Information Technology Of Automation Of Life Cycle Of Construction Objects

Kateryna Kyivska[a], Yevgen Borodavka[b], Svitlana Tsiutsiura[c], Tetyana Honcharenko[d]

[a,c,d,]Department of Information Technology, Kyiv National University of Construction and Architecture, Kyiv, Ukraine
[b] Department of Information Technology of Design and Applied Mathematics, Kyiv national university of construction and architecture, Kyiv, Ukraine

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Abstract: The article is devoted to solving an important scientific and practical problem of automation of the life cycle of construction objects. The methodological principles of development of the unified extensible information technology of automation of life cycle of building objects with the use of the generalized model of the building object are offered, the kernel of the model is created on the basis of the basic set of graphic primitives and attributes. The classification of software used at different stages of the life cycle of a construction object and their generalized model is also proposed. In order to optimize the database containing information about the model of the construction object, it is proposed to use the created method of binary data packing

Keywords: building object, life cycle, building object model, automation information technology, basic set of graphical primitives, database optimization methods, Object Relational Mapping, modified R-tree, invariant metadata database, architectural and construction CAD, CAx-systems.

1. Introduction

In the modern world economy, continuous development is observed in all sectors. The construction industry is not an exception. Even despite periodic crises, it does not stand still – construction technologies are constantly being improved, new buildings are being built instead of old ones, the volume of housing construction is increasing, as the world's population is constantly growing. Along with the constant development of the construction industry, requirements for construction projects are also growing – they should be built as quickly and efficiently as possible. And this, in turn, is impossible without the use of information technology in the field of automation of the life cycle of construction objects. The life cycle of a construction object consists of several stages, but the most voluminous, from the point of view of the resources used, are the stages of designing a construction object and managing the construction of a construction object. The first of them uses computer-aided design (CAD) systems, and the second uses automated control systems (ACS) [1].

In recent years, a lot of work has appeared related to the development of CAD and ACS in construction. All of them are an important scientific asset and have taken a worthy place in the development of construction CAD and ACS. The aim of this work is not just the development of the next building CAD or ACS, but the creation of a theoretical basis and description of the methodology for constructing universal extensible information systems based on the life cycle of a building object.

In this work is proposed models for presenting information about a building object, methods for converting and using this information, basic algorithms that are necessary for implementing information technology for automating the life cycle of a building object [2], taking into account new requirements, including the dynamics of economic development and the construction industry. In modern Western information technologies in construction, the concept of BIM has appeared – Building Information Modeling. In fact, BIM is a special case of PLM in construction. Today in Ukraine, the methodological foundations are not sufficiently developed, describing not only CAD and/or ACS for solving certain problems in the design of construction projects, but they provide a full range of models, methods, tools and instruments for their creation to develop information technologies for automating the life cycle of construction projects.

2. The purpose and objectives of the study

The aim of the study is to develop information technology for computer-aided design of construction objects, taking into account the characteristics of their models of providing information at various stages of the life cycle, as well as software implementation of the technology and evaluating the effectiveness of its use.

The main objectives of the study are: the study of the stages of the life cycle of a building object and models for the presentation of information about the building at each stage; research of modern automation tools and their classification to determine the stages of the building life cycle for which automated design is performed, as well as the models with which they operate; determination of the basic requirements for universal extensible information technologies for automation, covering the entire life cycle of a construction project [3]; analysis and classification of types of building elements and methods of their presentation at each stage of the building's life cycle; definition of a basic set of graphic primitives and attributes to describe the core model of a building object at all stages of its life cycle [4]; development of methods for expanding the core model of a building object based on the modular principle; creating a conceptual model of a data structure that describes a building object at all stages of its life cycle; development of a binary data packaging method to reduce the volume of the data structure and speed up information processing; creation of an invariant information model and a set of metadata to expand the data structure of a building object; research and analysis of the basic methods of spatial indexing of objects to determine the optimal structure for optimizing graphic data; development of a modified R-tree for optimal use of the hierarchy of graphic objects that simulate the building; study of the basic methods for constructing computer graphics subsystems and highlighting the most unified approaches; design and development of a prototype of information technology for automating the life cycle of a building project using the developed methodology; evaluation of the effectiveness of the developed prototype of information technology according to the proposed methodology.

3. Studies of the life cycle of construction projects and analysis of existing means of its automation

There are several classifications of computer-aided design systems according to various criteria of narrowly focused use, intended use and generalizing the classical direction [5].

