BIM-based Computer-Aided Architectural Design

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ABSTRACT

Computer-aided architectural design is evolving from CAD(Computer-aided drafting) to BIM(building information modeling), which represents a progression from assisting designers to produce construction drawings to facilitating design plan decision-making and integration of AEC industry teams, which involves the key aspects of information processing and exchange during the design stage. Information processing and exchange during the design stage can be accomplished using a building information model, which can yield the benefits of (1) comprehensive information, no omissions, and inclusion of all information needed for operations; (2) no redundant information; and (3) no mutual contradictions plus effective search and analysis functions. This study analyzes and compares the information processing and integration methods of CAD and BIM systems from the perspective of computer-aided architectural design (CAAD), and proposes that BIM-based CAD can boost the horizontal integration efficiency of cooperating teams, and achieve vertical integration of information between different stages. Now that BIM software is available, designers must transfer existing CAD systems data into BIM databases, and use BIM technology to perform architectural design and transmit design information, boosting the effectiveness of cooperation between architectural teams. In accordance with the AIA's level of detail (LOD) standards, this study divides the design process into three stages (LOD100 to LOD300) corresponding to the design key points and objectives during each stage, and conducts an actual design case. Two design objectives are achieved through BIM use: (1) sustainability design of a green building and (2) the use of BIM technology to perform building planning and design.

Keywords: building information modeling (BIM), information integration.
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1 INTRODUCTION

Designers currently still think about design employing CAD(Computer-aided drafting) system operating models. The fact that design information is entered into BIM software only after a design plan has been completed commonly leads to disconnected, redundant information operations. As far as team cooperation is concerned, plan, elevation, section, and detailed design drawings, 3D model, budget estimates, and project materials analysis must be performed separately for each design case. When these tasks are assigned to different workers, redundancies and conflicts commonly occur due to lack of complete design information. And when designers use drawings as a basis for transmitting design information, the lack of correlation between drawings family causes gaps in design information, which can lead to project management difficulties.

This study proposes the use of BIM(building information modeling)-based computer-aided architectural design (CAAD) to achieve the transmission and integration of designer-oriented auxiliary design information. Designers can use BIM software from the initial development of an architectural design, employ architectural models with 3D information as integration tools, and store all information needed for designs in a database via BIM. Since the BIM can provide all design drawings and budget estimates, repeated design investigations, design changes, and the transmission of information become much easier. BIM technology can closely link personnel participating in a project, improving cooperation between architectural teams.

2 DEVELOPMENT OF COMPUTER-AIDED ARCHITECTURAL DESIGN: FROM CAD TO BIM

2.1 What is CAAD?

Computer-aided design employs computer tools to perform plan simulation and production, facilitating designers' design plan conceptualization, simplifying complex design problems, enabling rapid decision-making, boosting working efficiency, and promoting group cooperation. With the arrival of ubiquitous computer hardware, CAD has widely applied to different research fields, including machinery, industrial engineering, product design, and architecture. From the perspective of industrial design, CAD refers to the use of computers to aid design, modification, and analysis, with the ultimate goal of optimizing design results[1]. In the field of architecture, Prof. Mitchell's 1977 book Computer-Aided Architectural Design[2] investigates relevant computer functions, introduces the principles of CAAD, analyzes the role computers can play in design, and shows that they can boost working efficiency. According to Schmitt[3], CAAD is a new type of design pathway helping designers to make decision, automating the design process, and easily transmitting information from one stage of the design process to the next, giving designers the ability to access a much greater quantity of information. CAAD is not just a design tool, but rather a way of thinking, and can provide a channel for communication for people and computers, creating a distributed, networked design culture [4].

2.2 From CAD to BIM

The development of CAAD represents the evolution from CAD(Computer-aided drafting) to BIM (building information modeling), and from helping designers produce construction drawings to facilitating design plan decision-making and integrating AEC industry teams. The key element of CAAD is the processing and exchange of information throughout the design stage. Table 1 pairs CAAD development and research directions with development of computer tools during different periods of time. It can be seen from Table 1 that the development of CAAD was influenced by the evolution of computer hardware, and such issues as design automation, computer-aided drafting and

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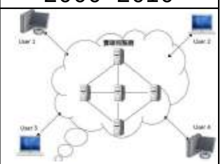
manufacturing, databases, digital buildings, environmental simulation assessment, and parametric design evolved continuously over time and spawned various design methods and CAD software. The emergence of the Internet has also influenced the CAD work environment by changing working times, locations, and methods, and facilitating team cooperation and collaborative design. With the passage of time, CAD has evolved from a single person working at a single computer to online multi-person multi-project cooperation, and architects who once used computer-aided drafting software now use BIM software to assist management of design information.

