International Journal of High-Rise Buildings
June 2013, Vol 2, No 2, 97-104

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Impact Analysis of BIM Spread on Mechanical Design Process Based on Consciousness Survey among Japanese Mechanical Engineers

Kyosuke Hiyama[1], Yunting Diao[2], Shisuke Kato[3], and Makoto Koganei[1]

[1]*Faculty of Engineering, Yamaguchi University, Japan*
[2]*Azbil Corporation, Japan*
[3]*Institute of Industrial Science, the University of Tokyo, Japan*

Abstract

Recently, the demand for Building Information Modeling (BIM) construction drawings and specifications has increased rapidly. Many countries have also started to implement BIM. The BIM implementation can change the design flow of buildings including high-rise buildings. Against this background, many companies are focusing on the development of BIM software. BIM involves a three-dimensional CAD program that can examine the placement of ductwork and machinery. It significantly increases the efficiency of a mechanical design through data unification using standard Industry Foundation Classes (IFC). In addition, BIM functions as a database to simplify the use of simulation technology for designing air-conditioning systems. To further develop BIM, it is important to know the expectations of mechanical engineers who will become frequent users of BIM in the future. A survey was conducted among Japanese mechanical engineers using a questionnaire to analyze the expectations of mechanical design using BIM. The results show that many respondents strongly recognize BIM as a three-dimensional CAD program. However they also expect that BIM can help the optimization of their design works and enhance design functionality by running simulations utilizing BIM.

Keywords: BIM, Consciousness survey, Mechanical engineer

1. Introduction

In recent years, growing attention has been paid to Building Information Modeling (BIM). The General Service Administration (GSA) in the USA has adopted BIM as a real estate general service (U.S. GSA, 2007). Likewise, Wisconsin and Texas use BIM for public buildings. It is also used in Singapore for applications in building certification. BIM has been adopted in many projects all over the world (Hooper and Ekholm, 2010; Hitchmough et al., 2011; Gu and London, 2010). The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan asked to use BIM for a government office building in 2010; thus, it is expected that the use of BIM for architectural design will certainly increase in the future in Japan. BIM is known as a three-dimensional Computer-Aided Design (CAD) program and as a way of implementing data unification based on standard Industrial Foundation Classes (IFC) data (Björk and Laakso, 2010). Likewise, research on and development of BIM as an information/database tool to improve the efficiency of the design process is currently underway. The U.S. Green Building Council (USGBC) proposes to make the Leadership in Energy and Environmental Design (LEED) rating system more efficient by using BIM (Azhar and Carlton, 2011). In a similar manner, the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) research and development committee of Japan Sustainable Building Consortium formed a CASBEE-BIM support work group to research the use of BIM in automating the CASBEE ratings process (Iwamura et al., 2010). The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan created a BIM/CFD (Computational Fluid Dynamics) modularization subcommittee. To widely spread the use of thermal load calculation and airflow simulation in mechanical design, which was previously performed manually, they have investigated modularizing using sampling boundary conditions and air-conditioning information from BIM (Kono et al., 2011). BIM is expected to help the implementation of simulations at each design stage to optimize the building design (Diao et al., 2011).

Improving the functionality of mechanical designs requires detailed CFD analysis and system simulations. However, because it requires intricate data entry, its use is limited to small parts of a project. Time will be saved in data entry by adopting BIM and using this technology more frequently and widely. Mechanical designs developed using BIM can improve quality and decrease their

†Corresponding author: Kyosuke Hiyama
Tel: +81-836-85-9711
E-mail: hiyama@yamaguchi-u.ac.jp

impact on the environment. As a result, we hope this will provide an opportunity to significantly improve mechanical design in the whole architectural design field.

To advance research and promote BIM, understanding the expectations of designers and engineers who design air-conditioning systems via BIM is required. This paper reviews the results of a survey questionnaire given to mechanical engineers in Japan (Hiyama, 2011b) and examines the direction of BIM research and the development for mechanical design with discussions including cross tabulation which concerns different roles in the design process.

