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Prototype Development for BIM based Thermal Insulation and Condensation Performance Evaluation of Apartment Housings

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Abstract Insulation and condensation performance evaluation (I&CPE) is an important energy analysis. While considerable amount of data are already represented in a Building Information Model (BIM), the lack of interoperability between BIM modeling and I&CPE programs prevents the simulation process from being efficient and accurate. This study proposes a prototype of a BIM-based I&CPE simulation program, in order to enhance the interoperability between BIM modeling and I&CPE programs. This study discusses the information flow process, defines the required information and its level of detail, develops standardized libraries, and finally proposes a prototype that consists of a data extraction module, conversion module, and performance module. The assurance of interoperability between systems might greatly benefit architects and energy professionals.

Keywords: BIM, Insulation and Condensation Performance Evaluation, Interoperability, Library

1. INTRODUCTION

Green building or sustainable building is a rapidly emerging trend in the Korean construction industry. A rise in the awareness regarding the critical role of buildings in the overall energy consumption results in greater use of building energy performance simulations to quantitatively justify building design and operation decisions.

Insulation and condensation performance evaluation (I&CPE) is an important energy analysis in terms of both energy saving and improvement of living conditions. According to a recent research (Ministry of Land Infrastructure and Transport, 2010), 34% of defects in apartments are due to condensation. The defects due to insulation and condensation cause civil complaints and result in psychological and financial burden. Hence, in order to reduce the psychological and financial losses, the Korean Ministry of Land, Infrastructure and Transport (MOLIT) published a "Design Guideline for Condensation Prevention in Apartment Housings" in May 2014.

Building Information Model (BIM) has been widely adopted by the Korean construction industry and gradually broadened from the design phase to construction and operation phases. BIM is a digital representation of physical and functional characteristics supplied by all participants of the building design, procurement, construction, operation, and management processes throughout its lifecycle. It facilitates effective collaboration between the different stakeholders. BIM can therefore be defined as an integrated database that contains design, process, and function. The use of BIM in energy performance simulations that aim to reach highly efficient and sustainable outcomes is also being taken into consideration. BIM provides an opportunity for carrying out sustainable performance analysis because BIM allows multi-disciplinary information to be superimposed within the modeling. Eventually, BIM might potentially increase efficiency and accuracy in energy simulations.

On the other hand, a typical process of I&CPE is labor and time intensive, and also error prone. The inefficiency and inaccuracy are mainly caused by data conversion from architectural drawings. Inadequate interoperability has been estimated to cause unnecessary expenses of $15.8 billion per year in the U.S. construction industry, which amounts between 1–2% of the industry revenue (Gallaher et al. 2004). Because BIM technology was introduced to facilitate the solution for the exchange and

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interoperability problem, it might be ideal to automatically convert most data required by the I&CPE from a BIM. However, although BIM applications and tools have rapidly developed, the data interoperability problem between a BIM application and the energy simulation model is yet to be unsolved. While considerable amount of data already exist in a BIM, the required data is fragmented between the systems and the data must be re-entered manually into the simulation model. It is still unclear how a BIM could be used and what are the requirements for managing the interoperability problem. Based on the motivation, this study proposes a prototype of a BIM-based I&CPE simulation program, in order to enhance the interoperability between BIM modeling and I&CPE programs.

2. RESEARCH SCOPE AND OBJECTIVES

The final purpose of this research is to propose an automatic system that provides seamless data conversion from BIM modeling to an I&CPE program through the reuse of the geometric and property data that already exist in BIM modeling.

The development of a BIM-based I&CPE system consists of five steps: 1) rearranging the data interoperability process between the BIM modeling and I&CPE program; 2) defining both data and its level of details required by the system; 3) developing the BIM libraries; 4) proposing a prototype model; and 5) developing an add-on program that provides automatic data conversion.

The scope of this paper includes the first four steps of the system development, which is called a BIM-based semi-automatic I&CPE. The main objective of this paper is to demonstrate the efficiency of the proposed system in terms of time saving and accuracy improvement. In order to achieve the objective, the paper discusses the following topics:

1) literature review and analysis on limitations on the current I&CPE process,
2) data conversion process among various types of software applications,
3) requirements on metadata and geometric level of detail (LOD) for I&CPE, and
4) library development including property data and graphical details

3. NEEDS FOR AUTOMATIC DATA TRANSFORMATION

Energy performance of buildings has recently become a major concern in the construction industry. As mentioned earlier, a BIM represents the building as an integrated database composed of geometric and parametric data. It might be ideal if most of the data needed for supporting green design could be automatically extracted from the building information model when needed. Eventually, the use of BIM for energy simulation might lead to a better efficiency of the process of design modification when aiming to achieve a set of performance criteria.

