

The Relationship between Building Information Modeling (BIM) and Precast Concrete Structures

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Abstract

Due to the fact that a major part of the financial resources of each country is spent in the construction industry of that country, the effectiveness of governments from this industry, especially in developing countries, is very high. In recent years, it has been noticed in the world. Among the advantages of using the prefabricated industry, we can mention the production of parts in a short period of time, low cost and high quality. Currently, many projects undergo such changes that it is necessary to reduce the negative effects imposed on projects by using management techniques and tactics as well as the use of modern technologies. Among the negative effects imposed, we can mention things such as capital wastage (increase in cost), increase in construction time, and at the same time decrease in quality. At the same time, all construction management activities, based on the contract documents, depend on the two categories of plans and project specifications. In the traditional methods of construction management, various executive plans such as structural, architectural and facility plans are prepared separately but in coordination with each other. These maps are two-dimensional and even if three-dimensional maps are prepared from them, the system will not be able to identify mistakes, interferences and changes. The purpose of this article is to examine the relationship between building information modeling and precast concrete structures and the implementation of that system in precast concrete structures.

Keywords: building information modeling, prefabricated concrete structures, construction, construction cost, construction time

1- Introduction

In the past half-century, with population growth and increased demand for housing, contractors have realized that conventional on-site construction in large cities leads to significant time loss due to transportation of the workforce to the project site through heavy traffic. The limited space for material storage and equipment maneuvering, frequent trips for gradual delivery of materials, and the need for the removal of construction waste exacerbate the situation. As a result, intense on-site activities lead to traffic congestion, disorder, dust, noise pollution, air pollution, and other issues. Precast concrete structural elements, such as wall panels, beams, columns, slabs, etc., are manufactured under controlled conditions in a factory and then transported to the project site. Moreover, since the transportation and installation of precast components usually occur during off-peak hours, they cause less traffic and disturbance. Precast concrete structures have shown good performance in many parts of the world and have

demonstrated considerable durability even under severe earthquakes. However, during recent earthquakes, poorly designed and constructed precast concrete structures sustained significant damage or collapsed due to improper performance during seismic events (Narehi et al., 2024). The construction of volumetric prefabricated buildings is growing in most developed countries. In contrast, the significant advancements in modern technologies and their associated benefits are rarely seen in Iran's construction industry (Mirshojaian Hosseini & Khezhini, 2023). Given that most civil engineering projects are accompanied by unique complexities and challenges, it is necessary to utilize state-of-the-art technologies to address these challenges. This is essential to ensure that two critical factors, time and cost, which have a profound impact on the success or failure of projects, are not adversely affected. Currently, significant progress has been made in introducing various methods and techniques. For example, in recent years, many engineering organizations, particularly civil, architectural, and mechanical engineers worldwide, have become familiar with Building Information Modeling (BIM) technology and its integration with reengineering processes. They are leveraging its remarkable benefits in the construction and implementation of civil engineering projects, especially precast concrete structures.

In parallel with the direct negative effects on the project, indirect harmful effects may also arise, such as a loss of credibility for the builders. However, when forced to adopt modern technologies to combat imposed changes, positive effects may also emerge. This leads to a systematic transformation by introducing new technology into the construction engineering community, which can be viewed as a positive factor. One such useful and effective technology, introduced into the country's construction sector in recent years, is Building Information Modeling (BIM). The introduction of this technology has brought about a significant revolution in civil and architectural engineering. Hence, conducting sufficient research in this field is essential to take meaningful steps toward improving the construction conditions in the country. Therefore, the present study examines the relationship between Building Information Modeling and precast concrete structures.

1.1. Research Background

Farshad et al. (2023) conducted a study titled Ranking Precast Concrete Railway Bridges Using the TOPSIS Method for Maintenance and Repair. In this study, efforts were made to rank the precast concrete bridges of the Northern Iran Railway Department based on maintenance and repair criteria using the TOPSIS method. This was done by considering past experiences, field studies, and expert opinions, along with data from inspection checklists and statistical information to properly identify the deterioration of concrete bridges. The results help employers and responsible managers manage bridges correctly, considering limited resources and funding (Farshad et al., 2023).

