptive, and resource-saving solutions. In this context, the development of automated design systems is not only an engineering issue but also one of the important tools for ensuring economic efficiency.

Particularly in transport and logistics systems, increased cargo flows, multi-level management structures and real-time decision-making require the use of new approaches based on information technology. In such systems, operational data processing, integration of various sources and adaptive management mechanisms have a direct impact on economic results. Therefore, the development of design tools with flexible and open architecture is formed as a relevant research direction from both technical and economic perspectives.

This article investigates the issue of forming the architecture of a flexibly reconfigurable design tool in the ADS environment and substantiates the structural principles of the integration process. The proposed approach is aimed not only at expanding the functional capabilities of design systems but also at increasing their structural adaptability and dynamic management capabilities. At the same time, the presented architecture is of economic significance in terms of integrating data flows, optimal resource management, and improving the efficiency of decision-making processes in complex transport and logistics systems.

In the context of modern global economic and technological development, green transformation [13] acts as one of the strategic directions in the formation of production and logistics systems. This approach is based on the principles of efficient use of resources, increasing energy efficiency, and minimizing negative environmental impacts. In this regard, the proposed architecture of the Adaptive Design Tool (ADT) serves not only to increase economic efficiency but also to ensure ecological sustainability. In particular, real-time data integration and processing capabilities enable the optimization of routes in logistics systems, reduction of empty runs, and, consequently, minimization of carbon emissions. At the same time, the adaptive and open architecture of the system allows the integration of additional analytical modules for monitoring and managing energy consumption, thereby creating conditions for the practical implementation of the concept of sustainable development. Thus, the ADT architecture can be evaluated as a comprehensive technological solution ensuring the synergy of digital and green transformation.

For this purpose, a structural decomposition of the design environment has been carried out, the interaction mechanism of data flows between architectural blocks has been considered, and an integration approach based on existing CAD platforms has been formed. The proposed system has an open and extensible architecture.

The conducted research shows that adaptive architecture accelerates the search and selection of components in the design process, ensures dynamic adjustment of tool configurations, and expands the integration capabilities of the system. This approach is considered effective especially for application in flexible manufacturing environments and in the interface design of mechatronic devices.

2. Stages of Development and Conceptual Approaches of Automated Design Systems

The design process consists of a set of time-consuming procedures, and until the mid-20th century, the lifetime of the designed object (the period during which it was in operation) was in most cases equal to or longer than the time spent on its design, development, testing, and implementation. Starting from the 1970s, the increase in the variety of manufactured products and the necessity of replacing products with others within a short period in accordance with demand led to a reduction in the operational lifetime of the designed object. At the same time, the long duration of the design process significantly reduced efficiency.

In this case, the solution to the problem consisted in reducing the design time through the use of automation tools and ensuring the flexible automatic or automated design of the object.

Among the concepts for the creation of automated design systems (ADS), the most widespread are fully automatic ADS and human–machine systems [1]. Figure 1 illustrates the scheme of conceptual approaches of ADS.

The concept of creating fully automatic ADS has certain difficulties, such as the high interconnectedness of the design process and the presence of a large number of undefined factors, which require the use of human creative capabilities; therefore, it is not yet widely applied.

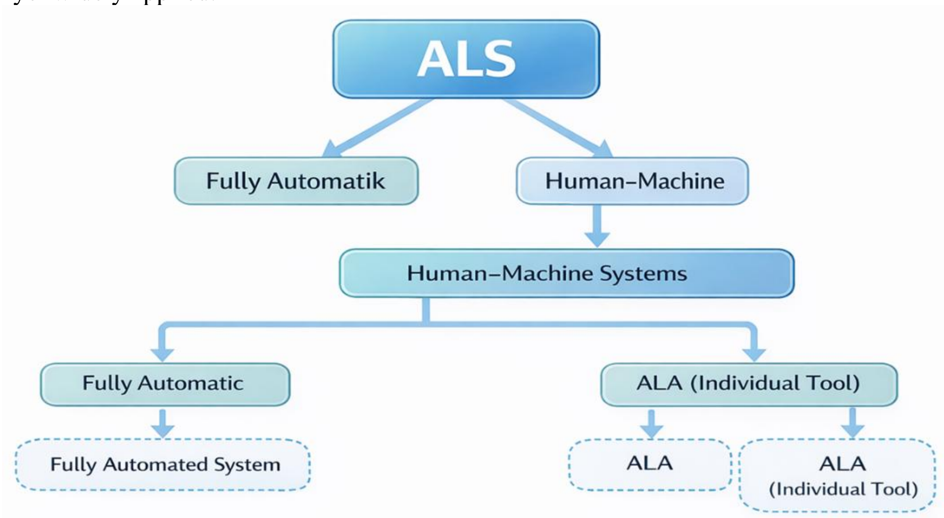

Fig. 1. Conceptual Approaches of Automated Design Systems (ADS)

