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Research Article

An Advanced Process of Condensation Performance Evaluation by BIM Application

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There is increasing interest in sustainable design for saving energy and improving living conditions. In particular, condensation performance evaluation is a major part of the design phase in which condensation defects in apartment housing are considered. The aim of this work is to propose an advanced process for improving the efficiency and accuracy of evaluations of condensation performance. For this aim, an analysis of the traditional process was performed. The results support a proposed advanced evaluation process, which was then applied to develop a building information modeling (BIM) application. The proposed process can be an alternative to the current evaluation process through the use of a BIM application for the automatic process. A case study showed that the advanced process of condensation performance evaluation could save 75.8% of the time compared with the current process. Additionally, from interviews with professionals, it is expected that the proposed process offers a practical means of increasing the efficiency and accuracy of the whole evaluation process.

1. Introduction

Condensation performance evaluation (CPE) has a significant impact on designing sustainable buildings during the early design phase in terms of energy saving and improving living conditions [1–3]. The importance of controlling condensation is reflected in the regulations in the International Standard Organization (ISO) 10211:2007 "Thermal bridges in building construction—heat flows and surface temperatures—detailed calculations" and in the British Standard (BS) 5250:2002, "Code of practice for control of condensation in buildings." In 2014, the Korean government legislated the "Design guideline for condensation prevention in apartment housing" following a survey that found that 34% of defects in apartment housings are the result of condensation [4, 5]. Accordingly, the evaluation of insulation and condensation performance is essential for supporting design decisions to control condensation.

However, traditional CPE processes are inefficient because of their inaccuracy and low productivity [6, 7]. These inefficient processes include reviewing architectural drawings, preparation work for use in the software, and human errors caused by manual tasks and repetitive work. Moreover, because of the high demand of the legislation, it is difficult with the traditional "document-based computer-aided design (CAD) planning" to integrate energy simulation in design decision-making [8–11]. Additionally, the traditional CAD-based energy analysis requires engineers to rebuild building models with energy analysis software based on traditional CAD-based architectural drawings [12–14]. These problems apply to almost all energy simulation processes and also to CPE simulation. Most errors in energy analysis programs occur when engineers are converting the drawings manually. Moreover, errors occur by manually rebuilding model and input data and repeating the entire process when the design changes.

BIM technology is suitable for improving the traditional CPE process [11]. The application of BIM has been widely expanded in the construction industry [6] and numerous studies discuss the benefits of the BIM application on sustainable building projects [11]. The traditional process of simulation in physical calculation models requires importing geometry or manually rebuilding information [6, 11]. On the other hand, a superimposed model that uses BIM contains multidisciplinary information that could be easily used for sustainability measures and performance analysis [3]. Correspondingly, it is time to consider a method to implement the use of BIM and find an alternative to the expanding use of BIM in the simulation process.

The aim of this study was to find a CPE improvement process by developing a BIM application to reduce inefficient work procedures. To find a new process for CPE, we analyzed each step of the traditional process and conducted improvements of inefficient tasks. The study focused specifically on the traditional CPE process as applied to apartment housing, where condensation matters most and affects living conditions. To establish an advanced CPE process, a BIM application was developed to improve the efficiency of the traditional CPE process. Consequently, we verified the effectiveness of improving the traditional process through a case study and interviews with authorized professionals working in the field. The advanced CPE process with the BIM application will replace the traditional process by significantly improving accuracy and efficiency.

2. The Traditional CPE Process

2.1. Traditional CPE Process Description. In general, the CPE process begins when engineers receive a drawing set from architects after the basic design. Upon receiving the drawing set, the engineers analyze the drawings to convert the drawings into a model for running the CPE simulation software. In this study, Physibel Trisco® was selected as the CPE simulation software, and this software complies with various international standards, including ISO/FDIS10211, EN ISO 6946, and EN ISO 10077-2. The traditional CPE process is summarized in Figure 1.