2. Summary of BIM and the Importance in Mechanical Design

BIM is an architectural modeling process that generates three-dimensional information about objects using CAD (Singh et al., 2011). By using BIM, it is possible to create a virtual building that is a mirror image of an actual building in a virtual space. Because this technology is object-oriented, the model produced is easily understood. Thus, BIM output has the advantage of providing intelligible information to a client who does not have any professional knowledge. Previous design processes required coding from a two-dimensional drawing plan to construction drawings and specifications. Using BIM, it is possible to model a collection of three-dimensional objects directly. In other words, in conventional design processes, a three-dimensional existing building image is first projected onto two-dimensional documents such as a ground plan and an elevation at the design stage, and is reconstructed onto three-dimensional real building at the construction stage. BIM, however, makes it possible to directly draw a three dimensional building image as it is. With object-oriented features, it is easy to unify design elements of a model or treat them separately. Architectural design requires documents creation for each division, such as design, structure, and equipment in parallel. Then the function is great potential for improving productivity. Because all design documents share IFC data, information succession can be performed smoothly from design to construction. Furthermore it can be probably extended to future building management. With the three-dimensional CAD function, it is easy to detect problems causing interference of objects at the early design stage. This can reduce the labor of modifying an inconsistent design at the construction stage. Especially, BIM is expected to reduce the labor of design process for buildings with multiple stories based on the typical floor plan like high-rise buildings.

The introduction of BIM will bring many benefits to each field, architectural design, construction, and operation management. Moreover we especially expect it to be a great benefit for the mechanical design field. Generally, a mechanical design plan is created by overlaying architectural drawings. In addition, a construction plan is required to examine the placement of piercing beams. For system examination, information from other divisions is very important in calculating the thermal load. Because of their importance to mechanical design, architectural designs, construction plans, and electrical equipment plans need to be updated continuously in the early design stages.

Furthermore, by adopting BIM, it is possible to improve the functionality of mechanical design to meet the various requests of clients. This may highlight the significance of mechanical design in the whole architectural design process. A mechanical engineer's job is not only to secure a comfortable indoor thermal environment on an extremely hot day of summer (and an extremely cold day of winter) but also to improve energy savings and productivity. To achieve this mission, it is necessary to possess advanced simulation technology, such as system simulation or CFD analysis (Pratt and Bosworth, 2011; Hiyama et al., 2010, 2011a). However, simulation technology is not widely used because it requires intricate data entry. By making data entry efficient through BIM, optimized designs based on finely calculated models with these simulations will be generated. Moreover, the time used to communicate with other divisions (design, construction, and electricity) and create drawings and specifications by using two-dimensional CAD can be reduced. The reduced time can instead be spent for improving design functionality or system examinations.

Because environmental impact is an important consideration today, a mechanical engineer must have the ability to come up with an optimized plan based on detailed analysis (Suga et al., 2010). In recent years, investments in building utilities in Japan have tended to be valued not only for direct benefits, such as the budgetary reduction of running costs, but also for indirect benefits, such as environmental considerations and health improvements. Clients' demands of a mechanical engineer are diverse as well. With the high credibility of detailed simulations, it is possible to provide a client with information that could not be shown in conventional design documents using two-dimensional documents. Thus, having utilizing BIM will make a big difference in a company's merits. It is also possible to show information to a client much more easily using three-dimensional CAD. A client's impression changes immeasurably by depicting a physical environment, such as a flow distribution or temperature field. It influences the quality of architectural design, depending on whether engineers have these skills or not. Thus, BIM is expected to enhance the importance of mechanical engineers by allowing them to play an important role in architectural design.

3. Summary of a Questionnaire

Table 1 shows the select review of the questionnaire (See previous literature (Hiyama, 2011b) for the entire

Table 1. Content of Questionnaire (select review)

