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DEVELOPMENT OF DATABASES INTERCONNECTION "ESSENCES" INFORMATION MODEL FOR CYBER-PHYSICAL PRODUCTION SYSTEMS ADDITIVE CYBER DESIGN CREATION AUTOMATION

РОЗРОБКА ІНФОРМАЦІЙНОЇ МОДЕЛІ ВЗАЄМОЗВ'ЯЗКІВ «СУТНІСТЬ» БАЗ ДАНИХ ДЛЯ АВТОМАТИЗАЦІЇ СТВОРЕННЯ АДИТИВНОГО КІБЕРДИЗАЙНУ КІБЕРФІЗИЧНИХ ВИРОБНИЧИХ СИСТЕМ

Vladyslav V. Yevsieiev
vladyslav.yevsieiev@nure.ua
ORCID: 0000-0002-2590-7085
Artem I. Bronnikov
artem.bronnikov@nure.ua
ORCID: 0000-0003-3096-7653

В. В. Євсєєв,
канд. техн. наук, доцент
А. І. Бронніков,
ст. викладач

Kharkiv National University of Radio Electronics, Kharkiv
Харківський національний університет радіоелектроніки, м. Харків

Abstract. The development of modern high-tech and competitively capable production is not possible without the introduction of the Industry 4.0 concept and the Industrial Internet of Things (IIoT) technologies. On the basis of the concept and technologies at this point in time, research related to the development and implementation of Cyber-Physical Production Systems (CPPS), which are based on the principle of "Digital Twins" (DT). The synthesis of these concepts, technologies and principles allows to implement the approach to "Smart Manufacturing" (SM), which in turn makes it possible to achieve the indicators of "Lean Production" (LP).

The CPPS development is a physical parameters complex synthesis that are obtained directly from sensors and actuators and, on the other hand, the cybernetic component, which implements the received for the user information visualization, provides control mechanisms and decision-making depending on received data. A critical analysis of CPPS development publications showed that at this point in time there is no methodology, models, methods and technologies that made it possible to automate the development CPPS process, and the existing architectural models for 5C, 8C, RAMI 4.0 development are descriptive and recommendatory.

As a result, a complex scientific and applied problem arises: the development of new approaches to automate the CPPS additive cyber-design creation at the early stages of CPPS development. This article presents an automated control system structural diagram for complex CPPS development, which is based on an alternative approach the HMI additive cyber design for CPPS development automation using the concepts of applying the parameters properties and an object-oriented programming language graphic elements (GUI) events. For the implementation of the tasks, the authors developed a logical database scheme, based on large amounts of information necessary to provide all the functions of the system being developed, it was divided into separate blocks depending on the information that is stored and processed in them.

For each main block, an information model was developed for the reference and cumulative databases "entities" relationship. The results of these studies were implemented in the form of physical database models for the "Automation of CPPS Development Management Processes" system, which makes it possible to synthesize the user's HMI based on a "rigidly" structured tabular data presentation for parsing and generating additive cyber design. This approach will reduce the HMI development time, considering the technical task (TOR) requirements with the customer involvement, which will provide the most attractive and informatively understandable HMI for the CPPS end user.

Key words: Industry 4.0; Industrial Internet of Things; Smart Manufacturing; Cyber-Physical Production Systems, Additive Cyber Design, HMI, GUI.

Анотація. Розвиток сучасного високотехнологічного і конкурентноздатного виробництва не можливий без впровадження концепції Industry 4.0 і технологій Industrial Internet of Things (IIoT). На базі даних концепції і технологій були проведені дослідження, пов'язані із розробкою і впровадження Cyber-Physical Production Systems (CPPS), які базуються на принципі "Digital Twins" (DT). Синтез цих концепцій, технологій і принципів дозволяють

