Visualization of construction infrastructure objects

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Abstract. Building information modeling provides an integrated three-dimensional environment applied to the management of large-scale engineering projects, allowing you to reduce the cost and time for planning structures and requirements for the reliability of buildings. The purpose of this work is to develop a methodology for changing the layout and reliability factor during the visualization of three-dimensional models to improve the analysis of building plans. This approach will allow you to combine different analytical methods and approaches when planning different structures. The results of this work suggest new directions for future research in the field of information visualization for the construction complex. The system is compatible with portable and scalable mobile devices. The proposed system can also be used for pre-project architecture and augmented visualization, where proprietary developed methods are used to achieve the quality of photorealistic rendering.

1. Introduction
Currently, the information technology industry is developing intensively. It is already impossible to imagine our life without information technologies. In our country, much attention is paid to the training of specialists in this field. However, the question is how to use 3D information technologies most effectively.

The real estate and construction sector is widely recognized as one of the most promising applications for IT technology. The latest developments in data processing and volumetric modeling are helping to reduce costs for the real estate and construction sector, allowing the introduction and use of new technologies. For example, one of the possible ways to use IT technologies in the field of real estate and building construction is the visualization and verification of tasks and plans during construction work. Some advanced construction sites are already beginning to replace paper drawings with 3D models as reference materials for construction workers. In addition, at any time you can look at the layout in different projections to determine future or past actions, its relative position between three-dimensional geometries, intuitively indicates the tasks that are necessary to strengthen the structure of buildings.

Modeling plays a key role in computer-aided design systems, primarily because it helps identify design errors at an early stage and quickly eliminate many unnecessary design choices.

The system showed clear design uncertainties, identified conflicts between workspaces, and helped analyze other design problems. The results and contributions of this article offer new directions for future research in the field of information visualization for the building complex industry.

The relevance of the presented work is manifested in the need for technological modernization and the introduction of an innovative approach in the field of information visualization for the construction complex in order to improve the quality and visibility of the information received. For example:
students of the construction direction will be able to acquire a virtual practical experience of interacting with various structures in conditions as close as possible to real ones, and will also be able to study the structures and details of individual components and assemblies that make up complex and expensive systems;

students in the design areas of training will be able to see the 3D model of the designed building, its design.

The concept of the work was based on the generalization and systematization of advanced foreign and domestic experience in the field of design, in particular, the construction of three-dimensional models.

2. Related work

After analyzing the key work in the direction of information visualization in the construction sector, we can conclude that this direction is relevant.

For example, a team of scientists led by Peng Wang reviewed the possibilities of using three-dimensional technologies in construction and engineering. It has been found that 3D technologies have evolved over time, from desktop to virtual reality with support for building information modeling (BIM). In the paper, the authors presented future directions of research, including the integration of virtual reality with new educational paradigms and visualization technologies [1-2].

The importance of assessing potential improvements in the environmental performance of buildings in the early stages of design is shown in [3]. The authors propose a building information modeling (BIM) approach to assess a wide range of construction options and their embodied environmental impacts. The paper uses a conceptual BIM model to evaluate different compositions of materials for different building elements.

In their works [4-7, 9], the authors reviewed the main activities for which building information modeling (BIM) is relevant. We visualized the various components of the project, creating a so-called 4D model. With the possibility of detailed visualization of construction processes, 4D models allow you to carefully study the selected design method or feasibility schedule, taking into account the space required for various tasks. As a result, any decisions made regarding the constructiveness of the project based on existing 4D models ignore the risks of delays in completion and the resulting potential conflicts of constructiveness. It is shown that such a method has great potential for providing input data for more accurate analysis of constructiveness.

Pingping Liu and Zhaopan Lu have developed an algorithm to design pre-operation operating conditions and reduce the risk of serious accidents in the coal mining industry by analyzing the characteristics of an underground mine environment using virtual reality technology combined with 3d Max and VC ++ modeling techniques invoking GUI techniques OpenGL, and progressive mesh LOD optimizations for edge collapse [8].

