TOWARD AUTOMATED DIMENSIONAL QUALITY CONTROL OF PRECAST CONCRETE ELEMENTS USING DESIGN BIM

NISHA PURI & YELDA TURKAN
School of Civil and Construction Engineering, Oregon State University, USA

ABSTRACT

Dimensional quality control of precast concrete elements is one of the crucial tasks during concrete construction, where geometrical properties of precast concrete elements are inspected to determine whether the specified tolerances are satisfied or not. The failure of constructed elements to fall within the specified tolerances may be the result of an unsatisfactory level of precision applied during construction or the inability to interpret the information provided in the specifications correctly. The consequences of improper dimensional quality control measures have adverse effects on the aesthetics of the elements, and, in severe cases, the structural strength of the elements. The dimensional quality control practices that are prevalent in today's industry do not only provide room for random errors associated with manual measurements, but also exploit two of the most valuable assets of a construction project: time and labor. Nevertheless, if appropriate steps are taken during the design phase, the majority of these tolerance issues during the construction phase can be prevented. Therefore, this study focuses on the tolerance issues arising during the construction phase by combining design BIM and tolerance specifications within the same database. A text-parsing algorithm in MATLAB environment was used to tag elements in an IFC Building Information Model (BIM) with textual-tolerance information. The output IFC BIM including textual-tolerance information would be used by project engineers and inspectors during the construction phase. This would enable access to all tolerance-compliance-related information within the same database, which would help make timely decisions to prevent rework and schedule delays.

Keywords: IFC BIM, tolerance compliance, quality control, text parsing.

1 INTRODUCTION

There are a number of unique challenges arising in the construction industry due to the increasing complexity of construction projects, which has necessitated the integration of information technology into traditional construction practices. Building Information Modelling (BIM) is one of these technologies that has revolutionized the traditional ways of information retrieval and management in the construction industry [1]–[3]. BIM enables the 3D parametric representation of building elements and facilitates "a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration" [2]. Accordingly, 2D CAD drawings for documenting as-designed and/or as-built state of buildings are slowly being replaced by BIM [4]. The current level of BIM adoption is higher in the design and construction phases compared to the maintenance and operations phases. However, there is a growing interest in implementing BIM for facilities management, which would require accurate as-built information input into BIM. The quality of as-built information acquired from project sites heavily affects the work that they are being used for. For the purposes of dimensional compliance checking and control, as well as renovations, it is extremely important to have access to data that is very accurate. Terrestrial Laser Scanning (TLS) is a popular technology used in today's construction industry for acquiring accurate as-built information of existing conditions [5]–[8].

In current practice, upon the completion of a project, as part of quality control requirements included in contracts, a contractor highlights the changes made during the

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construction on paper/electronic-based as-designed 2D plans and submits them to the owner. Often, as-built plans of cast-in-place concrete elements fail to accurately reflect the geometrical attributes of elements that were originally specified in the as-designed plans [9]. Due to the changes made during the construction phase, the dimensions and location of an element specified in design plans may be different from the ones present in as-built plans. Accordingly, it is not realistic to perfectly align design and as-built plans with each other since changes during construction are inevitable. However, potential rework as a result of those discrepancies can certainly be minimized by specifying appropriate tolerances, which would make construction work easier for contractors, superintendents, foremen and inspectors, while helping keep the project on schedule and within budget [10].

As-built information collected from construction projects is vital for decision-making in various stages of a project's lifecycle, including dimensional quality control and assessment [11]–[13], project progress monitoring [7], [14], [15] and facilities/asset management [3], [16]–[19]. Renovation/restoration/remodeling activities require the use of as-built information to meticulously plan the dimensional features and locations of new installations and assign working groups accordingly. Modern non-contact-based measurement systems such as TLS enable to collect as-built data with millimeter-level accuracy while decreasing the time required for data collection. Accurate as-built data would help determine any discrepancies present between design and as-built models, which would help assess dimensional tolerance compliance during construction. Accurate 3D as-built models can further be used for a variety of purposes during the operations and maintenance (O&M) phase. At the same time, accurate as-built information could also support contractor's tasks during project closeout such as creating 2D drawings or 3D models as part of the submittal documents.