Period	Mainframe age	Work stations age	PC age	Internet age	Cloud computing age
Decade	1960-1970	1970-1980	1980-1990	1990-2000	2000-2010
Photo					
Explanation	Computers were first used in architectural design research during the 1960s. In that time of large mainframe computers, users had to write their own programs in programming language to use computers. Research directions during this period consist of design automation and conjecture whether computers can perform their own design work.	Thanks to the emergence of practical applications in the 1970s, computers are used to replace paper-and-pencil drawings, improving drafting speed. The ease of copying and pasting reduces the need for repetitive tasks. Design conceptualization is still performed using paper drawings and sketches. Computer drafting is performed only after a design plan is confirmed. The final computer construction drawings enhance working	The appearance of the PC in 1980 ensured the widespread adoption of a graphic interface, and spared users complicated program writing and compilation tasks. The gradual maturation of AutoCAD software enables designers to shift from 2D plan drawings to 3D models.	The improved tools and more powerful computers available after 1990 enabled the liberation of architectural forms and spaces; computers can now be used to handle complex calculations and forms that cannot easily be rendered using compass and ruler. CAD has a significant influence on architectural design during this period, increasing the diversity of architectural forms and shortening construction time.	Following the rise of the Internet following 1990, researchers began adopting online cooperative architectural design and virtual design research. The Internet is used to link collaborators in different fields, and databases are employed to integrate design information. Following the start of the cloud computing age in 2010, architects have used BIM to construct all object information in a building's life cycle,

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		efficiency, but can only be produced in 2D, and do not provide significant assistance to design thinking.			enhancing architectural design planning and management.
Goal	To write applications programs to undertake repetitive, tedious tasks. Design automation replaces traditional pencil-and-paper drawings and physical models.	The development of CAD systems (for drafting and manufacturing) enables computers to be used as drafting tools in architectural design.	The adoption of graphic interfaces providing simple and direct operations eliminates the need for complex programming languages.	The use of various information media as auxiliary tools enables teams in different locations to cooperate, facilitating design decision-making.	During collaborative architectural design projects, the provision of assistance and information to collaborators helps design teams to develop design plans.
Operating system	Each computer has its own operating system	Each computer has its own operating system	MS-DOS Windows 3.0	Windows XP, Mac OS	Windows 7, Internet, and computers
Software	User-written programs enabling the computer to perform calculations	User-written programs enabling the computer to perform drafting tasks	AutoCAD	3DMAX, FormZ, Sketchup	Revit, ArchiCAD, MicroStation
Interface	Text interface	Text interface	Graphic user interface	Graphic user interface	Object-oriented interface
Uses	Computers are used as recording and calculation tools	Computers are employed as drafting tools and auxiliary tools in the manufacture of products	Use of computing functions to begin the liberation of architectural forms	Computers are used to integrate design teams in collaborative architectural design projects, and are employed for property management	Emphasize is placed on sustainability design and analysis, conflict detection, construction planning, and building life cycle management.

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Transmission method	Drawings	Drawings	Drawings ,DWG, DXF,	DWG, DXF, XML,	XML, IFC
Type of communication	Person-to-person communication	Person-to-person communication	Person-to-person communication, human-machine communication	Person-to-person communication, human-machine communication	Person-to-person, human-machine, and machine-to-machine communication
New trends	Development of theory, design automation	CAD system development	Expert systems, databases, artificial intelligence, graphic user interfaces	Project databases, collaborative design, virtual reality, data mining	Code checking systems, IFC, IPD

Tab. 1: Comparison of CAAD research and development during different time periods.

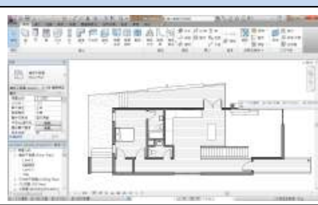
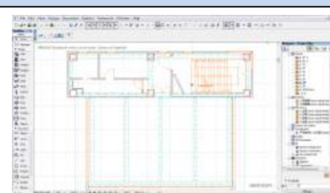
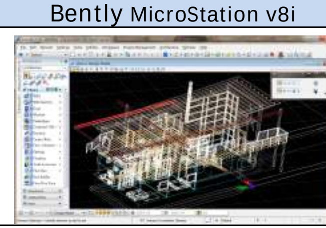
3 THEORY AND METHOD

3.1 Building Information Modeling Information Transmission and Integration

"BIM is a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format.[5]. "

BIM is an applications tool used for building information management and integration. It can be used to enhance the conceptual planning of architectural designs, and can improve on the past use of 2D drawings in communication and thinking by employing 3D model and 4D animation in project design. BIM can strengthen communication and coordination between architectural teams, boosting working efficiency while reducing project risk, errors, and cost. The use of BIM tools can strengthen architectural planning and management [6].

