An Analysis of the Problems of BIM-Based Drawings and Implementation During the Construction Document Phase

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Abstract –

As construction projects become larger and more complex and the amount of information increases, the necessity of introducing BIM becomes bigger and the importance of BIM-based drawing extraction is also increasing. In particular, the construction document (CD) stage draws and documents the subjects determined from the project planning stage so that actual construction can be possible. Therefore, information management and drawings using BIM in the CD stage have a great impact on the design, construction, and maintenance stages. However, in practice, the BIM results in the CD stage do not include all the necessary information in the construction stage, and the practical use of the drawings extracted from BIM is low.

To solve this problem, this study first analyzed the current status and level of BIM-based drawings in the CD stage by investigating projects that apply BIM in the Korean construction market. Next, the limitations and problems of BIM-based drawings are analyzed from a practical perspective by experts using the Delphi method. Finally, based on the results, methods to improve BIM-based drawings and work efficiency are discussed.

The results of this study can be interpreted based on how the BIM is perceived in different country. However, this study analyzes the current status and problems of BIM applications from general and practical perspectives. It will contribute to further activation of BIM in the architecture, engineering, and construction (AEC) industry if BIM-based drawing standards are established based on this study and follow-up studies are conducted on the development of quality and consistency review models for BIM-based drawings.

Keywords –

BIM; BIM-based drawings; Construction documents; Construction drawings; Construction document phase

1 Introduction

1.1 Research Background and Purpose

As construction projects become larger and more complex and the amount of information increases, two-dimensional (2D) based drawing information systems are switching to three-dimensional (3D) building information modeling (BIM) based information systems [5][11][17]. However, even with this change, drawings remain as a contract standard or legal unit; hence, creating and managing drawings in a BIM-based information system is important [4][7][9]. In particular, the construction document (CD) stage draws and documents the subjects determined from the project planning stage so that actual construction can be possible. Therefore, information management and drawings that use BIM in the CD stage largely affect the design, construction, and maintenance stages. However, in practice, an inefficient and limited collaborative environment exists among the participants, and the BIM results in the CD stage do not include all the necessary information in the construction stage [1][3][10].

To solve this problem, our laboratory has researched rational methods to extract drawings from BIM in the CD stage and investigate the consistency between the BIM results and design drawings in the CD stage. As part of this study, this paper presents the analysis results of our previous works.

First, we analyzed the current status and level of BIM-based drawing in the CD stage according to the construction work and drawing types by investigating an actual BIM application project in the Korean construction market. Second, we analyzed the limitations and problems in BIM-based drawings from the practical viewpoint of experts using the Delphi method. Finally, from the analyzed results, methods to improve BIM-based drawings and work efficiency are discussed.

The results of this study may be different depending on how BIM is implemented in each country. However,

this study aimed to analyze the current status and problems of the BIM application process from a general and practical perspective. If a BIM-based drawing standard is established and follow-up studies on the quality of drawings and development of a consistent review model are carried out according to the results of this study, it would help enable the automation of drawing extraction and verification in the CD stage using BIM. Therefore, the results of this study will strengthen the BIM-based design process and further promote the activation of BIM in the architecture/engineering /construction (AEC) industry.

1.2 Research Scope and Method

In this paper, we present the necessity and direction of BIM-based drawing plans by discussing the analysis of actual practical problems and the current situation regarding BIM-based drawing works in the CD stage.

To investigate the current status of the BIM-based drawings, actual drawings and BIM performance reports of three office buildings where BIM was applied in public construction projects in Korea were analyzed. In addition, a survey among experts was conducted using the Delphi method to analyze the problems and limitations of BIM-based drawings. The Delphi method statistically and systematically analyzes survey results using two or more questionnaires provided to an expert group in a specific field of expertise [6][12]. This is an efficient method for analyzing results when empirical evidence is lacking or when objective data collection is difficult [6][12]. Therefore, in the present study, two surveys and interviews were conducted with 10 design experts and five construction engineers who are experienced in BIM-based drawings in the CD stage. In the first survey and interview, the problems and limitation factors of BIM-based drawing-extraction works from a practical viewpoint were derived. The second survey, which applied a five-point scale (very low: 1 point to very high: 5 points) on the drawing-hindrance factors obtained from the first survey, was carried out to analyze the average values and stability (standard deviation/calculated average). From this analysis, we verified the severity and reliability of BIM-based drawing-hindrance factors.