The human–machine automation concept is implemented in two main directions: In the first direction, the ADS created replaces existing traditional design systems and is applied as a ready-made system (this approach proves effective when designing new production fields, as well as when developing and implementing new information technologies);

The second direction is the idea of creating an automated design tool (ADT) for the designer (constructor, technologist, etc.) [2]. In this case, the main objective is to develop the ADS step by step, depending on necessity, in the form of ADTs for design procedures, and ultimately integrate them into a logically complete system, achieving the level of an ADS functioning as a complex system.

The article examines the issue of creating an ADT operating within the environment of systems that automate the design of electronic devices, especially considering the expansion of the integration of the element base of microelectronics, the increasing demand for new-purpose multifunctional integrated circuits, and their design automation.

At present, two main approaches dominate in the development of Automated Design Systems (ADS):

• **Fully automatic ADS:** Due to the large number of interconnections and undefined factors in the design process, it is not yet widely applied, since it is difficult to replace human creativity.

• **Human–machine systems:** This concept develops in two directions: the application of ready-made systems and the creation of individual design tools (ADT).

The ADT concept provides for the step-by-step development of ADS based on essential procedures and its eventual integration into a comprehensive system.

By generalizing the analysis of the main directions of research conducted in this field, the following key conclusions can be highlighted [3]:

- the idea of creating an ADS environment (CAD framework) to enable users operating at local levels to benefit from the wide capabilities of multifunctional ADS has played an important role not only in automating the design of electronic device components but also in the automated design of other fields of science and technology where electronic devices are applied;
- the competitive environment among leading companies in the field of automated design of electronic engineering tools has contributed to the expansion of system functionalities and significant technological advancements. In this regard, systems such as P-CAD and OrCAD can be noted as products of leading firms. These systems ensure comprehensive automation of all main stages of electronic design, including schematic design, modeling, analysis, and printed circuit board design. It should be noted that the final result of any ADS, regardless of its purpose, is usually represented in the form of design documentation and graphical representations of constructive solutions.

However, practice shows that creating a dedicated graphical module within the system to visually represent the results of each specific task in printed form is not always justified. For this purpose, integration of existing ADS tools with multifunctional software packages is more efficient. The "KOMPAS-GRAFIK" system developed by "Askon" Joint Stock Company and its ESK 5 library environment enable the execution of documentation procedures in the automated design of electrical and electronic devices.

3 Integration Issues and Application Directions in the CAD Environment

At the present stage, the field of automated design of electronic devices is highly commercialized and represented by technologically mature systems. The analysis of the structural and functional characteristics of these systems makes it necessary to assess the current situation and determine future development directions.

Summarizing the main results, it can be noted that there are numerous systems developed by leading global companies for the automated design of electronic circuits and devices. Although these systems do not differ significantly from one another, they are applied depending on how well they meet user requirements. Continuous theoretical and practical research is being conducted to improve these systems and expand their functional capabilities.

It should be noted that existing ADS systems are primarily intended for professional users and serve for the development of large-scale projects in research institutions and design centers.

The application of electronic circuits and devices to new topologies, their improvement through ADS, and the use of these devices require the improvement-and in some cases, the restructuring-of automated systems developed in other fields of science and technology. This is particularly evident in flexible manufacturing environments created through the application of industrial and intelligent robots. In this regard, the development of ADS tools that ensure the local design of physical connection interfaces between mechatronic devices of flexible manufacturing systems and computers is of significant importance.

The current state and prospects of Internet development enable ADTs to operate within the environments of systems of any leading company, which increases the relevance of this direction.

The concept of the ADS environment was first introduced by Harrison D.C. and co-authors [4]. The idea of the ADS environment has played an important role not only in automating the design of electronic device components but also in the automated design of other fields of science and technology where electronic devices are applied.