- Question about usual design work.
Q1. How much (in percentage) do you use the below-mentioned technical computing for your design? Please tell us the estimate for roughly the last one year (e.g., Used on half of all projects = 50%) i. Energy Simulation (Annual thermal load calculation) ii. System Simulation iii. LCA (Life Cycle Assessment: LCCO2 etc.) iv. Construction Environmental Efficiency Rating (CASBEE etc.) v. CFD Analysis
Q2. Please choose the most applicable among the listings below of your reasons to use the 3D indoor environment estimation tool (Multiple answers allowed.) - To optimize for a comfortable thermal environment - To optimize the air flow (designs for natural ventilation) - To ensure against creating an uncomfortable thermal environment - To optimize the outdoor wind environment (securing cool outdoors breezes) - To ensure against creating a windy zone (building-induced wind) - To create explanatory documents corresponding to a client's request - Because of company and group policy - Unknown because not used
Q3. Which one from the list below should be applied to optimize designs (to improve design quality)? (Multiple answers allowed) - Energy Simulation (Annual thermal load calculation) - System Simulation - LCA (Life Cycle Assessment) - Construction Environmental Efficiency Rating (CASBEE etc.) - CFD Analysis - None
Q4. How much labor do you use for one design project? Please answer with rough percentages (please include calculations and designs for outside orders.) - Preliminary design / Concept design - Schematic design - Detailed design
Q5. How much labor do you use for one schematic designing? Please answer with rough percentages. - System examination, Decision making for facility system, Summary of schematic design - Correspondence to clients, Office negotiation - Coordination with other design teams (Architectural, Construction, and Electricity)
Q6. How much labor do you use for one detailed designing? Please answer with rough percentages. (please include calculations and designs for outside orders.) - Detailed design calculation - Creating detailed design plan - Correspondence to clients, Office negotiation - Coordination with other design team (Architectural, Construction, and Electricity)
- Question about BIM (Building Information Modeling) Definition of BIM: It is a database of a digitalize 3D building accompanied with attribution data, such as machinery parts and materials data. Today, some software programs are available on the market that can make it possible to automate thermal load calculation and verify the error and problems in overlaying architectural/constructed/facility models.
Q8. Please choose therr from the list below that you think provide the best advantege in using BIM for facility designs. - It is possible to examine the placement of ductwork/piping and the machinery room. Also, it is easy to check design errors in advance. - It can secure integrity and consistency for design works, design drawings, and specifications, as BIM automatically creates the design dreawing and specification during the design process. - It reduces the labor in data entry for thermal load calculation. - It reduces the labor in data entry for construction efficiency rating tools, such as CASBEE. - It facilitates integration (picking up) or creating an operation plan. - It makes communication between the project team smooth. - It can be used for a design presentation to a client. - It can be used for facility management.
Q9. Assume that the BIM software listed below exists on the market. Please choose one of the BIM products that you would to use most and a secondary product you would want to use. Product 1: Automation of ductwork placement and energy simulation Product 2: Automation of ductwork placement and CFD analysis Product 3: Automation of CFD analysis and energy simulation

questionnaire). Q1, Q2, and Q3 contain questions related to the present use of simulation technology and the expectation for its future use. It is important to clarify the cost and effect when considering the implementation of BIM. Thus, Q4, Q5, and Q6 contain questions related to the present allocation of labor in the design process, which helps analyze the cost and effect. With the implementation of BIM, smooth communication between the person in charge of architectural design and construction, the elimination of time spent coding two-dimensional plans, and the automation of simulation data entry can be expected. These questions intend to fully capture effective ways of improving the productivity of the design process fully. Q8, and Q9 ask for desired functions utilizing BIM. The questionnaire was filled online, and the URL was sent to companies with Mechanical Electrical Plumbing (MEP) design facilities. The respondents were limited to mechanical engineers. The period of the questionnaire was 15 days, from July 1st to 15th 2010.

4. Result and Analysis

4.1. Respondents' attributes

There were a total of 100 respondents. Figure 1 shows the results according to type of industry. Figure 2 shows the percentage of respondent's role in the mechanical design process. Half of the respondents were supervisors and the other half designers or engineers. It means the answers reflected the respondents' perspectives of their duties as designers or supervisors.

4.2. Labor allocation in the designing process

Figure 3 shows the results from Q4, Q5, and Q6, questions about labor allocation in the design process, such as preliminary designing, schematic designing and detailed designing. It shows that detailed designing consumes half of the entire process and that drafting the detailed design plans consumes about 18% of the design labor. Previously, we referred that it was necessary to create construction drawings and specification coding from two-dimensional design plans in conventional design process. BIM eliminates this process through the creation of three-dimensional plans using three-dimensional objects to develop a building model. Therefore, this can make the detailed design process much shorter. This process is not only limited to detailed design; there is a report of 20% higher efficiency in a whole design process as well (Percio, 2010). Coordination in the design project teams (Architecture, Construction, Electricity) accounted for 9% of the labor in schematic design, followed by 10% of the labor in detailed design. A total of about 20% of the labor is spent in coordinating with other fields. One of the advantages in introducing BIM is being able to manage all of the information from each field in one place, thereby saving much time in project coordination. Furthermore, it is possible to reduce 14% of the labor associated with system examination in schematic design and 11% of the labor associated with detailed design calculation by developing BIM data entry automation for simulation. Overall, it is expected that BIM can save up to 20 to 30% of the labor in the future project. Construction was not included in the questionnaire because the focus was on examining the allocation of labor in the design field. If the construction of auxiliary functions with BIM is included, a lot more comprehensive architecture labor can be saved. The time saved by BIM adaption can be used for the more technical review to increase the design quality.