In 2023, Sheikhpour et al. conducted a study titled Proposing an Empirical Relationship for Estimating the Fundamental Period of Precast Concrete Bearing Wall Frames and Comparing it with the 002 Standard Provisions. In this research, the aim was to propose an empirical relationship to determine the fundamental vibration period of precast concrete frames. The results of this study could be considered a verified proposal for determining the vibration period of precast concrete frames in future revisions of the 2800 standard (Sheikhpour et al., 2023).

Mokhber Takmeh Dash et al. (2023) conducted a study titled Examining Building Information Modeling (BIM) in the Development of Smart and Precast Concrete Construction. This paper adopts a research method that combines field research, on-site testing, and technology development to explore quality control in prefabricated building construction and integrate prefabricated structures with smart construction. Focusing on three key technologies in prefabricated building construction—component installation, on-site design, and steel connections—the study investigates technical principles, operational processes, and application effects. Additionally, it develops technologies related to smart construction, such as precise alignment of precast components, smart layout technologies, and synchronized self-locking connections for multiple steel elements. Furthermore, two types of rapid steel assembly equipment were developed. These findings provide resources for further integration of precast concrete construction with smart construction (Mokhber Takmeh Dash et al., 2023).

Koupayee Zadeh et al. (2023) conducted a study titled Laboratory Evaluation of the Cyclic Behavior of a Precast Concrete Frame System with Steel Shear Walls. This study aimed to integrate steel shear walls with precast concrete systems to achieve stable and resilient structures against lateral loads. Due to the limited number of experiments conducted on precast concrete systems with steel shear walls, the ductility factors, overstrength, and energy absorption behavior of this integrated system compared to precast concrete systems without steel shear walls have not been published experimentally. To achieve this goal, two steel shear wall samples made of black steel and galvanized steel (energy absorber) were tested. Additionally, for comparison, a sample precast concrete frame without steel shear walls was also tested. The results showed that steel shear walls significantly increase the stiffness, ultimate strength, and behavioral performance of precast concrete buildings (Koupayee Zadeh et al., 2023).

In 2023, Behrami and Pouri Rahimi conducted a study titled "Technical Analysis of Precast Concrete Defensive Shelters Resistant to Explosion Loads." In this research, various types of bunkers, command centers, and concrete hospitals from the Sacred Defense era were reviewed from the perspective of commanders and Sacred Defense specialists. To evaluate these structures, in addition to library studies, the performance of these types of structures was analyzed through interviews and distribution of questionnaires among veterans in the field of Sacred Defense engineering. After gathering opinions, a comprehensive analysis of the role of these structures, their technical advantages and disadvantages was provided, and then suggestions were made to improve these structures for current use. One of the main drawbacks of these structures is the heaviness of precast concrete components, and among the solutions proposed for current use is increasing resistance to withstand impact and explosion loads. To examine this topic, a numerical analysis was conducted on the effect of increasing steel fibers on concrete slabs under impact and explosion loads using MATLAB programming. The results show that using steel fibers up to 2% significantly increases the flexibility and resistance of concrete under impact loads, making it recommended for use in war zones (Behrami & Pouri Rahimi, 2023).

In 2023, Sanjari and colleagues conducted a study titled "The Effect of Connection Type on the Performance of Precast Segmental Columns." This article examined the behavior of different connections in precast columns and compared them with cast-in-place columns. The use of

precast columns increases construction speed and reduces project costs. However, due to the seismic behavior of these columns and the lack of sufficient information about the appropriate type of connection between the segments, the use of these columns has been limited. A lot of research has been conducted on various types of connections between segments, and in this article, several published papers in this field are reviewed. General conclusions about different connections are drawn to reach an optimal connection (Sanjari et al., 2023).