1. By the level of formalization of the tasks to be solved: the systems are built on fully formalized methods for solving project tasks, carry out design work that cannot be fully formalized; systems when additional techniques are developed to solve informal tasks; systems that organize the search for solutions to informal tasks.
2. By functional purpose: settlement and optimization systems; graphic and graphoanalytic systems; systems of computer-aided design of structures; systems for the preparation of technical documentation; systems for processing the results of experimental studies; Information Systems; systems for technological preparation of programs for numerical control machines.
3. By specialization: specialized systems and invariant systems.
4. By technical organization: systems with central processor control; systems with automated workplaces of the designer (AWP); systems with their own computing resources.

In domestic science and literature, the concept of CAD is quite broad and covers a wide range of tasks in various industries. In foreign literature, more specialized concepts are used, which in recent years have increasingly penetrated into our literature. Now the common English term is used, which refers to various automation technologies using a Cax – Computer Aided. In turn, CAx technologies are divided into functional areas. Among them, there are three main components: Computer Aided Design (CAD). CAD applications are traditionally divided into: architectural and construction (Architecture Engineering and Construction CAD – AEC CAD); mechanical (Mechanical CAD – MCAD); electronic (Electronic CAD – ECAD or Electronic Design Automation – EDA); technological (Computer-Aided Process Planning – CAPP); Computer Aided Engineering (CAE) – computer-aided design; Computer Aided Manufacturing (CAM) – automated production.

From all the given classifications, the most accurate and understandable, in our opinion, is the classification that came to us from foreign literature, which separates all CAD systems in directions, makes it very convenient and understandable. For greater convenience and understanding of the hierarchy of CAx-systems, it is proposed to present their classification in the form of a diagram (Figure 1).

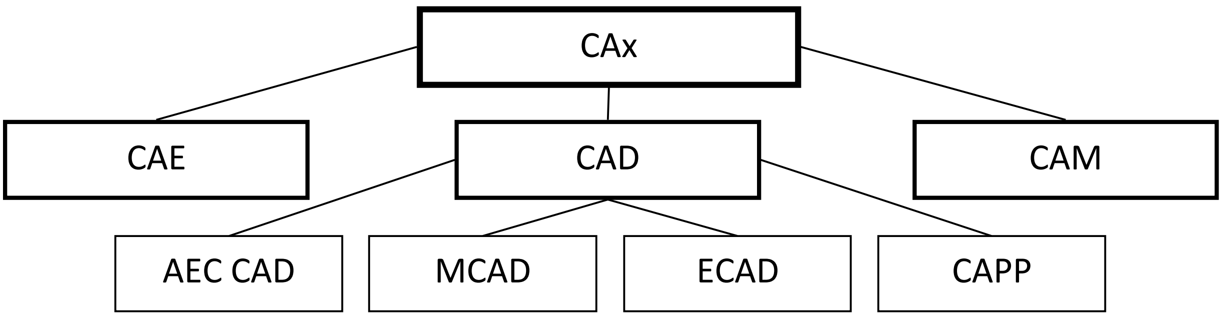

Figure 1. Classification of CAx-systems

Of course, this is by no means a complete list of all areas of CAx-systems, decomposition can be continued further, but we are only interested in the direction of architecture and construction. In the future, we will call Cax-systems of this direction simply AEC CAD or architectural and construction CAD systems in order to avoid the ambiguity of the concept of CAD systems, which is generally much wider, as mentioned above.

First of all, we will try to improve the classification of AEC CAD, and we will do this by different methods. Classification is an important part of creating a methodology for constructing design systems for building objects, since it allows us to formalize the tasks that developers of specific software tools have for the entire life cycle of construction objects.

AEC CAD classification is proposed to be performed in the form of a hierarchical structure, where decomposition into functional directions will be carried out at each level. The following classification of AEC CAD by types of construction objects is proposed:

1. AEC CAD of industrial buildings.
2. AEC CAD of civil buildings.
3. AEC CAD of specific structures (bridges, roads, tunnels, etc.).

It is further proposed that all AEC CADs be classified by design automation directions and linked to types of construction object [6].

