Research on the simulation framework in Building Information Modeling

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ABSTRACT

In recent ten years, Building Information Modeling (BIM) has been proposed and applied in the industry of architecture. For the high efficiency and visualization, BIM and correlative technologies are welcomed by architects, engineers, builders and owners, thus the technologies on modeling for design has been widely researched. However, little attention is given to simulation while simulation is an important part of design for building, maybe because it is seen as somewhat less related to the technologies on modeling for design.

The paper proposed a simulation framework with four stages of design: concept stage, scheme design stage, preliminary design stage and construction drawing design stage. The principles of simulation are different in each stage, and were given in the paper. In concept stage, simulation focuses on the blocks of building, and the unit of simulation grid is comparable with the unit of field. And the objects of simulation in the stage are wind, light and sound. In scheme design stage, the unit of simulation grid is similar to the one in concept stage. The objects of simulation in the stage are heat, wind, light, energy consumption and sound. In preliminary design stage, simulations turn to pay attention to the systems of the building, such as the energy system, power system, transmission and distribution system, air-conditioning system and ventilation system. The unit of simulation grid is comparable with the unit of indoor space of building. In construction drawing design stage, the details of system is the main objects of simulation, the unit of simulation grid is usually 100-500mm.

The data conversion is also discussed, because data conversion is important for the simulation in BIM system. Previous simulation paid much more time on modeling because the buildings were often designed with 2D floor plan while simulation models often were 3D model. The simulation in BIM process makes the modeling easier and quicker. However, the data of different formats have difficulties on modeling conversion.

Several main formats of 3D-model are discussed in the paper. The models of gbXML, Sketch Up, 3ds, CATIA, Rhino and Revit can be transferred to simulation software and modified to meet the need of simulation. The transfer principles of each format during different stage are discussed in the paper. The gbXML and Revit have advantages as less workload on modification, less information lost in the conversion and quick response to the change of model.

An example of whole process of simulation in BIM design is proposed in the paper. The simulations for the BIM process are applied in the design of Zhuhai Grand Theater. The simulation in Zhuhai Grand Theater also can be divided into four stages. The example mainly focused on the indoor and outdoor wind environment and energy consumption, and the data conversion is applied in the simulation. The efficiency of such simulation process was compared with the traditional process and the result showed that new simulation process in BIM has advantages as time saving, simple and easily controllable.

1. INTRODUCTION

In recent ten years, more and more advanced technologies have been applied in the industry of architecture. Three-dimension (3D) design, virtual reality technology and integrated design are popular in research field as these technologies bring higher efficiency and lower working load to design and construction. Thus, a technology, which combines most advantages of above technologies, certainly attracts attention to its development. The technology is Building Information Modeling (BIM), which is considered to be the trend of architecture design in next few years. For the high efficiency and visualization, BIM and correlative technologies are welcomed by architects, engineers, builders and owners, thus the technologies on modeling for design has been widely researched. In design process, BIM and correlative technologies have been used in some project (Dawood *et al*., 2003). With the BIM system, architects, structure engineers and MEP (Mechanical, electrical and Plumbing) engineers can work in a uniform software platform to accomplish collaborative design.

However, little attention is given to simulation while simulation is an important part of design for building, maybe because it is seen as somewhat less related to the technologies on modeling for design. In fact, simulation in architecture enters the 3D field earlier than design. At present, there are many problems in simulation technology applications in the architectural design process: simulation technology has been three-dimensional, however, most of the architectural design is still in the two-dimension (2D) stage, the dimension difference brings the data conversion process between 2D design and 3D model with problems as information transmission and additional work load to modify the model; software maker is lack of understanding on the whole process of architectural design, the architectural design of whole process cannot be effectively cooperated with the simulation software; due to the lack of standardization, the experience of software users has been the only element to guarantee the quality.

The appearance of BIM technologies has proposed a reasonable solution to above problems, the model in the BIM system can be used in several types of simulation without cumbersome modification. The information of space, location, distance and other parameters which are used to describe the building will be transferred between the design model and simulation model. It is necessary to complete the simulation framework as the research on the simulation still stays on the early stage.