The traditional CPE process method varies depending on different techniques or guideline within operating software. In order to avoid subject judgment, the study uses Physibel Trisco for simulation software which was selected in ISO 10211-Thermal bridges in building and incorporated detailed calculations of heat flows and surface temperatures. Professional engineers have authenticated the traditional CPE process is objective and universal.

Through in-depth interviews and by observing engineers from environmental engineering firms, we analyzed the traditional process in detail for each phase (see Figure 1). To run three-dimensional (3D) calculations for CPE by the simulation software, a 3D geometrical model and input data of the thermal property information is required. The traditional CPE process is divided into two main stages: (1) a design process by architects and (2) an evaluation process by environmental engineers.

In the first stage, the architect's design work and drawing sets provide a basis for the geometric model. Included in the drawing set are the following: floor plans, sections, elevations, reflected ceiling plans, specification of thermal performance, and so forth. In the second stage, the engineer's evaluation process is divided into four phases: (1) planning for the conversion process/additional settings; (2) modeling in the simulation software; (3) running the simulation in the simulation software; (4) calculating the temperature factor in the simulation software.

In the first phase, a comprehensive understanding of the drawing set is required to define the expected area of condensation. At this stage, the engineers perform scheme modeling of the expected areas by converting 2D drawings to the 3D model. In addition, the required values were collected from the drawing set to be used for modeling in phase (2). In particular, factors such as Grids, Blocks, and Colours, which are essential information for generating a model in the simulation software, are collected from the drawing set. In the second phase, engineers directly convert expected areas in 2D drawings to 3D models in the simulation software. This process is divided into three main tasks, such as inputting collected values of the drawing set (see Figure 2) and matching the geometric model with the drawing set to confirm. In Figure 2, (i) Grids contain the distances between the surface of materials and provide a basis for blocks, (ii) Blocks contain the minimum and maximum values of the grid for x, y, and z, and (iii) Colours may be solely classified in metadata that refer to thermal property information. The input variables are name, type, temperature, conductivity, emissivity, and so forth, depending on type. The completed model in simulation software is shown in Figure 2.

In the third phase, before running the simulation, autosplitting the Grids and setting the temperature range is required. To run a simulation, the user simply clicks on a calculation button in the functions menu of the software. In the fourth phase, when the simulation is done, the software automatically carries out calculations and generates a graphic output with indicative Colours (Figure 3). Clicking a button automatically generates a list of calculations. The result includes heat flow divergence, temperature factor, and surface condensation (Figure 4).

When the series of four phases is completed, the engineer decides whether the temperature factor satisfies the CPE standard regulation. If the result satisfies, the architects' drawing set should be completed. However, if the temperature factor does not satisfy the regulation, architects should be asked to revise their drawing with a better insulation method. The entire process must be repeated to check whether the revised drawing set complies with the standard.

2.2. Analysis of the Traditional CPE Process. We conducted an analysis of inefficient factors that reduce efficiency and accuracy in the traditional CPE process. Each factor was analyzed through in-depth interviews with engineers who run simulations for CPE in the field. First, the working time by each phase was analyzed. The working time was measured from the first step of the actual evaluation process after receiving the drawing set. Next, we classified the factors

