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NAMED AFTER MUHAMMAD AL-KHWARIZMI

MUHAMMAD AL-XORAZMIY NOMIDAGI
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THE IMPORTANCE OF 3D MODELING IN THE APPLICATION OF BIM TECHNOLOGY FOR MODERN ARCHITECTURE

T.A.Khujakulov¹ Doctor of Philosophy, Associate Professor, Tashkent University of Applied Sciences, Tashkent, 100149, Uzbekistan mehr_toj@mail.ru

A.A.Bahromov² Senior Lecturer, Tashkent University of Applied Sciences, Tashkent, 100149, Uzbekistan asrorbek.bahromov2112@gmail.com

Abstract - This article analyzes the role and importance of 3D modeling in supporting BIM (Building Information Modeling) technology for modern architecture. BIM technology is widely used to improve the efficiency of architectural design, construction planning, and building management processes. The article provides detailed information on the concept of BIM, its main capabilities, the mathematical foundations of 3D modeling, and its implementation using modern software tools such as Revit. Special attention is given to how 3D modeling enables the creation of accurate digital representations of buildings, allowing architects and engineers to visualize structures before construction begins. Through BIM-based 3D models, project participants can analyze design solutions, detect possible conflicts, and improve coordination among different specialists involved in the project. The study also highlights the role of mathematical modeling and algorithms in generating precise geometric forms and spatial structures. In addition, information is provided about the challenges and opportunities of applying 3D modeling technologies in architectural practice. As a result, the integration of 3D modeling with BIM technology significantly enhances the quality, efficiency, and sustainability of modern architectural design and construction processes.

Keywords - BIM (Building Information Modeling), 3D modeling, visualization, clash detection, MEP systems (Mechanical, electrical, and plumbing), HVAC systems (Heating, Ventilation, and Air Conditioning).

Introduction

BIM (Building Information Modeling) is a technology that digitally describes buildings and structures and plays a key role in modern architecture. The main part of BIM is 3D modeling, that is, the process of depicting the geometric parameters of a building in digital format. BIM technology is not simply the preparation of 3D drawings, but an intelligent system that contains multidisciplinary information (architecture, construction, industrial systems and costs).

BIM (Building Information Modeling) is a process that digitally describes buildings and infrastructure projects. Unlike 2D drawings, this technology creates a 3D virtual model and stores information such as material properties, price, time, energy efficiency, etc. in it, in addition to geometric shape.

The main features of the BIM system:

1. 3D modeling - a model that digitally depicts the full 3D shape of the building;
2. Intellectual objects - stores information about each element (wall, door, window);
3. Coordination collaboration - different disciplines (architecture, construction, MEP) work on a single model;
4. Automatic document generation - 2D drawings and tables are generated from the 3D model.

Programs such as Revit, ArchiCAD, BIM 360 are the main tools of BIM. Autodesk Revit is the most widely used in this field and its market share is 40 percent.

The importance of 3D modeling

*T.A.Khujakulov*¹, *A.A.Bahromov*²
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3D modeling is the foundation of BIM technology, which provides the following capabilities:

1. Visualization - shows the shape, color and details of the building in a realistic way. Users and clients will be able to see the project before construction begins.

2. Early detection of problems - different areas (details, lines, pipes, etc.) are checked for overlap. This is called "clash detection". If a problem is found, it is eliminated before construction.

3. Accuracy - since the 3D model is a computer model that fully represents the size, location and connected components of each element, calculations are performed automatically and accurately.

4. Convenience - 2D drawings (plan, elevation, section) are automatically generated from the 3D model. If the model changes, the drawings are also automatically updated.

Results achieved through 3D modeling

Modern studies show that projects built on the basis of BIM and 3D modeling have significant improvements in the practical results:

Time savings: Projects using BIM technology save an average of 20 percent of time. For example, the Crossrail project (London) (Figure 1), a complex project over 100 kilometers long, involving 30 different organizations and 10,000 workers. With the help of BIM technology, the time spent working together was significantly reduced.



Figure 1. Crossrail project (London)

Cost reduction: BIM 3D modeling reduces project costs by an average of 15 percent. The reason:

- Design issues are identified - problems are found earlier and resolved before construction;

- Accurate materials are calculated - automatic material quantities are calculated from the 3D model, so no excess raw materials are ordered;

- Reduced rework - errors are found during construction, which can be costly to fix. If they are found before construction, they can be fixed much more cheaply;

- Reduced design errors: According to a McGraw-Hill Construction study, 70 percent of BIM users admit that the quality of their projects has improved. 3D modeling reduces errors by 30 percent.

- Faster document preparation: In the Shanghai Tower (China) project, the complex structure of the BIM 3D model allowed for faster document preparation and project completion on time.

Technical Fundamentals of 3D Modeling

3D modeling is based on mathematical and geometric principles. Revit and other BIM programs use the following formulas:

Parametric relationship formula:

$$y = f(x_1, x_2, x_3, \dots, x_n)$$

Here:

y – position of the model element

x_1, x_2, x_3, \dots – parameters (window width, wall height, concrete grade, etc.)

If the x_1 value is changed (for example, changing the wall height from 3 meters to 4 meters), the y value (the corresponding part of the resulting model) is automatically updated.

Coordinate system: In a 3D model, each point is defined by three coordinates:

$$P(x, y, z)$$

For example, if a wall starts at $0,0,0$ and is 4 meters high, its coordinates will be:

- bottom point: $P1(0, 0, 0)$

- top point: $P2(0, 0, 4000 \text{ mm})$.