This study employed the BIM-aided design concept to manage project documents and maintain design data. When using a BIM system, the computer will automatic update data when there is a design change during the project design process, and designs and drawings will simultaneously be updated. Use of a BIM system to share important information with collaborators can enhance cooperation and integration in the architectural design process, and improve environmental simulation assessment and analysis, conflict detection, and construction planning. Table 2 compares three types of BIM software (Revit Architecture 2012 [7], ArchiCAD 15 [8], and Bently MicroStation v8i [9]) in terms of advantages and disadvantages, system architecture, programming language, project management, and software support. This study employed Revit as its main operating software.

Item	Revit Architecture 2012	ArchiCAD 15	Bently MicroStation v8i
Interface			
Advantages	Easy for designers to use, full functionality, currently the	Easy to use, full functionality, drawing output settings	Offers powerful file management functions in large architectural

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	most commonly used BIM software		cases, has been used in many large building projects
Disadvantages	Software requires great hardware resources System architecture is difficult to modify	Many 3D restrictions, software requires few hardware resources	Software functions are designed from the perspective of the program developer, some functions are hard to understand and use, and there are few instructional resources.
Programming languages	C#, VB, VC#, Revit SDK	GDL	UCM, MicroStationBasic, MDL, JMDL,CSL
File format	rvt, rvf	pln, pla	dgn
Project management	Uses families to manage all objects, uses model views to display design drawings	Uses overlays to manage projects	Uses parts and components to define objects, uses overlays to manage projects
Software support	MEP: Revit MEP Structure: Revit Structure Analysis: ecotect	MEP: MEP Modeler Structure: Tekla Analysis: EcoDesigner	MEP: Building Mechanical Systems Structure: Bentley Structure, Generative Components(GC) Analysis: ecotect

Tab. 2: Comparison of BIM software.

3.2 Investigation of Level of Detail (LOD) and Architectural Design Processes

This study divided the design process into three stages based on LOD standards [10], and established BIMs in accordance with design focal points and goals during each stage to gain an understanding of the BIMs' functions and information integration methods (Fig. 1). Designers should use BIM software from the early stages of the design process to facilitate design thinking. Most design units currently only regard BIM technology as a modeling tool, and do not enter data into BIM software (3D) until after completion of plan design (2D), which causes design information transmission interruptions and obstacles. Relevant international organizations (AIA, Building Smart) have adopted a multi-stage review approach to BIM modeling standards; their intention is to process design information in stages, and thereby confirm the transmission of design information. Architectural design teams should lead the establishment of BIMs during the design stage. Information suitable for each professional team should be output using information modeling based on the plan proposed by the design team during each stage. This information is turned over to the professional teams for analysis and proposal of revisions. Finally, the architectural design unit will integrate proposals into the overall information model.

