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BIM-Assisted Workflow Enhancement for Architecture Preliminary Design

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Abstract: China's urban housing demand has directly influenced urbanization development. To stabilize the level of urbanization, it is urgent to optimize the whole life-cycle efficiency of construction and the preliminary design as the first step is even more significant. Building Information Modeling (BIM) is widely used as information technology in the construction industry to promote the implementation and management of projects. However, the traditional preliminary design approach still occupies the mainstream market without forming a systematic BIM workflow, which causes inefficiency. To address this issue, this research aims to construct a BIM-assisted workflow to enhance the preliminary design efficiency of architecture. This study creates traditional and BIM-assisted workflows for comparative analysis to capture duration data with a questionnaire and validate by practical simulation. The findings show that the BIM-assisted workflow consumes less time than the traditional workflow. This research indicates that the BIM-assisted workflow can significantly reduce operation time to enhance preliminary design efficiency and deserves to be strongly promoted in the Chinese Architecture, Engineering, and Construction (AEC) industry.

Keywords: architecture preliminary design workflow; building information modeling; visualization programming; design efficiency

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1. Introduction

China's urbanization has escalated in the short term, leading to demographic changes that have accelerated the demand for urban housing [1]. As an important industrial sector, the Architecture, Engineering, and Construction (AEC) industry has a considerable impact on local market development and should take responsibility for this current social issue [2]. For instance, the AEC industry in China reached 3.5 trillion dollars of Gross Domestic Product (GDP) in 2018, which is 20 times more than in the past [3]. In response to the challenges of urbanization development, the AEC industry requires enhancing the efficiency of preliminary design programming as the initial stage, thus reducing the duration of the overall project [4]. Building Information Modeling (BIM), a computer-assisted design tool to integrate data, is gradually becoming a trend in the current AEC industry [5].

The preliminary design is a precursor to the project's formal development, laying the foundation for the subsequent tender [6]. Furthermore, e-tendering is gradually replacing traditional bidding approaches with a simplified digital system to increase the efficiency of project bidding implementation to adapt to market demands [7,8]. The preliminary solution specifies the performance parameters such as building shape, structural system, orientation, and spatial layout. [9]. During the early design stage, the lack of information and instability often leads to bias in the designers' decision making [10]. The highly project-oriented construction industry also involves multiple stakeholders in the preliminary design, and inappropriate communication causes conflicts to reduce efficiency [11]. BIM was proposed in 2002 by Jerry Laiserin [12] for constructing digital virtual models to integrate and share data throughout the life cycle as an essential basis for decision making [13]. Due to the increasing complexity and scale of construction implementation, a single design method or concept cannot provide holistic support [14]. Compared with the existing conventional methods, BIM covers the whole life cycle to complete different tasks, such as design, implementation, maintenance, and demolition [2]. Ng, Graser, and Hall [15] conducted a multi-case analysis of BIM design for different structures and found that BIM is mainly adopted for public infrastructure [16,17] and commercial buildings [18,19].

However, the preliminary design workflow based entirely on BIM is still a minority in the AEC industry. Although the Chinese government currently has issued policies to promote the application of BIM, most construction companies apply two-dimensional (2D) traditional approaches to produce preliminary outputs [20,21]. BIM is already maturely employed in the construction process but rarely involved in the preliminary design. If collaborative BIM participates in preliminary design, its benefits may enhance design efficiency [22]. The current BIM-assisted preliminary design research is mainly based on its single function, including building modeling, visualization and animation, cost control, building energy performance, etc. [23–29]. At the same time, the comprehensive analysis is still blank, so the practical efficiency of BIM for the whole preliminary design is ambiguous. Thus, the research aims to investigate the extent to which an entire BIM system enhances the efficiency of various stages of the preliminary design of architecture.

2. Background

2.1. Three-Dimensional (3D) Modeling of BIM

The 3D of BIM is created to enhance the Computer-Aided Design (CAD), adding more detailed information to improve the designers' efficiency [12]. BIM simplifies the barriers of spatial design with visual modeling in the preliminary design and collaborates on multi-user tasks throughout the project cycle to facilitate the management of subsequent stages [30,31]. However, 3D BIM incurs higher costs in the initial design than 2D, and its application brings considerable value to the overall project that remains of great interest to managers [12]. In particular, Autodesk Revit is currently the mainstream 3D modeling software, storing object information in the database and synchronizing other software to expand design functions, such as the clash detection of complex structures with Navisworks [32,33].

2.2. Building Visualization of BIM

The visualization of BIM includes rendering and animation, combined with the time for four-dimensional (4D) BIM to achieve faster project delivery [34,35]. Lumion is a typical architectural rendering software that accelerates the development of preliminary design solutions with 3D models to perform the desired visualization tasks [36]. 4D models can dynamically describe variables during construction to control the project schedule, such as Synchro Pro [37,38]. Especially for construction spaces, complex tasks, and emergency periods, 4D BIM assesses risks in preliminary design to manage projects [39]. In addition, visual design solutions are presented to the clients in a more understandable form during the current project bidding to evaluate the architecture [40].

2.3. Cost Estimation of BIM

Similar to 4D BIM, cost as an element is expanded into a five- dimensional (5D) model to transform from manual billing to automatic estimation [35,41]. The precision of construction cost estimation in the design phase is affected by the information, BIM tools for project life cycle analysis and forecasting can effectively improve the appraisal accuracy [42]. The cost estimation of projects as a decentralized and resource-intensive process involves information and data that are constantly changing due to the influence of different stakeholders, resulting in final project inputs that exceed the budget by 40% [43]. The 3D model created by Revit can automatically calculate the quantity and generate the Quantity Take-Off (QTO) [41,42]. Compared with conventional methods, 5D BIM can reduce the time and manual error rate to promote estimation accuracy [44]. In particular, the scripting tool Dynamo reassigns building component attributes with mapping codes from which the required project costs are calculated [45].