A team of scientists led by K. Akahoshi has developed an Application Domain Extension (ADE) for urban planning, covering the attributes of urban objects and the global analysis engines required for urban planning. The effectiveness of the ADE application was assessed through experimental visualization in three municipalities in Japan. The authors believe that this application will help the development of human resources in municipalities in order to contribute to the revitalization of cities. [10]

The paper [11] presents possible models of visualization of three-dimensional objects for the construction industry. The authors presented a new computational model and visualization system that help domain users interactively explore jointly limited accessible regions, street segments, and points of interest (POI). In particular, the system for visualizing the accessibility of urban structures is built on the Min-Max joint recruitment model, in which specially designed recruitment operations not only represent the available regions, but also calculate the minimum and maximum access times to urban structures from joint constraints. Calculations and visualizations are supported by a new graphical model.
that takes into account the real dynamic traffic situation and the geographic parameters of city street segments and POIs.

3. Mathematical model
In the system, all geometry, regardless of its original height, is displayed along the z-axis using the same reference system: the horizontal plane located at the bottom of the vertical axis, which is the base of the foundation. The end z-coordinate of each feature is calculated using the following equations:

\[ Z_{obj} = Z_{plane} + \left(\frac{\text{result} - c}{b - c}\right) \times \text{Size} \]

\[ b = c + \text{Count} + \text{Days} \]

These equations perform the linear value of the final object (result) on the current effects of various factors on the three-dimensional model, \( b \) is the reliability of the structure, and \( c \) are external factors affecting the structure. In this case, \( b \) and \( c \) can vary both from the time of day and from the season, which are set as variable values. The user can change the date by which the object will be built and configured at a certain moment \([12]\).

The level of smoothing of landscape objects located along the axes after increasing it is determined by the following formulas:

\[ \text{morph}_x = \left( \frac{\text{Size} \times \text{NodeMEX} \times \text{Size}}{\text{TER} \times \text{MaxTr}^2} - 0.5 \right) \times 2, \]

\[ \text{morph}_y = \left( \frac{\text{Size} \times \text{NodeMEY} \times \text{Size}}{\text{TER} \times \text{MaxTr}^2} - 0.5 \right) \times 2, \]

\[ \text{morph} = \text{Max} (\text{morph}_x, \text{morph}_y), \text{Max}(\text{morph}_y, \text{morph}_y) \]

where \( \text{NodeMEX}, \text{NodeMEY} \) - the maximum number of errors along the X axis and Y;
\( \text{MaxTr} \) - defines the maximum terrain detail;
\( \text{morph}_x, \text{morph}_y \) - "smoothing" of the terrain object after enlarging it.

The splitting continues until the morph factor is less than one. Each leaf square of the tree is divided into triangles and forms one dip.

An additional rule is introduced on the border of squares of different sizes to simplify their joining with each other without gaps. Any square can border on one side no more than two other squares, and when such situations arise, additional divisions of the squares into triangles are performed.

4. Practical part
Systems modeling languages provide users with:

- a methodology for preliminary analysis of the system and the creation of a formal description, including tasks such as identifying the structure of the system and highlighting functional elements;
- the methodology for conducting simulation, that is, reproducing the functioning of the system on the model;
- the general methodology of the statistical experiment.

3D objects are introduced by defining a class for each type of object and then by instantiating those classes at a specific point in the model / simulation time. Figure 1 shows an example of creating an object class when modeling a solid.
All the variables presented (such as \( v, v' \) and mode) are implicitly functions of the scope of the model. Variables introduced in a private section of a class are the state of any objects of that class. The value assigned to each variable is the initial value it has when the object is created. \( v' \) denotes the derivative of volume over time. Thus, given the initial value of the variable \( v \), if \( v' \) is defined, then the value of \( v \) will be automatically determined for the future value of the object. The switch statement allows you to use different sets of rules to control the behavior of the model under different conditions. The applicable case is determined by the value of the variable mode. If mode is 0, then the first if statement is active. If the value is 1, then the second if statement is active.