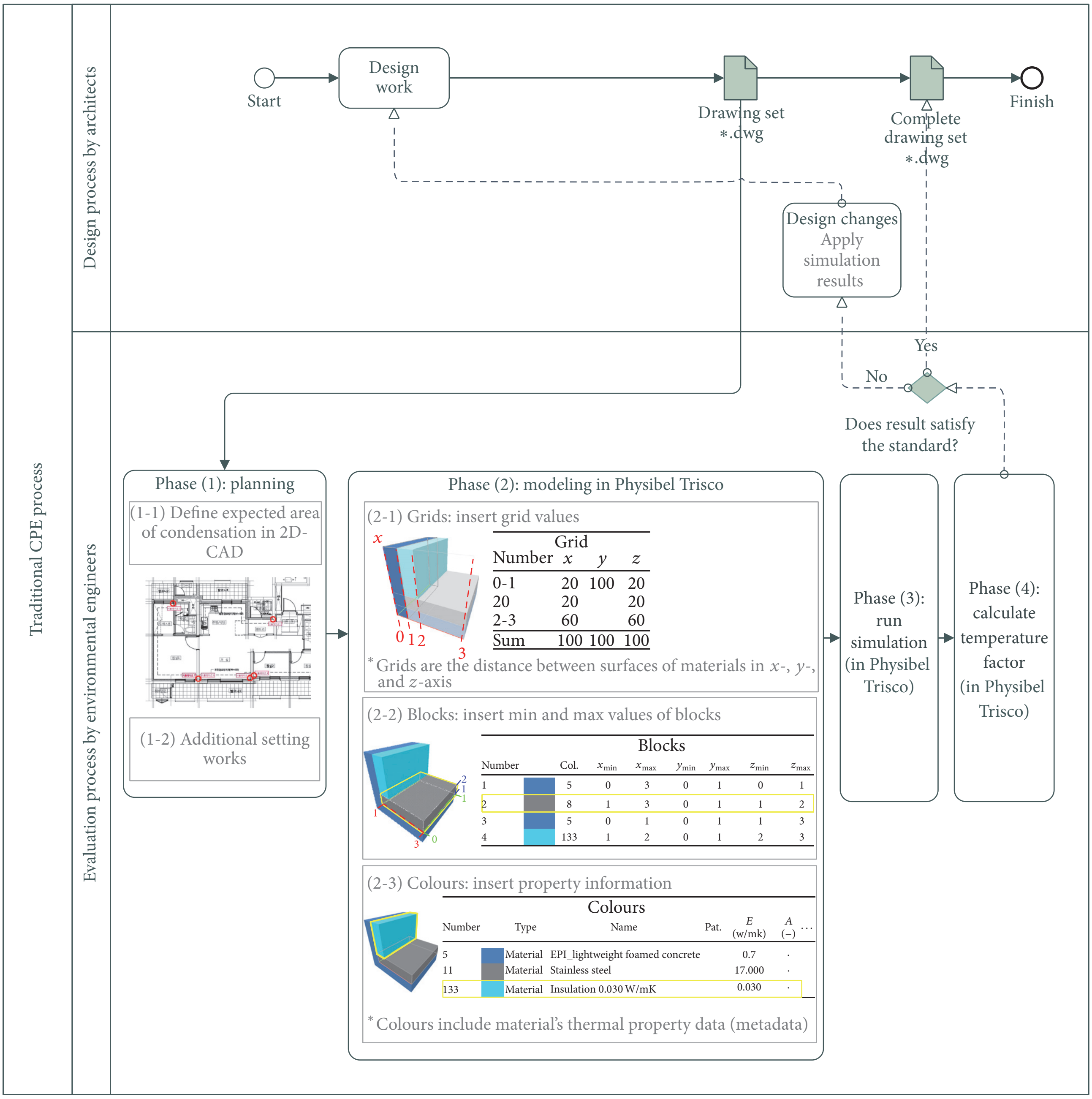


Figure 1: The traditional CPE process.

that contributed to the inefficiency by manual processes and subjective decisions. The results of working time, manual processes, and subjective decisions in each phase are presented in Table 1.

The first phase takes approximately 30 min. This phase involves the engineer's subject decision. From the engineers' interviews, it was concluded that the conception of the scheme modeling plan is a highly inefficient phase in the process. In the second phase, the average time for inputting geometric values for one expected area is 30 min, which takes up to 50% of the entire working time. Phases (3) and (4) did not require special improvements of the simulation and calculation process. Therefore, it was necessary to improve efficiency and quality in phases (1) and (2) of the process.