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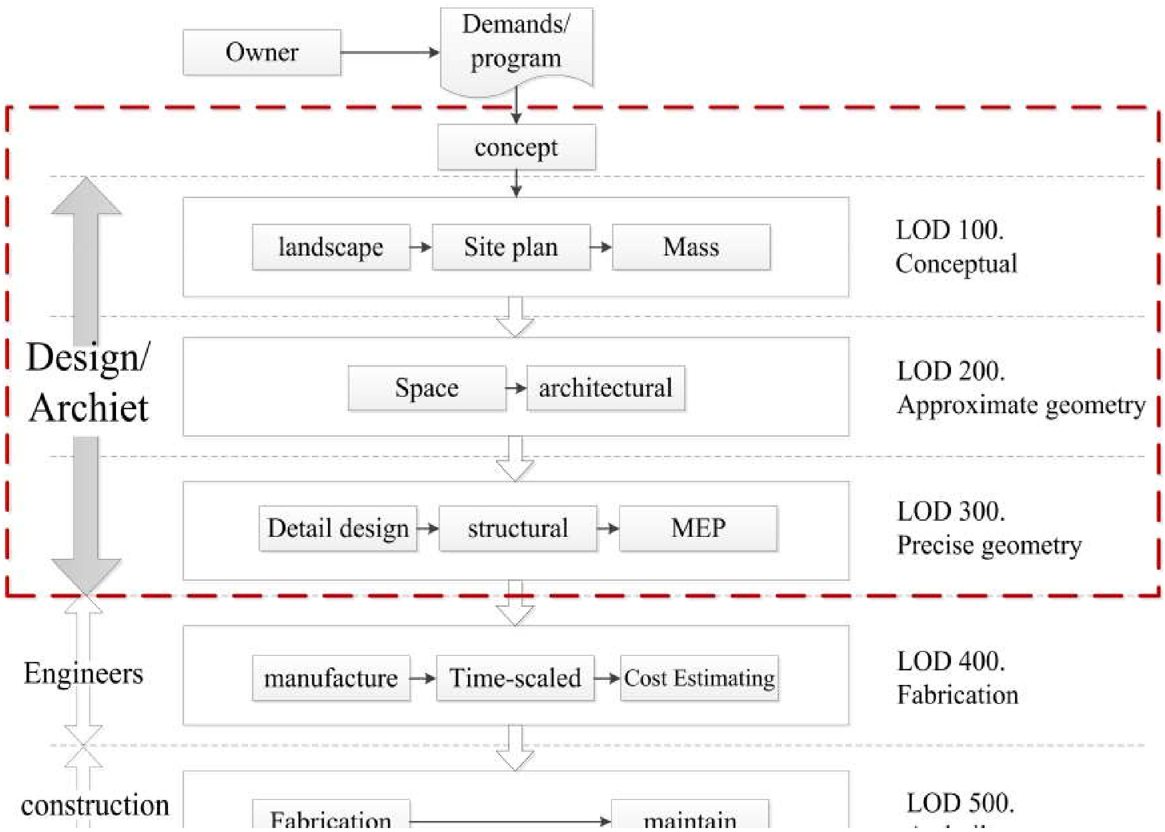

Fig. 1: International LOD modeling standards during the design stage.

4 CASE IMPLEMENTATION—BIM ARCHITECTURAL DESIGN PROCEDURES FOR THE ACADEMIA SINICA LABORATORY BUILDING

The Academia Sinica ñ Taiwan's leading research organization ñ wishes to build a laboratory building in Taipei to meet its research and development needs. The project's design objectives are: (1) to design a sustainable green building [11] and (2) use BIM technology to perform planning and design of the building's piping. This study used Revit Architecture to construct a building information model, Ecotect, to provide a simulated building environment (passive design), and Revit MEP to perform building equipment planning (active design). The latter two softwares are complementary, and their results were mutually adjusted and revised to obtain an optimal design plan. We first used Revit Architecture to construct the building massing and peripheral site in gbXML format, so that they can be imported by Ecotect. Employing the results of analysis, the designers returned to Revit Architecture and revised the building's layout and mass form in order to achieve an optimal layout, enabling the development of the spatial and architectural design. Finally, we used Revit MEP together with Revit Architecture to complete the building's piping design. Revit MEP provided collision checking (presented in 3D), allowing the building's spatial design to be revised (Fig. 2). In addition, in order to strengthen coordination between different teams, we have established an online collaboration platform enabling each team to upload various information, present their specific needs, and also share files; the online platform thus plays an important role in promoting team cooperation and communication.