2 Literature Review

Despite the advantages of using BIM and its major technological advances, BIM has not been fully established in the Korean construction industry because of practical problems and limitations [5]. In particular, as the necessity for effective linkage between BIM and existing 2D drawings in the design-process stage has increased, studies on the problems of introducing BIM into the design process and development plan of BIM-based drawings have been carried out. According to literature reviews, the problems of extracting drawings using BIM can be divided into the following three categories:

1. Inevitable additional work

- In BIM, additional information should be supplied to the first automatically generated drawing to complete the drawing [2][4][9][10][19].

2. Limitations of drawing representation according to the level of details

- The level of details expressed by a BIM model does not reach the level of existing drawings [2][3][10][19].

3. Slow working speed

- If the level of details is increased to that of existing 2D drawings, the modification and creation of the BIM model become slow [2][10].

To solve these problems, Chae and Lee [2] developed alternative solutions for the problems of existing drawing-representation methods using Korean and American cases when introducing BIM to architectural drawings. They also suggested an improvement plan for drawing licensing and delivery efficiency that are applicable to the Korean construction industry. In addition, Oh et al. [17] proposed the need for a BIM-based integrated design system to solve problems such as data loss, communication difficulties, and poor work efficiency resulting from the use of different BIM-based software among designers in the design stage. Lee and Jeon [11] also suggested a BIM-based integrated design process to improve the inefficient drawing-generation process due to institutional constraints. Kwon and Jo [9] proposed the development direction of 2D electronic drawing standards for effective introduction of BIM-based drawings.

Studies were also made on specific BIM software. Song and Jeon [18] classified the main functions provided by the Revit BIM software and conducted a survey on architectural design offices relative to the user perception of the BIM process and the current status and problems of BIM design works. Lee, Jeong, and Oh [10] compared the method of applying Revit to construction drawings of wall-type apartments with the existing 2D-based work method to analyze the additional work required and the work efficiency of BIM-based construction drawings. Cho and Lee [3] verified the possibility of printing the working-design drawings to the same level as those that used existing computer-aided design (CAD) systems when printing drawings using Revit.

To maximize the efficiency of BIM, Kim et al. [8]

developed an automatic 2D drawing program at the level of design development (DD) stage. Studies on the automatic generation of BIM-based drawings mainly focused on drawings for licensing at the DD level and extraction of shop drawings for production of specific materials. Zaki [19] developed a parametric model for automatic generation of shop drawings and detailed quotations for block walls in BIM. Manrique et al. [15] proposed a parametric and BIM-based automatic extraction of detailed drawings (FRAMEX) for wood members. Liu et al. [13] presented a solution that can automatically extract the layout configuration and material-cutting plan for a light residential building using BIM.

Previous studies related to BIM-based drawings presented methods to improve the efficiency of BIM drawing by deducing the problems that arise from a specific construction work field (referred to as "work type") or specific BIM software. However, research on the problems and application in the CD stage has been insufficient. Studies have been conducted on the extraction of drawings in the DD stage or shop drawings for product fabrication; however, no studies on BIM-based drawing automatic generation have investigated drawing extraction in the CD stage. Therefore, the present study aims to analyze the practical problems and limitations of BIM-based drawing works from a practical point of view, instead of focusing on the specific construction or software problems in the CD stage.

3 Analysis of current status of BIM-based drawings

3.1 Application of BIM-based drawings by work type

To investigate the current status and level of BIM-based drawings in the CD stage in terms of the construction work type and to identify the problems of each type, actual drawings and BIM performance reports of three office buildings, which are public construction projects in Korea, were analyzed. The analyzed work types were architecture, structure, machine equipment, electricity, and fire protection where BIM was applied during the CD and construction stages in the three cases.

3.1.1 Architecture and structure

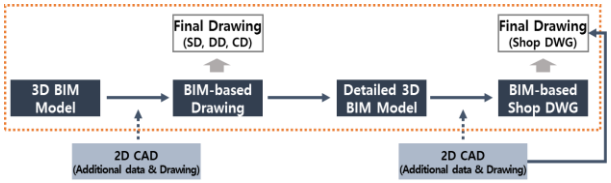

Figure 1. Current status of BIM-based drawings in the field of architecture and structure

In the architectural and structural work cases, BIM-based drawing work was performed using a 3D BIM model. Here, depending on the drawing type, additional 2D CAD work or 2D CAD drawings were performed. Extracting the drawings in the schematic design (SD), DD, and CD stages and the shop drawings during the construction stage could be possible.