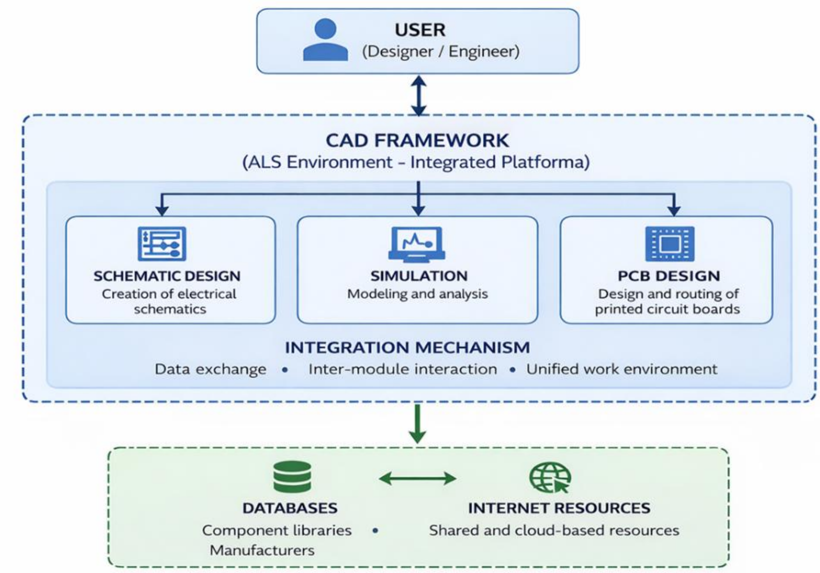

Fig. 2. Tool Integration Scheme in the CAD Environment

The concept of the ADS environment (CAD framework) implies that the designer has the ability to use all available tools and modules of a multifunctional automated design system within a unified platform. For the implementation of this approach, the ADS must be provided with a highly functional network infrastructure and automated workstations.

4. ADT Architecture

The architecture of the ADT proposed for designing specialized interfaces of electronic devices is presented in Figure 3.

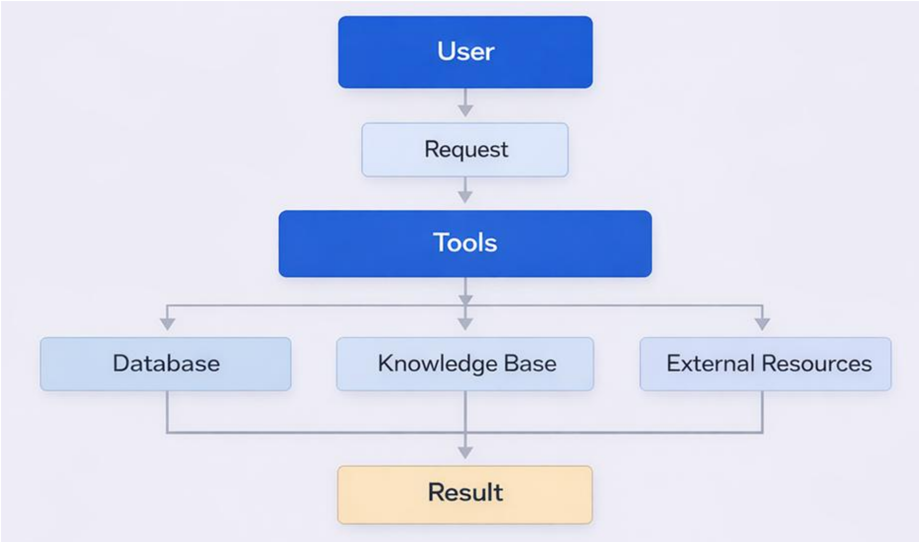

Fig. 3. Architecture of the ADT (Adaptive Design Tool)

As can be seen from the ADT architecture, it is intended that the user can flexibly create a design tool for each specific case in order to design specialized interfaces of electronic devices.

In the ADT architecture, the working databases of data and knowledge (WDB, WKB) store the information required for solving each specific problem. If these data and knowledge are used periodically in design processes, their accumulation in the ADT's accumulation databases of data and knowledge is ensured.

The accumulation database is also intended to store mathematical and graphical models of newly designed specialized interfaces created by the user.

The elements of the standard tool block for individual design objects in the ADT are determined by the user during the design process.

In the ADT architecture, the standard tool block is organized based on the functional capabilities of existing ADS systems that ensure the design of electronic devices and electrical circuits and are integrated via the Internet.

As an example, in the article, the standard design block of the ADT has been formed using the standard tools of OrCAD version 9.2. This block includes system-level design tools that provide access via the Internet to more than 200,000 components, a library of mathematical models of 16,000 analog and mixed analog-digital devices formed based on the accumulation of experienced designers' work, as well as tools intended for the design of printed circuit boards of electronic devices. The standard tool block has an open structure and can be expanded with additional software modules depending on the requirements of the design process.