There are many energy simulation software applications that aid professionals in predicting a building's performance and ameliorate both quality and cost throughout its life cycle. Applications such as Ecotect, EcoDesigner, and eQuest directly implement a BIM platform, such that they can automatically use data from the BIM models. As the use of BIM in construction projects becomes more popular, the data interoperability between software applications becomes more important. Interoperability refers to the ability of two different systems or software applications to communicate and exchange data with each other. This ability contributes to reduce redundancies, deficiencies, and errors in the data input, process, and output phases between applications. In particular, interoperability of BIM software applications has a vast impact on data quality and efficiency. However, despite the obvious benefits of BIM-based energy analysis, most of the energy simulation applications do not use data extracted from BIM and instead require manual input of data that already exists in the BIM models.

Various types of research pertaining BIM-based energy simulations have been published. Sun and Light (2012) proposed a Web based Green BIM System, Cospec (2012) developed a solution of BIM-based environmental analysis and evaluation, and VitualBuilders (2013) developed a BIM-based solution for energy performance evaluation. While studies concerning general energy simulations using BIM are now widely available, I&CPE using BIM has been rarely studied until now. This is due to the fact that I&CPE is a specialized area in the general energy analysis, thus its findings have been more focused on basic theory. Jang (2012) reviewed an experimental method to improve condensation resistance of windows, Han (2013) proposed a performance guideline and standard to prevent condensation, and Cho (2014) proposed some methods for evaluating the tests of condensation resistance aimed at measuring insulation and condensation performance.

According to ISO 15099, the use of a computer program is highly recommended for energy simulation. The software applications such as Window and Therm, and Physibel, are widely used in Korea as building thermal simulation tools. I&CPE is a dynamic analysis of the energy performance of buildings that uses computer modeling and simulation techniques. In general, these applications evaluate some expected defect area. In this evaluation process they require

1) 2D re-drawing of the defect area applicable their software platform;
2) geometric information of the area, including the layout and configuration of surfaces and volumes; and
3) thermal property information of the area, including internal or external thermal loads, boundary conditions, construction materials and their conductivity and emissivity, film coefficient, etc.

Energy and performance analysis are typically performed after the architectural drawings and construction documents have been produced, if at all. As with traditional 2D drawings, the evaluation of building performance based on graphic representation of conventional CAD or object-CAD solutions requires a great deal of human intervention and interpretation, which renders the analysis too costly and/ or time consuming (Moakher and Pimplikar, 2012). The traditional process of I&CPE from 2D drawings to software is described in Figure 1. The process may have problems such as omission, miscalculation, subjective geometry simplification, and inaccurate data input on purpose or by mistake. In other words, the traditional process may lead to data inaccuracy, considerable time and effort consumption, and additional expenses.

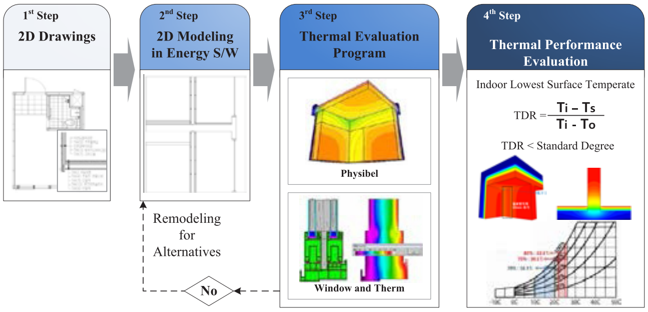

Figure 1. Traditional Process of Insulation and Condensation Performance Evaluation

Exchanging models and other data between different software platforms remains one of industry's biggest challenges undertaken by fully integrated and collaborative project teams (Bahar et al. 2013). One of the obstacles for the limited use of BIM in environmental analysis domain is the lack of interoperability between BIM models and performance analysis programs (Moon et al. 2011).