4.3. Usage of simulation technology

Figure 4 shows the frequency of simulation usage (Q1) with the average rate and difference in box-plot form. It shows that the construction environmental efficiency rating such as CASBEE is used most frequently in deter-* mining construction, and more than a fourth of the respondents use this simulation technology on all projects.

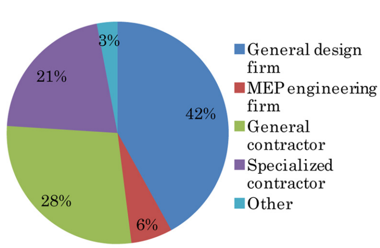


Figure 1. Type of industry.

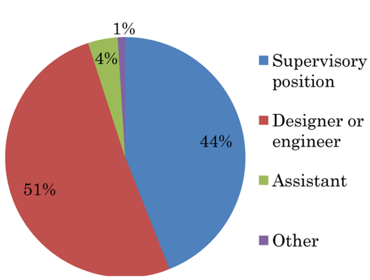


Figure 2. Role in designing.

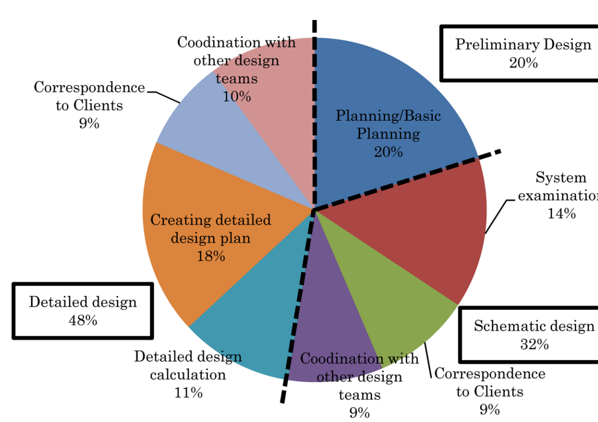


Figure 3. Q4-6: How much labor do you use for one design project?

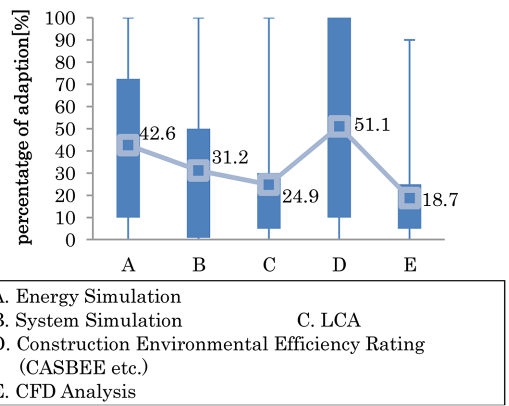


Figure 4. Q1: How much do you use the technical computing for your design?

Energy simulation comes second in the list, followed by system simulation, LCA (Life Cycle Assessment), and CFD analysis. Although some answered that they use LCA and CFD analysis on all projects, three-fourths of the respondents showed indicated 30% usage. CASBEE, which utilizes Excel, or Energy simulation, which is in high demand, require comparatively less data entry labor. CFD analysis requires more intricate data entry (creating three-dimensional models) than other simulations.

Although it changes according to clients' demands and it is difficult to infer simply, the frequency of simulation use seems to drop significantly with more intricate data entry. Figure 5 shows the results from Q3 concerning the expectations from using simulations in the future. CFD analysis received the most interest, followed by system simulation and energy simulation. Compared to LCA (both LCA and CFD analysis showed low usage in Q1), CFD analysis has hope for design optimization, even with intricate data entry. Using BIM to automate data entry for CFD analysis has great potential. Because there was high usage reported in the construction environmental efficiency rating in Q1, its result for future usage was low.