The analysis of the ADT architecture shows that the efficiency and operability of the system depend on the speed of decision-making in the design process and the flexibility of information support. This is ensured through real-time search, processing, and use of information stored both in external resources (obtained via the Internet) and in internal data and knowledge bases.

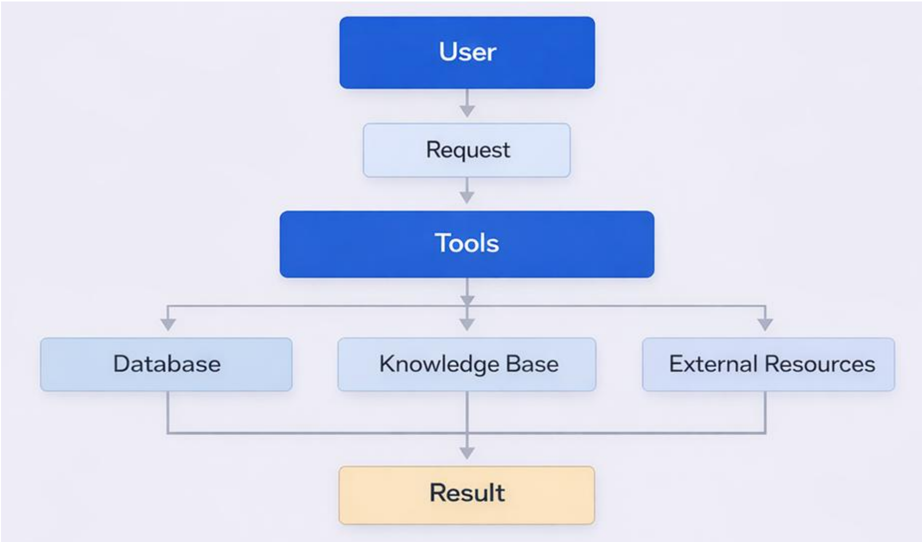

Fig. 4. Operating Principle of the ADT Architecture

The functional operation of the ADT architecture begins with the formation of a user request. Based on the design requirements entered by the user, the system selects appropriate tools and modules. This process is carried out on the basis of analyzing the information stored in data and knowledge bases and evaluating the level of compatibility.

After the formation of the selected tool block, the design process is carried out dynamically, and the results are presented to the user in real time. This approach ensures flexibility and efficiency in the design process.

The main advantages of the proposed ADT architecture are as follows:

- ensuring flexible tool configuration in the design process;
- integration of distributed resources within a unified environment;
- effective use of data and knowledge bases;
- expansion of real-time decision-making capabilities;
- ensuring knowledge transfer between projects.

The application of the ADT architecture enables the optimization of design processes in various industrial fields, particularly in microelectronics, mechatronics, and automated manufacturing systems. This approach not only ensures faster and more efficient design of complex systems but also creates conditions for the optimization of resource utilization.

5. ADT Architecture in Logistics Systems and Economic Efficiency

Some characteristics of the ADT architecture:

• flexible, adaptive, and integrated system architecture;

• real-time data integration;

• management of distributed resources, etc.

These are also the main problems of logistics systems. For this reason, the proposed adaptive design tool (ADT) architecture has application potential not only in the field of electronic device design but also in the management of complex and distributed transport-logistics systems. In particular, in multi-component and multi-level infrastructures such as the East–West transport corridor, one of the main problems is the integration of various information sources and the formation of a unified management environment. In this regard, the modular structure envisaged in the ADT architecture, the joint use of data and knowledge bases, as well as Internet-based real-time integration mechanisms, create a methodological basis for the effective management of information flows in logistics systems.

In addition, issues such as variability of cargo flows in transport corridors, route optimization, and operational decision-making necessitate adaptive and flexible management approaches. The dynamic configuration capability and open system principles of the ADT architecture can be applied to solve such problems. Thus, the proposed approach can be considered a promising conceptual model for increasing operational efficiency in transport-logistics systems, ensuring optimal resource allocation, and improving inter-system interaction.

Within the framework of the East–West transport corridor, the management of logistics systems is accompanied by a number of complex problems. These include the integration of infrastructure elements, coordination of information flows, optimization of transit times, and ensuring continuity of cargo transportation [7, 8, 9]. The existence of different management standards and the fragmented storage of data limit the operational efficiency and effectiveness of logistics systems [5, 6].