The two if statements follow a parallel pattern: their true branch contains a contiguous value (\([=]\)), and their false branch contains a discrete value (\(=\)). The main difference between discrete and continuous values is that discrete values block the progress of logical time in the sense that the simulation cannot progress beyond a certain point in time until all discrete tasks have been completed. Continuous tasks, on the contrary, occur continuously, do not create special restrictions on what happens at a given time.

We will design the layout of the building and the necessary structures. For each model of buildings, we will write down our parameters of reliability and strength, we will set the values of humidity and wind coefficient. The result of the work is shown in figure 2.

The next step is to translate all the prepared models into a three-dimensional projection. This will allow you to optimally determine the size of the required scene, the required relief and textures that need to be added to the rendered scene. These results are shown in figure 3.
After preparing all the required models, we will apply textures and a background to these objects for a better display of the scene (figure 4).

Let's start the process of emulating the projected rendered scene, which takes into account external factors such as wind, humidity, etc. (figure 5).

We will change the foundation of the building for this type of surface and weather conditions to improve the reliability of the building structure. The result is shown in figure 6.
5. Conclusion
The work done presents information modeling of buildings, integrated into a three-dimensional environment, applied to the management of large-scale engineering projects, allowing to reduce the cost and time for planning structures and requirements for the reliability of buildings. A technique for changing the layout and the reliability factor during the visualization of three-dimensional models is presented to improve the analysis of building plans, which allows combining various analytical methods and approaches when planning various structures. The obtained results suggest new directions for future research in the field of information visualization for the construction industry. The presented system is compatible with laptop PCs and is scalable for mobile devices. The proposed system can also be used for preconstruction architecture and augmented visualization, where own developed methods of achieving the quality of photorealistic rendering are used. The next development step is to introduce into the project the possibility of working with augmented and virtual reality.

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References
[1] Wang Peng, Wu Peng, Wang Jun et al. 2018 A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training International Journal of Environmental Research and Public Health 15(6) 1204
[2] Martinez P, Al-Hussein M and Ahmad R 2019 A scientometric analysis and critical review of computer vision applications for construction Automation in Construction 107 102947
[3] Röck M, Hollberg A, Habert G and Passer A 2018 LCA and BIM: Visualization of environmental potentials in building construction at early design stages Building and Environment 140 153-61
[4] Akpan I and Shanker M 2017 The confirmed realities and myths about the benefits and costs of 3D visualization and virtual reality in discrete event modeling and simulation: A descriptive meta-analysis of evidence from research and practice Computers & Industrial Engineering 112 197-211
[5] Xianfei Yin, Hexu Liu, Yuan Chen and Al-Hussein M 2019 Building information modelling for off-site construction: Review and future directions Automation in Construction 101 72-91
[6] BuHamdan S, Duncheva T and Alwisy A 2021 Developing a BIM and Simulation-Based Hazard Assessment and Visualization Framework for CLT Construction Design Journal of Construction Engineering and Management 147(3)
[7] Porter D and Glick S 2019 Spatial Visualization in Construction Management Education: A
Review and Validation of the Literature Using Professionals and Related Practitioners

Automation in Construction 101 72-91

[8] Pingping L and Zhaopan L 2017 Construction and Visualization of 3D Landscape ICCNEA 28-32

[9] Xiao Li, Peng Wu, Shen G et al. 2017 Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach Automation in Construction 84 195-206

[10] Akahoshi K, Ishimaru N, Kurokawa C et al. 2020 I-urban revitalization: conceptual modeling, implementation, and visualization towards sustainable urban planning using citygml XXIV ISPRS Congress 179-86

[11] Kamw F, Al-Dohuki S, Zhao Y et al. 2020 Urban Structure Accessibility Modeling and Visualization for Joint Spatiotemporal Constraints IEEE Transactions on Intelligent Transportation Systems 21(1) 104-16

[12] Charikova I, Zhadanov V, Charikova V and Popov I 2018 Epistemological projections of knowledge in information modeling training VII International Symposium Actual Problems of Computational Simulation in Civil Engineering 456 1-6