The paper proposed a basic simulation framework with four stages of design: concept stage, scheme design stage, preliminary design stage and construction drawing design stage. The principles of simulation are different in each stage, and were given in the paper. The data conversion was then discussed, because data conversion is important to support the simulation in BIM system. The transfer of several main 3D-model formats used in architecture design were also discussed in the paper. A test example of whole process of simulation in BIM design was proposed in the paper to show that new simulation process in BIM has advantages as time saving, simple and easily controllable.

2. SIMULATION FRAMEWORK

2.1 General design process

Generally, a complete design process can be divided into four stages: concept stage, scheme design stage, preliminary design stage and construction drawing design stage. Concept stage refers to the stage that the architects, engineers, builders and owners provide their requirement on the planning building, the architects and engineers should propose a concept building with occupied space, dimension and basic shape by the end of concept stage (Ciborra, C., 1996, Holmström *et al*, 2001). The scheme design stage is a stage that the basic functions become feasible with the construction technologies of architects and engineers after the building functions have been identified. For example, the basic structure of building should be chosen to adapt the shape and the size. The orientation, the basic shape, the structure system, the main entrance layout and other building elements should be determined by the end of scheme design. When the schedule turns to the preliminary design stage, architects and engineers need to determine the functions of every floor, the location of structure node, the water system, the ventilating system, the electrical system and some parameters of main equipments. By the end of construction drawing design stage, all detailed design towards each room should be done, and technologies should be achieved with guidelines to construction and operating strategies.

With the BIM technologies, the process will be more compact as the design process will be finished on the uniform model, and all designers can finish their work on a mutual model. It means that if one modifies the design drawing, others will soon find out the location and the modification. If there are several components occupying the same specific space, the space will be marked for all designers to find out the problem.

2.2 Simulation framework in whole design process

Simulation techniques involve into the design process from the concept stage to the end of the construction drawing design stage. The task of simulation in the concept phase and scheme design stage is evaluating the feasibility of the building techniques, meanwhile the principle of energy saving, environmental protection and green should be considered in the simulation; in the preliminary design stage, many aspects of design can be obtained by simulating building energy consumption, indoor air, indoor lighting and structure; in the construction drawing design stage, the simulation can be used to solve some detailed problems of the construction plans to make the indoor wind, light, heat and sound environment meet the design requirements. The structure node and hydraulic node design problems are also depended on the simulation result. Following the above principle, a simulation framework is proposed in Figure 1.