реалізувати підхід до "Smart Manufacturing" (SM), що дає можливість досягти показників "Lean Production" (LP). Розробка CPPS є складним синтезом фізичних параметрів, які виходять безпосередньо з датчиків і виконавчих механізмів, і є кібернетичним складником, у якому реалізується візуалізація отриманої інформації для користувача, забезпечуються механізми управління і прийняття рішень залежно від отриманих даних.
Критичний аналіз публікацій із розробки CPPS показав, що нині не існує методології, моделей, методів і технологій, які б дозволили автоматизувати процес розробки CPPS, а існуючі архітектурні моделі розробки 5C, 8C, RAMI 4.0 мають лише описово-рекомендаційний характер. Внаслідок цього виникає складна науково-прикладна задача – розробка нових підходів до автоматизацій створення адитивного кібердизайну CPPS на ранніх етапах створення CPPS.
У цій статті представлена структурна схема автоматизованої системи управління розробкою складних CPPS, яка базується на альтернативному підході до автоматизацій розробки HMI адитивного кібердизайну для CPPS на базі концепцій застосування властивостей параметрів і подій графічних елементів (GUI) об'єктно-орієнтованих на мову програмування. Для реалізацій поставлених завдань авторами було розроблено логічну схему БД, ґрунтуючись на великих обсягах інформації, необхідної для забезпечення усіх функцій системи, що розробляється. Вона була поділена на окремі блоки залежно від інформацій, яка зберігається і обробляється у них. Для кожного основного блоку була розроблена інформаційна модель взаємозв'язку «сутностей» довідкової та накопичувальної БД.
Результати досліджень були реалізовані у вигляді фізичних моделей БД для системи «Автоматизація процесів управління розробкою CPPS», яка дає можливість синтезувати HMI користувача на базі «жорстко» структурованого табличного представлення даних для синтаксичного аналізу і генерацій адитивного кібердизайну. Такий підхід дозволить скоротити час розробки HMI з урахуванням вимоги технічного завдання (ТЗ) із залученням замовника, що забезпечить максимально привабливий та інформативно-зрозумілий HMI для кінцевого користувача CPPS.
Ключові слова: Індустрія 4.0; індустріальний Інтернет речей; розумне виробництво; кіберфізичні виробничі системи; Additive Cyber Design; HMI; GUI.

FORMULATION OF THE PROBLEM

Development of additive cyber design for the CPPS cybernetic component automated systems creation is a complex scientific and technical task that combines not only software and functional organization, but also storage and processing of large amounts of data. In this article, information models of the main "entities" interrelationships for the cumulative and reference database are developed using the Backus-Naur metalinguistic formula, which makes it possible to systematize and implement access to large structured information arrays for solving automation problems; creating an additive cyber design for the CPPS cybernetic component.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The work of Andrea Bonci, Massimiliano Pirani, Sauro Longhi reveals the "Digital Twins" CPPS development complexity for real production, in particular the authors touch on specific problems in the database development [1]. The PriMa integrated approach proposed by Fazel Ansari draws attention to the complexity of database structures to a large amount of multimodal and heterogeneous data collected from multidimensional CPPS sources efficient processing implementation [2].

In the article Yuqian Lu, Xun Xu [3], Chin-Feng Fan, Ching-Chieh Chan [4], Zhang H. and Yan Q [5] reveal the problems in the CPPS development and modeling associated with the creation of convenient, dynamic and additive cyber design for information visualizations (HMI) at all levels of SCADA, MES, ERP. As a result of these publications analysis, it can be concluded that the development of "entities" interrelationships information models for automation systems, additive cyber design development, is one of the complex tasks that must satisfy all the requirements that are imposed on a relational database, but also the specifics.

GENERAL PROBLEM PREVIOUSLY UNRESOLVED PARTS SEPARATION

Cyber-Physical Production Systems (CPPS) are a complex organizational and technical object that reflects real production the "Digital Twins" concept, as a result of which the such systems development is a complex scientific and technical task. A critical modern literature analysis has shown that for the implementation of additive cyber design development automation, it is necessary not only to develop new models, methods and technologies, but also to implement the storage of large data amounts: language elements, actions on data, data organization, etc.

In this case, it is necessary to ensure the following: the transmitted data integrity control; data presentation completeness i.e. the data in the database should adequately represent all information about their parameters and properties GUI elements, links between "Linguistic variables" and "Solution containers" which contain program code fragments; flexibility of data structure for adaptability and scalability of the developed automation system for the additive cyber design development.

THE AIM OF THE STUDY

The purpose of the research is to develop the "entities" relationships information models for the system "CPPS

development management processes automation" based on the Beckus-Naur metalinguistic formula

METHODS, OBJECT AND SUBJECT OF RESEARCH

The article uses the methods of object-oriented programming (abstraction, polymorphism, encapsulation), the extended Backus-Naur form, as well as methods of organizing and building relational databases.

The object of the research is the processes of CPPS additive cyber-design managing development. The subject of the research is forms parameters and properties informational representations methods, GUI elements and links for storage in a database, as interrelated "entities" complex for solving automation development problems of an HMI interface at drafting technical specificationsearly stage.