In addition, the lack of interoperability between architectural drawings and the simulation software is inefficient factors. A disintegrated software between architect and engineer reduces efficiency by repeating the entire process when a design change is needed to implement the engineer's feedback. In addition, human errors occur during manual work such as an engineer entering an incorrect grid value that does not match the drawing. Unfortunately, incorrect input data cannot be detected by the program and handled properly.

Table 1: Analysis of the traditional CPE process.

Phase		Description	Working time (average, min)	Manual process	Subjective decision
(1)	Planning in 2D-CAD	Define expected area of condensation	10		√
		Additional setting works	20		√
(2)	Modeling in simulation software	Insert grid values	10	√	
		Insert min and max values of blocks	10	√	
		Insert property information	10	√	
(3)	Run simulation in simulation software		1		
(4)	Calculate temperature factor		1		

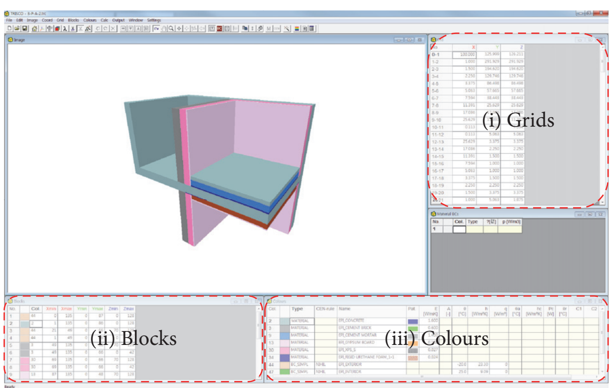


Figure 2: Main screen of the simulation software and detailed information.

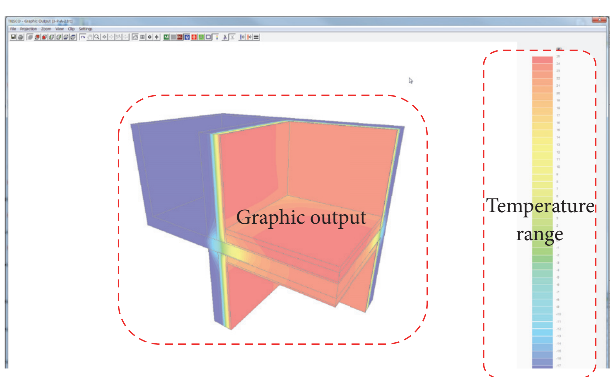


Figure 3: Result of graphic output and temperature range.

Therefore, the traditional process can be improved by an automatic function for exporting graphic data and metadata of the expected area and converting them into the file format to be used in the software. This function no longer requires scheme modeling in phase (1) and eliminates inputting values of Grids, Blocks, or Colours in phase (2). This automatic function can save significant time and prevent human errors. In particular, it contributes to the entire evaluation process by quickly evaluating the design change.

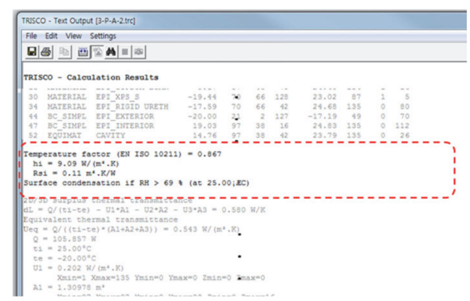


Figure 4: Result of calculations.

3. Advanced CPE Process

3.1. Development of BIM Application. In this chapter, we have developed an application to realize the previously mentioned automatic function. As the application cannot operate in various software packages, we selected Autodesk Revit Architecture 2015®, which is one of the most commonly used BIM software packages during the design phase.

