Increasing the economic efficiency of design and construction solutions due to the automated identification of construction works and structural elements of information models

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Abstract. Currently in many countries around the world there is an active introduction of information modeling technologies in the construction industry. This process is largely aimed at optimizing approaches to the formation of design estimates for capital construction objects. However, the established views on the development of project documentation do not always fit into the concept of new approaches. In an attempt to fit traditional processes of identification of construction works and structural elements into information modeling technologies modern engineers are faced with the problems of optimizing and automating established processes. Modern software for the identification of construction work and structural elements although is developed taking into account the interaction with information models, does not change the previously established design approaches. This article explores a methodology that can significantly increase the economic efficiency of design and construction solutions by automating the identification of construction work and structural elements using information modeling technologies.

1. Introduction

Undoubtedly the introduction of information modeling technologies (IMT) in the construction industry is a global trend. Everywhere in most countries of the world at the state level implementation plans, development strategies and other driving aspects are being developed. The use of the IMT for the design of construction projects receives all kinds of preferences from government customers. In Russia it is increasingly becoming mandatory to develop project documentation only by means of the IMT, which is clearly indicated in the technical specifications of State contracts. In 2019-2020 state expert organizations began accepting projects of construction projects only in electronic form with the possibility of presenting them in the format of information models. Several such projects have already successfully received positive opinions and despite the fact that this was the first experience the projects were examined on IMT and in some cases even earlier than the deadline [1].

The advantages of the IMT using in the development of design documentation for construction projects over traditional design methods are obvious. The IMT have certain disadvantages as all new technologies especially those that are introduced so intensively. They are expressed in the use of foreign software IMT (software IMT), which is usually developed under the state standards of the development country. For example, at the output of the process of generating architectural and construction drawings documentation is generated that does not meet the design requirements established by the Russian
Federation. Design engineers have to modify the generated drawings in manual mode, which in some cases is comparable to the development of such drawings by the traditional method. Although solutions are provided for joint work in information spaces on the subject [2].

This trend can be traced throughout the design process using the IMT. This is the incompatibility of the data exchange formats between the IMT software developed by many vendors, the lack of feedback between the generated output information and the information model, the lack of the IMT solutions for the development of specialized sections of project documentation and so on. Despite this IMT allow not to be limited only to the development stage of design and estimate documentation but are successfully applied at all stages of the life cycle of the object under consideration [3].

The situation with the preparation of estimate documentation is a standing out from the whole mass of the IMT shortcomings. This is due to the fact that the formation principles of estimate documentation are of a purely territorial nature. The process of drawing up estimates differs not only between countries but sometimes also between regions of a single country. For example in the Russian Federation in different regions, different collections of estimated standards are used and if you re-calculate the estimated cost of construction using different regional collections the total amounts will differ quite significantly. One of the options for solving the problem of estimated norms variability is the use of enlarged estimated standards in the process of creating an information model but this option for constructing a price model gives significant errors as a result of calculations [4].

In addition to differing territorial estimate standards, the goals - for which in fact the development is being carried out - have a strong influence on the principles of developing estimate documentation. In many countries including the Russian Federation, estimate documentation can be attached to the concluded contracts and have legal force along with the terms of the contract. In some countries the estimate documentation is only informative in nature and may not be drawn up at all [5]. In the Russian Federation the development of estimate documentation is mandatory for objects that are financed with the involvement of the state budget. For other capital construction projects, the preparation of estimate documentation is allowed but not mandatory [6].

According to state statistics in 2018 in the Russian Federation the share of state financing in investment and construction projects amounted to more than 70% of the total mass and if given the trend of commercial customers to establish requirements for the estimates inclusion in project documentation, moreover it was developed according to state budget standards and not according to firm prices, it can be assumed that in the Russian Federation in 80% of project documentation cases development estimates were also developed [7].

For many people the estimate documentation is presented in the form of ordinary calculations, sometimes not always objective sometimes the estimate starts to be studied only when the project has passed the state expert review.

This is due to well-established design principles, which imply the development of cost estimates as they say "post facto" that is engineering - technical solutions are put ahead of the economic component. It is connected with limited possibilities of automated design systems (CAE) and the estimated program complexes (EPC) used at traditional approaches of working out of the design-budget documentation. However with the IMT arrival in the construction industry the concept can and should change [8]. The IMT priority directions should be the technology of a construction object as the objects are built not for the construction or implementation of some engineering solutions but have real goals both in the development of the state and in commercial terms.