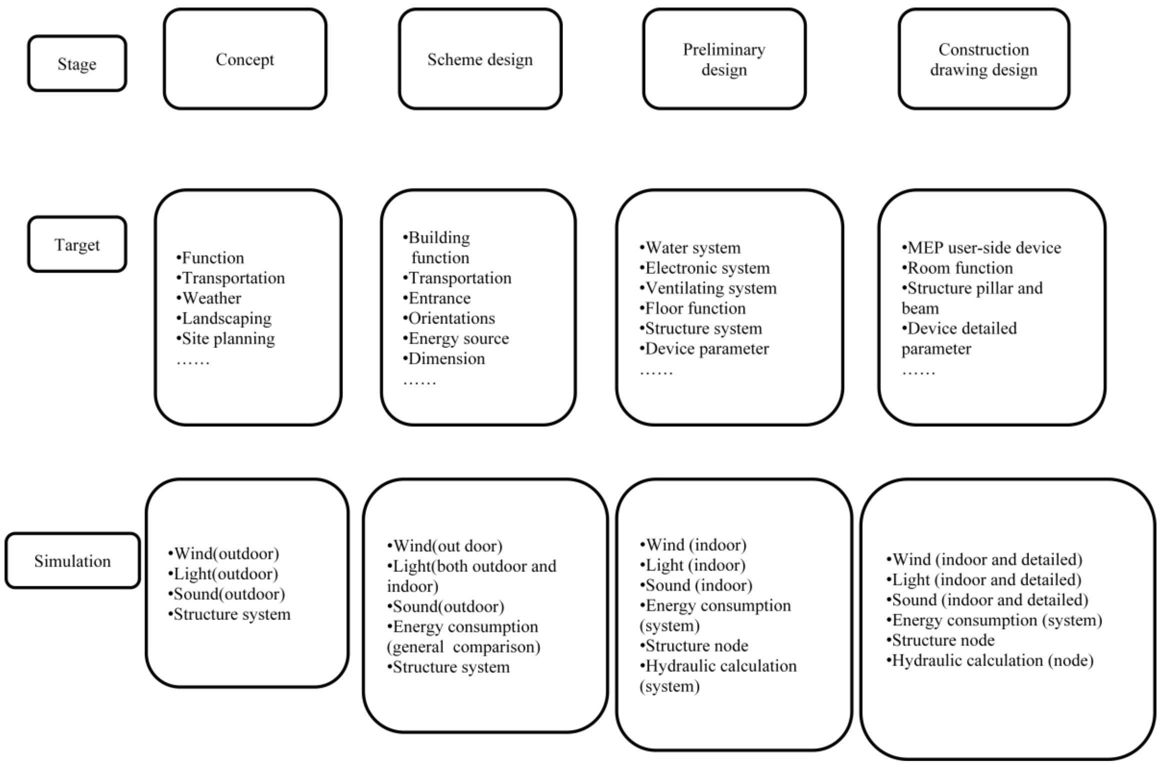

Figure 1: Simulation framework in whole design process with four stages

The principles of simulation are different in each stage as the simulation objects are different. In concept stage, simulation focuses on the blocks of building, and the unit of simulation grid is comparable with the unit of field. According to the field, the grid is usually 1-3m. In scheme design stage, the unit of simulation grid is similar to the one in concept stage. In preliminary design stage, simulations turn to pay attention to the systems of the building, such as the energy system, power system, transmission and distribution system, air-conditioning system and ventilation system. The dimension of simulation grid can be chosen in the scope of 500mm to 1000mm. The unit of simulation grid is comparable with the unit of indoor space of building. In construction drawing design stage, the details of system is the main objects of simulation, the unit of simulation grid is usually 100-500mm. In some examples which are focused on the local corner, the grid is even 50-100mm.

2.3 Simulation framework in stages

For each stage, the detailed framework is proposed to illustrate the specific scope of simulation and corresponding task in the stage. The general flow chart in each stage can be seen in Figure 2. A simulation process can be divided in to five steps: identifying the target, identifying the simulation tool, pre-processing, calculation setting and postprocessing. It can be seen in Figure 2 that the modeling and modification of model is the main time-consuming task, where two steps have relationship with the task. In actual design, when some demands of users change, the model and grid will take engineers more time to deal with it.

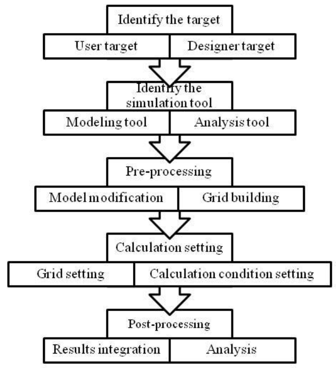

Figure 2: The flow chart of simulation process

In concept stage and scheme design stage, the input data is the basic demand of the investor and designer, and the site plan condition. Simulation results can be used to judge whether the concept building is feasible and which basic shape can be used in preliminary design stage. As a result, the simulation in the two stages may be focused on the sunlight, sound and wind field simulation. The specific simulation and corresponding task in the two stages can be shown in Figure 3. The difference between concept stage and scheme design stage is that the building shape and size have been determined by the end of concept stage.