Some recent research studies have produced conceptual frameworks to test the interoperability and capabilities of others have created tools that are integrated into building information modeling (Welle et al. 2011; Feng et al. 2012). However, little is known about the integration between BIM modeling and sustainable performance analysis. In particular, only few studies have been conducted so far to improve data interoperability between BIM models and a specialized area such as insulation and condensation evaluation in the energy performance simulation.

4. DEVELOPMENT STEPS OF A PROTOTYPE MODEL

Literature reviews explain the need for interoperability between BIM modeling and I&CPE. A lack of interoperability hampers I&CPE simulation in the building design phase and thwarts the review of design alternatives. Starting from this context, this study proposes a prototype model that implements an automatic data exchange method between BIM modeling and I&CPE analysis programs. The proposed model is consists of the following five steps: 1) rearrange the data interoperability process between BIM modeling and I&CPE program; 2) define the data and its level of details required by the system; 3) develop the BIM libraries; 4) propose a prototype model; and 5) develop a program that provides automatic data conversion.

(1) Interoperability Process

The lack of interoperability between architecture models and building energy models hinders the efficient use of simulation in the building design process. As mentioned before, the traditional process may lead to data inaccuracy, considerable time and effort consumption, and additional expenses. For the purpose of developing a prototype model, a process that analyzes the information flow both within the BIM modeling and I&CPE program, and between the systems themselves, is necessary. The detailed information flow for the process from BIM modeling to I&CPE program is presented in Figure 2. The required information and its level of detail (LOD) defined in the BIM modeling depend on the information used in the analysis program. This study uses Window & Therm and Physibel as programs for I&CPE, because they are software applications widely used and recommended by Korean MOLIT.

(2) Required Information and Its LOD

In order to define the required information and its LOD, this study analyzes how Window & Therm and Physibel are used for I&CPE. Window & Therm is a two-dimensional (2-D) finite element program used for calculating heat transfer in fenestration systems and other constructions with building envelopes. In addition to conduction heat transfer, the program also handles detailed radiation heat transfer, based on view factors. The program also incorporates a convection heat transfer modeling feature applied to glazing cavities.

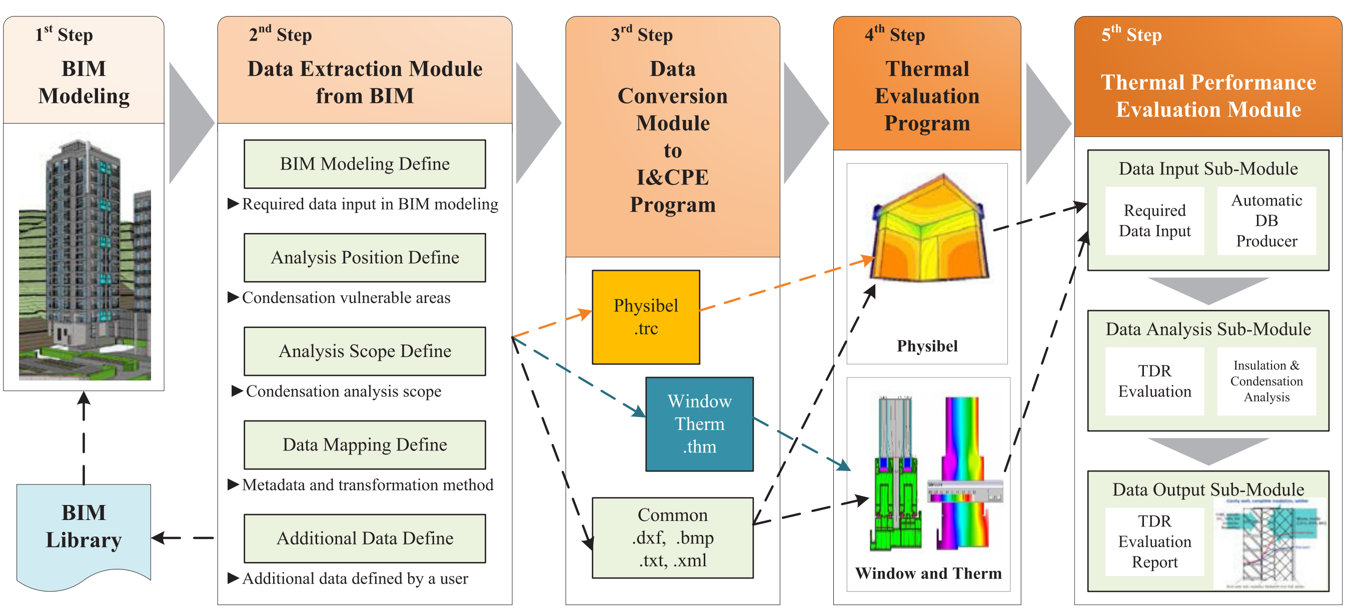

Figure 2. Information Flow Process from BIM modeling to I&CPE Program

Physibel is a 2D and 3D finite element program used for analyzing heat transfer and thermal transmittance of building components. The geometry is described in the software by a list of rectangular blocks that should be encoded manually by a user. Figures 3 and 4 illustrate the level of thermal analysis of the respective tools.