2.4. Energy Performance Analysis

Apart from the building project's quality, time, and cost, the six-dimensional (6D) BIM concept is introduced in the preliminary design to consider the energy consumption and sustainability to meet the usage requirements and environmental concepts [29,46]. Leadership in Energy and Environmental Design (LEED) is the dominant energy efficiency standard [28]. BIM optimizes solutions in the preliminary design phase based on visual analysis of a building's thermal and energy performance to achieve high LEED scores [47,48]. For example, Grasshopper or Dynamo simulates the design process with parametric programming to realize a truly sustainable building [49,50].

3. Methodology

This paper utilized traditional and BIM-assisted methods to define the architecture preliminary design workflow, so that the workflow duration can be compared and analyzed to derive the enhanced solution for preliminary design. This research followed the approaches of the previous study related to preliminary design activities. The methodology followed in this paper can be divided into four main parts, as shown in Figure 1.

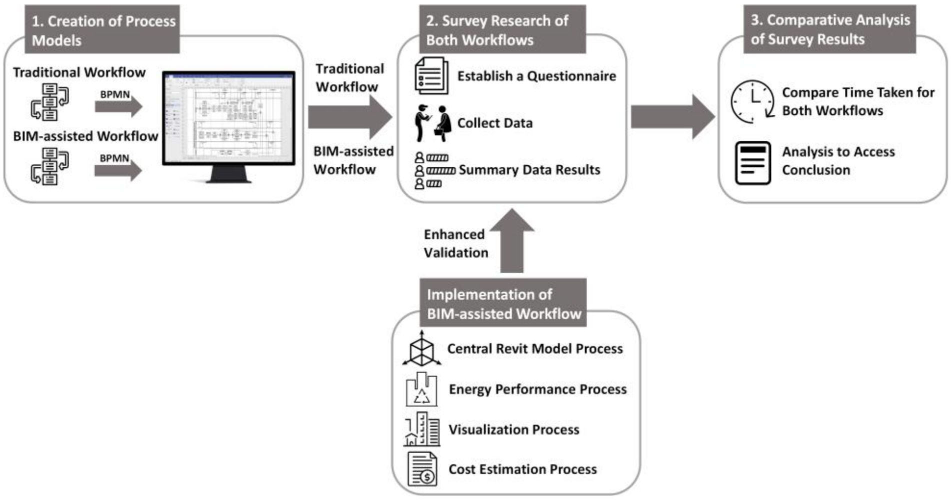


Figure 1. Overall process of methodology.

3.1. Creation of Process Models

The process model serves as the initial step of the preliminary design to describe design activities, roles, and data exchange. It is represented by Business Process Model and Notation (BPMN), which reflects the business process description, simulation, and execution capabilities with processes and symbols [51].

The process model explains the design logic and data exchange for traditional and BIM-assisted preliminary design outputs. The outputs include design drawings/models, performance reports, visualization documents, and cost estimation reports. The clients' responsibility involved in both workflows is to assess output quality. The design drawings/models act as the primary design activity for both workflows to perform the subsequent design tasks. During the traditional workflow, the process starts with the stakeholders, including clients, architects, rendering designers, energy performance analysts, and cost engineers producing the corresponding outputs using Autodesk CAD, 3DMax, PKPM, and Glodon [52–55]. As for the BIM-assisted workflow, the stakeholders involved in the design activities are clients, BIM engineers, visualization designers, energy performance analysts, and cost estimators to generate the outputs with Autodesk Revit, Grasshopper in Rhino, Lumion, and Synchro Pro [38,53,56,57]. The process model is presented in the Process model.pdf linked to Mendeley data.

The process model describes the data exchange flow between design activities. The output files in the traditional workflow include CAD design drawings, rendering documents, energy performance reports, and budget reports. Clients review these files and send feedback to stakeholders with a modification form. PKPM modeling also involves the XML format file for performance analysis. Glodon pricing requires quantity data in QTO. In addition, the output files of the BIM-assisted workflow corresponding to the traditional workflow are central Revit models, visualization documents, energy performance reports, and cost estimation reports. The BIM-assisted workflow contains a Navisworks conflict modification form besides regular modification forms. In addition, the visualization parameters in Grasshopper assist Revit modeling. Lumion modeling involves the DAE format file, and Synchro Pro modeling includes XML and SPX format files.

3.2. Survey Research of Both Workflows

The questionnaire survey conducted for the quantitative analysis aims to determine the time consumption for implementing traditional and BIM-assisted workflows. The questionnaire is developed by consulting with industry experts and integrating relevant literature on the preliminary design of the architecture. To increase the efficiency and professional accuracy of the questionnaire data collection, the questionnaire is administered directly to local companies and organizations with relevant industry qualifications and a certain degree of prestige via web and email. The valid results are filtered based on the actual feedback received.

This questionnaire is based on the same building case to serve as the basis for the research. The case context is a staggering structured parking lot building with a total floor area of approximately 9000 m^2 and four floors. Each floor from the 1st to 3rd floor is about 2600 m^2, and the rooftop floor is approximately 1000 m^2. The functional zoning of the parking lot is divided into parking spaces, restrooms, stores, and offices.

This questionnaire involves 19 questions divided into two parts: traditional and BIM-assisted workflows. In particular, questions 1–11 summarize the operational steps based on the main design phases of the traditional workflow, including the CAD drawing, rendering, energy performance, and budget. Questions 12–19 correspond to the procedure steps of the BIM-assisted workflow, containing the central Revit model, energy performance, visualization, and cost estimation. The time range of questionnaire options is defined by the pre-survey, calculating the duration depending on the feedback. In addition, the time results obtained from this questionnaire are measured in the unit of 6 h per working day. The complete questionnaire information can be found in the Questionnaire.pdf associated with Mendeley data.