Figure 6 displays the reasons for using three-dimensional indoor environmental estimation tools such as CFD

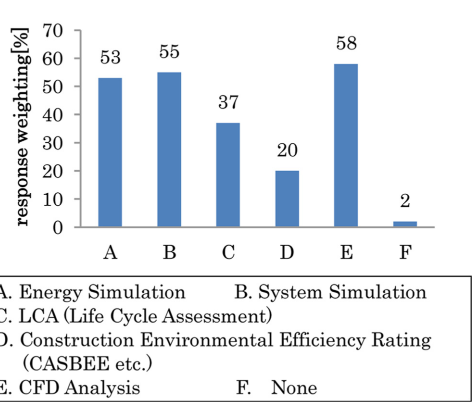


Figure 5. Q3: Which one from the list should be applied to optimize designs?

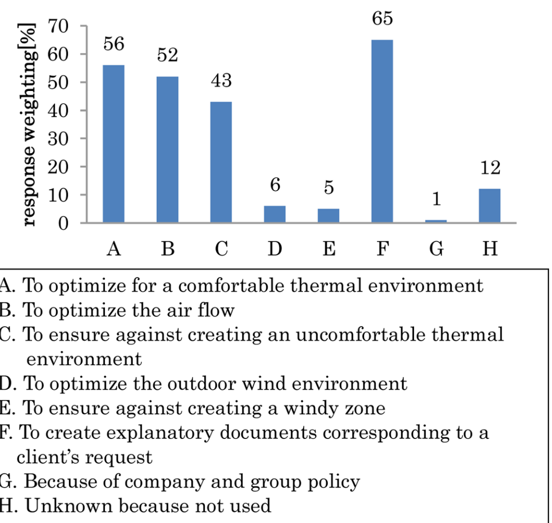
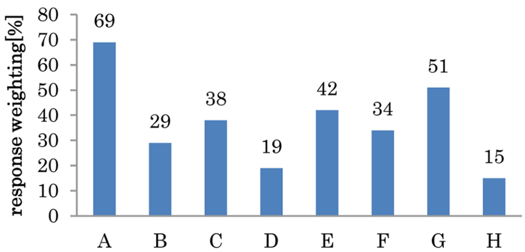


Figure 6. Q2: Please choose the most applicable among the listings below of your reasons to use the 3D indoor environment estimation tool.

analysis (Q2). A large amount of respondents indicated that it is useful in presenting a design to a client, followed by thermal environmental analysis, natural ventilation, and indoor environmental analysis. It was also shown that it is rare for mechanical engineers to analyze the outdoor wind environment. To promote CFD analysis in projects, it is important to demonstrate that BIM is useful in visualizing designs for clients and convenient for analyzing indoor environments.

4.4. The expectations of facility design engineers for BIM development

Figure 7 shows the responses to Q8, a question about what the respondents think the advantages of BIM are. "It is possible to examine the placement of ductwork/piping and the machinery room. Also, it is easy to check for design errors in advance" received the most responses, followed by "It can be used for a design presentation to a client". These two answers came first because the respondents seem to have an idea of BIM as a three-dimensional graphic tool. "It reduces the labor in data entry for thermal load calculation" and "It facilitates integration (picking up) or creating an operation plan" ranked next in importance. BIM might be thought of as a database function. One of the selections, "It reduces the labor in data entry for construction efficiency rating tools, such as CASBEE", is also a database function. As mentioned above, because it is already used frequently, it did not appear as an advantage of using BIM. It also showed that engineers do not feel that CASBEE data entry constitutes much of their labor. "It can be used for facility management" ranked very low in the results. However, The General Service Administration (GSA) in the USA guidelines list facility management as one of BIM's merits. Here, the respondents did not demonstrate awareness of



A. It is possible to examine the placement of ductwork/piping and the machinery room. Also, it is easy to check design errors in advance.
B. It can secure integrity and consistency for design works, design drawings, and specifications, as BIM automatically creates the design drawing and specification during the design process.
C. It reduces the labor in data entry for thermal load calculation.
D. It reduces the labor in data entry for construction efficiency rating tools, such as CASBEE.
E. It facilitates integration (picking up) or creating an operation plan.
F. It makes communication between the project team smooth.
G. It can be used for a design presentation to a client.
H. It can be used for facility management.