THE MAIN MATERIAL

Based on the proposed the CPPS development management process automation architectural and logical model [6] and GUI elements parameters, properties and events formalization method, [7] for the development of additive cyber design, the following block diagram of an automated control system for the CPPS development was proposed, which is shown in figure 1.

The purpose of the automated control system each block for CPPS development is:

1) text editor of the modeling language (ML) / module for nput data analyzes from MS Excel (*.xls), designed to enter data into the system using the developed ML and makes it possible to read the output data in an alternative way through MS Excel (*.xls) only the cybnetic component of the developed CPPS if necessary. The input data format has a rigid tree-like hierarchy, which makes it possible to immediately determine the objects visualization structure and their relationship, subordination in the HMI based on the GUI;

2) the module for the input data syntax analyzes checks for the adequacy and correctness of the initial data specification, their completeness necessary for the developed CPPS implementation. When critical errors of logic inconsistency, lack of data occur, an error file is generated, in which errors or warnings are recorded;

3) module for logical connections and dependencies building between visual interface components and events that are imposed by developers on these events actions. The check is carried out using the execution relationships control in accordance with the functioning algorithms and the technical task requirements, limiting the each component functionality, which depends on the database completeness and can be supplemented;

4) module for generating queries to the database, generates queries in SQL in accordance with the components used, and the events (actions) that they must perform program code. During the execution of the request, a program code list templates is generated that match the selection conditions and the logic of the module;

5) module for the results analyzes from the database, parses the results obtained, determines the most suitable fragment of the program code, which matches the selection conditions depending on the specified search conditions;

6) the module for generating the source file of the program code, connects the necessary libraries, observes the structure syntax, design rules and presents it as a files package required to open the developed software product in the development environment specified by the user;

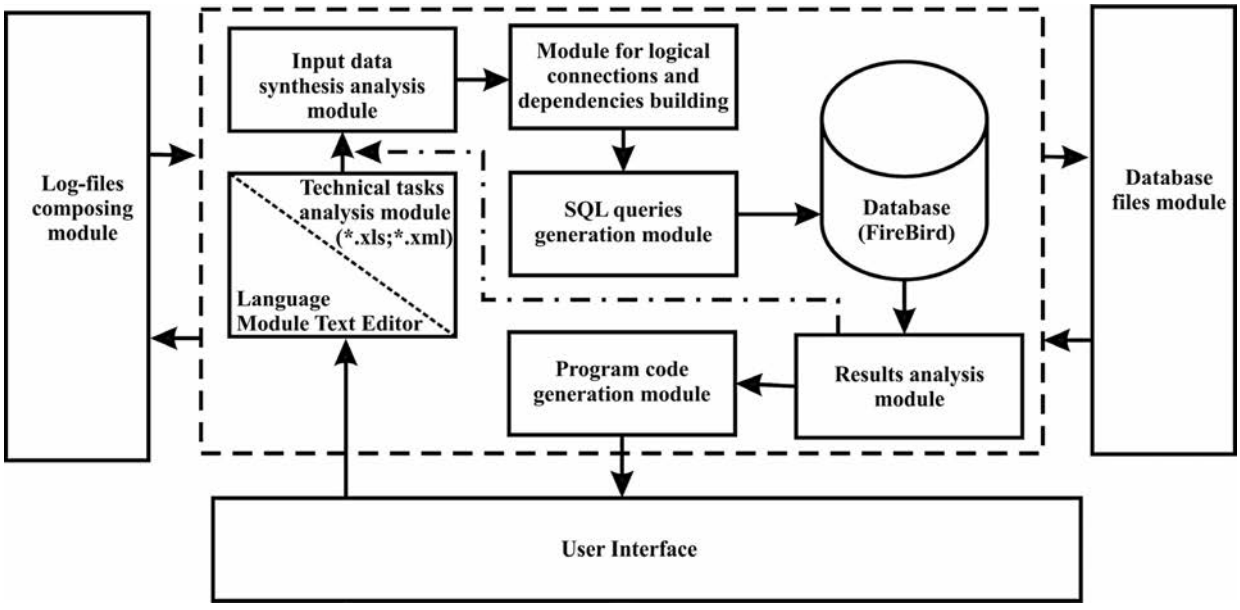


Fig. 1. Structure of an automated control system for CPPS development

7) module for log files compilation, which contain reports on the work of each module at the design stages;

8) database (Fire Bird) a free cross-platform relational database management system that stores all the necessary information and links to files that contain fragments of program code (*"Container Solutions"*);

9) DB file module is intended for storing files *"Container Solutions"*.