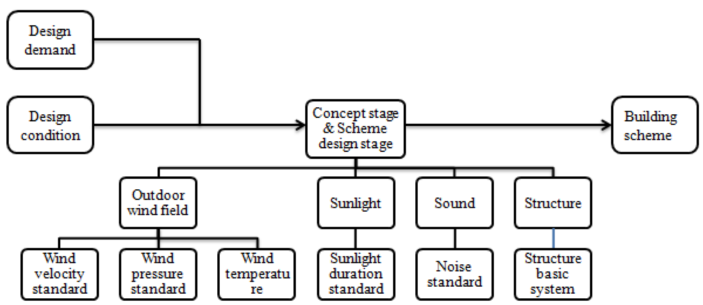

Figure 3: Simulation framework in Concept stage & Scheme design stage

In preliminary design stage, the input data is the building scheme and corresponding technologies. Simulation results in preliminary design stage can be used to validate whether the building conditions can meet the need of users and technologies. In general, the simulation in the stage can be divided into two types. The passive measures which do not need energy to reduce the energy consumption and achieve the functions are natural ventilation, natural lighting and building envelope technology. The specific simulation and corresponding task in the stage can be shown in Figure 4.

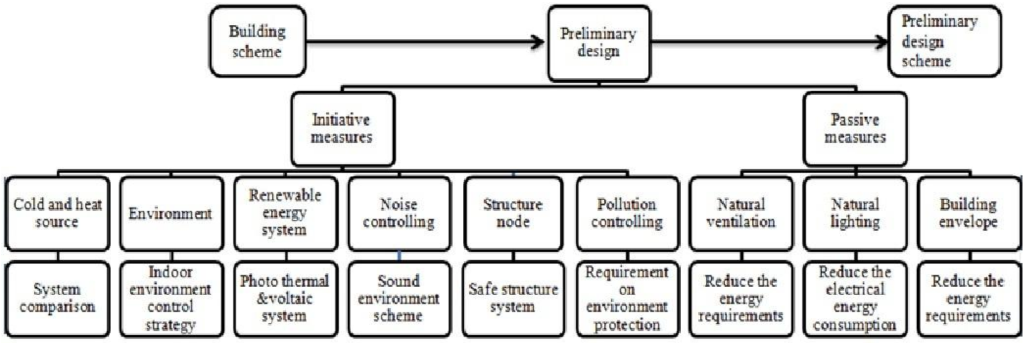

Figure 4: Simulation framework in preliminary design stage

In construction drawing design stage, the input data is the preliminary design and the system schematic diagram. Simulation results are used to guide the construction. The simulation objects in the stage are similar to the ones of preliminary design stage. The only difference is the local detailed simulation in construction drawing design stage.

3. DATA CONVERSION IN BIM SIMULATION

3.1 The data conversion in BIM simulation system

The data conversion is fatal to the simulation with the background of BIM as the simulation in whole process need to deal with quite a lot of modeling problems. A uniform building model could reduce huge work load on the modeling, and the information in the model can be transferred from one stage to another through the timeline without serious information loss. The advantage on the data conversion in BIM mode is especially obvious when the building model need to be modified, while the modification in concept stage, scheme design stage and preliminary design stage is normal and frequent. Even in the construction drawing design stage, some projects still encounter the problems of repeating modification (Eastman *et al*, 2008).

As each stage have specific tasks and simulation work, the data conversion process for each stage is also different. For Computational Fluid Dynamics (CFD) in architecture, there are already some research results to standard the simulation process (Yoshie, 2005, Franke *et al*, 2004). However, no research has been carried on with the demand of whole design process. In the paper, the basic data conversion principle on different stages is proposed based on the practice in several projects.

In the concept stage, the whole building model is analyzed on the outdoor conditions, the main body of building and all the objects blocked wind, heat, light and sound. Some elements which have little influence to building can be ignored in modeling. In general, the building boundary is suggested to select a height which is 2-5 times of the building height in the surrounding area. And for the blockage, it is considered that a close blockage which have sufficient influence to the building should have a volume which is larger than 5% of the the main building. In the scheme design stage, analysis is still outdoor-based, aiming to consider the various options of the building envelope to facilitate the energy consumption. Unlike the previous stage, the scheme design needs to consider the height of the small blockage as trees and low buildings. In the preliminary design stage, due to the outdoor conditions have been determined; simulation objects are turned to indoor environment. Main considerations are focused on major division of space, doors, windows and walls. The physical parameter of components as the size of the entrance and the height of plumbing system must be added to the model, and the beams and other structural components can be ignored. In addition to the modeling principles of preliminary design stage, modeling in the construction drawing design stage can be considered the volume of each device, decoration storey, vents and other refined elements.