In the above classifications, only AEC CAD was considered apart from the entire life cycle of the construction site. But in modern science and technology, CAx systems are considered in the context of a product life cycle management (PLM) system. Therefore, when developing any computer-aided design system for construction objects, it is necessary to take into account the possibility of its inclusion in the PLM of these objects. And for this, it is necessary to consider all the components of the life cycle of a construction project (design, construction, operation, disposal), highlight and detail those that can use CAx systems, software and information technologies. At the present stage of development of construction, the most automated stages of the life cycle of a construction object are design and construction management, and partly the operation phase. If you select and detail only them, then we will get the following diagram (Figure 2).

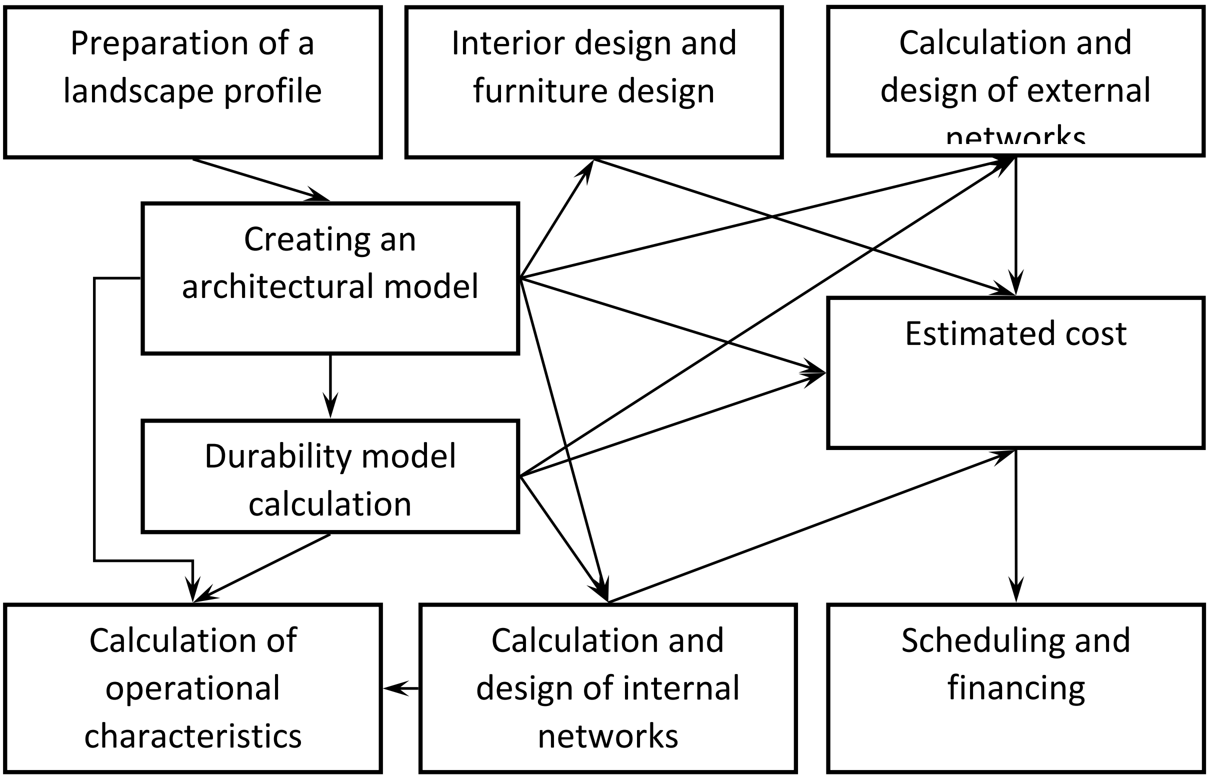

Figure 2. Detailed fragment of the life cycle of a construction object

As can be seen from the diagram (Figure 2), AEC CAD is not enough to automate all components of the life cycle of a construction object. The AEC CAD classification needs to be expanded by supplementing it with components of automated management systems (AMS) and software for calculating operational characteristics (lighting, noise insulation, environmental pollution levels, etc.) of a construction object. All of these components fall under the common name CAx, because they use computer-based automation. An examination of these components will reveal common features for all CAx systems used to create a construction object. And this is important when developing a methodology for creating unified expandable automation systems for the life cycle of construction projects, since it will allow to identify and take into account the directions of expansion and integration of AEC CAD with other components that are used in PLM.

As a result of the analysis, we conclude that research and classification only by AEC CAD does not give a complete picture of the information and the types of presentation for use in PLM construction projects. Therefore, along with AEC CAD, it is necessary to consider and develop new ACS and specialized software for use in the PLM system.