To simplify and systematize the storage of information necessary to solve the problem, it was decided to split the logical database structure into modules that will be combined according to the stored information "essence" and the relationship between them will be implemented using "foreign keys" of the "One-to-infinity" connection type. The following logical structure of the database is proposed, presented in figure 2.

The database logical structure is presented in the modules form that perform the following functions:

1) reference database is a tables hierarchy that contains information about programming languages, the code structure, libraries and their relationship, necessary procedures and functions that can be used, events and possible handlers for actions on graphical interface elements, built-in procedures.

All data stored in the reference database are subject to the criteria for choosing a development environment and programming language. The reference database is implemented the extension and adaptation to a particular development environment, a user with administrator rights can add new code templates and bind them to events called during the execution of actions, or to internal procedures or functions;

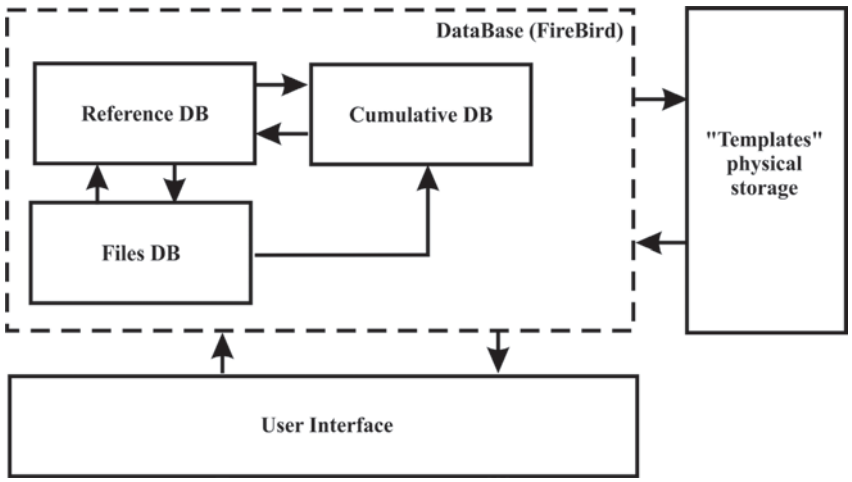


Fig. 2. The logical structure of the database

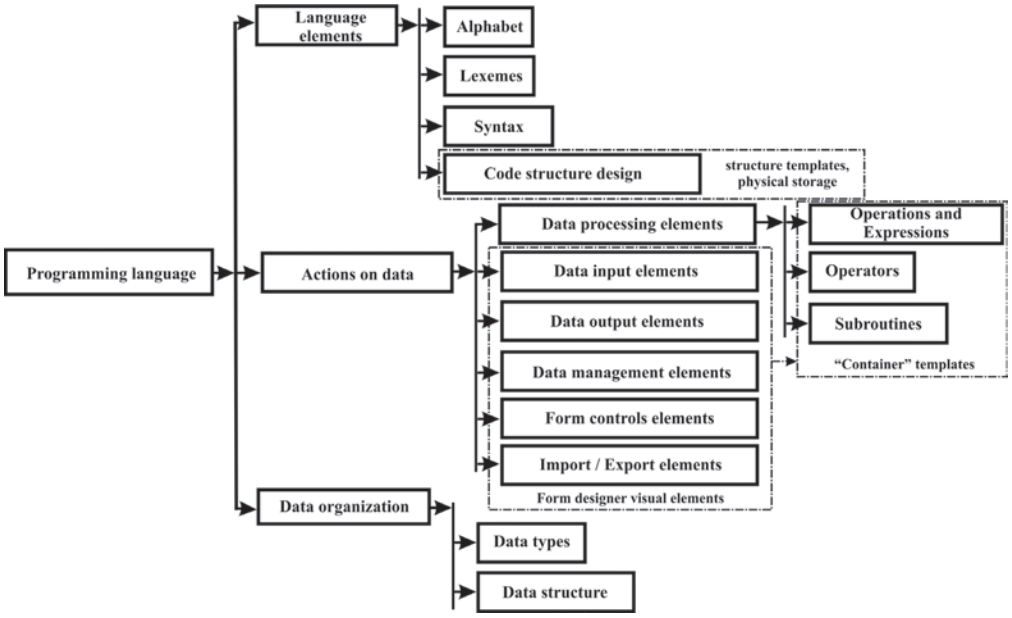


Fig. 3. Relationship information model of the main reference database "entities"