Figure 7. Q8: Please choose three from the list below that you think provide the best advantage in using BIM for mechanical designs.

added value other than the optimization of their present design process. Similarly, research in the USA did not show that a client has many demands for Operation and Management (O & M) (MacGraw HILL, 2009).

It is important to develop an additional function in BIM if we want to promote its use. Thus, we asked what kind of function in BIM a mechanical engineer desires. We conducted a conjoint analysis, using facts about functions, such as "Automation of ductwork placement," "Automation of energy simulation", and "CFD analysis automation" (Q9). We used PASW Conjoint 18 software for this analysis. "Ductwork" here represents only the regulated work in mechanical design. The desire to automate the placement of ductwork will result in reduced labor in mechanical design. "Energy simulation" is necessary for design optimization. Many projects have already incorporated this feature. This simulation makes a process more efficient. Although "CFD analysis" is also necessary for design optimization, it is used less frequently than the other functions. The addition of CFD analysis to previous design processes will likely improve and optimize the mechanical design itself. Table 2 shows each the value of each function. When a respondent chooses a product accompanied with each function and indicates a high value. The results show that energy simulation was highest in value, while duct and CFD analysis were almost the same. Overall, the engineers expect energy simulation to be more efficient and applicable than previous design technologies by using BIM.

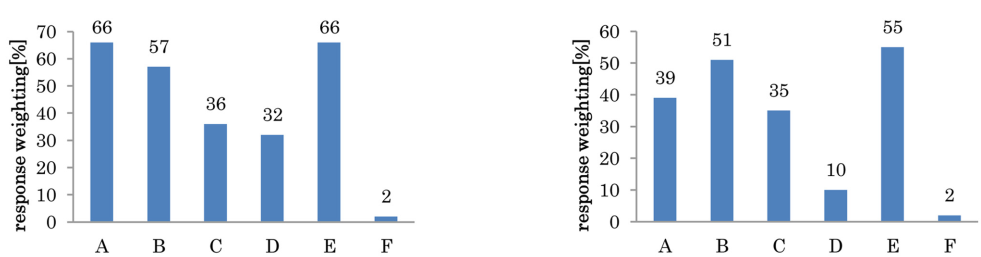
Table 2. Value of each function

Functions	Value
Ductwork	31.3
Energy simulation	38.3
CFD analysis	30.3

4.5. Divergence in awareness of a role

We used a cross tabulation based on different roles in the design process. Figure 8a shows the results of a supervisor's desire to run a simulation (Q3). Figure 8b shows the answers of designers and engineers. There is a difference in their answers regarding energy simulation and construction environmental efficiency rating. Design supervisors want to use energy simulation more than designers. Both energy simulation and construction environmental efficiency ratings are already widely used. Supervisors seem to hope for an improvement in design quality. On the other hand, designers and engineers tend to be satisfied with their present tools.

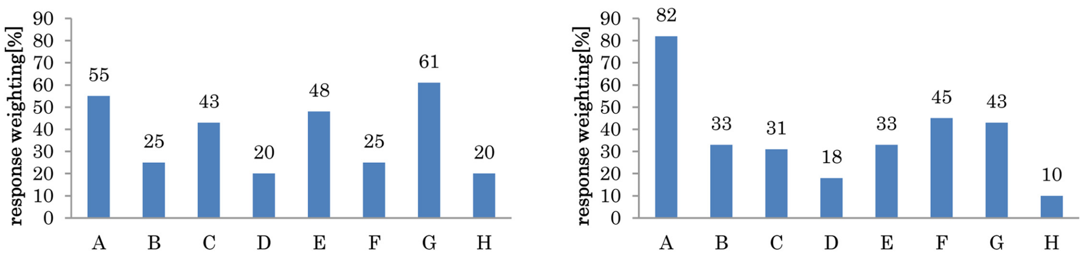
Figure 9a shows supervisors' answers about what they think are BIM's advantages (Q8), and Figure 9b shows designers' and engineers' answers. Designers and engineers tend to think BIM is useful: "It is possible to examine the placement of ductwork/piping and the machinery room. Also, it is easy to check design errors in advance". On the contrary, supervisors tend to think an advantage of having BIM is the following: "It can be used for a design presentation to a client". A designer who desires to improve the efficiency of the designing process differs in opinion from a supervisor who seeks additional



A. Energy Simulation B. System Simulation C. LCA (Life Cycle Assessment)
D. Construction Environmental Efficiency Rating (CASBEE etc.) E. CFD Analysis F. None

a) supervisory position b) designer and engineer

Figure 8. Divergence in Awareness of a Role for Q3.