In the first chapter also discussed how to represent a building object at various stages of its life cycle (Figure 3).

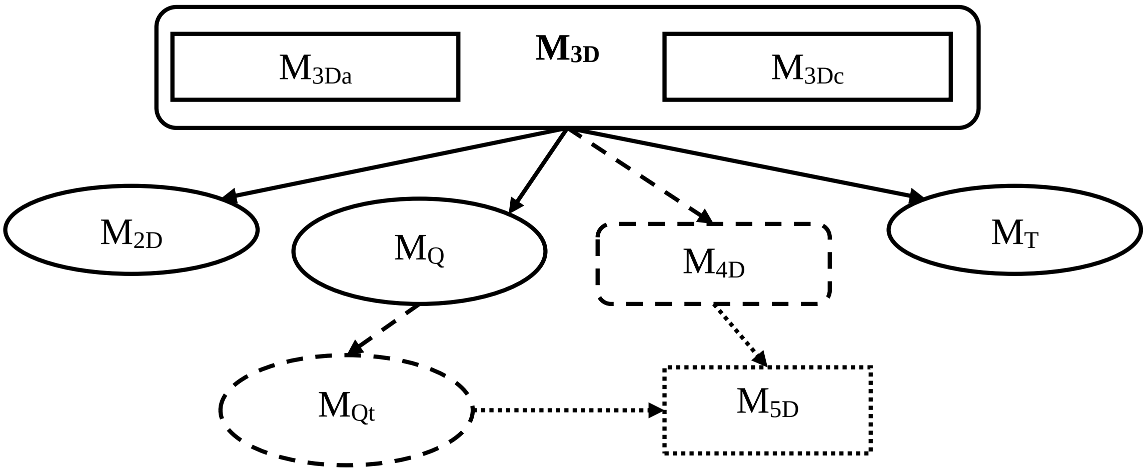

Figure 3. Types of models of a building object and their relationship

Next, we will classify the information that operates these types of models. To highlight the types of information we use the decomposition method. That is, we will try to decompose each of the considered types of models into types of information with which they operate.

The three-dimensional model (M_{3D}) primarily contains geometric information (I_G) about the elements of a building object. This information about the placement of elements in space, their shape and dimensional characteristics:

$$I_G = \left\{ \sum_k \left[O_k(X,Y,Z,W), S_k \left(\sum_n G_{k,n} \left[\sum_i (x_i, y_i, z_i, w_i) \right] \right) \right] \right\}, \quad (1)$$

where O_k – the anchor point of each k-th element in global homogeneous (W≠1) or ordinary coordinates (W=1);

S_k – geometric shape of each k-th element of a three-dimensional model;

$G_{k,n}$ – set of graphic primitives of which the graphic form of each k-th element of the three-dimensional model consists of.

The next type of information that must be present in a three-dimensional model is topological information (I_T). This information indicates the geometric relationships between the elements – which elements are interconnected, which are subsidiary to others or cut holes in them, etc.:

$$I_T = \left\{ \bigcup_i \bigcup_j [e_i (\cup \mid \bowtie \mid \cap) e_j]; e_i, e_j \in E, i \neq j \right\} \quad (2)$$

where E – set of all elements of a three-dimensional model of a construction object.

In general, the types of information described above are enough to build a basic three-dimensional model of a building object. However, architectural and construction CAD systems most often use either an architectural or design extension of a three-dimensional model. Therefore, to complete the model, it is necessary to use one more type of information – attributive (I_A). Attributes can be any information: numerical, text, graphic, and the like. For a building object and its elements, important attributes are the type of element, its material and other additional specific attributes (for example, calculation formulas) depending on the tasks facing a specific AEC CAD tool:

$$I_A = \left\{ \sum_i \left[T_i, M_i, \sum_j P_{i,j} \right] \right\}, \tag{3}$$

where T$_i$ – type of each i-th element of a three-dimensional model of a building object;

M_i – material of each i-th element of a three-dimensional model of the construction object (element is optional);

$P_{i,j}$ – j-th specific parameter of the i-th element of a three-dimensional model of a building object.