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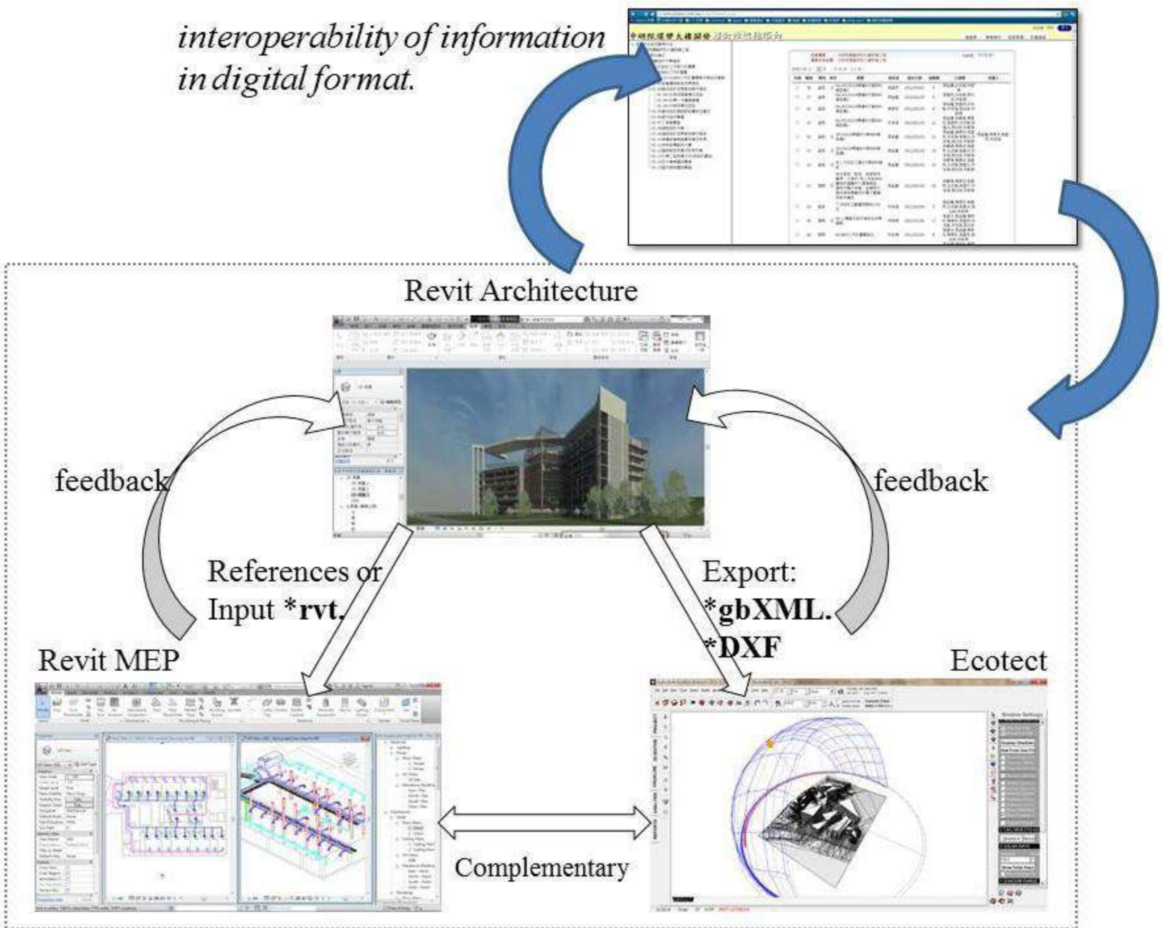

Fig. 2: Use of common file formats in different programs to perform design information exchange, provide mutual support, and implement feedback and revision. Files can also be uploaded to the online platform for file sharing and information updating.

The following is an explanation of this study's information processing and exchange procedures during the design stage as the model was gradually constructed from LOD 100 to LOD 300:

4.1 BIM Construction during the Site Planning Stage (LOD 100)

The information model during the site planning stage included site context such as roads, topography, vegetation, layout of open spaces, the forms of existing or newly-built building masses on the site, the use of space in different areas, and structural methods and materials. The design team could use the information model from the LOD 100 to perform various estimates and analysis, enabling them to determine whether the preliminary design concept met the needs of the building plan, and helping them draft a design plan.

The information model at the LOD 100 stage had to provide the following functions:

1. Output of information concerning surroundings roads, site context, buildings setbacks, and heights to facilitate review of whether the building's location and height meets the requirements of laws and regulations, and whether the building plan meets the goals of site planning.

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2. Output building massing, floor areas, outer wall and roof area and height, basic building construction approach, and basement excavation volume, circumference, and area, which will facilitate estimation of the project's construction cost and help the architects and owner to control the project budget.
3. Output the areas of the site's landscaped spaces, the layout of green areas, and the façade area of the building mass in all directions, which will facilitate analysis of impact on the existing natural environment, etc. Estimate the window ratio in each façade on the basis of spatial use in the building plan, assess the building's impact on the environment after reflecting local weather data, and estimate the building's operating energy consumption. Use of Revit Architecture to create a LOD 100 massing model, which is exported to the Ecotect or Vasari software for simulated environmental assessment to revise the building massing and layout, and obtain an optimal site plan. (Fig. 3).