3.3. Comparative Analysis of Survey Results

The time spent on both workflows is acquired by questionnaire. The total duration of both workflows and the time for each design process are compared in a chart. The results determine the efficiency enhancement of the BIM-assisted workflow for the preliminary design process.

3.4. Implementation of BIM-Assisted Workflow

The simulation of the BIM-assisted workflow aims to validate the credibility of the BIM-assisted workflow duration from the questionnaire. The collaborative design of outputs is based on four main processes with associated BIM software, including the central Revit model, energy performance, visualization, and cost estimation.

3.4.1. Central Revit Model Process

The central Revit model is the core part of the BIM-assisted workflow, providing the design foundation for the following steps. The project's design direction is determined by considering the project information, design specifications, and clients' needs. The model is divided into architectural, structural, and Mechanical, Electrical, and Plumbing (MEP) sections for easy integration. When Navisworks detects models of different sections to be conflict-free, further validation is performed by specialists to accomplish the central Revit model. In addition, the Revit version required for the study was Autodesk Revit 2020.

3.4.2. Energy Performance Process

The energy performance process is based on the created central Revit model, using Rhino as its host platform and running the Ladybug plug-in for visual programming through the built-in Grasshopper in Rhino. Energy performance analysis is conducted mainly for the specific region's climate, skylight, and radiation. The performance scheme can be optimized to meet energy performance requirements to enable architectural design. The parametric design requires the Rhino inside Revit plug-in to realize the model information's bidirectional input and output, breaking the past need to switch between different platforms [58]. Figure 2 presents that Rhino was upgraded to version 7.10 to run properly.

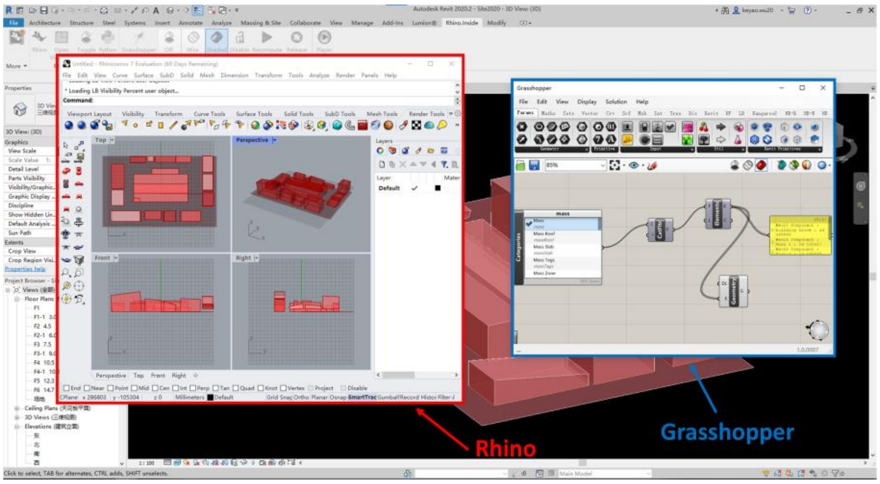


Figure 2. Rhino inside Revit.

The functions provided by Ladybug are available for the analysis of direct sun hours and incident radiation. The feature panels are selected for parametric programming according to specific analysis requirements. EnergyPlus Weather Map (EPWMap) as a general feature panel for the parametric design offers weather data support for subsequent programming. For instance, EPWMap retrieved the past weather data of the area where the building is located and delivered it into ImportEPW to output the target panel from different ports. Furthermore, the time parameter was set in AnalysisPeriod to determine the study period and imported into Sunpath with the weather data. Sunpath accessed DirectSunHours while setting LegendPar and other impact items to generate the direct sun hours analysis.

Incident radiation analysis enables the evaluation of the extent to which buildings are affected by solar radiation. The weather data and study period were delivered from ImportEPW and AnalysisPeriod to SkyMatrix. Furthermore, SkyMatrix was linked to SkyDome and IncidentRadiation, respectively. With LegendPar, Scale, and additional parameters set, SkyDome derived the total radiation distribution, and IncidentRadiation produced the radiation impact results for the building.

3.4.3. Visualization Process

Lumion and Synchro Pro perform the visualization process of the BIM-assisted workflow to satisfy both exterior effects and construction details. Lumion adds realistic materials to the model framework to recreate the building's appearance and generate exterior rendering images and videos for project requirements. In addition, Synchro Pro produces construction simulation videos, which simulate the complete construction process by assigning the Revit model to the corresponding schedule.

Lumion supports adding a variety of resources to simulate actual architectural effects. Figure 3 shows the settings of the resource library. Designers can adjust the parameters of weather, landscape, materials, and objects libraries to construct a visual representation of the building depending on the practical needs. To avoid format incompatibility between Revit and Lumion, the Lumion LiveSync for Autodesk Revit plug-in converts a DAE format for direct transfer [59]. Lumion's effect display for the exterior consists of images and videos. Based on the completed material layout of the framed model, it performs the image and video rendering editing. The image rendering editing process is to customize selected views to reach the target effect. Video rendering is the process of choosing frames to determine the animated content, adjusting the interval between frames to control the length of the video, and then rendering the visual product. Additionally, the version of Lumion in this study was Lumion 8.5.