The BIM application developed in this study is divided into three main functions (see Figure 5). First, the application displays a selected floor of the BIM model to easily approach the target floor on the screen. This function links the BIM model and the selected floor that is generally categorized into four types: lowermost level, typical upper level, typical lower level, and uppermost level. The second function selects the expected areas of condensation within each level. To realize the "Select" function, the application links the mouse cursor with a cube box that is identical in size to the expected area in the simulation. When the selected areas are converted, these cube boxes include all the information required for simulation, such as graphic data or metadata. Finally, the last function exports all the information in the cube boxes and converts it into the ∗.trc file format to be imported in simulation software.

The BIM application developed in this study is a powerful automation tool that converts the model into the ∗.trc file format. The main function of the application is automatic conversion of graphic data and metadata in a file format that can be used in CPE simulation software. Once the ∗.trc file has been created, the temperature factor can be calculated by clicking a button in the simulation program.

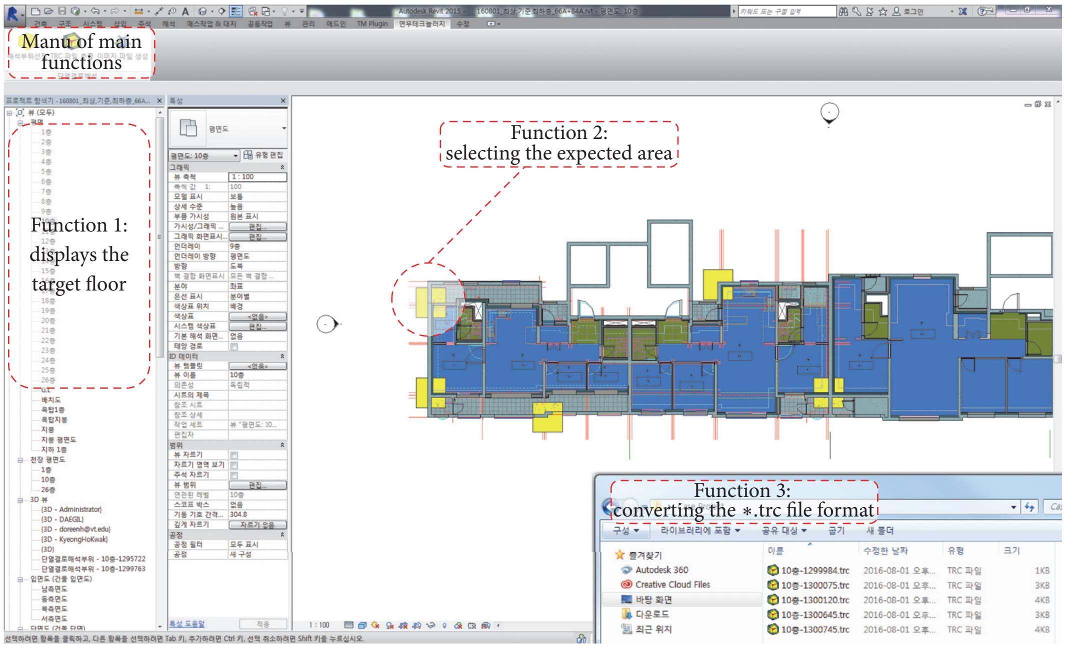


Figure 5: Main functions of the BIM application.

3.2. Advanced Process. To improve the traditional CPE process, an advanced process was specifically designed by analysis of the traditional process with consideration of the BIM application developed in this study (see Figure 6). As demand for BIM-based architectural drawings increases, we present BIM-based CPE process as a solution for improving the traditional process with interoperability between software packages. BIM is not only an appropriate solution for process automation in design but using the BIM application could eliminate most of the manual tasks assigned to engineers.

The concept of an advanced CPE process is to utilize the inbuilt information in the BIM software. In an advanced process, creating a customized family library for building components such as walls, floors, windows, and doors requires graphic data and metadata. To conclude, this process can be more easily done with BIM software than with CPE simulation software.