3.1.2 Machine equipment

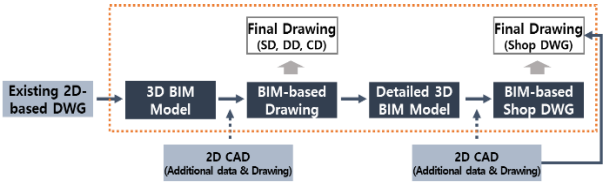

Figure 2. Current status of BIM-based drawings in the field of machine equipment

In the machine equipment case in the Korea AEC industry, the 3D BIM model was constructed from existing 2D CAD drawings, and the constructed model was processed using BIM, if necessary. Similar to the architectural and structural works, during the BIM-based drawing, extracting the drawings in the SD, DD, and CD stages and the shop drawings in the construction stage was possible, depending on the drawing type, using additional 2D CAD works or 2D CAD drawings. However, implementation of the BIM-based drawing work was low during the design stage.

3.1.3 Electricity and fire protection

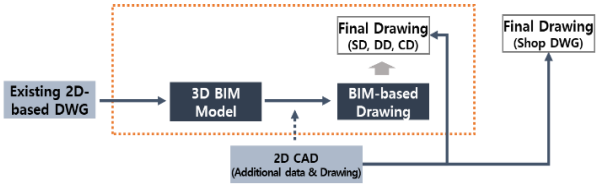

Figure 3. Current status of BIM-based drawings in the field of electricity and fire protection

In the electricity and fire protection work cases, similar to the machine work, the 3D BIM model was constructed from existing 2D CAD drawings, and the constructed model was processed using BIM, if necessary. During the BIM-based drawing, depending on the drawing type, extracting the drawings in the SD, DD, and CD stages was possible by performing additional 2D CAD works or 2D CAD drawings. In the shop drawings in the construction stage, 2D CAD drawings were utilized in most cases.

3.2 Utilization of BIM-based drawing according to drawing type: Architecture and structure

The level of utilization of a BIM-based drawing is different according to the work type. For the architecture and structure work types, the BIM model was not built according to the 2D CAD drawings, but the BIM-based drawing was performed after the BIM model was developed.

On this basis, this section presents our analysis of the BIM-based drawing extraction methods according to the drawing type of the architectural and structural works. The BIM-based drawing extraction result in the CD stage according to the three drawing methods is listed in Table 1.

Table 1. BIM-based drawing methods according to the drawing type

Classification	Drawing method
① BIM	Extraction of drawings from BIM
② BIM + CAD	Additional 2D CAD work on the BIM-extracted drawings
③ CAD	Drawing using CAD

3.2.1 Architecture

In the architectural work cases, 10% of the drawings were extracted from BIM, 54% of the drawings were completed by additional 2D CAD works on the BIM-extracted drawings, and 36% of drawings were CAD drawings. In other words, according to the characteristics of each drawing, 64% BIM-based drawing work was performed, and 36% was performed using CAD (Table 2). The drawing-extraction methods for each type of drawing were classified as listed in Table 3.

Table 2. Current status of the BIM-based drawing methods: Architecture

Classification	Percentage (%)		Note
① BIM	10	64	BIM utilization
② BIM + CAD	54		
③ CAD	36	36	CAD utilization
Total	100	100	-

Table 3. Drawing method according to the type of drawing: Architecture

Classification	Drawing type
① BIM	Floor plan, elevation, main section, window section, etc.
② BIM + CAD	Plot plan, plan drawing, enlarged plan, enlarged cross-section, plane/elevation details, etc.
③ CAD	Site planimetric map, interior material finish schedule, other detailed drawings, etc.

3.2.2 Structure

In the case of structural works, 10% of the drawings were BIM-extracted drawings, 44% were completed by additional 2D CAD works on the BIM-extracted drawings, and 46% were CAD drawings. In other words, 54% of BIM-based drawing work was performed, and 46% was performed using CAD (Table 4). Compared with the architectural works, the utilization rate of the CAD drawings was relatively high. The drawing-extraction methods in each drawing type are classified as listed in Table 5.