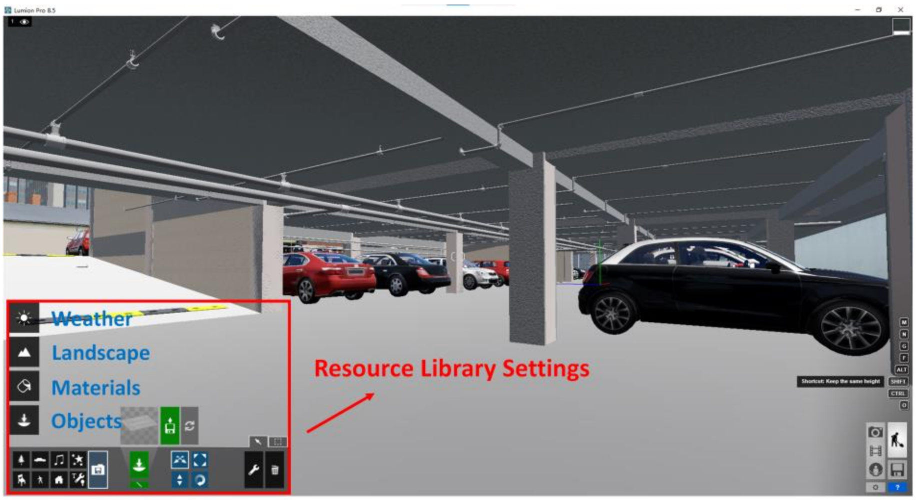


Figure 3. Resource library setting.

Synchro Pro produces construction simulation videos for the visualization process to display precise construction details. The application of Synchro Plugin for Revit improves file transfer efficiency between Revit and Synchro Pro [60]. SPX format can be generated directly from Revit by the plug-in and imported into Synchro Pro along with the schedule plan in XML format for operation. The Synchro Pro version in the research was Synchro Pro 2020. In Figure 4, the desired components in the 3D objects or 3D view were selected and assigned to task properties in construction order. In addition, it is possible to avoid construction logic conflicts by dragging to the progress bar to preview the build order of the model. The construction simulation video is rendered with an animation editor to define the total video length and camera angles.

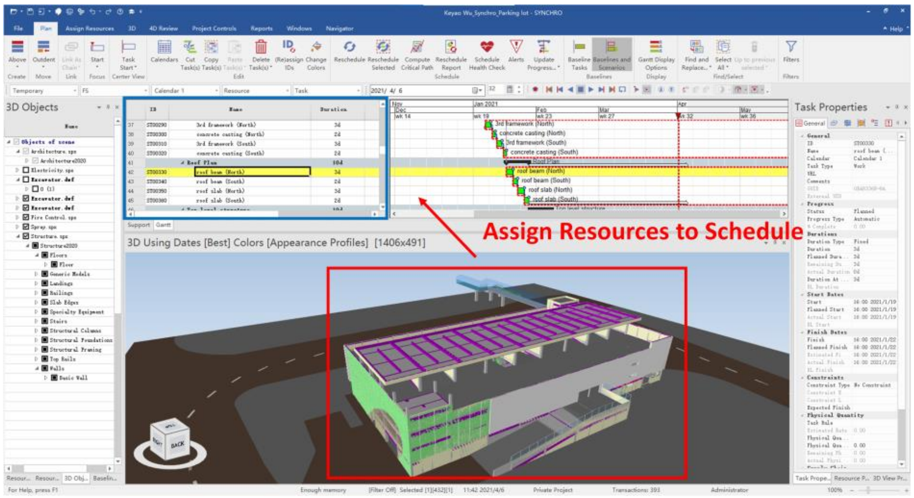


Figure 4. Synchro Pro operation process.

3.4.4. Cost Estimation Process

The BIM-assisted platform allows cost estimation reports produced directly in the Revit. The QTO is achieved by classifying the category of the target component. For example, schedule properties provided by Revit contained family and type, count, cost, volume/area, and calculation formulas. The QTO will be updated automatically if the Revit model is changed with regional price quotas to set prices for the QTO to generate final cost estimate reports.

4. Results

This research has leveraged traditional and BIM-assisted workflows to perform pre-design tasks of the project. Therefore, it demonstrated the operational process of both workflows to satisfy preliminary design requirements. The result of this study proved the enhanced efficiency of the BIM-assisted workflow by comparing the duration results of both workflows.

4.1. Creation of Process Models

The process models (Process model.pdf) were created to display the implementation details of traditional and BIM-assisted workflows. Different types of preliminary design workflows produced design items with specific tools. Design activities in the traditional workflow consisted of the CAD drawing, rendering, energy performance, and budget. The BIM-assisted workflow involved the central Revit model, energy performance, visualization, and cost estimation. The process models were also intended to clarify the design roles. For example, the stakeholders in the traditional workflow included the client, architect, rendering designer, energy performance analyst, and cost engineer. The client, BIM engineer, visualization designer, energy performance analyst, and cost estimator were the corresponding BIM-assisted workflow. The information exchange of the process could be explicitly illustrated in the model.

4.2. Survey Research of Both Workflows

The survey targeted industry workers and experts to investigate the time required for both workflows. The industry background and proportion of participants are presented in Table 1. Among the total of 102 questionnaire responses received, there were 35 (34.3%) from architecture design institutes, 25 (24.5%) from civil engineering firms, 20 (19.6%) from BIM design firms, six (5.9%) from university teachers of related industries, six (5.9%) from engineering cost firms, six (5.9%) from project general contractors and four (3.9%) from green building firms. In particular, the number of valid feedback was 85 by identifying and filtering the participants' completion.

Table 1. Survey participants' backgrounds involved.