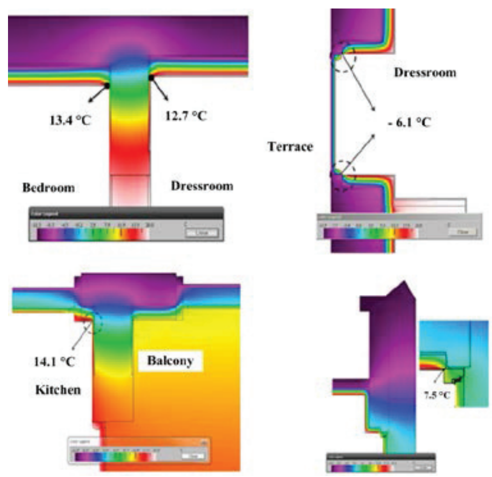

Figure 3. Model Configurations Represented by Window & Therm

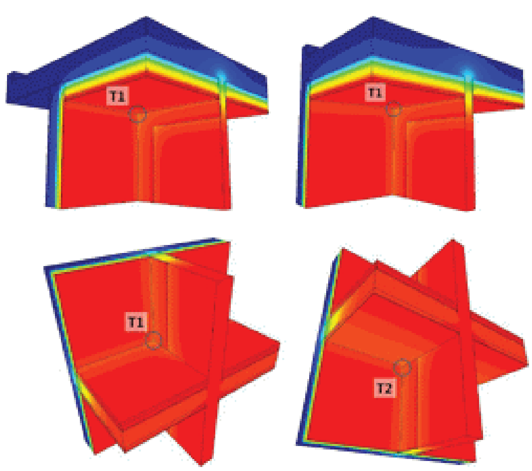

Figure 4. Model Configurations Represented by Physibel

In general, the required information for model configurations in these programs could be categorized by the thermal values of exterior or interior material, boundary condition, and cavity layer. Required detailed data for each category are listed in Table 1, 2, and 3.

Table 1. Required Data Attributed to Construction Material Type

Property	Contents	Type
Col.	Identification Number	Number
Name	Work Section (Structure, Waterproof, Insulation, etc.)	String
Type	Material Type	String
Conductivity	Conductivity of a Material (W/mk)	Number (the third decimal)
Emissivity	Emissivity of a Material (W/m2)	Number (the first decimal)
Color	Color Name (RGB)	String

Table 2. Required Data Attributed to Boundary Conditions

Property	Contents	Type
Col.	Identification Number	Number
Boundary Condition	Direct or Indirect Outside, Inside, etc.	String
Type	Component Type	String
Temperature	Standard Temperature	Number (the first decimal)
Film Coefficient	Ratio of Surface Heat Transfer	
CEN-rule	NIHIL	Number (the second decimal)
Color	Color Name (RGB)	String

Table 3. Required Data Attributed to Cavity Layer

Property	Contents	Type
Col.	Identification Number	Number
Boundary Condition	Direct or Indirect Outside, Inside, etc.	String
Type	Component Type	String
Temperature	Standard Temperature	Number (the first decimal)
Film Coefficient	Ratio of Surface Heat Transfer	
CEN-rule	NIHIL	Number (the second decimal)
Color	Color Name (RGB)	String

The type of material depends on each building component; therefore, the required data attributed to a construction material type can be represented as properties within a BIM object. Data from boundary conditions and cavity layer, instead, require additional definitions in BIM modeling. In case of an apartment unit, for instance, it is possible to generalize a room's boundary condition according to its function. This means that the kitchen, living room, or bathroom can be defined as "interior"; a corridor as "indirect outside"; and a balcony as "direct outside." The proposed prototype model would involve the use of the automatic algorithm, but a user could still perform a manual operation if the generalization is inappropriate. This study also develops four types of libraries to represent a cavity layer. A space or room is usually closed by walls and floors; therefore, the cavity library is attached to a wall or floor in BIM modeling.