A two-dimensional model (M_{2D}) is characterized by the same types of information as a three-dimensional one. That is, the main thing here is the geometric type of information (I_G), but in a simplified form. Formula 1 is also valid for a two-dimensional model, in the absence of a fourth homogeneous coordinate (W=1) and under the following conditions:

$$(Z = 0;\ X, Y \in R) \vee (X = 0;\ Z, Y \in R) \vee (Y = 0;\ Z, X \in R). \tag{4}$$

As in the three-dimensional model, the two-dimensional also contains topological information (I_T), which describes the relationship between the elements of the model (2). Also in the M_{2D} model, as in the M_{3D} model, the presence of attributive information (I_A) is desirable, which fills the model with wider content. Therefore, we can say that the M_{2D} model operates with the types of information that the M_{3D} model does even in a somewhat simplified form with respect to geometric information.

Now let's consider a topological model (M_T). From its name it becomes clear that the main type of information used here is topological information (I_T), since for this model the most important point is the relationship between the elements of the model. Of course, the elements of the model must have certain characteristics, so the need to use attribute information (I_A) in this model is quite obvious.

In fact, the following types of information are quite sufficient for the functioning of the topological model. But for greater clarity and ease of use, the topological model is often used in conjunction with a two-dimensional model (M_{2D}), and it «entails» in addition to described, the geometric information (I_G). Although formally in the model (M_T), geometric information is not included.

The standard estimate model of M_Q actually consists of one type of information – attributive (I_A). But the classical concept of an attribute, described by a pair of «name – value», is not enough to fully describe this model. To describe the M_Q model, an information structure is needed that would allow us to describe a matrix of parameters. This type of information is proposed to be called parametric (I_P). Therefore, in fact, the M_Q model consists of one type of information - parametric, which allows any element or group of elements of a building object to be described by an attribute matrix, can expand both in «height» and in «width». Here we can make a remark that the attribute type of information (I_A) is a subset of the information of parametric type (I_P):

$$I_A \subseteq I_P. \tag{5}$$

Additional models M_{4D} and M_{Qt} inherit the informational content of their basic models – M_{3D} and M_Q respectively. The temporal characteristics used in them can easily be included to the attribute type of information (I_A). Therefore, they do not generate or use any additional types of information.

Thus, we determined the informational composition of all models of the construction object, applying decompositions to them. Now, to build the classification of types of information, we use the aggregation method, that is, combine the types of information of all models of a building object (I_B):

$$I_B = (I_G, I_T, I_A) \cup (I_G, I_T, I_A) \cup (I_T, I_A) \cup (I_P) = (I_G, I_T, I_A, I_P). \quad (6)$$

As a result, we received four types of information used in all representations of the construction object model.

Since the aim of this work is to develop a methodology for creating information technology life cycle of construction projects, it is quite obvious that such information technology should operate with all of the above models. That is, the model of a building object in information technology life cycle of construction projects (M_B) will be the union of all the models discussed above or their extensions, which is more universal:

$$M_B = M_{2D} \cup M_{4D} \cup M_T \cup M_{Qt}. \quad (7)$$

The information circulating in information technology life cycle of construction projects is divided into four types, which were defined above. But here it is necessary to consider another aspect. We considered information as an integral part of each model. However, any type of information can be divided into two types: information that is actually in a particular model (I_B) and invariant (general) information (I_I), which can be used for any model of a building object. For example, in a single building project, elements of type A and type B are used, and elements of type C and D are not used. However, they must be described somewhere by the necessary types of information. For information technology life cycle of construction projects, the composition of the invariant information (I_I) is the same as for the model information (I_B).

In order to ensure the extensibility of information technology life cycle of construction projects without the intervention of developers, it is necessary to provide the possibility of forming new information objects. That is, you need to have the type of information that allows you to generate information objects of one of the four types described above. Such information will be called meta-information (I_M).

4. Conclusion

The article presents theoretical and practical results in accordance with the purpose and objectives of the study – the solution of scientific and practical problems in the creation of theoretical bases and methodology for the formation of universal information technologies for the automated design of construction objects and the development of models and methods of information presentation in the construction process at all stages of its life cycle, as well as methods for building computer graphics subsystems.

In the process of solving the tasks, the following results were obtained: the main stages of the life cycle of a building object were investigated and models for presenting information at each stage were proposed; the study and research of modern tools of computer-aided design systems were conducted and their classification by tasks at the stages of the construction project life cycle was carried out; a conceptual model of the data structure has been created that describes a building object at all stages of its life cycle and developed methods for expanding the core of a model of a building object based on the modular principle; a model of invariant information and a set of metadata was created to extend the data structure of a building object; designed and developed a prototype of information technology for the automation of the life cycle of construction projects.

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