Industry Background of Participants	Percentage of Participants (Size)
Architecture design institute	34.3% (35)
Engineering cost firm	5.9% (6)
Green building firm	3.9% (4)
Civil engineering firm	24.5% (25)
Project general contractor	5.9% (6)
BIM design firm	19.6% (20)
Higher education institution	5.9% (6)

4.2.1. Duration Results of Traditional Workflow

Questions 1–11 of the questionnaire measured the duration of the main phases of the traditional workflow. Figure 5 presents the feedback of the questionnaire. For the CAD drawing phase, 37 participants (43.5%) answered that the architectural CAD design takes about 10 days to complete, 39 participants (45.9%) indicated that the structural CAD design requires about 10 days, and 33 participants (38.8%) considered about 5 days for the MEP CAD design. There were 42 participants (49.4%) who reflected that the delivery of CAD documents to the client and receiving feedback takes approximately 7 days. For the rendering phase, 53 (62.4%) participants considered that the 3DMax modeling takes about 10 days, while 37 (43.5%) of the participants estimated that the post-rendering requires about 3 days to complete. For the energy performance phase, 39 (45.9%) participants answered that the time required for the PKPM modeling is approximately 5 days, while 47 (55.3%) participants indicated that the post-modeling performance analysis takes about 10 days to complete. For the budget phase, 41 (48.2%) participants estimated that it requires about 10 days to create the Glodon model, while 37 (43.5%) considered that the quantity calculation takes 3 days to complete. Meanwhile, 36 (42.4%) participants answered that it takes about 7 days to set the price for the list of quantities. The survey feedback data are presented as Questionnaire feedback.pdf linked to Mendeley data.

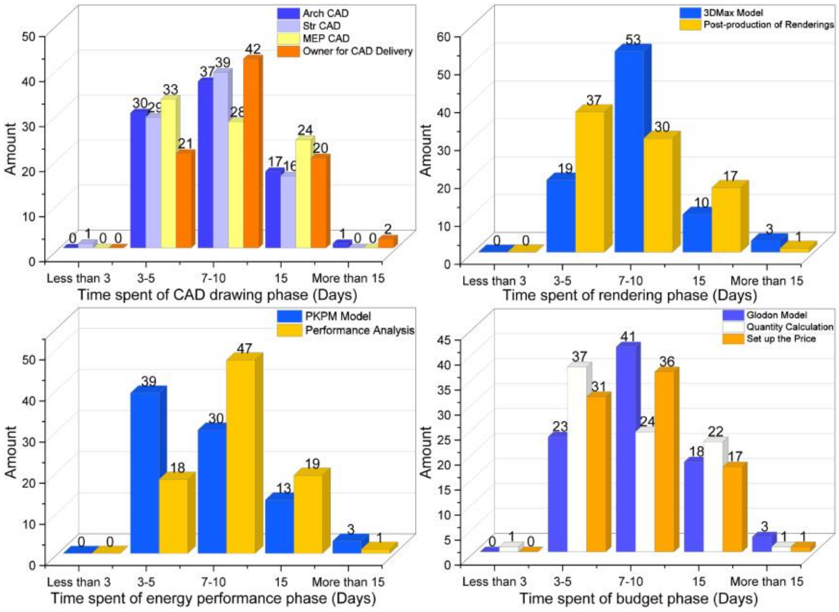


Figure 5. Questionnaire feedback on traditional workflow.

According to the data analysis from the survey feedback, the duration summary of the traditional workflow is shown in Table 2. The CAD drawing phase spent 192 h, the rendering phase took 78 h, the energy performance phase consumed 72 h, and the budget phase required 120 h. Therefore, the total duration of the traditional workflow was 462 h.

Table 2. Duration results of traditional workflow.

Phases of Traditional Workflow	Required Time (Hours)
CAD drawing phase	**192**
Architectural CAD drawing	60
Structural CAD drawing	60
MEP CAD drawing	30
Client's review and feedback on CAD	42
Rendering phase	**78**
3DMax model	60
Post-production of renderings	18
Energy performance phase	**72**
PKPM model	30
Energy performance analysis	42
Budget phase	**120**
Glodon model	60
Quantity calculation	18
Set up the price	42
Total	**462**

4.2.2. Duration Results of BIM-Assisted Workflow

Questions 12–19 evaluated the duration of multiple processes of the BIM-assisted workflow, as shown in Figure 6. For the central Revit model process, 26 (30.6%) participants answered that the time required for the Arch-Str-MEP Revit model is about 30 days, while 26 (30.6%) participants indicated that the model review with specialists takes approximately 7 days. For the energy performance process, 30 (35.3%) participants estimated that it requires about 10 days to perform the Grasshopper parametric programming, while 25 (29.4%) considered that the energy performance analysis takes 2 days to complete. For the visualization process, there were 30 participants (35.3%) who reflected that the creation of the Lumion model spends approximately 4 days, while 27 participants (31.8%) answered that the Synchro Pro model takes about 5 days to construct. For the cost estimation process, 26 (30.6%) participants considered that the quantity calculation by Revit takes about 2 days, while 29 (34.1%) of the participants estimated that it takes approximately 7 days to set up the price.

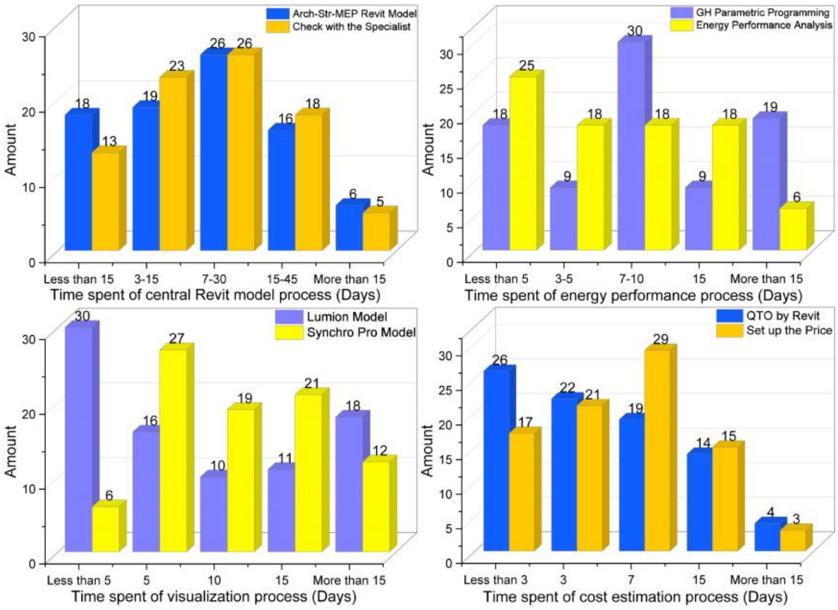


Figure 6. Questionnaire feedback on BIM-assisted workflow.