3.2 Some main 3D model formats and software in BIM system

There are now several types of 3D model, and no authoritative classifications have been given to guide the software users. In general, there are four types usually used in BIM process: IDEF (Integrated computer aided manufacturing

DEFinition); UML (Unified Modeling Language); BPMN (Business Process Modeling Notation); STEP (STanard Exchange of Product data model) (Yan W. *et al*, 2007).

However, the data conversion has its standard in BIM process. IFC (Industry Foundation Classes) is the standards established by IAI (the International Alliance for Interoperability). The IFC has little relation with the software chosen to deal with the BIM design process (Bazjanac, 2003). It can enhance the information sharing to improve the communication, productivity, time, cost and quality throughout the life cycle of a construction project. Now there are more and more projects in the construction industry which applies the IFC standard data exchange interface. For those software used in design, the data flow cannot be transferred directly as the software developers has different format to support (Sun, J.*et al*, 2011). At present, most of the main format and the corresponding software have support the data transfer through IFC. The relative software list can be seen in the Table 1, while there are still many formats not listed. With the software list, it is possible to plan a whole process with BIM design and BIM simulation.

Table 1: The BIM software and format list

Software	**Function**	**Formats**
Affinity	Planning	SKP, DWG, RVT
Allplan	3D design, structure design, cost management	IFC, DWG, DXF
ArchiCAD	Modeling, cost management	IFC
Bentley	Modeling, design (whole process)	IFC, DWG, gbXML, DGN, STEP, SKP
Bluethink	3D residence design	IFC, DWG
CATIA	Modeling	DWG, DXF, IGES, STL
CostOS BIM	Cost management	IFC, DWG
CFX	CFD Simulation	IFC, DWG,VRML, STL, STEP, CATIA
DDS	MEP design	IFC, DWG
Digital Project	Navigator	IFC, DWG, VRML
DProfiler	Cost management	IFC
e-specs	File system	IFC, RVT, BENTLAY
EaglePoint suite	Cost management, data analysis	IFC, DWG, DXF, RVT
Ecotect	Energy consumption simulation, sunlight analysis	IFC, gbXML, DWG, SKP
Energyplus	MEP analysis	IFC
ETABS	Structure design and analysis	IFC, RVT, STEP, IGES
Fastrak	Structure design	DXF, RVT
Field BIM	Construction guided under design	IFC, RVT
GBS	Energy consumption simulation	gbXML
IES	Energy consumption simulation, green analysis	DWG, DXF, gbXML, SKP
Innovaya	Simulation	IFC, DWG, DXF, RVT
MEP Modeller	MEP Modeling	IFC, DWG, DXF, RVT
Navisworks	Navigator	DWG, DXF, RVT
Newforma	Design viewer	IFC, DWG, DXF, RVT, BENTLAY
Onuma	Planning	IFC, DWG, DXF, RVT
Revit	Design (all process)	IFC, DWG, gbXML
RISA	Modeling, analysis	DXF, RVT
SAP	Modeling	IFC, IGES
SDS/2	Structure design	IFC, DXF, VRML
SketchUP	Modeling	IFC, DXF, VRML
Solibri	Design viewer	IFC
Tekla	Structure design	IFC, DWG, DXF, DGN
Tokoman	Cost management	IFC, RVT, ARCHI
Vectorworks	Modeling	IFC, gbXML, DWG, SKP, STL, IGES
VICO	Cost management	IFC, RVT, ARCHI
VBE	Model viewer	IFC

4. APPLICATION

4.1 Introduction of the Zhuhai opera house

As one of the building types which are common in modern architecture, opera house usually has some characteristics including large space, high population density and high heat flux. Architects and engineers are willing to use passive and active methods to deduce the energy consumed in opera house while the spectators still have high comfort. The Zhuhai Opera House locates in the south of China. The total building area is 59,000 m^2 with three main functional spaces: main theater, little theater and public space. The seating capacity of main theater is 1,600, while the one of little theater is 600. The two theaters share an entrance hall. As the building is complicated and the energy consumption is quite high, the simulation was used in the project to optimize the energy system.