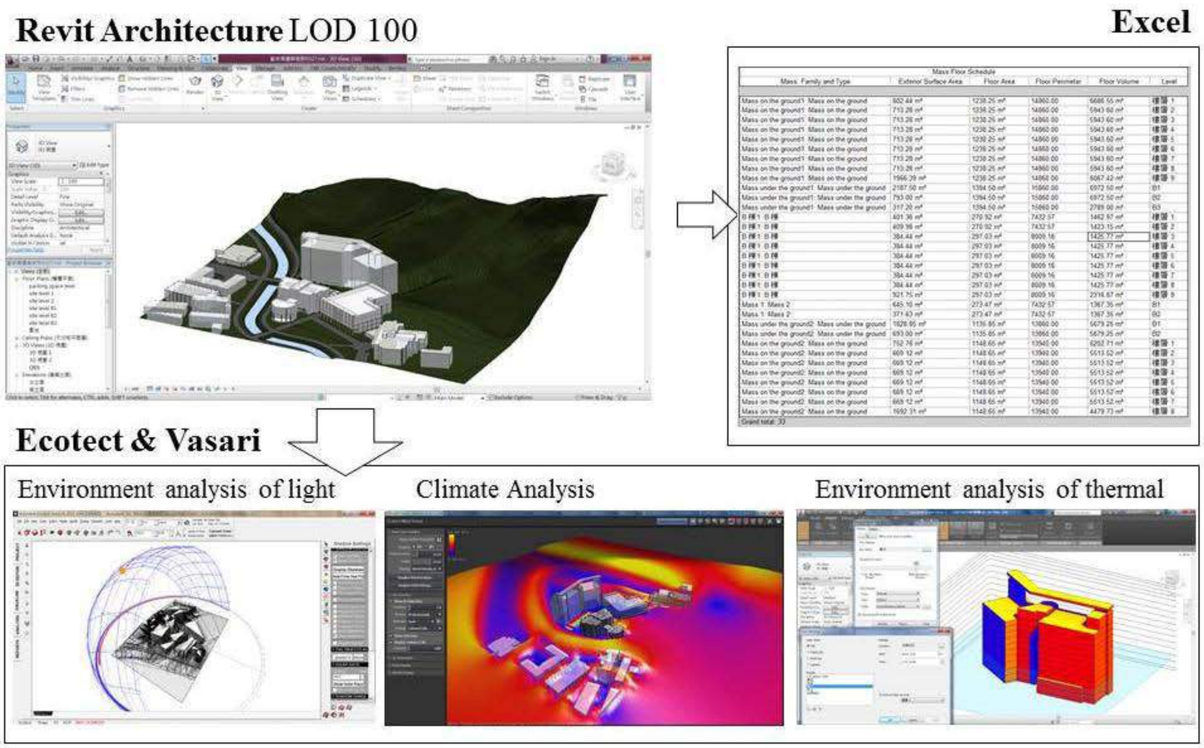

Fig. 3: Use of Revit Architecture to create a LOD 100 massing model. The building was designed by C.C. Hsu & Associates of Architects and Engineers.

While the LOD 100 stage information model is extremely simple, the results of analysis in this stage have the largest impact on the final building. It costs the least to change to design during this stage, but it is the most cost effective stage in the BIM design process is used.

4.2 BIM Construction during the Basic Design Stage (LOD 200)

BIM construction during the basic design stage should correspond to LOD 200 regulations, and focus on component sizes and materials for columns, beams, floor slabs, and other structural systems. The architectural design focuses on elements such as spatial layout, stairs, elevators, outer

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walls, partition walls, window and door openings, and roofs, and addresses the materials, usage, 3D form, and other relevant attributes of each element.

The functions of the LOD 200 stage information model are explanation as follows (Fig. 4):

1. Calculation of the volume, area, and lengths in all dimensions of architectural elements, which are output along with the materials and specification; integration with unit price information for all elements, enabling detailed assessment of project construction cost.
2. Determine whether all spatial areas, locations, lines of motion, and opening ratios meet the needs of the building plan in terms of the areas and physical environment of different functional spaces.
3. Output relevant information concerning statutory audit items among technical regulation; for instance, the escape paths for all spaces and their distances, sizes of stairways, heights of spaces, and widths of openings. This information will assist review of compliance with technical regulations.
4. Output various floor plans, elevations, and sections needed for review of compliance with urban design regulations. The BIM system can improve drawing efficiency, employ that all drawings are consistent, and perform correct quantitative calculations of spaces and materials.