Like the traditional CPE process, the advanced CPE process is divided into design and evaluation processes. Architects must follow the guidelines to implement the required information for running CPE software in the BIM model. Once an engineer receives the complete BIM model, the engineer's evaluation phases are (1) planning in the BIM model; (2) selecting and extracting the planned areas in the BIM application; (3) running the simulation in simulation software; and (4) calculating the temperature factor in simulation software (see Figure 6).

In the first phase, as in the traditional CPE process, engineers review the architect's BIM model to determine the expected areas of condensation. Second, the BIM application runs to substantially execute the advanced CPE process. The second phase extracts graphic data and metadata of selected areas where condensation is expected. As shown in phase (2) (2-1) of Figure 6, the application automatically extracts all the information included in the cube boxes located in the selected areas. Finally, the last function exports all the information in the cube boxes and converts it into the ∗.trc file format to be imported in simulation software. As soon as the engineer imports the ∗.trc files in simulation software, the software automatically creates a model as shown in the traditional process in phase (2) and without any preparation work and ready-to-run simulation.

Inevitably the advanced CPE process was revised implementing application to remove inefficiency of the traditional CPE process. In other words, it can be defined as the process to implement application. Case study and interview with practitioners were used to authenticate that the advanced CPE process is objective.

4. Case Study

4.1. Case Description. The new process was applied to a case project to verify its efficiency in comparison with a traditional process. The efficiency of the advanced CPE process was verified by comparing the average working time in each process. The case project has two for each two types ($66\ m^2$ and $84\ m^2$), four units in total, on each level in a 26-story building of apartment housing (Figure 7). The working times were measured by engineers with 9 years of experience in CPE, targeting one floor.

4.2. The Process Application. First, we measured working time in the traditional CPE process. The working times were recorded based on minutes, and times less than a minute were rounded up. The range of measurements included the entire process from engineers analyzing the delivered drawing set to evaluating the possibility of condensation. The case study had nine expected areas of condensation on one floor. However, in

