The methodology of storing the information model of building structures at various stages of the life cycle

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Abstract. The paper presents an analysis of the current state of processing the results of laser scanning to build information models of construction objects at the operational stage. The authors proposed a new methodology for combining project documentation and executive (as build) documentation (obtained via laser scanning procedure), presented an application of this methodology in the context of the entire life cycle of a construction project. The authors do not try to process point clouds (laser scanning results) and convert them into BIM objects (existing approach) but offer a methodology for working with raw data as BIM object.

1. Introduction
The process of designing buildings and structures has gone through several stages of development. So, at the beginning of its history, drawings were created on paper that was associated with some problems, such as a low speed of execution of drawings; a low level of documentation quality, difficulties associated with making corrections.

The creation of the first computers and two-dimensional “drawing” programs, such as AutoCAD, took the design to the next stage, which subsequently contributed to the development of programs that allow working with 3D objects and their properties.

Today, computer-aided design (CAD) systems are entire sets of tools for designing and modelling objects at various stages of their life cycle (LC). The founding industries in this achievement were construction and mechanical engineering.

In addition, recently the technology of information modelling of construction objects has been developing, when in parallel with the geometric properties of the object, all the information flows necessary for the construction and operation of the object are modelled.

Today an increased attention is paid to development of CAD systems, their use in various fields of science and technology, the problems of data interoperability, that fact is confirmed by several scientific papers [1-11, etc.]. A lot of research works are also devoted to the development of information modelling technology [12-20, etc.]

In the research work [21] the authors found that the BIM model (information model) is a specially organized information on the object, which has a numerical description, and can also be used both at the stage of design and construction of the object, and during its operation.

Research works in the designated area has led to the fact that the relationship between the construction of the facility and information technology become stronger, and in some cases, there is even a merger of these technologies. So, for example, the Autodesk Revit software package allows to connect the Dynamo add-on.
Dynamo is a powerful tool, but it isn't for everyone. The main separating factor is its programming nature which caters to users who are in tune with programming languages. Advanced coding experience is not necessary, however the logic of instructing Dynamo to do what you want is essential and this helps to have basic coding experience. Users with Python experience can maximize the functionality of Dynamo by taking advantage of Dynamo’s custom code block interface to write custom scripts.

Considered, information modelling technologies allow us to describe the “design state” of the structure using design and working documentation. At the same time, these design systems, as a rule, store data in the form of node coordinates and distances between them.

There are some attempts to entry data about structural defects from the operation stage obtained by laser scanning into the information model of the object. However, the accuracy of transferring such data to the model is affected, because engineers, as a rule, follow the path of simplification of the data obtained.

The main approach in these cases comes down to creating meshes/ surfaces based on point clouds data, which reflected the real state of the object. However, in the process of converting point clouds data in the surface, there is a significant loss in accuracy, which, for example, is critical in projects for the restoration of historical heritage sites. In addition, working with point fields, as a rule, does not allow to select individual objects, which carries certain inconveniences. Working with such files comes down to working with a huge array of unstructured data, in which the operator is forced to make measurements or build sections exclusively in accordance with his knowledge and qualifications.

In addition, there is an open problem with transferring data between models using the IFC standard described in ISO 16739-1: 2018 “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries - Part 1: Data schema”.

This format is intended for the exchange of data on geometry, attributes and relationships between elements of information models of capital construction objects. However, even on the basis of one program (for example, Autodesk Revit), exporting to IFC and then importing it into the same program violates the integrity of information about the construction site.

Thus, there is a need to develop a technology that allows to solve the following problems: to combine information on project documentation and various stages of operation, in order to describe the behaviour of structures at various stages of the life cycle and to ensure the integrity of storage and transmission of the information model.

2. Methodology
The conversion of the format of point clouds into the surface and their storage in the information model, as well as the use of the IFC format for information transfer, violate the integrity of the information, therefore this storage method is not optimal.

It is logical to go the opposite way and convert the design model into point fields. Moreover, each object has its own sets of point fields. And the same thing can be done with laser scanning files by breaking the common field of points into “fields of various objects”. Thus, it becomes possible to bring design documentation and laser scanning files to a common denominator.

It is possible to use databases of the type Microsoft SQL / MySQL / PostgreSQL for storing information of this nature, namely arrays of points. It is proposed to store information about the geometric state in the format of the so-called “point clouds” (xyz), dividing inside the database into columns (x, y, z).

At the design stage, the designer is asked to specify characteristic sections for observing future processes and, together with the converted design model (xyz format), information on geodetic reference points, place this information in the database.

In the future, this base must be supplemented with various stages (executive documentation, operation stages, etc.) of an object based on laser scanning and/or photogrammetry technologies. The positioning of these stages in relation to the design is planned to be carried out by reference to
geodetic reference points. Thus, this database will allow to combine information about the object at various stages of the life cycle.

3. Results
The database structure containing the Information model of the object at various stages of the life cycle is shown in Fig. 1.