Calculating volume: The volume of a wall is calculated using the following formula:

$$V = \text{length} \times \text{height} \times \text{thickness}$$

$$V = 10m \times 4m \times 0.3m = 12 \text{ cubic meters}$$

Revit automatically calculates this volume and determines the amount of material when building a 3D model.

Clash detection in 3D modeling

Revit and Navisworks automatically detect intersections between different disciplines (MEP – Mechanical, electrical, and plumbing). This process identifies the following:

1. Pipe and concrete intersections – to ensure that the water supply cylinder does not pass through the steel trusses;
2. Electrical cables and MEP systems – to ensure that expensive systems do not intersect;
3. Door and wall intersections – to ensure that the door opens properly.

Clash detection algorithm. If element A and element B exist, the system performs the following check:

If (A. coordinate \neq B. coordinate) and a connection point is found \rightarrow CLASH (error)

If (A. coordinate \neq B. coordinate) and no connection point is found \rightarrow OK

Real-world example: In the renovation of Denver International Airport (Figure 2), BIM clash detection optimized logistics and planning and reduced construction time by 10 percent.



Figure 2. Denver International Airport
3D modeling stages in Revit

Preparing a 3D model in Revit goes through the following stages:

1. Project Setup – the coordinate system, units (meters, centimeters), dimensions and standards are specified;
2. Creating walls – wall elements from the Revit library are used (for example, 30 cm thick, concrete material) and drawn on the plan. Revit automatically creates a 3D shape of this wall.
3. Floors, ceilings and other elements – each element is created in Revit in 3D form;
4. Adding MEP systems – industrial systems (electricity, water, air) are added;
5. Clash detection – intersections of MEP systems are checked using the Navisworks program;
6. Creating 2D drawings – Revit automatically generates floor plans, elevations and other 2D drawings from the 3D model;
7. Documents and tables - bill of materials, calculations, prices and other information are automatically generated.



Efficiency of this process: Using Revit, a 3D model and full documentation of a 1000 square meter building is prepared in 2-3 weeks. With the usual 2D AutoCAD method, this process takes 2-3 months.

Table 1: Comparison of 3D modeling and traditional 2D drawings

Parameter	3D Modeling (BIM)	Typical 2D
Visualization quality	Very good - realistic look	Graphic view
Finding problems	Avtomatic clash detection	Manual verification required
Document preparation	From automatic 2D drawings	Each drawing is separate
Cost	A lot at first, but ultimately savings	Little at first, but a lot in the end
Working time	2-3 weeks + 1000 sq.m.	2-3 months + 1000 sq.m.

3D modeling in real projects

<p>1. One World Trade Center (New York) – This 54 story, 541 meter high building was 3D modeled using Revit due to its complex structure. With real-time monitoring, the project was completed on time and on budget.</p>	
<p>2. Sydney Opera House Renovation (Australia) – The complex facade of the historic building was reconstructed using 3D modeling. Detailed 3D modeling helped the team work efficiently.</p>	
<p>3. Shanghai Tower (China) – One of the tallest buildings in the world (632 meters). Its complex 3D model of the structure</p>	

<p>allowed for the efficient design and construction of the 120.000 square meter building through the use of BIM technology.</p>	
<p>4. Heydar Aliyev Cultural Center (Baku) – 3D modeling of the building with a magnificent facade was carried out using parametric design tools.</p>	

Material and Energy Efficiency through 3D Modeling

BIM 3D modeling significantly increases material and energy efficiency.

Material cost reduction: Automatic material quantities are calculated from the 3D model. Revit calculates the quantity of each wall, floor, and window in the computer model and provides the data to supply management. This reduces over-ordering by 10-15 percent.

Energy efficiency: According to a study by the American Institute of Architects (AIA), BIM 3D modeling can reduce the energy consumption of a building by 30 percent. Reasons:

- The geometry of the building is completely accurate in the 3D model;
- The location of the grids is optimally solved through constructive analysis and dynamic simulation;

- Energy savings are achieved when the size of HVAC (Heating, Ventilation, and Air Conditioning) systems is accurately calculated.

Layout efficiency: The layout can be designed in a more comfortable way in the 3D model. For example, Revit can help us determine how much natural light enters a building, allowing us to optimally select window sizes.

Problems and Opportunities in 3D Modeling

Along with the advantages of 3D modeling, there are also some problems:

Problems:

1. Initial costs – a lot of money is spent initially on BIM programs and training;
2. Training time – it takes 3-6 months to master Revit and other programs;
3. Interoperability – each program has its own format, and problems may arise when transferring files.

Opportunities:

1. Cloud Technology – today, using AWS, Google Cloud, Autodesk Cloud, 3D model data can be stored on the Internet and team members can access it from different locations;
2. Virtual Reality (VR) – a 3D model can be viewed through VR technology. Users can walk inside the building and feel it;
3. Artificial Intelligence – in the future, BIM 3D models can be automatically developed and optimized using AI;
4. 3D Printing – complex elements can also be printed on a 3D printer.

SUMMARY

3D modeling, which is the basis of BIM technology, is of particular importance in modern architecture. 3D modeling is not only visualization, but also the best tool for finding problems early, increasing material and energy efficiency, facilitating collaboration, and improving the quality of projects.

According to statistics, projects built using 3D BIM modeling:

- Time is prepared 20 percent faster;
- Costs are reduced by 15 percent;
- Design errors are reduced by 30 percent;
- Material efficiency is increased by 10-15 percent;
- Energy consumption is saved by 30 percent.

In the future, 3D modeling combined with Cloud computing, VR, and AI can make the construction industry more reliable, cheaper, and more environmentally friendly. For modern architecture, 3D modeling is not just a technology that can be used, but also a necessary tool.

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