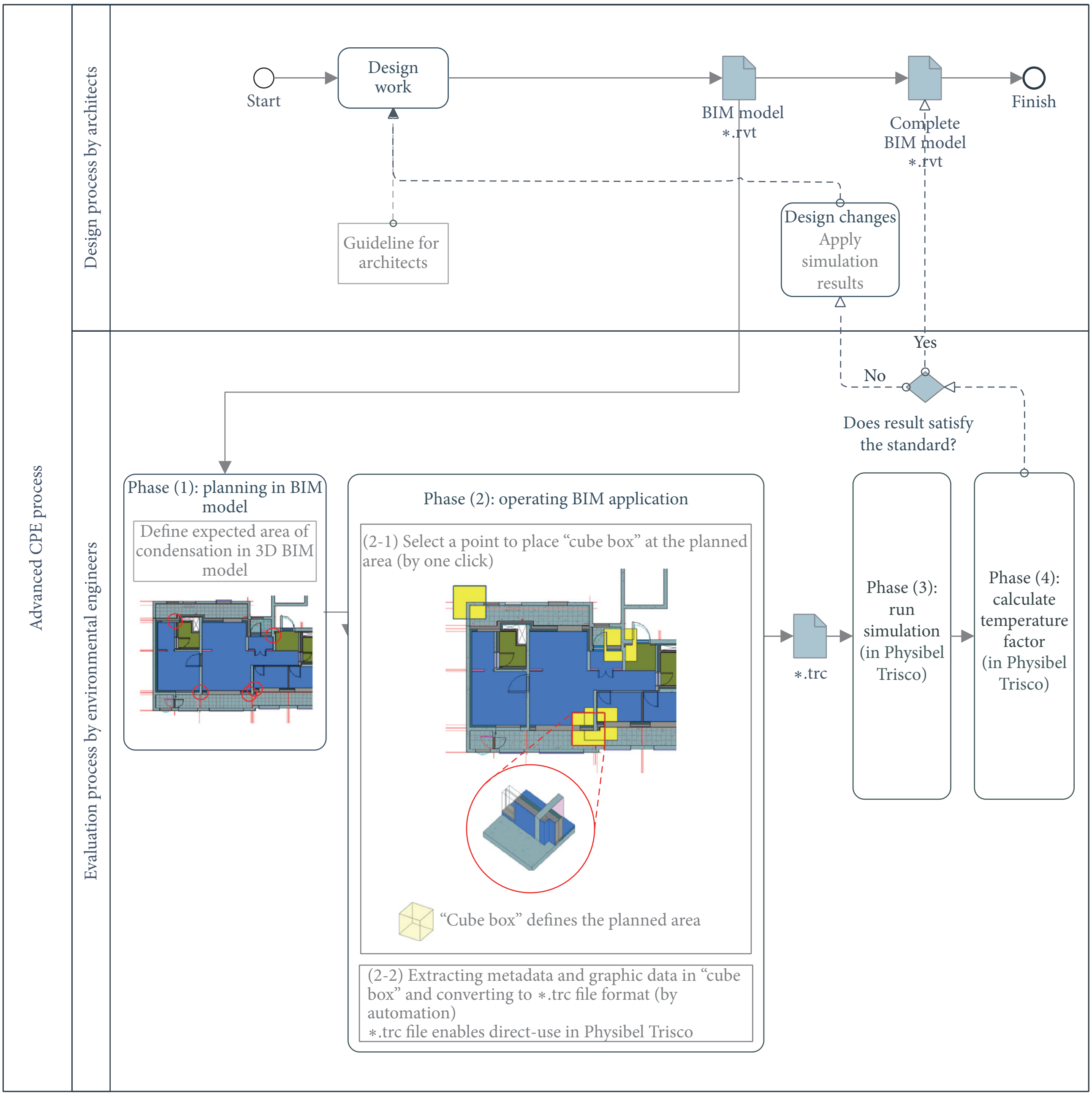
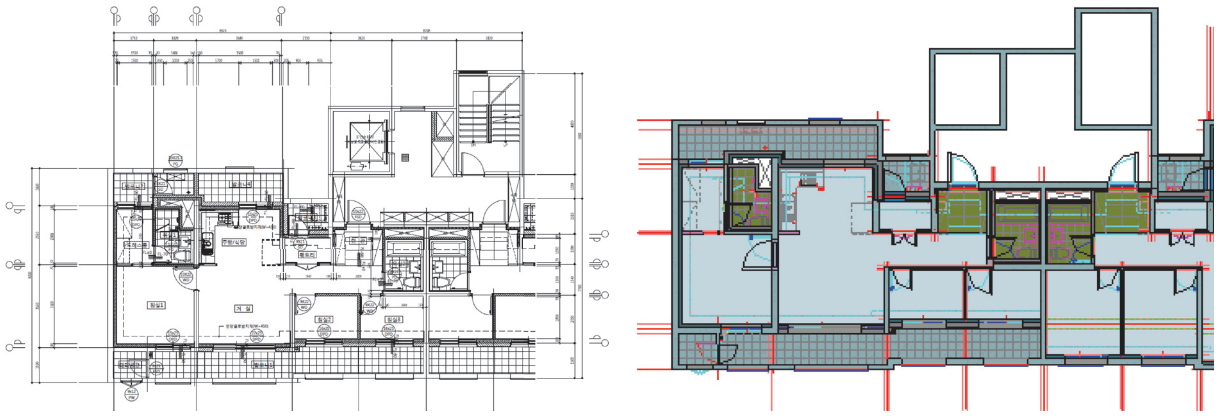


Figure 6: Advanced CPE process.

practice, only five areas were evaluated because the two types of units had a symmetrical plan (Figure 8). Subsequently, the working times for the advanced CPE process were measured. The working time for defining expected areas and simulation were identical to the traditional CPE process. Table 2 shows the results of the case study for one area.