Various sources in the literature describe the failure in design–construction integration as one of the prime reasons for such discrepancies [20]–[22] and focus on eliminating the sources of errors prior to construction. Several codes have been established to ensure the dimensional compliance of as-built elements, but it can be inferred that the defect can only be corrected after they occur [9]. Possible solutions for each perspective exist. In order to efficiently carry out post-construction assessment, a tolerance compliance checking framework could be devised. Such a framework would have the advantage of carrying out timely and accurate measurements, but would not solve the core problem of why the problems exist in the first place. Instead, this approach could be extended to include as-built modelling from available data to assess the existing conditions during renovation work involving the removal of components or installation of new ones. A compliance checking framework could be devised prior to construction so that owners, designers and contractors could establish acceptable tolerances, integrate that information in design BIM, and then begin construction. This would help decrease/eliminate problems related to dimensional quality control by integrating tolerance specifications in design BIM, thus on 2D plans, and make the overall process more efficient by integrating all related information into a single digital platform.

2 TOLERANCE ISSUES IN AEC INDUSTRY

In the architectural, engineering and construction (AEC) industry, it is commonly assumed that compliance with design and building codes eliminates the need for explicitly checking tolerance compliance [23]. In some cases, where tolerances are specified, the lack of consideration to tolerances and unclear specifications give rise to various problems during construction [24]. Such tolerance issues are the leading contributors of geometric errors in as-built elements, and, thus, rework and project delays. The accumulation of tolerances that are non-compliant is identified as an additional cause of variations between the as-built and as-designed conditions of a project [25]. The ineffective implementation of tolerance control during construction stems from failing to document errors and any related information on site that can be used for tolerance control and review processes [21], [26]. Additionally, inexperienced workers and/or insufficient attention to details contribute to tolerance errors [21], [27]. Talebi et al. [21] have identified the defects and chains of waste, and unsatisfactory performance of buildings as the two major consequences of tolerance compliance issues. The rework activities resulting from such errors lead to an increase in project costs and duration, while simultaneously compromising the quality of the work being performed [27], [28].

In the meantime, several studies have focused on detecting and quantifying the geometric errors present in concrete elements after they have been manufactured. Various techniques related to dimensional quality assessment of precast concrete elements using TLS and BIM have been described in Kim et al. [11], [13] and Wang et al. [29]. Bosché [12] developed an algorithm for checking tolerances of as-built concrete elements' locations, without much focus on the profile and orientation tolerances. Gordon and Lichti [30] examined the vertical displacement of loaded beams using TLS and focused on only the profile tolerances. Shih and Wang [31] used color maps generated from TLS to assess wall thickness. Puri and Turkan [32] implemented Continuous Wavelet Transform (CWT) on TLS data of a concrete slab to characterize the surface waviness of the slab. Detecting existing geometric errors, i.e. tolerance non-compliance, after construction is completed has been well studied, while only a few studies have focused on developing methods to improve tolerance management that could eliminate the root causes of the existence of such errors [21], [27].

In recent years, BIM has become a popular choice for 3D, 4D and 5D design, clash detection and energy analysis. Although BIM technology provides a platform for users to explore the physical and functional characteristics of each element and different elements combined, poor modelling practices result in discrepancies. A design BIM may lead to constructability issues during the construction phase if it is designed only from the viewpoint of an architect. A modeler needs to possess construction experience to make proper judgements regarding the practicality of the design. Addressing this issue is especially important in the case of specifying construction tolerances. BIM is a smart and effective tool for clash detection and performing energy analysis, but still lacks tools for analyzing the implications of incorrectly specified tolerances. For example, a HSS (Hollow Structural Solutions) 4" × 4" columns placed inside a 4" metal stud wall may be accurately represented in design BIM but the model fails to account for the plumbness that may arise in the columns. Such design BIM cannot be used for tolerance compliance checking if it fails to incorporate the tolerance information about ½" for every 10'–0" of column length. In another scenario, during construction, there may be areas where critical (minimum) tolerances have to be ensured.

Therefore, this study proposes a preliminary but novel approach that focuses on eliminating some of the root causes of tolerance issues often encountered during construction. This paper describes a framework that integrates tolerance information for precast concrete elements from ACI (American Concrete Institute) 117 specification documents into the IFC BIM (design model) by using a text-parsing algorithm implemented in MATLAB. The text-parsing algorithm analyzes the attributes of each element in IFC BIM, and adds tolerance specifications to the corresponding elements. The output is an IFC BIM enriched with corresponding tolerance information for each element. Integrating tolerance specifications into design BIM during the design phase could help eliminate the existence of tolerance problems in the later stages of a project. Furthermore, having access to tolerance specifications along with the corresponding model on the same platform (IFC BIM) would allow accommodating and updating any design changes, and thus, tolerance specifications, in timely manner.