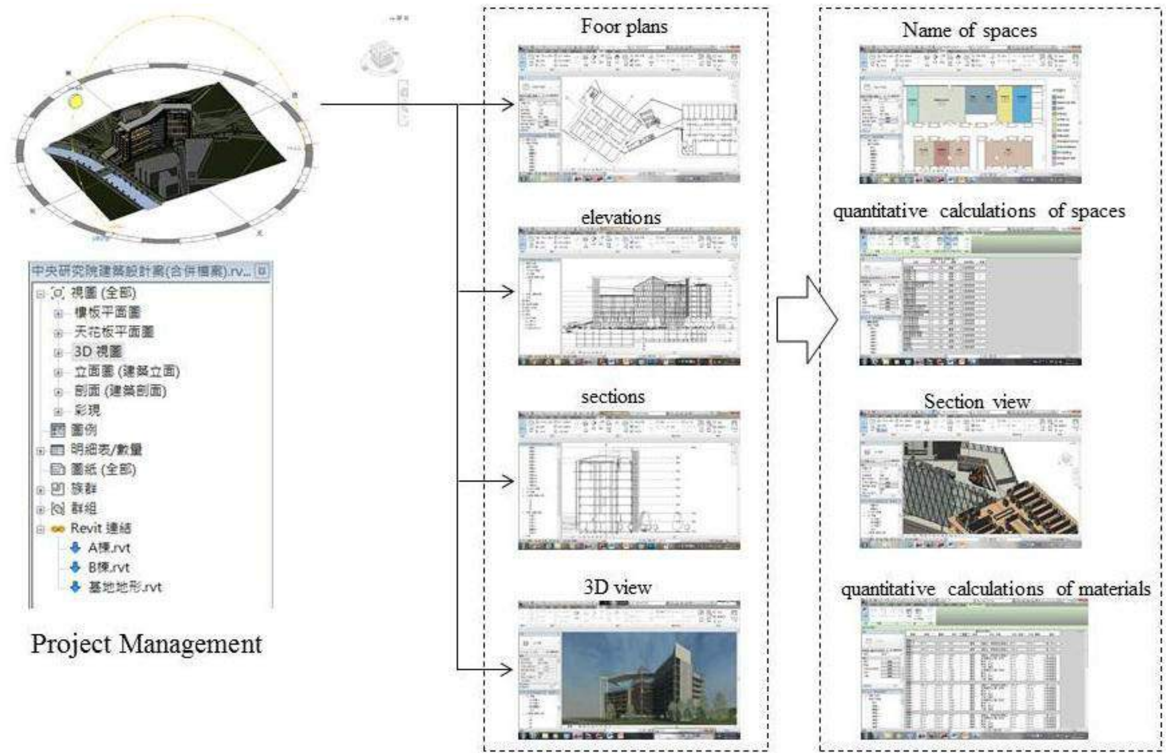

Fig. 4: BIM construction during the basic design stage (LOD 200). The building was designed by C.C. Hsu & Associates of Architects and Engineers.

4.3 BIM Construction during the Detailed Design Stage (LOD 300)

The detailed design stage includes the forms and specifications of piping for the air conditioning, fire safety, utilities, E&M, gas, laboratory exhaust, and air supply systems.

LOD 300 stage BIM construction specifications are able to satisfy the following needs (Fig. 5):

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1. The LOD 200 model is used to produce blueprints used to draft construction drawings, and the quantities of construction materials needed for the project are automatically calculated on the basis of the detailed design structure; a specifications form is output to facilitate production of a budget.
2. To confirm design quality, spatial interference inspection is performed addressing the various piping and structural systems. This study used the Revit interference inspection function[12] to perform this analysis and obtain spatial planning reference information for use during the design stage.
3. Output various information needed for physical environment and energy consumption assessment as part of green building design. Compared with the LOD 100 stage, the information output in this stage is able to provide an even more detailed analysis of energy needed to maintain the quality of the physical environment during the building operation period.