A. It is possible to examine the placement of ductwork/piping and the machinery room. Also, it is easy to check design errors in advance.
B. It can secure integrity and consistency for design works, design drawings, and specifications, as BIM automatically creates the design drawing and specification during the design process.
C. It reduces the labor in data entry for thermal load calculation.
D. It reduces the labor in data entry for construction efficiency rating tools, such as CASBEE.
E. It facilitates integration (picking up) or creating an operation plan.
F. It makes communication between the project team smooth.
G. It can be used for a design presentation to a client.
H. It can be used for facility management.

a) supervisory position b) designer and engineer

Figure 9. Divergence in Awareness of a Role for Q8.

value for a project. Moreover, a supervisor has more expectations for the improvement of tools than designers and engineers, as indicated by the responses "It reduces the labor in data entry for thermal load calculation" and "It reduces the labor in data entry for construction efficiency rating tools, such as CASBEE". This result is related to the answer concerning supervisors' hopes for expanding the use of tools in Q3.

5. Discussion

We will examine the important points for spreading the use of BIM in the mechanical design process in this chapter. First, we take a look at the optimization of the designing process. As shown in Figure 3 (Q4, Q5, and Q6), half of the labor is spent on detailed designing in the mechanical design process. Most time is occupied by the stage after a construction specification is settled, such as in the creation of a detailed design plan and detailed design calculations. Because calculating a bill can be automated by applying BIM, a lot of labor can be saved. This time saved can be transferred to preliminary design/schematic design or improvements in design quality. Mechanical design engineers can showcase their skills at their best in this process. Therefore it is important to publicize this fact as a benefit of BIM use.

Second, we examine the optimization of designs when BIM is implemented. As we mentioned previously, a mechanical design can be improved as follows:

- Confirmation of positioning by a three-dimensional CAD function.
- Facilitation of data sharing between software (easy data entry of simulation).
- Seamless database function from design to operation and management.

Figure 7 (Q8) shows that there were many respondents who believe BIM is advantageous in identifying problems in ductwork. This is the primary reason to use BIM for design optimization. As Table 2 (Q9) shows, an expectation for BIM software is not only the automation of ductwork placement but also energy simulation. Thus, the second listed advantage would be possible after improving current BIM software. The software needs to be of higher quality, and the function needs to be expanded so that BIM can be recommended to the mechanical design field more. There were only a few respondents who thought that the advantage of BIM is that it can be used for facility management (in Figure 7 (Q8)). This leads to the third listed advantage, which is not well known. Because BIM is not well recognized even in the architectural design process, it is still too early to expect end-users in facility management. Today, investment is dropping with the low numbers of new building construction projects in Japan. Thus, we believe that it is important to add value to construction by enriching service. The facility management of BIM is part of this. It is necessary to demonstrate the possibility of using BIM for industrial development and to present how it works as an advantage.

6. Conclusion

Many countries have recently started to shift architectural design methods from creating two-dimensional drawings and specifications to using BIM database construction. However, Japan is responding slowly. Particularly in the mechanical design process, BIM is barely used. BIM has the advantage of significantly improving design functionality. In addition, we can expect to connect design optimization with the innovation of simulation technology using database functions in BIM. Thus, we conducted a survey of 100 mechanical engineers to investigate the use of BIM in the future. A summary of the results is shown below:

- 19% of labor is used in coordinating with other design project teams (Architecture, Construction, and Electricity), 18% in creating a detailed design, 11% in detailed design calculation, and 14% in system examination. We estimate 20 to 30% of labor in a whole design process can be reduced by applying BIM to streamline these processes.
- Below 20% reported the use of CFD analysis in their design. However, about 60% reported that to improve the design process, utilization of CFD analysis is highly desired for the future. Users can improve the frequency of using CFD analysis with the efficient data entry provided by BIM.
- Mechanical engineers understand that the primary advantage of using BIM is to be able to confirm the placement of ductwork/piping and to provide documents for a client using three-dimensional functions.
- However, mechanical engineers hope to use more convenient design tools, such as energy simulation, more than the automation of format works, such as the automation of ductwork placement when BIM can facilitate those functions more.
- We can expect that a lot of labor saved by applying BIM can be transferred to design optimizations based on sophisticated simulations utilizing BIM.