3 RESEARCH METHODOLOGY

The research methodology is summarized in Fig. 1. First, the as-designed BIM of a 4-story building (in Revit format), as shown in Fig. 2, was converted into IFC (Industry Foundation Classes) format. The textual tolerance information for various elements was obtained from the American Concrete Institute (ACI) 117 document and included in the framework. A text-parsing algorithm was implemented in MATLAB that searches the IFC file for the line representing the specified IFC element and updates the information in that line with the respective tolerance information from the input file. The pseudocode of the text parsing algorithm is provided in Fig. 3. The output IFC text file includes tolerance information for each building element.

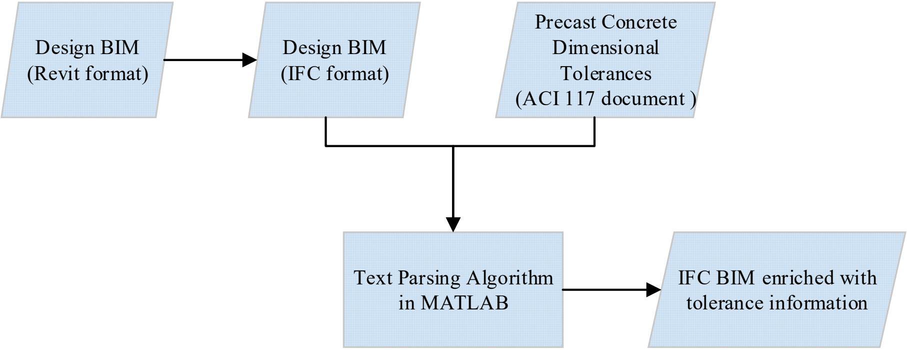

Figure 1: Summary of the methodology.

Figure 2: The input BIM model.