The comparison method was applied in the project because the BIM simulation is not frequently applied in China. As the normal process and BIM process were both used, the result can be seen as the convictive evidence that the BIM simulation process has more advantages than the normal process. The comparison result can be seen in following statement.

4.2 The data conversion in application

The normal and BIM data conversion process in Zhuhai opera house are shown in Figure 6 and Figure 7. The normal process was finished with DeST and CFX, and the BIM process was dealt with the Energy plus and CFX. In concept and scheme design stage, the architecture input model is built in RHINO and SketchUP. The model in preliminary design and construction drawing design stage is built in Revit.

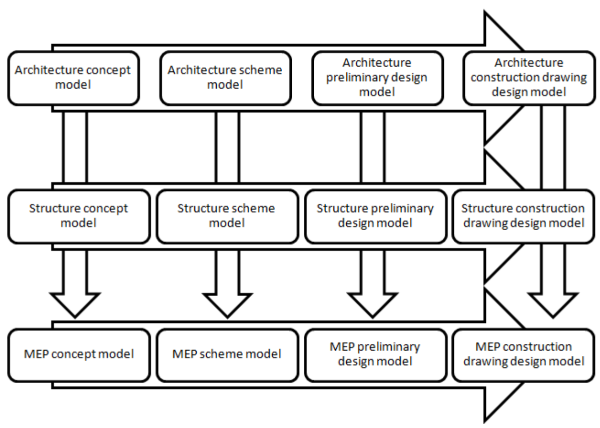

Figure 6: BIM Simulation process

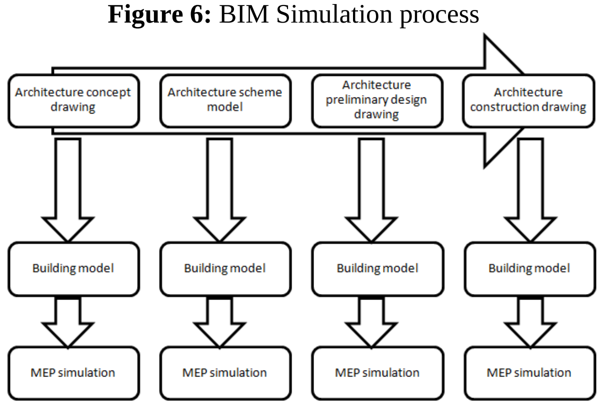

Figure 7: Normal Simulation process

The actual time consumed in modeling, grid-setting and simulation can be seen in Table 2. The "First building" in the table means the initial process on building the simulation model. The "Modification" means the process on modifying the model with some changes of parameters or locations. From the comparison in Table 2, it is obvious that the modification in BIM simulation system is much less time-consuming. The difference lies on the modification of model. For BIM system, more time may be consumed on building the model while the modification spent much less time. The BIM system can be easily controlled as the model used previous can be used in modification.

Table 2: The comparison of BIM and normal process

	Concept stage		**Scheme stage**		**Preliminary stage**		**Construction drawing stage**	
	First building	Modification	First building	Modification	First building	Modification	First building	Modification
Normal process (wind simulation)	3	3	5	4	8	6	9	7
BIM process (wind simulation)	4	1	5	2	5	2	5	3
Normal process (energy simulation)	7	5	7	5	11	7	12	6
BIM process (energy simulation)	5	2	6	3	9	3	10	3

(Unit: day)

5. CONCLUSIONS

Based on the research and application of simulation in BIM process, several conclusions have been obtained:

- A basic simulation framework with four stages of design was proposed: concept stage, scheme design stage, preliminary design stage and construction drawing design stage. The principles of simulation are different in each stage.
- The data conversion was discussed, as data conversion is important to support the simulation in BIM system. The transfer of several main 3D-model formats used in design were also discussed. The list of main 3D-modeling software and formats showed that the data conversion system is mature to form a real BIM system.
- A test example of whole process of simulation in BIM design on wind and energy simulation was proposed in the paper to show that new simulation process in BIM has advantages as time saving, simple and easily controllable.

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