Table 4. Current status of BIM-based drawing methods: Structure

Classification	Percentage (%)		Note
① BIM	10	54	BIM utilization
② BIM + CAD	44		
③ CAD	46	46	CAD utilization
Total	100	100	-

Table 5. Drawing method according to the type of drawing: Structure

Classification	Drawing type
① BIM	Structure plan, column center plan, structure cross section, etc.
② BIM + CAD	Enlarged structure plan, Enlarged column center, partial structure cross section, etc.
③ CAD	Structure general items, schedule, detailed drawings, etc.

4 Limitations and problems of BIM-based drawing from a practical perspective

From the analysis of the BIM-based drawing applications discussed in Section 3, the problems and limitations of the BIM-based drawing-extraction work in the CD stage were investigated. For this purpose, the BIM model and the extracted drawings from the BIM project were analyzed. In addition, a survey using the Delphi method was conducted twice from 10 design experts and five construction engineers who were experienced in BIM-based drawings in the CD stage. In the first survey and interview, the problems and limitation factors of the BIM-based drawing-extraction works from a practical viewpoint were obtained. To verify the severity and reliability of each item in the drawing-inhibition factors obtained from the first survey, the average and stability (standard deviation/calculated average) of each item were analyzed through the second survey, which applied a five-point scale (very low: 1 point to very high: 5 points). Thus, the present study verified the severity and reliability of the BIM-based drawing-hindrance factors. The limitations and problems of the BIM-based drawing obtained in this process from the practical viewpoint are described in the next section.

4.1 Functional problems in BIM software

Because of the functional limitations of the detailed expressions of BIM-based drawings using the BIM software, cases arise where drawings created using 2D CAD are used as they are, or drawing elements extracted from the BIM model are used after being modified using the BIM software (Table 6).

Table 6. Results of the Delphi analysis of the limitations or problems: 1

Limitations or problems	Average	Standard deviation	Stability
Inevitable additional work	4.60	0.49	0.107
Functional limitations for detailed drawings of BIM software	3.20	0.75	0.234

The plan and cross sections of the delivered architectural and structural works of the three analyzed projects were created from the BIM drawing-extraction method (Tables 3 and 5). From the analysis results of extracting the expression elements in each drawing using the following two methods, extracting approximately 75% of the architectural plan without additional work using BIM was made possible. In the structural cross section, 80% of the drawing elements could be generated by additional work using BIM (Table 7).

- Method 1: Automatic extraction
  - Elements that can be used as drawing elements without additional work after extraction from the BIM model
  - Examples: grid, architectural wall, window, elevator, etc.
- Method 2: Additional work
  - Elements that require additional work after extraction from the BIM model
  - Examples: leader line, structural wall, parking lamp, equipment-related facility, etc.

Table 7. BIM-based drawing element-extraction method

Drawing type		BIM-based drawing-work method according to element (%)		
		Automatic extraction	Additional work	Total
Architecture	Plan	75	25	100
	Section	56	44	100
Structure	Plan	60	40	100
	Section	20	80	100

4.2 Differences in the application and utilization level of BIM according to work type

Participant collaboration and integrated management among works are the main purpose and greatest advantage of utilizing BIM [4][14][16]. However, because the utilization level of BIM-based drawings among works is different (as discussed in Section 3), limitations exist in integrating project management using BIM-based drawings. In particular, in the mechanical, electrical, and plumbing (MEP) field, which corresponds to machine equipment, electricity, and fire-protection work types, the capacity of the BIM model was approximately three times larger than that of the architecture or structure type. In addition, restrictions on the drawing work in the CD stage appeared because a detailed model was not determined. Furthermore, the participant ability to perform BIM was lower than that in the architectural and structural works. Therefore, BIM was performed by the service supplier, and utilization of the BIM model was low. In the MEP case, fitting and route changes frequently occurred at the construction site. Hence, confidence on the pre-verification using BIM was lacking. Because according to the contract, the specialized company was not responsible for the quantity, it did not empathize with the need to confirm the interference and to calculate an accurate quantity in advance using BIM.