As shown in Figures 3 and 4, the model configuration represented by Window & Therm and Physibel includes component surface lines according to each specific type of material. In these programs, a user has to manually, redundantly, and individually input the thermal values for each type of finishing material. The types of finishing material are already represented in the BIM architectural modeling in the detailed design phase even though finishing types such as wallpaper or painting are unnecessary in BIM modeling representation, because thermal analysis programs do not evaluate the finishing types. Figure 5 presents modeling examples containing a specific required level of detail. Specific patterns of these finishing types are represented as a library in BIM modeling. The reuse of this library that contains respective thermal values for various finishing types provides a great potential to improve efficiency and accuracy in data processing.

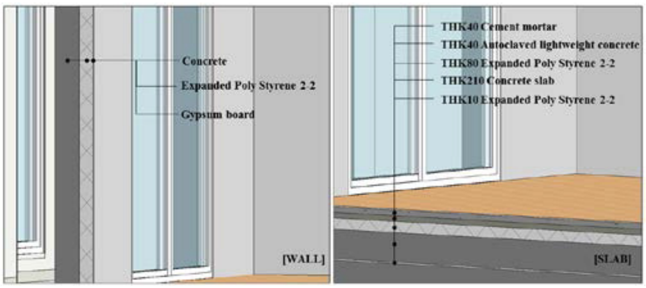

Figure 5. A Required level of detail of BIM Library to Implement I&CPE Analysis

(3) Development of BIM Library

A BIM modeling can be considered as an assembly of libraries; therefore, a library is a basic information unit containing geometric and property data used in the modeling. BuildingSMART describes the issue in the following way:

"One definition that seems to be shared amongst several projects is that they see a 'product library' as some kind of a 'resource' containing a number of pre-defined products/objects with relevant properties and information attached to them The information about each object may or may not also include a graphical representation, i.e. a 3D symbol (Stangeland, 2011)."

The prototype model proposes the use of standardized libraries to simplify the complex data processing procedure between a BIM modeling and an analysis program.

A standardized library contains geometric properties such as length, area, volume, etc.; component properties such as name, type, position, etc.; material properties such as concrete, mortar, gypsum board, etc.; and thermal properties such as conductivity, emissivity, film coefficient, etc.

A total of 97 libraries were developed in this study, comprising 41 component objects, 41 material objects, 11 space objects to represent boundary conditions, and 4 cavity objects. Figures 6, 7, 8, and 9 show these standardized libraries created by Revit Architecture 2014®.