Acknowledgements

I would like to express my deepest gratitute to Mr. Kentaro Suga from Arup Japan, Mr. Makoto Ohura from Autodesk, Inc., Dr. Mutsumi Yokoi, Dr. Hikaru Kobayashi, Mr. Takeshi Ogawa, Mr. Keiko Sugawara from Taisei Corporation to help for the questionnaire.

References

Azhar, S., Carlton, W. A., Olsen, D. and Ahmad, I. (2011). “Building information modeling for sustainable design and LEED® rating analysis.” *Automation in Construction*, 20, pp. 217~224.

Björk, B. C. and Laakso, M. (2010). “CAD standardisation in the construction industry A process view.” *Automation in Construction*, 19, pp. 398~406.

Diao, Y., Kato, S. and Hiyama, K. (2011). “Development of an optimal design aid system based on building information modeling.” *Building Simulation*, 4, pp. 315~320.

Gu, N. and London, K. (2010). “Understanding and facilitating BIM adoption in the AEC industry.” *Automation in Construction*, 19, pp. 988~999.

Hitchmough, M., Holden, N., Johnson, M., Kingstone, D., Phillip, M., Speakes, N. and Webster, J. (2011). The design of the co-operative head office, Manchester. Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, Australia.

Hiyama, K., Kato, S. and Ishida, Y. (2010). “Thermal simulation: Response factor analysis using three-dimensional CFD in the simulation of air conditioning control.” *Building Simulation*, 3, pp. 195~203.

Hiyama, K. and Kato, S. (2011a). “Integration of three-dimensional CFD results into energy simulations utilizing an advection-diffusion response factor.” *Energy & Buildings*, 43, pp. 2752~2759.

Hiyama, K., Diao, Y. and Kato, S. (2011b). Analysis of influence on mechanical design process by BIM spread: Consciousness survey to BIM by questionnaire of mechanical engineer. Transactions of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, 169, pp. 39~48. (in Japanese)

Hooper, M. and Ekholm, A. (2010). A pilot study, Towards BIM integration - an analysis of design information exchange & coordination. Proceedings of CIB-W78 2010: 27th International Conference, Cairo, Egypt.

Iwamura, K., et al. (2010). Study on Comprehensive Assessment System for Built Environment Efficiency (CASBEE) Part. 104: Study on development of CASBEE-BIM Connector, ummaries of technical papers of Annual Meeting Architectural Institute of Japan. D-1, Environmental engineering I: pp. 1037~1038. (in Japanese)

Kono, R., et al. (2011). Integration of BIM and modularization of elements for CFD in CAE software tools for architectural environment. Transactions of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, 174, pp. 15~21. (in Japanese)

McGraw_HILL Construction. (2009). Smart Market Report, The Business Value of BIM.

Percio, S. (2010). Don't Let your BIM Go ‘BOOM!’: Dealing with the Liability Issues of BIM, BIM Implementation: An Owner’s Perspective, Ashrae 2010 Winter Conference, Orland, USA.

Pratt, K. and Bosworth, D. (2011). Parametric Simulation: Experimental Methods. Proceedings of CHAMPS 2011: The 8th International Forum and, Workshop on Combined Heat, Air, Moisture and Pollutant Simulations, Nanjing, China.

Singh, V., Gu, N. and Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform, Automation in Construction, 20, pp. 134~144.

Suga, K., Kato, S. and Hiyama, K. (2010). “Structural analysis of Pareto-optimal solution sets for multi-objective optimization: An application to outer window design problems using multiple objective genetic algorithms.” *Building and Environment*, 45, pp. 1144~1152.

U.S. General Services Administration, Public Building Services, Office of the Chief Architect. (2007). GSA BIM Guide Series 01 BIM Guide Overview, U.S. General Services Administration.