In 2022, Panahi and Behnamfar conducted a study titled "Comparing the Cyclic Behavior of Precast Concrete Frames With and Without Steel Shear Walls." In this research, a system consisting of a precast concrete frame along with a steel shear wall is proposed. To understand this new system, an analytical comparison was made of the lateral behavior of a precast concrete frame with a steel shear wall (with semi-rigid connections) and a precast concrete frame without a shear wall (with rigid connections) using cyclic analysis. For this purpose, the lateral behavior of precast concrete frames with and without steel shear walls in different building stories (3, 5, and 10 stories) was examined, considering parameters such as lateral stiffness, yield strength, lateral displacement, and ultimate strength. To achieve the research goal and conduct the cyclic analysis, the OpenSEES software was used. To model the nonlinear behavior of members, the Concrete02 and Steel02 materials were utilized, which were analyzed using the SAC protocol. The results showed that precast concrete frames with steel shear walls (with semi-rigid connections) perform better in the aforementioned parameters as the number of building stories increases compared to precast concrete frames without shear walls (with rigid connections). Therefore, based on the research findings, the use of precast concrete frames with steel shear walls (with semi-rigid connections) is recommended compared to precast concrete frames without shear walls (with rigid connections) (Panahi & Behnamfar, 2022).

2.The Role of Building Information Modeling (BIM) in Precast Concrete Structures

Precast concrete refers to concrete that is produced and cured under factory conditions and transported to the project site after completing the construction and curing process. This type of concrete, given the factory production under suitable conditions, has high quality. Despite the application of BIM in construction projects, the need for this technology in the precast concrete industry is also considered inevitable. In general, BIM is a new concept that started with a limited definition, including only CAD models and related information, and has expanded to a broader definition throughout the lifecycle of the organization. When BIM is implemented correctly, it changes the roles and relationships of project partners and can reduce project costs and time (Kastman et al., 2011).

Today, Building Information Modeling (BIM) has found extensive applications, from design and construction to operation and even the demolition phase of buildings. This technology, by providing a digital representation of building characteristics, assists project managers and stakeholders in making informed decisions at every stage. Building Information Modeling integrates all construction management activities based on contract documents into two categories: drawings and specifications. Using the drawings, the quantity of work is defined, while the technical specifications define its quality. In fact, the criteria for evaluating the performance of contractors are determined based on these two categories.

We already know that in conventional construction management, on the one hand, drawings and specifications are presented separately, and on the other hand, the working drawings from different design teams are prepared separately but in coordination with each other. The issues with this method are well-known, and some of the worst problems are perhaps lack of



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coordination, errors, and rework, which not only increase construction costs but also lead to a decline in the quality of work. The main difference between BIM and a conventional 3D CAD model is the storage of important information for the entire construction process along with all its components. This information includes material specifications (such as weight, color, size, fire resistance, etc.), installation and assembly instructions, product warranty services, maintenance and repair requirements, component pricing information, and more.

Technically speaking, BIM is a CAD model connected to a database, where all project-related information can be stored. Thus, BIM acts as a shared information resource between the entire building design and construction team. The result of this information integration is increased coordination, reduced errors and waste, and ultimately improved work quality (Figure 1).

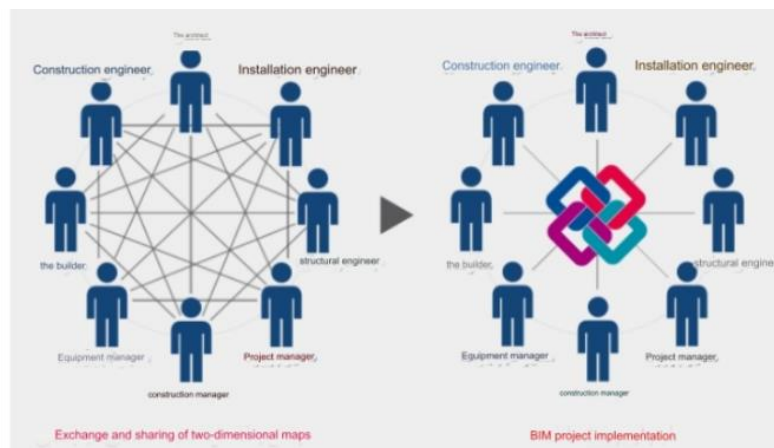


Figure 1: The Concept of BIM in Exchanging and Sharing 2D Drawings Through the Project Execution Process

In summary, it can be said that the background of research in the field of Building Information Modeling (BIM) consists of the following four main sections, which will be explained below:

1. Main Design
2. Initial 2D AutoCAD Method
3. Conventional Design Methods
4. Building Information Modeling

With the increasing use of precast concrete structures worldwide, which is due to their significant advantages compared to other technologies, it is necessary to use Building Information Modeling technology to better manage these structures and address any obstacles, problems, and potential complexities during the design and execution phases.