In most countries including Russia state collections of estimate standards are used for preparation of estimate documentation. The basis of the estimate rationing in Russia is the State elemental estimate standards (SEES) and methods of their preparation, updating and application. SEES are collections of tables with indication of resource requirements for building and construction works (BCW) and descriptive part (technical part of the collection) with indication of application peculiarities of this or that table positions depending on BCW performed. An example of a table from the collection of the SEES is shown in Figure 1.
Table SEES 06-01-012 Formwork (bottom) and supporting structures for high grillages

Scope of work:
01. Cutting and boards installation. 02. Installation of formwork panels. 03. Fastening of formwork elements with construction nails.

Meter: 100m² area of the grillages horizontal projection

| Resource code | Cost element name                                                                 | Unit of measure | 06-01-012-01 |
|---------------|----------------------------------------------------------------------------------|-----------------|--------------|
| 1             | Labor costs of construction workers                                              | mhrs            | 95,92        |
| 1.1           | Average work category                                                            |                 | 2,9          |
| 2             | Labor costs of machine operators                                                 | mhrs            | 0,34         |
| 3 021141      | MACHINES AND MECHANISMS                                                         | mash.hour      | 0,07         |
| 030101        | Cranes on the road while working on other types of construction 10 t             | mash.hour      | 0,27         |
| 400001        | Lifting loaders5t                                                                | mash.hour      | 0,1          |
| 4 101-1805    | MATERIALS                                                                        | t               | 0,0147       |
| 102-0053      | Construction nails                                                               | m³              | 0,32         |
| 102-0061      | Edged boards of coniferous species 4-6.5 m long, 75-150 mm wide, 25 mm thick, grade III | m³              | 0,42         |
| 203-0512      | Edged boards of coniferous species 4-6.5 m long, 75-150 mm wide, 44 mm thick and more, grade III | m²              | 5,44         |
| 405-0253      | Board panels 40 mm thick                                                         | t               | 0,021        |
| 411-0001      | Unhydrated lime for construction, grade I                                         | m³              | 0,061        |
|               | Water                                                                            |                 |              |

Figure 1. Example of a table from the SEES collection

As can be seen from Figure 1, the SEES table contains a brief description of the technological processes of this type of the BCW and departments with the need for manpower, mechanized equipment and construction resources. That is it contains information from which if desired it is possible to form resource sheets, to carry out calendar and network planning of works, to prepare schedules of materials delivery and so on [9-10], which is currently completely absent in the design process.

2. Formulation of the problem

In various IMT software the automation of identification of construction works and structural elements is implemented through the use of databases with “primary” and “secondary priorities”. The use of databases with "primary priority" is carried out by returning to the information model of elements containing estimated attributes. This method of automated identification of construction works and structural elements is widely used in large design and construction companies that are concerned about the economic and organizational components of their activities, and they have the ability to accumulate information on implemented projects and form their own corporate databases with "primary priority". This option of automated identification of construction work and structural elements is very effective but its application is possible only in the design and construction company of the database developer.

The approach to automation of construction works identification using databases of "secondary priority" is based on the application of collections of estimated standards post factum development of engineering solutions. This approach is the first attempt to automate the development of estimate documentation using the IMT [11].

As can be seen from the description of the current applied approaches to automate the identification of construction work and structural elements using the IMT although they fulfill the task but they have
a number of significant disadvantages. This is due to the lack of methods for selecting the most cost-effective design solutions and established technology for performing design work. Also, an essential factor that limits the adoption of cost-effective design solutions is the lack of approaches to the abundance of information contained in the SEES.

3. Methods and techniques

The proposed methodology for automated identification of construction works and structural elements in information models of capital construction objects is based on the use of “secondary priority” databases as “primary priority” databases. This is based on the methods of forming SEES, which indicates that the tables are not tied to a specific construction organization and reflect the average demand for material, technical, construction, and human resources for this type of BCW.

The proposed methodology for the automated identification of construction works and structural elements is based on the automated assignment principle of attributes of the corresponding SEES tables to the information model elements. From there having such a powerful tool as the IMT it becomes possible, already in the process of developing project documentation to track changes in the estimated cost of construction when enumerating possible types of technical solutions [12] as well as to obtain related information that will help to track changes in construction time, compare the resource availability of the construction region with the need for construction resources of the projected capital construction facility and perform many other related calculations. In this way having the technical ability and working prototypes of the automated identification system for construction works and structural elements by a small number of attributes assigned at the stage of the conceptual project design it remains to figure out their use in the development of building information models.

Consider an example: when developing project documentation, the design engineer considers an element of the information model "wall" as a free constructive space that can be filled with various materials: brickwork, wooden beams, foam concrete or tongue-and-groove blocks (Figure 2).

![Figure 2. Visualization of the options selection for filling the element "wall" (from left to right: the element "wall", options for filling 1, 2, 3, 4).](image)

Applying traditional approaches to the implementation of design work, the design engineer can choose any option since all four presented options are absolutely suitable for adoption into the project. The choice of a specific building material is usually based on the specification or the personal experience of the design engineer. In order to formalize the choice of one of the options the selection criteria are required, similar to the criteria of engineering and functional stability of life support objects [13]. From there having established the criteria for building materials it is possible to determine the indicator of their interchangeability.