In this context, the application of adaptive ADT architecture enables the formation of a unified information environment, real-time processing of data from various sources, and the establishment of coordinated management mechanisms. This, in turn, creates conditions for reducing delays in logistics operations, optimizing routes, and ensuring more flexible management of transportation processes.

From an operational perspective, factors such as variability of cargo flows in the transport corridor, technical failures, and the influence of external factors require adaptive management approaches. The dynamic configuration capabilities of the ADT architecture make it possible to respond promptly to such changes and ensure the continuous functioning of the system.

As a result, the application of this approach within the East–West transport corridor not only ensures the technical optimization of logistics processes but also generates significant economic effects in terms of increasing transit potential, reducing transportation costs, and strengthening interregional economic relations.

The model for applying the ADT architecture to a logistics system is illustrated in Figure 5.

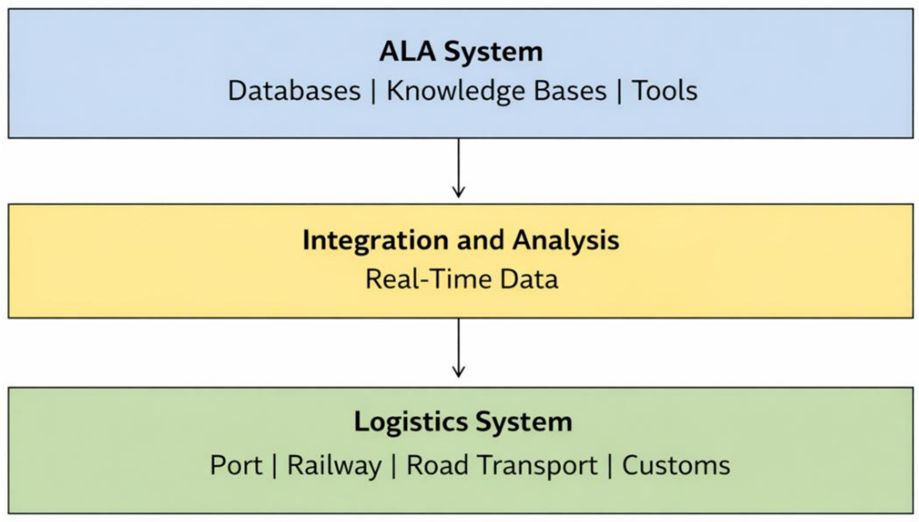

Fig. 5. Model of Applying the ADT Architecture to a Logistics System

It should be noted that the application of the ADT architecture in logistics systems leads to significant results not only from a technological perspective but also from an economic standpoint. In particular, the integration of information flows and their real-time management create conditions for the optimization of transportation operations, more efficient route planning, and the reduction of logistics costs [10, 11].

At the same time, adaptive management mechanisms ensure a more rational allocation of resources, increasing the overall productivity of the system and improving service quality. As a result, this approach enhances the economic efficiency of logistics systems, contributing to the formation of competitive advantages and sustainable development of enterprises [12].

6. Green transformation and sustainability in ADT-based systems

In the context of the modern global economy, green transformation has become one of the key directions in the development of industrial and logistics systems. This approach is based on principles such as efficient resource utilization, increased energy efficiency, and minimization of environmental impact. In this regard, the Adaptive Design Tool (ADT) architecture can serve as an important technological platform for implementing green transformation objectives.

The open and modular structure of the ADT architecture enables the integration of additional analytical and management modules. These modules allow monitoring of energy consumption, assessment of carbon emissions, and optimization of resource usage. As a result, both technical and environmental criteria can be considered during the design process [13].

Real-time data processing and integration from multiple sources enhance decision-making efficiency within the ADT system. Another important advantage of the ADT architecture in the context of green transformation is its capability for multi-criteria optimization. Unlike traditional design approaches, where optimization is mainly based on technical and economic indicators, the ADT environment allows the inclusion of environmental criteria into the decision-making process. This enables more balanced and comprehensive design solutions.

Moreover, the data collection and processing mechanisms of the ADT architecture can be extended using Big Data approaches. In this case, the system can analyze not only real-time parameters but also historical data to perform forecasting related to energy consumption and resource utilization. Such predictive capabilities significantly enhance the planning and implementation of green transformation strategies.

In addition, the ADT architecture can be integrated with intelligent management systems to support automated decision-making mechanisms. This approach is particularly important for real-time energy regulation, system load optimization, and minimizing environmental impact.