Table 3 presents the BIM-assisted workflow duration based on the summary of the questionnaire responses. The central Revit model process required 222 h, the energy performance process consumed 72 h, the visualization process took 54 h, and the cost estimation process spent 54 h. Thus, the total duration of the BIM-assisted workflow was 402 h.

Table 3. Duration results of BIM-assisted workflow.

Processes of BIM-Assisted Workflow	Required Time (Hours)
Central Revit model process	**222**
Arch-Str-MEP Revit model	180
Check with the specialist	42
Energy performance process	**72**
Grasshopper parametric programming	60
Energy performance analysis	12
Visualization process	**54**
Lumion model	24
Synchro Pro model	30
Cost estimation process	**54**
Quantity calculation by Revit	12
Set up the price	42
Total	**402**

4.3. Comparative Analysis of Survey Results

Figure 7 illustrates the total duration of the traditional workflow compared to the BIM-assisted workflow from the survey results. The BIM-assisted workflow took less time to produce output items than the traditional workflow, 60 h less.

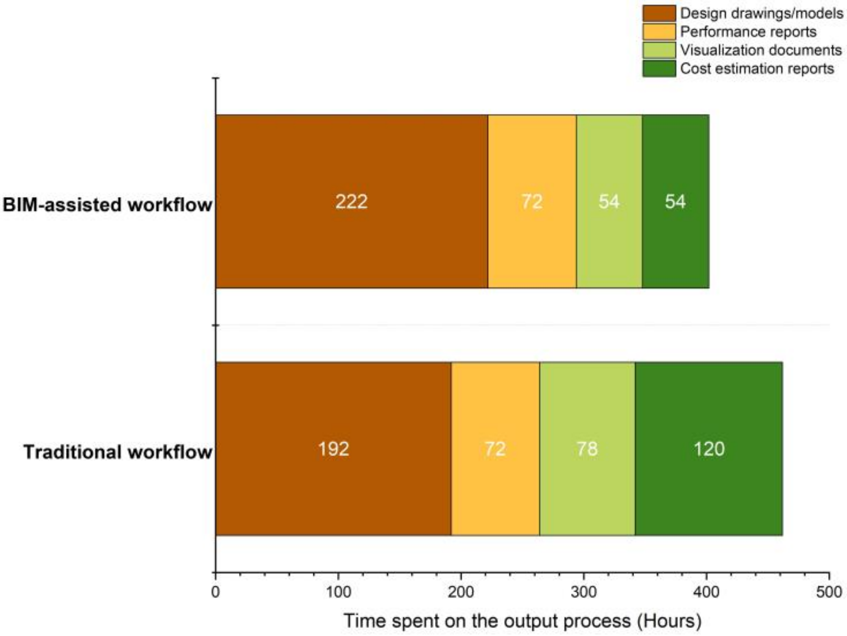


Figure 7. Total duration comparison of both workflows.

The comparison results also allow observing the time spent difference for each process of both workflows. The design drawings/models of the traditional workflow consumed 192 h, in contrast to 222 h for the BIM-assisted workflow, which took 30 h more. The time taken for the performance reports in the traditional workflow was the same as the BIM-assisted workflow: both 72 h. The BIM-assisted workflow consumed 54 h to produce the visualization documents compared to 78 h for the traditional workflow. The traditional workflow spent almost 1.5 times as long as the BIM-assisted workflow in the visualization process. The calculation of the cost estimate reports in the traditional workflow took 120 h, while the BIM-assisted workflow was just 54 h. The time required for BIM to evaluate costs was 55% less than the process in the traditional workflow. Thus, it is initially evident that the BIM-assisted workflow outperforms the traditional workflow efficiency.

4.4. Implementation of BIM-Assisted Workflow

4.4.1. Central Revit Model Process

To establish the Revit model of the parking lot case, the building project was divided into architectural, structural, and MEP sections based on its components. As shown in Figure 8, the task of the designing solution was performed by modeling each part individually.