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MATLAB pseudocode for text parsing
Step 1    Define an empty matrix Beamlist
Step 2    Separate Body, Head and Tail and add empty lines between lines of body
Step 3    Body contains row number that matches with the line number in IFC file
Step 4    Read the output file containing Body from Step 3
Step 5    Search line in the IFC file for 'IFCBEAM'
Step 6    Store the line number of IFC file into Beamlist if the string is found
Step 7    For each line in Beamlist:
              Split the string at the delimeter ',$,'
              Substitute delimeter '$' with tolerance information string
              Horizontally concatenate strings
Step 8    Add Head and Tail
Step 9    Generate output IFCfile
```

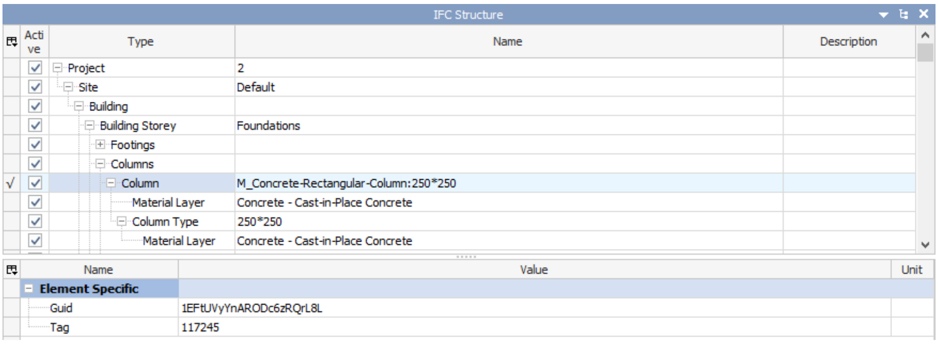
Figure 3: Pseudocode of the text parsing algorithm.

BIM Vision 2.3 was used for viewing the IFC file, and the IFC specifications were used to identify the entity of the object of interest. For assigning the tolerance information of elements, such as columns, 'IfcColumn' entity was used. A text-parsing algorithm coded in MATLAB [33] was used to evaluate each line in the input IFC text file and to add the tolerance information for that element. The line in the IFC text file representing a column was updated with a string containing tolerance information for that particular column. The enriched IFC model was viewed using BIM Vision 2.3 and found that the description field for the column was updated with the string added to the algorithm. The results are shown in Fig. 4.

Since the viewing software did not have a property field specified for displaying tolerance information, the tolerance information was displayed under the "Description" field. Fig. 4 presents the IFC model information displayed prior to the processing and after the processing. The algorithm was able to automatically detect each building element and label them with the corresponding tolerance information.

4 CONCLUSIONS

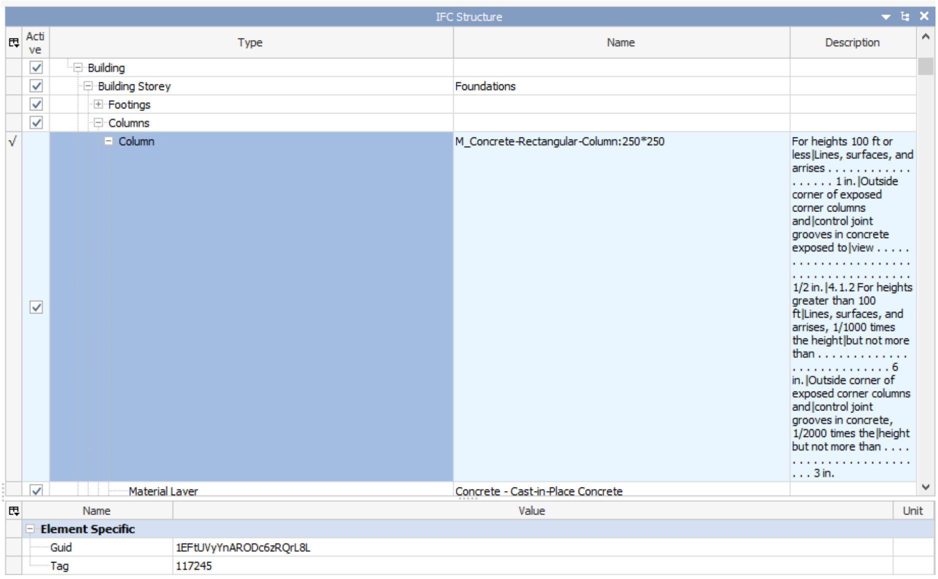
An effective way of preventing any tolerance-related issues during construction would be to start implementing an effective strategy during the design phase. BIM has been widely used in both the design and construction phases of a project for a variety of purposes including clash detection and energy simulation analysis. There is an opportunity for incorporating tolerance information of building elements in design BIM to prevent any constructability issues during construction. Currently available BIM software does not support the integration of tolerance specifications into the design model, which would greatly enhance constructors' access to geometric tolerance information during construction. To tackle this problem, in this study, IFC BIM and a text-parsing algorithm are used to incorporate tolerance information into design BIM. Text parsing can help achieve this by automatically adding the dimensional tolerance information of an element. By using the synergy between IFC files and a text-parsing algorithm, designers can conveniently add tolerance specifications into IFC files, which can be used by project engineers and inspectors during construction. This simple yet effective method could help solve tolerance issues to some extent. The results of this study suggest that adding tolerance information as textual data in design BIM could be an effective way to eliminate the possibility of having tolerance issues during construction.



	Active	Type	Name	Description
	☑	Project	2	
	☑	Site	Default	
	☑	Building		
	☑	Building Storey	Foundations	
	☑	Footings		
	☑	Columns		
√	☑	Column	M_Concrete-Rectangular-Column:250*250	
	☑	Material Layer	Concrete - Cast-in-Place Concrete	
	☑	Column Type	250*250	
	☑	Material Layer	Concrete - Cast-in-Place Concrete	

Name	Value	Unit
Element Specific		
Guid	1EFtUVyYnARODc6zRQrL8L	
Tag	117245	

(a)



	Active	Type	Name	Description
	☑	Building		
	☑	Building Storey	Foundations	
	☑	Footings		
	☑	Columns		
√	☑	Column	M_Concrete-Rectangular-Column:250*250	For heights 100 ft or less|Lines, surfaces, and arrises . . . . 1 in.|Outside corner of exposed corner columns and|control joint grooves in concrete exposed to|view . . . . 1/2 in.|4.1.2 For heights greater than 100 ft|Lines, surfaces, and arrises, 1/1000 times the height|but not more than . . . . 6 in.|Outside corner of exposed corner columns and|control joint grooves in concrete, 1/2000 times the|height but not more than . . . . 3 in.
	☑	Material Layer	Concrete - Cast-in-Place Concrete	

Name	Value	Unit
Element Specific		
Guid	1EFtUVyYnARODc6zRQrL8L	
Tag	117245	

(b)

Figure 4: (a) The IFC file of the input model before processing; (b) The IFC file after processing with the text-parsing algorithm.

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