2) cumulative database is designed to store current projects and projects implemented in this system. The structure of the cumulative database is a rigidly structured dependence on the customer's data, the name of the project and the reference terms, the generated source code sequence and user interface, with the ability to edit any structural element and templates that are used in this project. The user of the "Automated development CPPS management system" can edit the this project definitions and entities, change the relationship and insertion sequence of each template (container) with the program code, depending on the customer's requirements;

3) "templates" physical storage is a collection of entities obeying a reference database. This collection contains links to a physical folder, which contains files with the minimum and each programming language necessary structure for compiling an empty project.

Let's represent each module from Figure 2 as a database model. For the implementation of links in tables logical chains, it is proposed to use the Backus-Naur method of metalinguistic formulas (BNF language). This will make it possible to systematize: high-level programming languages in the form of blocks, program headers and program bodies, as "entities": language elements, organization of actions on data, data organization and subassembly "entities": alphabet, lexemes, syntax, design of program code, elements data input-output (interface elements (HMI, GUI), working with a database, working with files), data processing (events on form elements (operations and expressions, operators, organization and use of subroutines). The information model of the relationship between the main "entities" of the reference database is shown in Figure 3.

The proposed physical structure of the reference database is implemented in the form of 37 tables containing more than 110 fields for storing and interacting information dependencies, which fully comply with the laws of normalization, there is no redundancy and inconsistency between entities. All this makes the database flexible and adaptive in work.

To store information about current and completed projects, a cumulative database is proposed that implements the functions of working with the customer. It stores information about current CPPS projects, which allows you to adjust the source code, as well as use the accumulated database as templates for creating new projects with minimal adjustments.

This will reduce the development time of additive cyber design and maximize economic efficiency from the use of the "Automated CPPS development management system". The information model of the cumulative database is shown in Figure 4.

The proposed physical structure of the reference database is implemented in the form of 17 tables