In summary, the benefits of using precast concrete technology can be described as follows:

High speed of execution

High quality of produced components due to their manufacturing and curing under factory-controlled and standard conditions

Compatibility with various climatic conditions

Easy installation

Cost-effectiveness (especially if the factory is close to the project site)

At the same time, the use of Building Information Modeling (BIM) technology in precast concrete structures has the following advantages (Figure 2):



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Better visualization of the design, particularly to increase efficiency during the construction phase

Structural analysis capability

The ability to review construction stages

Accurate planning of site equipment

Scheduling and sequencing of the precast component construction process

Estimation of precast structure construction costs

Integration of subcontractor and supplier information

Coordination between systems

Implementation of design and on-site operations

Reduced maintenance costs

Elimination of clashes between precast components, which is crucial during installation, resulting in faster structure execution



Figure 2: The Application of BIM in Three Phases: Design, Construction, and Operation

At the same time, by implementing BIM, companies and manufacturers of construction equipment will be able to easily provide modeled information of their products to designers and specialists (Salman Ajer, 2008).

3. BIM Deployment and Implementation Plan

The BIM implementation plan is a detailed blueprint that defines how a project will be executed, supervised, and organized based on BIM. Therefore, the main goal of the BIM implementation plan is to provide an overarching strategy to ensure that all parties involved are well aware of their priorities and responsibilities in the implementation of BIM. This plan should be considered as a dynamic document, with flexibility for updates, while also ensuring adherence to the project's timeline.

In general, this plan outlines why BIM is necessary for project execution and includes the following elements (Vatankhah, 2015):

Project Information

Key Project Communications and Contacts

Project Goals
 Organizational Roles
 BIM Design Process
 BIM Information Exchanges

3.1. Benefits of BIM Implementation in Precast Concrete Structures

In general, the benefits of deploying and implementing BIM in various projects can be summarized as follows:

Improved design of precast concrete components with the desired dimensions and specifications

Better construction of components with higher quality and in compliance with global standards

Enhanced project operation (Figure 3)



Figure 3: Benefits of BIM Implementation

4. Stages of Using BIM in Precast Concrete Structures

Generally, in evaluating the building through BIM, there are three main stages, which are:

1. Pre-construction Stage
2. Construction Stage
3. Post-construction Stage

It should be noted that all the above stages are interconnected, and there is no clear boundary between them. By utilizing these stages, design strategies based on the life cycle can be achieved, focusing on minimizing the environmental impacts of the building.

In the pre-construction stage, the focus is on site selection, building design, and related processes until the installation of materials. Under sustainable design strategies, the environmental impacts of structural design, building orientation, its effect on the landscape, and the materials used are evaluated.

The construction stage refers to the phase of the building's life cycle when it is physically being built and operated. Sustainable design strategies focus on examining construction processes and building operations to find ways to reduce the negative environmental impact of resource

consumption. Moreover, long-term effects of the building on the health of its occupants are considered.

The post-construction stage begins when the useful life of the building has ended. In this stage, the materials used in the building are either reused for other constructions or returned to nature as waste. Sustainable design strategies emphasize reducing construction waste through recycling and reusing buildings and materials.(Figure 4)

In another classification of BIM execution stages, the process is divided into five main subcategories:

- step 1: Pre-construction
- step 2: Construction
- step 3: Detailed Design
- step 4: Initial Design
- step 5: Planning