The database is based on the objects_data table, which contain information about all structural elements at different stages of the life cycle.

- **id** is a unique element number that is constant for the element at various stages of the life cycle.
- **stage_number** is a number of stage (0 - design, 1 - executive, 2 - operational, etc.) is assigned by the designer.
- **object_name, object_number** are the name of the object and its number.
- **date** is a column containing information on the completion of the period of work (As an example: the date of issue of project documentation, the date of execution of executive documentation, the date of various observations of the object in order to replenish the properties and geometric characteristics of the constructed object).
- **link_to_source** is a column containing links to project documentation, information about reports, etc.

Each object of the objects_data table is associated with tables of geometric characteristics (in the example considered, shown in Fig. 1 - geometry_stage_0, geometry_stage_1) and properties of building materials of the structure (in the example - properties_concrete, properties_reinforcement).

Tables of the geometry_stage_... class are created on the basis of converted project documentation/point clouds data obtained by laser scanning/photogrammetry.

Consider a part of the geometry_stage_0 table, here

- **id** is a unique element number, taken from the objects_data table.
- **stage_number** is taken from the objects_data table.
- **x, y, z** are the coordinates of the points included in the point cloud.
Thus, knowing id and stage_number, you can uniquely identify a point cloud that determines the geometric characteristics of an object in a given period of time (stage number).

The number of tables of this geometry_stage__... class is unlimited and is populated as information about new stages of the object appears.

The tables of the properties__... class are designed to provide storage of the properties of building structure elements. The properties of elements can be different, so it is advisable to break down the properties of elements into different subgroups. So, for example, for concrete (properties_concrete):

- id is a unique element number, taken from the objects_data table.
- stage_number is taken from the objects_data table.
- B, W, F are the concrete properties, respectively, concrete strength class, water absorption level, degree of frost resistance.
- link_to_source is a column that may contain links to tests/information about reports, etc.

For reinforcement (properties_reinforcement):

- id is a unique element number, taken from the objects_data table.
- stage_number is taken from the objects_data table.
- class is a class of reinforcing steel.
- diameter is a diameter of the reinforcing bar.
- link_to_source is a column that can contain links to tests / information about reports, etc.

Thus, the data of the property table allows to store the parameters of the materials at various stages of the life cycle of the object, as well as evaluate the change in the properties of the material over time.

The properties that are presented in table data are given as an example, their quantity and content can be different and depend on the task.

The service_data table contains information about the position of geodetic reference points (x, y, z) and information on the characteristic sections selected by the designer. (In the future, if necessary, new sections can be added). This table is not associated with the main tables and is intended only to store reference information.

- Object_name and object_number are the name and number of the object.
- x, y, z are the coordinates designed to determine the location of the object.

The methodology for tracking the geometric state of a building object at various stages of the life cycle is presented in the Fig. 2., it is one of the possible ways to use the developed database.

At the first stage (the stage of project documentation), the project documentation is processed (the geometry is transferred from the presented documentation to the point cloud format, the properties of building structures are entered into the corresponding tables of the developed database). At the same stage, the designer must enter information on the position of the geodetic reference points (x, y, z) in the service_data table and can add information about the characteristic sections of the construction object (as a rule, these are the main axis of the structures).

At the “Executive documentation” stage, the designer updates the state of the model based on the results of the laser scan, enters information about the changed properties of building structures (if such information is available). Already at this stage, the designer, using the capabilities of the Structured Query Language (SQL), can receive sections on the building structures of interest in the xyz format, and subsequently analyze the discrepancy with the design documentation, etc.

At subsequent stages (operational stages), it is proposed to supplement this base with data similar to the “Executive documentation” stage. The accumulation of this information allows to consider the dynamic change in the building structure, which corresponds to the task.
4. Conclusions

The presented database allows storing and analysing different states of construction objects in a single information model, and the extensive capabilities of the SQL language allow, through queries, to obtain accurate information about various sections of objects at different time periods. This research work demonstrates the possibility of combining information obtained from various sources and at various stages of the life cycle of a construction project, which will significantly reduce the labour costs of examining buildings and structures. This database can also be used to create executive
documentation, develop documentation for reconstruction, and to create systems for monitoring displacements and deformations of building structures. In addition, the proposed approach demonstrates the merger of construction and information technologies.

Since the presented approach allows to store and transfer information (like any other database) not only about changes in the geometric characteristics of a building object, but also about the properties of objects, it is obvious that this development does not contain IFC format problems.

It is worth noting that, in contrast to the approaches considered, where the authors solve information modelling issues by converting a point cloud in the surface and then into solid objects, with a partial loss of accuracy, this methodology allows to accumulate and process raw data sets, i.e. e. without changing them. The second significant difference is that this approach considers not only the static state of the object at a certain point of time, but also the dynamic behaviour of the object at various stages of its life cycle.

Acknowledgments
This study was performed with the financial support of the RF Ministry of Education and Science, President Grant #NSh-3492.2018.8

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