To determine the interchangeability indicator, the following criteria are proposed, which can be obtained from the SEES collections:
- criterion C1: applicability in a specific filled space of the structure;
- criterion C2: the amount of human labor costs to perform the BCW
- criterion C3: the need for machines and mechanisms;
- criterion C4: the amount of associated construction resources.
For example during the parametric description of a “wall” element, the design engineer manually or using automated identification means assigns a “basic” building material - ordinary brick - to fill the considered structural space. Criterion C1 is determined by comparing the applicability of the considered BCW technology and if the value of the “partition” defined as a building element coincides criterion C1 is assigned a value equal to 100, otherwise -100. Criteria C 2, 3, 4 are calculated by comparing the difference value of the considered departments of the SEES tables to the "basic" building material and if the difference is negative, then the criterion is assigned a value of -10, otherwise the criterion is +10. The interchangeability index is calculated by the formula: 

\[ P(i) = C1 + C2 + C3 + C4; \]

The \( P(i) \) values can range from -140 to 140. Significant proportion of C1 in the calculation is assigned to exclude building materials that are not suitable for filling the space of the building structure, thus the selected SEES tables with the value \( P(i) < 60 \) are discarded and not used in further identification. For the rest of the case the resulting rating table of interchangeable building resources of the SEES is compiled.

In the case of applying the proposed approach of automated identification of construction works and structural elements the design engineer receives more complete information about the decisions made (Figure 3).

As can be seen from Figure 3, there is information both on cost and the duration of work, which allows to carry out the analysis of economic efficiency of accepted constructive decisions in a mode of real time instead of post facto drawing up of the estimate documentation. In addition to the interchangeability indicator the list of information returned from the SEES included labor costs based on the fact that the time factor may prevail over the economic component of a single construction object. The proposed methodology provides an opportunity to set appropriate priorities and perform invariant calculations.

Implementation of the proposed approach is also of variant nature. During the survey the approach was implemented as a plugin "Cost Assistant" for Autodesk Revit software (Figure 4).
Figure 4. The approach implementation in the form of a plug-in "Cost Assistant" for the software IMT Autodesk Revit

When selecting an information model element and calling the "Cost Assistant" plugin, the following information is available to the user:

- "DBase" - the current database of estimated standards (in the example, the SEES database as of Q1 2020 has been selected);
- "Element" – is the selected element type ("int_partition" - internal partitions);
- "Measurer" – is the unit volume meter of the element;
- "Value" – is the volume value per meter;
- "Var_1_...", "Var_2_...", "Var_t_...". – is the result of identification of a construction element in the selected database;
- "Cost priority" – is the priority (rating) among the selected options set by the price parameter ("2/4" 2 of 4);
- "Time priority" – is the priority (rating) among the selected options set by the time parameter.

As can be seen from the above the price and time ratings of filling the constructive space with the offered materials become available for the user. The plugin work can be provided both with manual assignment of one of the selected options and in automatic mode initially assigning priority to reduce the cost or duration of construction of the analyzed element of the information model.

Application of the proposed methodology already at the stage of sketch elaboration of volumetric planning solutions makes it possible to analyze the erection cost (filling the structural space) of various types of construction resources. As a result of the application of the proposed methodology for automated identification of construction works and structural elements it is assigning estimated attributes to the elements of the information model with the subsequent generation of estimated documentation in automatic mode.

The proposed approach significantly reduces the duration of the design documentation development by reducing the time for decision-making on the erected structural elements of the information model of the capital construction object.

4. Summary
The introduction of IMT in the construction industry is a breakthrough event that has brought huge opportunities for investment and construction projects. The potential of IMT tools in particular the selection of cost-effective technical solutions elements of information models of capital construction objects is very significant in comparison with the established technology of designing construction projects.
All this allowed to look at design processes in a new way and to develop methodology of automated identification of construction works and structural elements. The proposed methodology allows to make the most cost effective decisions already at the stage of sketch design development.

The proposed methodology is aimed at improving the economic efficiency of design and construction solutions through automated identification of construction works and structural elements of information models through the use of databases with "secondary priority" in the technology that provides for the use of databases with "primary priority". Assigning the elements of the information model attributes from the compendia of the SEES gives additional opportunities for planning the organization of construction processes, calendar and network construction schedules, as well as the implementation of related calculations of needs and the movement of manpower on the construction site, analysis of compliance with the resource availability of the region of construction and so on.

The proposed methodology has a significant potential, many times greater than currently available solutions to automate the estimated cost of construction as it provides optimization of the development of design documentation at all stages of design not only at the stage of making the estimated documentation.

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