Table 8. Results of the Delphi analysis on the limitations or problems: 2

Limitations or problems	Average	Standard deviation	Stability
Different utilization level of drawing according to work	4.60	0.49	0.107
Determination of MEP detailed model (design plan) at construction stage	4.60	0.49	0.107
Lack of ability of participants to perform BIM	4.50	0.50	0.111
MEP BIM model capacity size	4.40	0.66	0.151

4.3 Process and institutional issues

Problems are encountered in using BIM-based drawings from the process and institutional perspectives (Table 9). When a public organization that makes an order (owner) requests a delivery form based on existing 2D drawings and the criteria and guidelines of the delivery form of the BIM drawing and BIM-based drawing are not specified, delivering and utilizing the drawings extracted from the BIM are difficult. In particular, when a professional subcontractor who performs practical construction work participates in the construction stage, new design plans and decisions are often made, such as capacity to construct and interference. The resulting modification in the BIM model and the drawings represent considerable hindrance factors in BIM-based drawing-extraction work. In addition, when the service cost is not clearly specified according to the BIM work and application scope, BIM is passively utilized, resulting in a low BIM application effect.

Table 9. Results of the Delphi analysis on the limitations or problems: 3

Limitations or problems	Average	Standard deviation	Stability
Frequent design changes	4.60	0.49	0.107
Request delivery of 2D CAD form drawings (double drawing work)	4.10	1.22	0.298
Lack of criteria and guidelines for BIM-based drawings	3.80	0.40	0.105
Lack of BIM service costs due to low-cost bidding	3.40	0.80	0.235

5 Discussion

In this section, the factors that must be considered for promoting the use of BIM in the construction industry and improving the efficiency of BIM-based drawing work using the current status of BIM-based drawing works (Section 3) and analysis of actual problems

(Section 4) are discussed.

5.1 Establishment of a standard BIM delivery process

Establishing a standard BIM delivery process is necessary by standardizing the roles and responsibilities of each participant in each step of a BIM application project. Therefore, the BIM work system should be evolved into a system centered on the design and construction practitioners, rather than on the BIM-specialized service companies, by improving the drawing and delivery standards using BIM in the CD stage that serve as the BIM guidelines for practitioners.

5.2 Development of drawing templates

As presented in Sections 3 and 4, cases arise where some 2D CAD drawings are used or elements extracted from BIM are used as drawing elements through additional work in the BIM-based drawing-extraction process. Therefore, defining the minimum essential expression element for each drawing is necessary through the following: 1) considering the work efficiency from a practical viewpoint, 2) classifying and presenting the elements utilizing 2D CAD drawings and the elements that use the BIM model, and 3) gradually reducing the range of 2D CAD utilization factors that require unnecessary additional work. In addition, BIM-based drawing templates for each design stage should be developed so that the drawing-extraction work can be efficiently performed according to the work method in the BIM environment.

5.3 Automation of quality inspection and drawing extraction

The drawings extracted from BIM should be automatically updated when the BIM model is used. However, when the drawing element is not automatically extracted during the drawing extraction, additional works should follow. Therefore, examining the consistency between the BIM model and drawings is necessary. If the drawing elements in each drawing are defined and reviewed by classifying the extraction method for each element, the quality of the drawing (as well as the consistency), can be examined. Thus, if a checklist for the extraction method of each drawing type can be derived (and software can automatically check it), quality inspection and drawing-extraction automation will be possible.

6 Conclusion

This paper has presented the analysis results of previous works as part of a study to develop a rational method of deriving CD stage drawings using BIM and a model for examining the quality and consistency of the drawings derived from BIM.

First, we analyzed the current status and level of BIM-based drawing in the CD stage by investigating an actual BIM project case in the Korean construction market (Section 3). As a result, the level of utilization of BIM-based drawings in terms of the construction work type was different. The level and method of utilization according to the drawings also varied depending on the characteristics of the drawing and efficiency of the work.

Second, the limitations and problems of the BIM-based drawing works were derived from a practical viewpoint using the Delphi method involving experts. The derived limitations and problems can be categorized into the following three characteristics: 1) functional issues of the BIM software, 2) difference in the BIM application and utilization level in terms of the construction work type, and 3) process and institutional issues. The limitations and problem factors of each item were analyzed by applying a five-point scale. All stability values were 0.5 or less; therefore, the validity and reliability were determined.