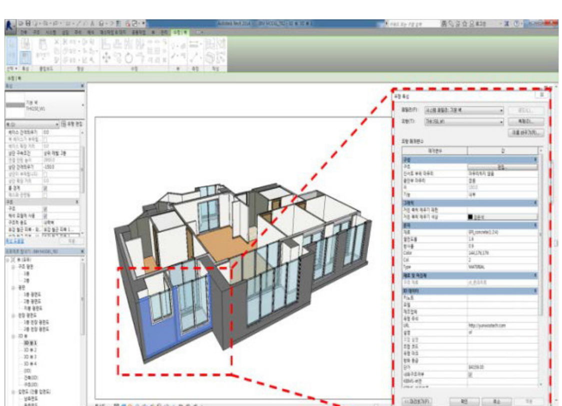

Figure 6. A Wall Library Involving Geometry and Thermal Properties

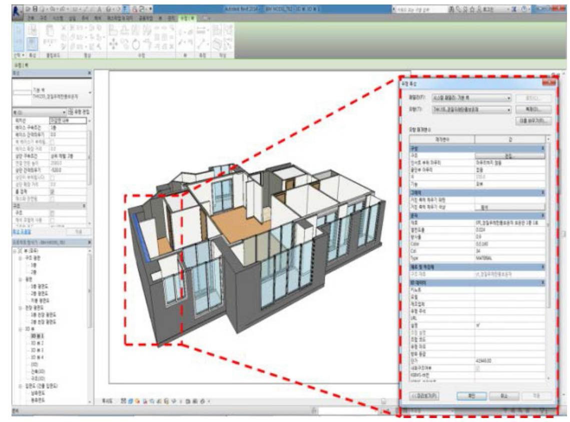

Figure 7. A Finishing Library Involving Geometry and Thermal Properties

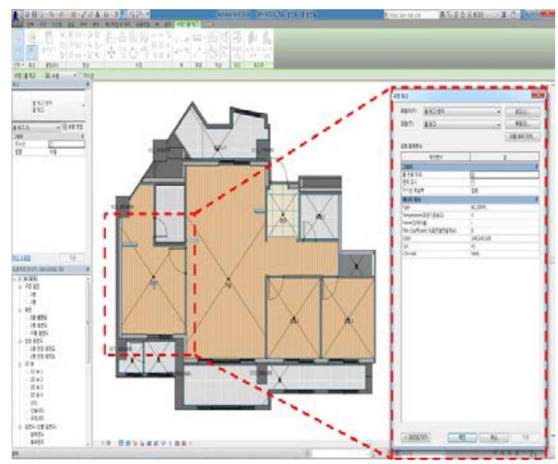

Figure 8. A Space Library Involving Geometry and Thermal Properties

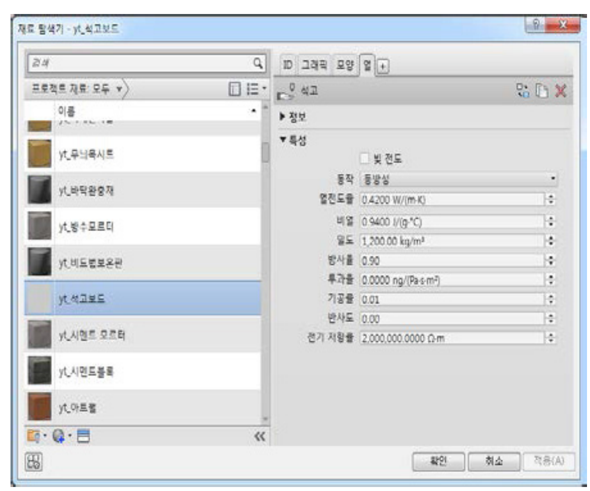

Figure 9. A Material Library Involving Thermal Properties

(4) Architecture of a prototype model

The prototype model has been under development until now. The BIM-based I&CPE Simulation Program is designed to provide automatic data conversion from BIM modeling to a thermal analysis program. The development includes three modules :1) a data extraction module from BIM modeling; 2) a data conversion module that contains a mapping of metadata and a 2D or 3D coordination algorithm; and 3) a performance evaluation module that reflects Korean domestic laws and guidelines. The overall system architecture is presented in Figure 10, 11, and 12.