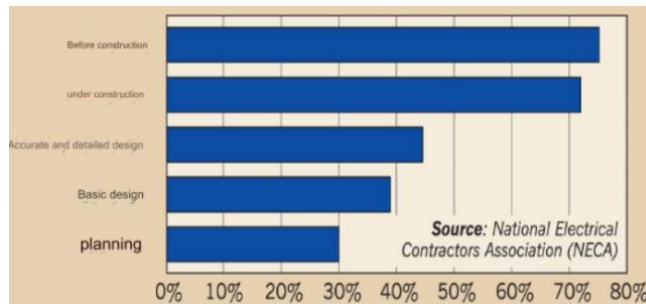


Figure 4: Stages of Using BIM in Precast Concrete Structures

It is clear that by utilizing BIM, in addition to creating intelligent connections between various design components, it enables all teams to virtually examine different aspects of the design. For example, one of these aspects could be rotating the building model and examining changes in energy consumption based on different angles of sunlight. Similarly, other design teams, including structural and mechanical engineers, can apply changes to their models and observe the effects of these scenarios on the architecture of the project. Additionally, contractors can virtually experience factors such as execution sequence, efficiency, construction, and installation during the design and development of the building model (Durbay, 2006).

5.Impact of BIM on Precast Concrete Structures

The overall impact of BIM on the technical specifications of precast concrete structures can be examined through the following factors:

Weight: Including the weight of the concrete component in the information data can greatly assist engineers. For example, by knowing the weight of the component, the installation engineer can choose the appropriate type and tonnage of the required crane, ensuring safety during installation. Additionally, the transportation of the component is carried out more systematically with suitable machinery, which also has economic significance.

Dimensions: By including the dimensions of the component in BIM data, appropriate equipment can be selected for transporting and installing the component. Furthermore, the position of the component and the sufficiency of space for its installation can be examined more accurately to prevent execution issues during installation.

Fire Resistance: Precast concrete components generally exhibit good fire resistance. One of the key objectives in designing and constructing concrete structures is their fire resistance. According to ASTM E119, the fire resistance of precast panels made of lightweight aggregates, silica, carbonates, and lightweight sand varies depending on the thickness of the component. In this standard, fire resistance is considered to be between one to four hours. Therefore, by knowing the fire resistance of a precast component, which depends on the materials used and the thickness of the component, suitable locations for its use (e.g., parking lots or high-traffic commercial centers) can be determined.

Curing Process: One of the most crucial and determining stages in the production of precast concrete components is the curing process. BIM can include the curing conditions, temperature, and other relevant factors.

Component Coding: By including the code and number of the precast component in BIM, the installation sequence and the position of each component can be examined.

Connections: Including the type of connection between precast members such as beams, columns, slabs, and foundations in BIM can lead to proper and correct installation of the components.

Materials Used: One of the important and influential factors in the production of precast components is the materials used and their physical and chemical characteristics. These specifications can also be included in BIM.

Design: The design data of precast members, the standards used, the percentage of reinforcement in the component, etc., can also be included in BIM.

Environmental Conditions: Depending on the materials used and the production method of precast to concrete components, the environmental conditions compatible with the component can be included in BIM (e.g., concrete components resistant to acids, sulfates, chlorides, etc.).

Tolerance: One of the key factors during the installation of precast concrete components is the tolerance levels. By including the related values in BIM, the installation process of precast components can be performed with greater precision and speed.

Safety: By using BIM data and information, safety can be significantly increased in various stages of precast concrete construction, particularly during installation and transportation. (Figure 5)

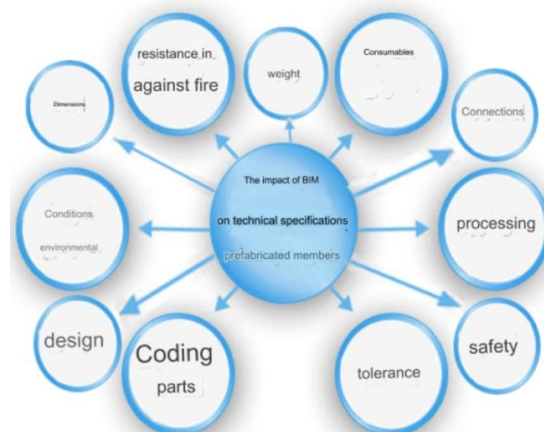


Figure 5: The Impact of BIM on the Technical Specifications of Precast Concrete Members

6. The Impact of BIM on Structure Safety

One of the most important and fundamental issues in construction projects is safety. Before starting any phase of the precast concrete structure execution, all safety aspects must be carefully examined, and potential risks during the production phase in the factory, as well as subsequent phases like transportation, temporary installation, and final installation, must be assessed and evaluated. Using risk assessment techniques, all risks should be classified according to their probability of occurrence and severity.