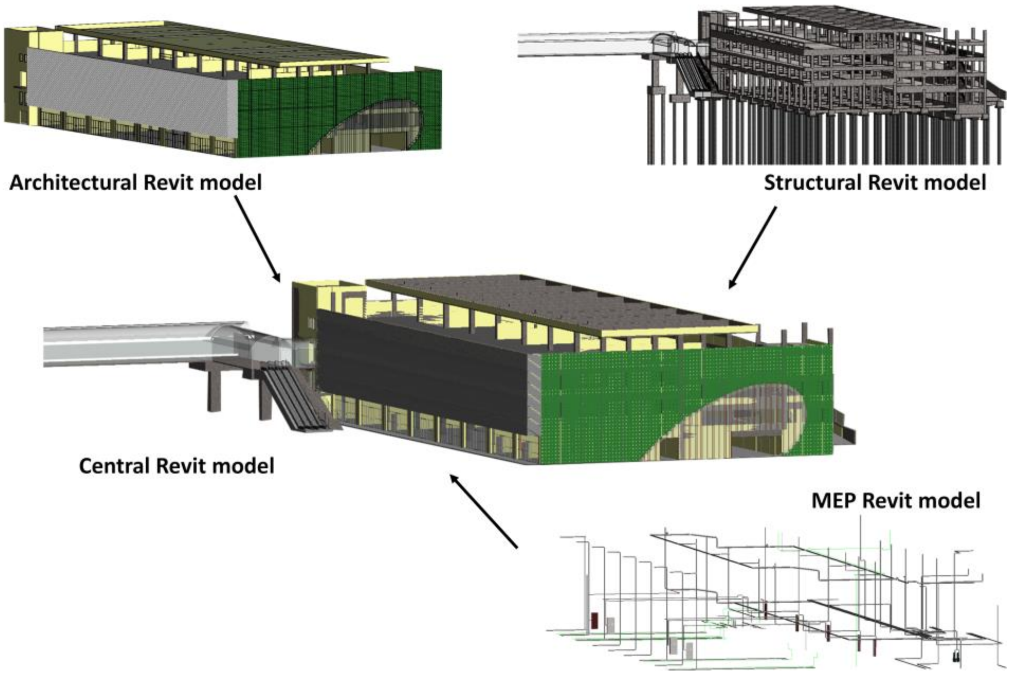


Figure 8. Central Revit model of a parking lot.

4.4.2. Energy Performance Process

Visual programming of direct sun hours and incident radiation was created to capture daylight time and radiation during summer and winter in Shanghai, China. Figure 9 displays the model results. The maximum direct sun hours exceed 14 h per day in summer and 10 h per day in winter. The average daylight time at the surrounding building-influenced sites remains about 7 h per day in summer compared to only 2–3 h in winter. In addition, the roof is exposed to direct solar radiation from the north and south sides during summer, producing a maximum energy of over 135.32 kWh/m^2. Due to the concentration of incident light on the south side, the south facade and roof are mostly illuminated for winter. Meanwhile, the north side is not heavily illuminated, generating a maximum of over 57.26 kWh/m^2 of radiant energy.

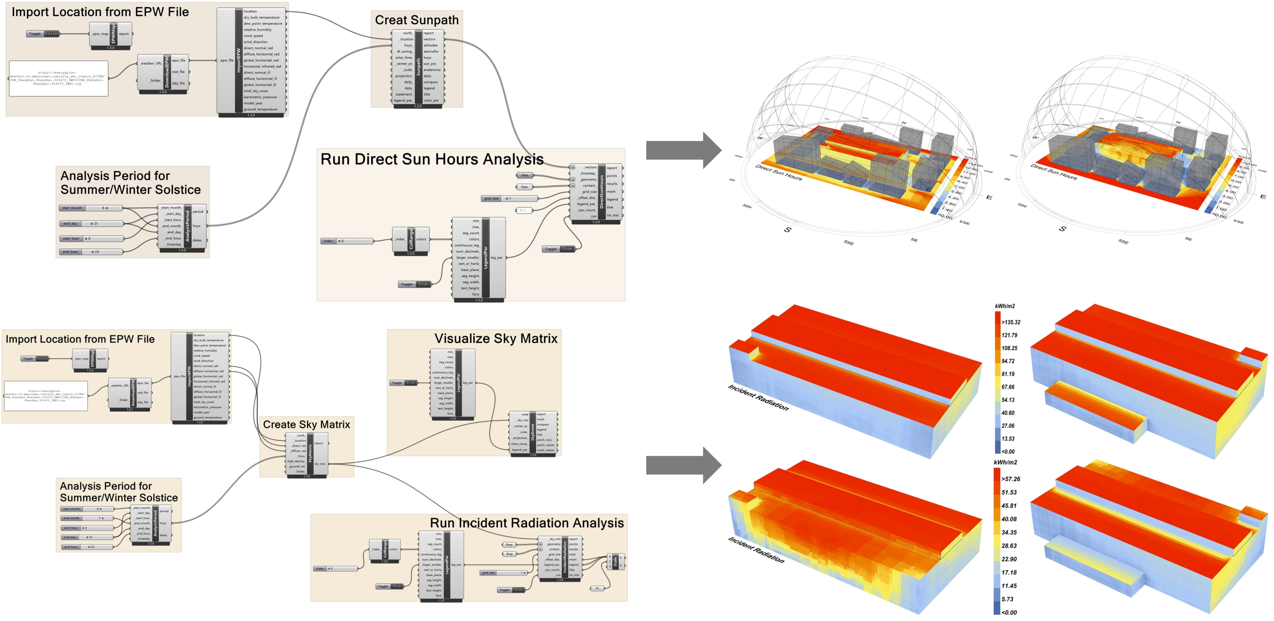


Figure 9. Energy performance analysis.