In summary, the traditional CPE process took 62 min for one area, whereas the advanced CPE process took only 15 min. This result shows that in the advanced CPE process efficiency improved by about 75.8% ((=62 – 15 min)/62 min). As a result, the case study project required 20 expected areas in total, adding five expected areas on each level with four types, such as the lowermost, typical upper, typical lower, and uppermost levels. Therefore, the advanced CPE process was evaluated as highly efficient with respect to total evaluation working time.

To evaluate utility and applicability of the proposed process using the developed application, a questionnaire survey was carried out with the environmental engineers who directly performed the evaluation. The users of the proposed process (two environmental consultants and five engineers) were asked to grade the satisfaction in terms of improving efficiency and accuracy, compared with the traditional process, on the five-point Likert scale. The Likert scale is a scale



(a) (b)

Figure 7: Drawing set (a) and BIM model (b) of the case project.

Table 2: Comparison of working time between the traditional and advanced CPE processes.

Phase		Description	Traditional CPE process (working time, min)		Description	Advanced CPE process (working time, min)
(1)	Planning in 2D-CAD	Define expected area of condensation	10	Planning in 2D-CAD	Define expected area of condensation	Same as left-hand side
		Additional setting works	20		Additional setting works	1
(2)	Modeling in simulation software	Insert grid values	10	Use of BIM application	Selecting a point to place “cube box”	1
		Insert min and max values of blocks	10			
		Insert property information	10		Extracting data and converting to ∗.trc	1
(3)	Run simulation in simulation software		1	Run simulation in simulation software		Same as left-hand side t
(4)	Calculate temperature factor		1	Calculate temperature factor		Same as left-hand side t

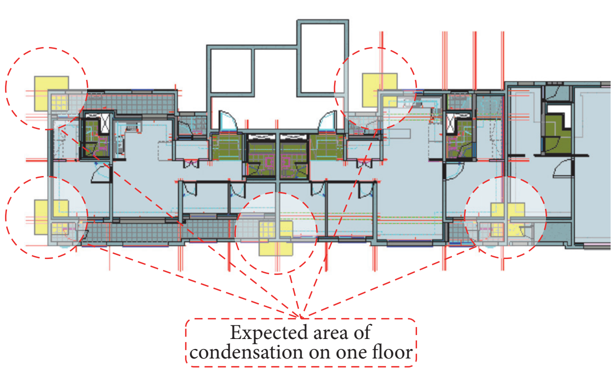


Figure 8: Expected areas of condensation on one floor.

of (1) to (5), where (1) is “highly ineffective,” (2) is “useless,” (3) is “moderately useful,” (4) is “highly useful,” and (5) is “highly effective.” The results of the questionnaire indicated a remarkable improvement in working time with an average score of 4.6 points and also in accuracy improvement with an average score of 4.4 points. These results show that a process including the application proposed in this study could be employed as a practical means for improving the efficiency of CPE work.

5. Conclusion and Future Work

Productivity in the construction industry lags behind that of other industries because of slow development and deployment of technology [6, 7]. Therefore, to improve productivity in this industry, it was necessary to analyze the current evaluation process and suggest a flexible and adaptive process that is easy to use in practice.

This paper proposes an advanced new process, including a BIM application that can serve as an alternative to the current process. By applying this new process to the pilot work in our case study, we found that the proposed process showed specific improvement in performance for the evaluation process as well as a high level of satisfaction with its feasibility.

Looking at the overall process, we have confirmed that revising the drawings and repeating the entire simulation process of revised drawings take too much time because of the disconnection between the design and simulation processes. Therefore, if architects could run a draft-level simulation on their own throughout of the design process, the overall process of evaluation could be more efficient, even if it must be confirmed accurately by environmental engineers. Using this study as background, we are in the process of developing a better method for improving CPE in further studies.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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