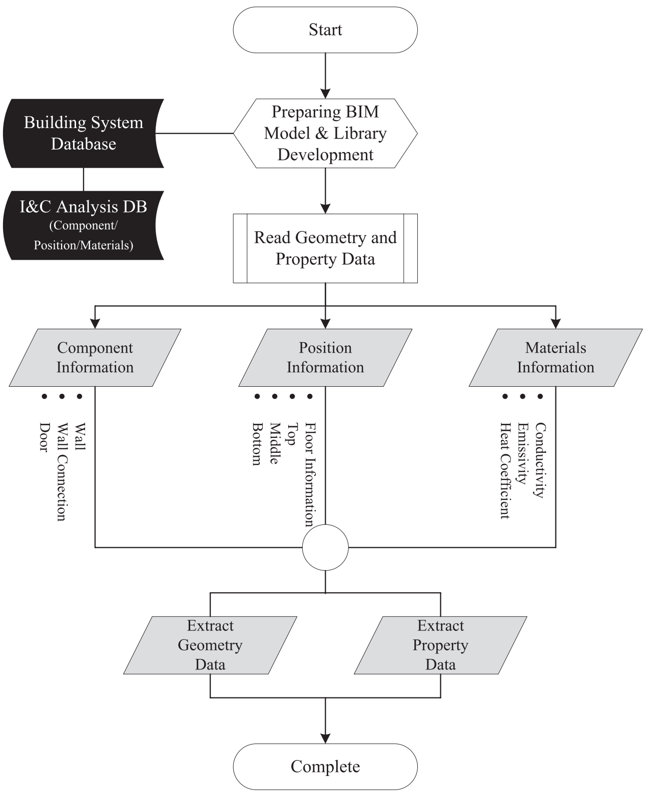

Figure 10. Data Extraction Module

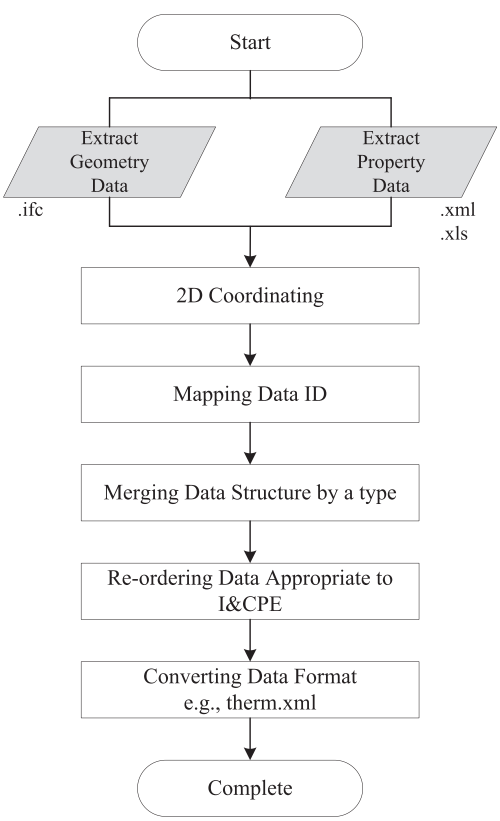

Figure 11. Data Transformation Module

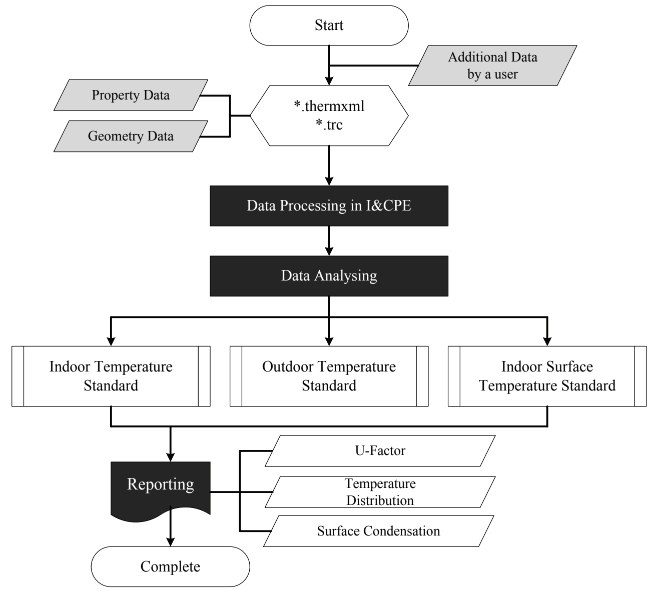

Figure 12. Performance evaluation module

5. CONCLUSIONS

Insulation and condensation performance evaluation (I&CPE) is an important issue in energy performance analysis in Korea. Although I&CPE simulation requires huge amount of input data and a complex process, current practices stick to a traditional method that requires remodeling from two dimensional drawings, and a manual and redundant input of data. The traditional method is prone to trigger data inaccuracy, requires considerable time and effort, and results in additional expenses. In view of the complexity of I&CPE simulations, there is a significant need for development of a new approach that enables seamless data conversion within a building simulation process.

The lack of interoperability between BIM modeling and I&CPE programs prevents the efficient use of simulation in the building design process. On account of the complexity of I&CPE simulations, there is a significant need for the development of a new approach that enables seamless data conversion between the systems. For this reason, in this study, a BIM-based I&CPE Simulation Program was developed.

This study discussed the limitations of current I&CPE processes and highlighted the interoperability problems. In order to overcome the limitations, the process of information flow from a BIM modeling to I&CPE program was rearranged, the required information and its LOD were defined, some standardized libraries were developed, and finally a prototype model comprising three modules was proposed.

The assurance that a BIM model and an I&CPE can interoperate has a great potential to benefit architects and energy professionals in terms of saving time and effort, and improving the accuracy in the face of design deviations, material changes, and what-if simulations.

As a final achievement, this study is expected to enhance the interoperability between BIM modeling and I&CPE programs; enable a more efficient input to be used for accurate simulations, which would support an improved design process run by the simulation; and finally provide an easy-to-use platform by reducing time and effort required for I&CPE simulations. The limitations of this study are mainly those inherent in the prototype development and the absence of the quantitative verification of the benefits of the proposed model.

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