This enables the selection of energy-efficient components, optimization of system parameters, and improvement of environmental performance already at the design stage.

Furthermore, the application of ADT architecture in logistics systems plays a significant role in green transformation. Route optimization, reduction of empty runs, and efficient cargo flow management contribute to lowering fuel consumption and carbon emissions. This leads to improvements in both economic efficiency and environmental sustainability.

Thus, the ADT architecture not only provides technological and functional advantages but also acts as a comprehensive system supporting green transformation and sustainable development.

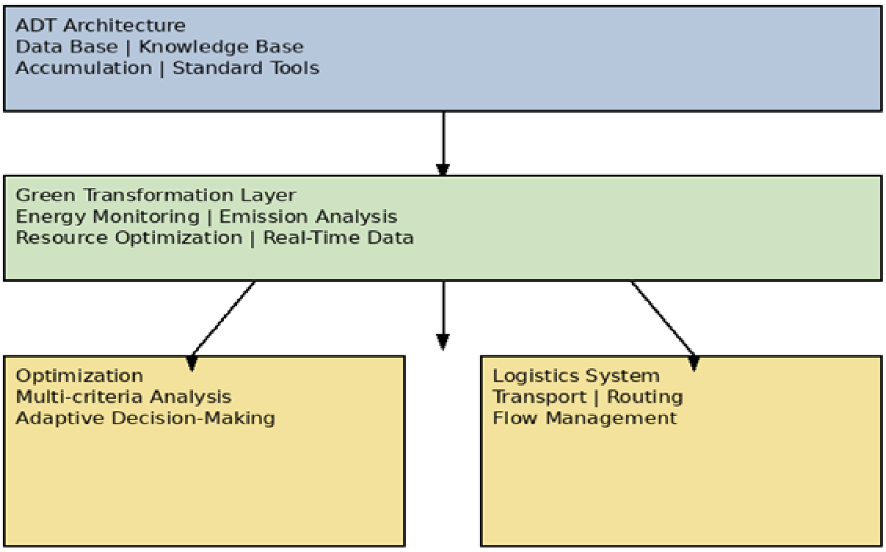

Fig. 6. Integration of ADT architecture with green transformation and decision-making processes

7. Conclusion

This study is devoted to the formation of an automated design tool (ADT) with a flexible and adaptive architecture for the design of electronic devices in the ADS environment. The conducted analysis shows that although existing ADS platforms have extensive functional capabilities, their fixed structural principle creates limitations in adequately responding to dynamically changing requirements of design tasks. In particular, adaptive configuration and integration mechanisms are of critical importance in the design of specialized interfaces and flexible manufacturing environments.

The proposed ADT architecture is based on the principles of a modular structure, integration of data and knowledge bases, an accumulation mechanism, and an open standard tool block. This model ensures the real-time use of internal and external information resources within a unified environment, thereby increasing information accessibility and the speed of decision-making in the design process. The accumulation of mathematical and graphical models in the accumulation subsystem enables knowledge transfer between projects and improves the efficiency of reuse.

The open structural principle of the architecture preserves system extensibility and provides integration capabilities with various ADS platforms. Thus, the proposed approach can be considered a conceptual model that enhances the efficiency, adaptability, and level of integration of the design process.

The application of the ADT architecture is particularly promising for increasing the efficiency of interface design in mechatronic systems and flexible manufacturing environments. This approach can be further developed in future research towards the formation of distributed and knowledge-based design systems. It can also be applied to solving integration and management problems in transport and logistics systems, particularly within the East–West corridor.

At the same time, the obtained results show that the proposed architecture is not limited to improving technical efficiency but also provides significant economic advantages. Specifically, the optimization of design and management processes ensures more efficient use of resources, reduces operational costs, and increases overall system productivity. In particular, its application in logistics and transport systems further enhances its economic effect by enabling the optimization of cargo flows, reduction of time losses, and improvement of decision-making processes, thereby strengthening competitiveness.

In addition, the conducted research demonstrates that the proposed ADT architecture is not limited to improving technical and economic efficiency but also serves as an effective tool for implementing green transformation principles. The open and adaptive structure of the system provides additional opportunities for increasing energy efficiency, optimizing resource usage, and reducing environmental impact.

In particular, real-time data processing and integration enable more environmentally justified decision-making in both design and management processes. This contributes to the reduction of carbon emissions in industrial and logistics systems and supports the achievement of sustainable development goals.

Thus, the ADT architecture can be considered a comprehensive approach that ensures the synergy between digital and green transformation.

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