Application of the results of this study may be different depending on the implementation in each country. However, this study is significant because it analyzed the current status and problems of the BIM application process from a general and practical perspective. In addition, stimulating BIM utilization in the AEC industry and improving the work efficiency of BIM-based drawings are possible if follow-up studies are conducted by considering the work environment and reality according to the status and problem analysis results. These studies should include the following: 1) establishment of standard BIM delivery process, 2) development of BIM-based drawing templates, and 3) automation of BIM drawing quality inspection and BIM-based drawing extraction.

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References

[1] Arayici, Y., Fernando, T., Munoz, V., and Bassanino, M. Interoperability specification

development for integrated BIM use in performance based design. *Automation in Construction*, 85, 167-181, 2018.

[2] Chae, K.S. and Lee, G. A study on the problems and the measurements for improving representations and drafting methods of architectural drawings by adopting BIM. *Transactions of the Architectural Institute of Korea*, 27(10), 67-74, 2011.

[3] Cho, Y.S. and Lee, H.W. A study on the possibility of 2D design drawing implementation by Revit Architecture. *Journal of Korea Academy Industrial Cooperation Society*, 14(10), 5243-5250, 2013.

[4] Eastman, C., Teicholz, P., Sacks, R., and Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.* John Wiley & Sons, 2011.

[5] Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., and Raahemifar, K. Building information modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, 75, 1046-1053. 2017.

[6] Hallowell, M.R. and Gambatese, J.A. Qualitative research: Application of the Delphi method to CEM research. *Journal of Construction Engineering and Management*, 136(1), 99-107, 2009.

[7] Kazaz, A., Acıkara, T., Ulubeyli, S., and Koyun, H. Detection of architectural drawings errors in 3 dimension. *Procedia Engineering*, 196, 1018-1025, 2017.

[8] Kim, I.H., Lee, M.J., Choi, J.S., and Kim, G.T. Development of an application to generate 2D drawings in automation using Open BIM technologies. *Korean Journal of Computational Design and Engineering*, 21(4), 417-425, 2016.

[9] Kwon, O.C. and Jo, C.W. A study on the improvement of 2D digital drawing standards considering the paradigm shift to BIM. *Journal of the Architectural Institute of Korea Planning & Design*, 24(5), 49-57, 2008.

[10] Lee, J.C., Jung, J.H., and Oh, H.O. Work efficiency analysis of BIM based structural drawing. *Journal of the Architectural Institute of Korea Structure & Construction*, 29(6), 21-28, 2013.

[11] Lee, J.H. and Jun, H.J. A study on the adaptability of BIM-based integrated building design process in domestic architectural design firms. *Journal of Korean Institute of Interior Design*, 16.6: 19-27, 2007.

[12] Linstone, H.A. and Turoff, M. (Eds.). *The Delphi Method* (pp. 3-12). Reading, MA: Addison-Wesley, 1975.

[13] Liu, H., Singh, G., Lu, M., Bouferguene, A., and Al-Hussein, M. BIM-based automated design and planning for boarding of light-frame residential buildings. *Automation in Construction*, 89, 235-249. 2018.

[14] Liu, Y., Van Nederveen, S., and Hertogh, M. Understanding effects of BIM on collaborative design and construction: An empirical study in China. *International Journal of Project Management*, 35(4), 686-698, 2017.

[15] Manrique, J. D., Al-Hussein, M., Bouferguene, A., and Nasseri, R. Automated generation of shop drawings in residential construction. *Automation in Construction*, 55, 15-24. 2015.

[16] Migilinskas, D., Popov, V., Juocevicius, V., and Ustinovichius, L. The benefits, obstacles, and problems of practical BIM implementation. *Procedia Engineering*, 57, 767-774, 2013.

[17] Oh, M., Lee, J., Hong, S.W., and Jeong, Y. Integrated system for BIM-based collaborative design. *Automation in Construction*, 58, 196-206, 2015.

[18] Song, K.M., John, Y.S., and Song, K.M. A comparative analysis on BIM usage between Korean & USA architectural firms regarding effective design process. *Journal of Digital Design*, 12(4), 523-533, 2012.

[19] Zaki, T. *Parametric Modeling of Blockwall Assemblies for Automated Generation of Shopdrawings and Detailed Estimates using BIM.* Thesis for Masters of Science in Construction Management, The American University, Cairo, 2016.