In the execution of these structures, two stages carry the highest risk: transportation and installation, with the installation phase being far more sensitive. Not using appropriate equipment, such as cranes that match the tonnage of the component, can lead to irreparable accidents. All chains should be continuously inspected before lifting the component. In this regard, BIM technology can play a positive role. For instance, the dimensions and tonnage of precast concrete components are modeled in BIM technology. Having access to the weight and dimensions of the components and identifying the center of gravity makes it easier to select the appropriate chain for lifting the precast member. Installation engineers can benefit greatly from BIM databases during various installation stages. (Figure 6)

In general, the greatest capability of this technology in safety management lies in modeling working conditions before execution, enabling the identification of risks and preventing accidents.

BIM can contribute to the following areas:

- Construction operations
- Equipment and personal protection
- Hazards related to machinery
- Risks during excavation operations
- Workshop design and setup

Overall, the feedback received from the use of this technology in construction processes has been very positive, especially in site safety management. This study focuses on preventing falls from heights, a major concern in construction. By integrating BIM into project safety planning, significant reductions in accidents can be achieved.

Given that most engineers and technical staff in construction sites in our country lack even a basic understanding of this technology, it is recommended that organizations and related institutions invest in programs to expand the use of BIM in projects. After an initial phase, they would start reaping the many positive results of this technology, one of the most important being an increase in site safety and a consequent reduction in accident rates (BIM, 2014).

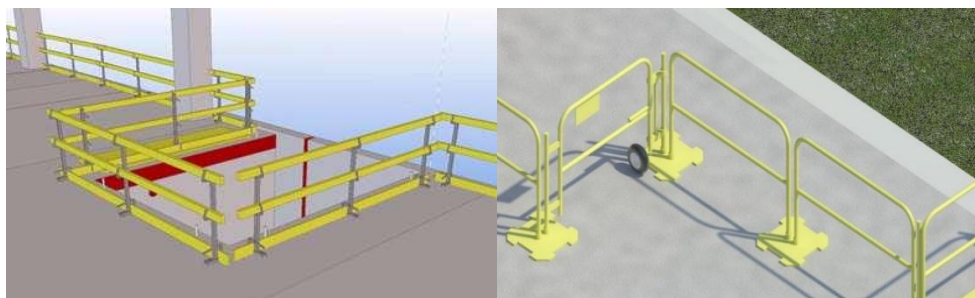


Figure 6: The Necessity of Using BIM Technology in Ensuring Safety for Precast Concrete Structures

In general, construction projects involve a wide range of work, the presence of various workgroups, and a lack of complete familiarity of contractors with the environment and working conditions, which encompasses a large number of accidents and hazards. By implementing a three-dimensional BIM model of the building, all points of the project can be easily visualized, and hazardous and critical areas can be identified, allowing for necessary precautions to prevent accidents (Ahmadzadeh, 2015).

7. Conclusion

The use of BIM in precast concrete structures offers numerous advantages, including reduced construction time, more efficient site management, installation of components at the desired location without any inadvertent errors, proper coding of components, and facilitation of installation processes. Additionally, it enables the production of high-quality precast concrete (due to monitoring the materials used and the factory production process), better management of transportation of components without any potential damage, and the appropriate selection of necessary machinery.

Given these advantages, it is recommended that BIM technology be utilized in all precast structures, whether low-rise or high-rise, to streamline construction processes and enhance precision and operational efficiency.

Considering the intricate details and execution specifics of precast concrete structures, which include connections, plates, reinforcement bars, openings, etc., employing BIM is essential to improve accuracy and avoid overlooking subtle details. Moreover, these precast components have varying production processes. Due to different materials used in various regions and the specific climatic conditions of each area, the concrete mixes produced can differ significantly from one another.

Overall, by using BIM technology in precast concrete structures, construction can be executed with greater precision from the design stage to operation, effectively eliminating the likelihood of unforeseen events that could cause project delays and incur additional costs.

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