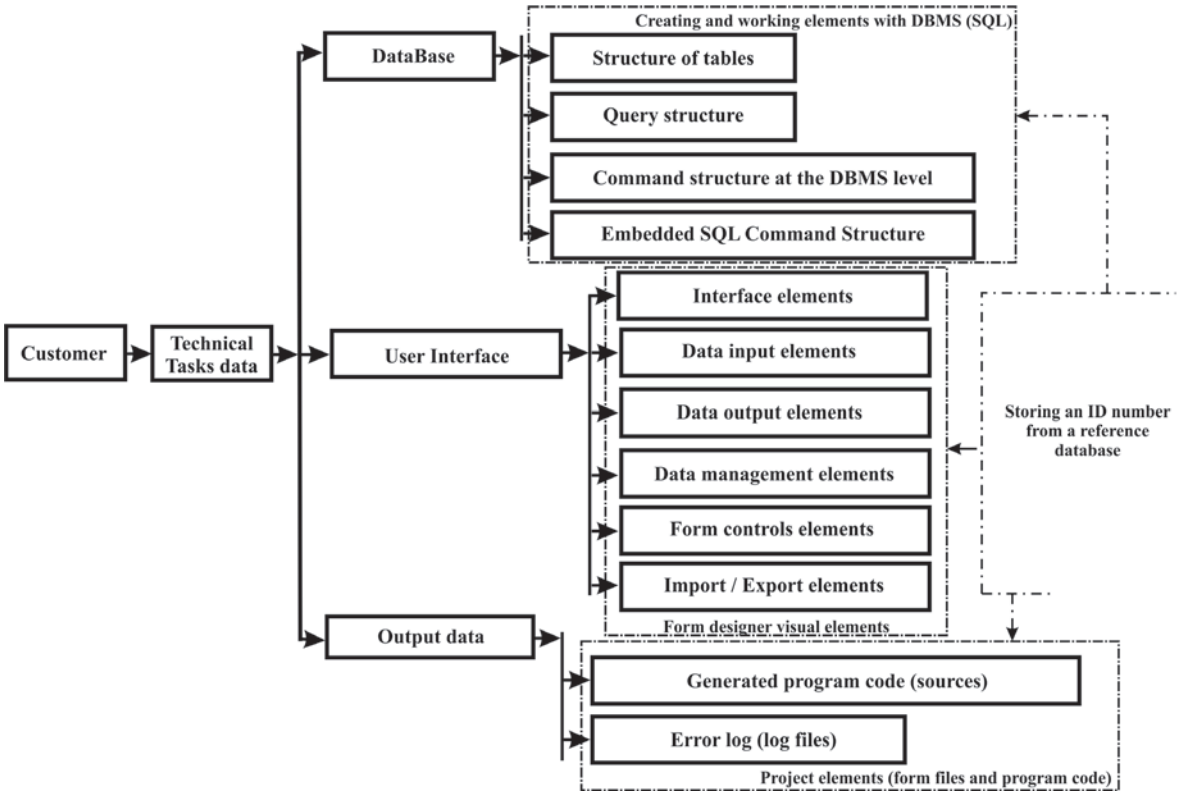
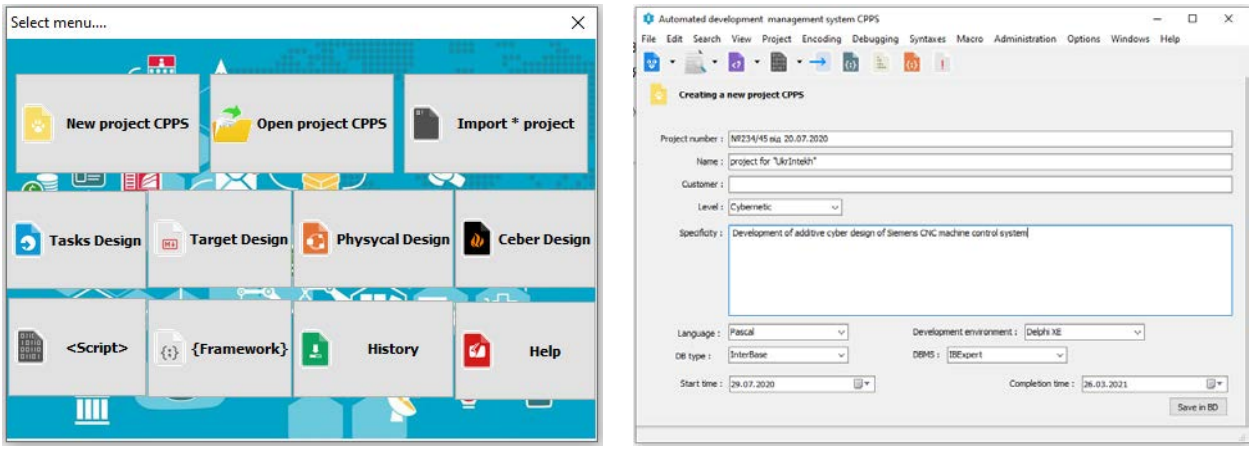


Fig. 4. Information model of a cumulative database



a) b)

Fig. 5: a) main function selection menu; b) window for creating a new CPPS project

containing more than 86 fields for storing and interacting information dependencies, which fully comply with the laws of normalization, there is no redundancy and inconsistency between entities. It is worth noting when developing a cumulative database, to avoid duplication of information, cross-references are used with the reference database.

DISCUSSION OF THE OBTAINED RESULTS

To implement the proposed structure of an automated CPPS development management system, the authors chose the Embarcadero RAD Studio XE3 development environment, on the basis of which the "Automated development management system CPPS" system was developed, the main menu "Select menu" with the choice of the main functions of the system is shown in Figure 5a.

The developed information models of the relationship between the reference and cumulative databases "entities" based on the BNF language are shown in Figure 5b, from which you can see the window for creating a new CPPS project, in which the user selects the required data from the reference database by the fields: "Lavel", "Language", "DB type", "Development environment", "DBMS" and fills in the key fields "Project number", "Name", "Specificity", after filling in all the fields the data is saved in the cumulative database.

CONCLUSIONS

The developed information models of the reference and cumulative databases "entities" interaction were implemented in the "Fire Bird" DBMS. When implementing these models, a physical database model was developed, which in total consists of 57 "entities" tables and 196 fields for storing information about GUI elements, "Linguistic variables" and "Solution containers" that contain fragments of program code.

To create an additive cyber design, the "Automated development management system CPPS" system was developed, which, on the basis of the proposed architectural logical models, formalization methods and HMI decomposition based on GUI elements, makes it possible to automate the CPPS development process, and therefore reduce time and increase the economic effect.

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