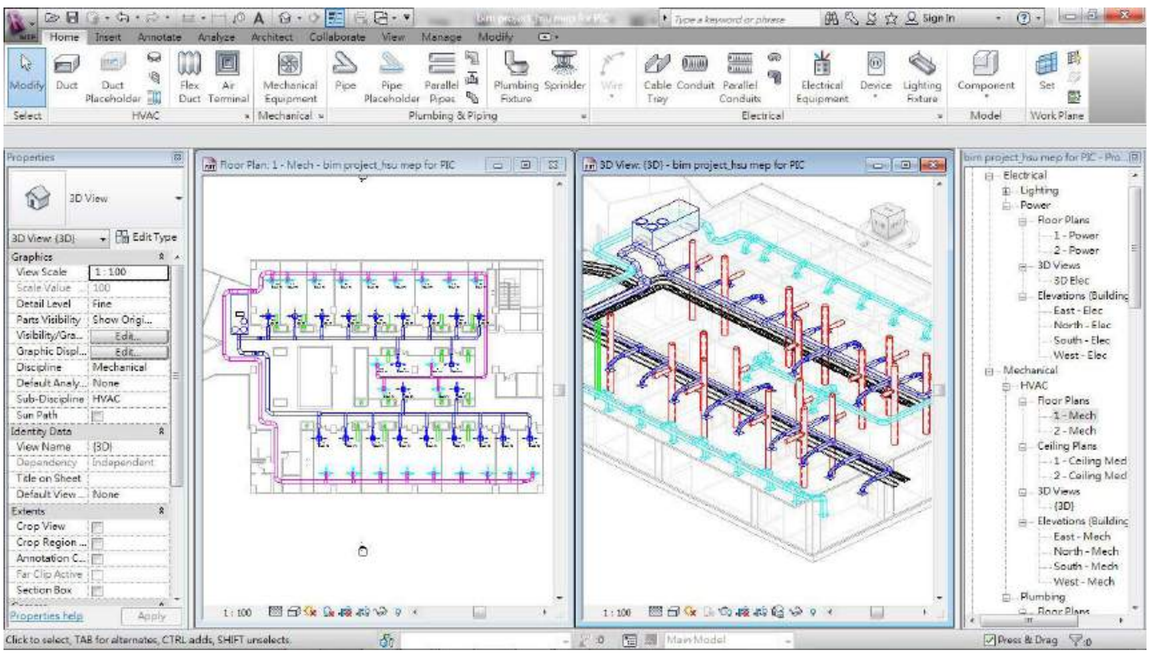

Fig. 5: Use of Revit MEP to construct the air conditioning piping system. The MEP project was designed by C.C. Hsu & Associates of Architects and Engineers.

After the designers completed the LOD 300 BIM, the information was handed over to the construction unit for development of an information model meeting LOD 400 requirements. During the construction stage, the designers still needed to revise the LOD 300 model on the basis of the construction unit's suggestions, and they also assisted use of the BIM during the construction period.

This study recommends that the BIM be linked with the project schedule during subsequent project management, and used to perform progress simulation (4D) and answer queries concerning time-related building material quantities and work items. Project schedule information created using a project scheduling program (such as MS project or P3) can be output in database format, and imported by a database management system. An ODBC (Open Database Connectivity) interface can be used to link the used BIM software (such as Revit or Bentley MicroStation) with a database management system. Establishment of a BIM enables linkage between architectural elements and work

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items on the project schedule, and a database query language can be employed to establish queries and analytical functions needed for project management. All architectural elements can be sorted by temporal order in the project schedule, and can be shown in 3D. This helps owners, the construction supervisors, and the construction team to stay on schedule, and provides the construction unit with a project purchasing and management reference. And when design changes are made, the BIM can be used to assess changes in the quantities of building materials in real-time, facilitating handling of project scheduling and calculation of building material quantities following the change, and ensuring that the project continues to progress.

5 CONCLUSIONS

The results of actual use in this study revealed that BIM-based CAAD uses quantitative presentation methods of information processing and exchange. Designers can control costs and design processes while complying with the requirements of the building plan, reducing errors and enhancing working efficiency. As far as computer-aided design thinking is concerned, it should be borne in mind that it is difficult to perform design planning when software does not provide certain functions or employs complex commands that are not consistent with designers' thinking and habits. Thanks to the development of object-oriented technology development and the increasingly maturity of code checking systems[13], the use of BIMs as a basis for architectural design review is growing trend. The use of BIM-based CAAD will therefore have the following future development directions:

1. Designers trained in BIM software use will use BIM software to think about the design plan starting from the conceptual development stage.
2. Management personnel with architectural design backgrounds will assist with project management, and handle exchange of design information and liaison with teams in other fields during each stage.
3. The development of API(Application Programming Interface) meeting designers' operating needs will provide functions currently absent in BIM software.
4. The use of a common ICFs(Industry foundation classes) format for information exchange in interdisciplinary team cooperation will enable the drafting of IDM(Information Delivery Manuals) and MVD(Model View Definitions) for cooperation, confirming information interoperability protocols and items.
5. Establishment of team collaboration platform: By facilitating project management and communication, an online platform can promote team collaboration, discussion, file sharing, and information exchange, and encourage design decision-making and project progress.

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