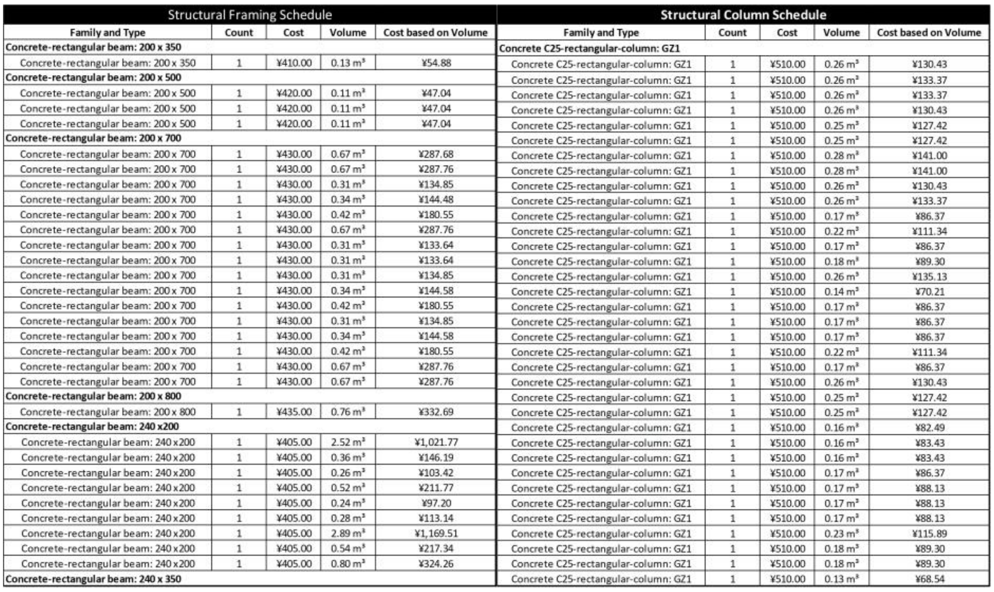
4.4.3. Visualization Process

Lumion and Synchro Pro implemented the visualization process. The rendering capabilities of Lumion were utilized to produce exterior rendering images and videos to visualize the external details of the building. Figure 10 presents the vertical view, front view, and side view. The rendering video can be found in the Demo_Lumion rendering video.mp4 linked to Mendeley data. Moreover, Synchro Pro combined the model and schedule to create an animation that displays the exact construction process with video. The construction animation is shown in the Demo_Synchro Pro animation video.mp4 attached to Mendeley data.

Figure 10. Exterior rendering images.

4.4.4. Cost Estimation Process

Revit automatically calculated the corresponding QTO based on the type and quantity of components. The unit price was defined as the quotation standard in Shanghai and adjusted for the actual situation to achieve an accurate budget result. To facilitate a quick inspection by clients and reviewers later, converting the cost estimation report in Revit to an Excel sheet is necessary; e.g., in Figure 11, the schedule was imported into Excel in TXT format in the Reporting option of Revit, and the table details were customized to achieve the cost estimation in XLSX format.



Structural Framing Schedule				
Family and Type	**Count**	**Cost**	**Volume**	**Cost based on Volume**
Concrete-rectangular beam: 200 x 350				
Concrete-rectangular beam: 200 x 350	1	¥410.00	0.13 m³	¥54.88
Concrete-rectangular beam: 200 x 500				
Concrete-rectangular beam: 200 x 500	1	¥420.00	0.11 m³	¥47.04
Concrete-rectangular beam: 200 x 500	1	¥420.00	0.11 m³	¥47.04
Concrete-rectangular beam: 200 x 500	1	¥420.00	0.11 m³	¥47.04
Concrete-rectangular beam: 200 x 700				
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.67 m³	¥287.68
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.67 m³	¥287.76
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.31 m³	¥134.85
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.34 m³	¥144.48
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.42 m³	¥180.55
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.67 m³	¥287.76
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.31 m³	¥133.64
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.31 m³	¥133.64
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.31 m³	¥134.85
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.34 m³	¥144.58
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.42 m³	¥180.55
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.31 m³	¥134.85
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.34 m³	¥144.58
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.42 m³	¥180.55
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.67 m³	¥287.76
Concrete-rectangular beam: 200 x 700	1	¥430.00	0.67 m³	¥287.76
Concrete-rectangular beam: 200 x 800				
Concrete-rectangular beam: 200 x 800	1	¥435.00	0.76 m³	¥332.69
Concrete-rectangular beam: 240 x200				
Concrete-rectangular beam: 240 x200	1	¥405.00	2.52 m³	¥1,021.77
Concrete-rectangular beam: 240 x200	1	¥405.00	0.36 m³	¥146.19
Concrete-rectangular beam: 240 x200	1	¥405.00	0.26 m³	¥103.42
Concrete-rectangular beam: 240 x200	1	¥405.00	0.52 m³	¥211.77
Concrete-rectangular beam: 240 x200	1	¥405.00	0.24 m³	¥97.20
Concrete-rectangular beam: 240 x200	1	¥405.00	0.28 m³	¥113.14
Concrete-rectangular beam: 240 x200	1	¥405.00	2.89 m³	¥1,169.51
Concrete-rectangular beam: 240 x200	1	¥405.00	0.54 m³	¥217.34
Concrete-rectangular beam: 240 x200	1	¥405.00	0.80 m³	¥324.26
Concrete-rectangular beam: 240 x 350				

Structural Column Schedule				
Family and Type	**Count**	**Cost**	**Volume**	**Cost based on Volume**
Concrete C25-rectangular-column: GZ1				
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥130.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥133.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥133.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥130.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.25 m³	¥127.42
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.25 m³	¥127.42
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.28 m³	¥141.00
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.28 m³	¥141.00
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥130.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥133.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.22 m³	¥111.34
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.18 m³	¥89.30
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥135.13
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.14 m³	¥70.21
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.22 m³	¥111.34
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.26 m³	¥130.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.25 m³	¥127.42
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.25 m³	¥127.42
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.16 m³	¥82.49
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.16 m³	¥83.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.16 m³	¥83.43
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥86.37
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥88.13
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥88.13
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.17 m³	¥88.13
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.23 m³	¥115.89
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.18 m³	¥89.30
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.18 m³	¥89.30
Concrete C25-rectangular-column: GZ1	1	¥510.00	0.13 m³	¥68.54

Figure 11. Sample of cost estimation report in Excel.

4.4.5. Duration Results of BIM-Assisted Workflow Simulation

The BIM-assisted workflow was measured in its time consumption in a practical operation that aims to validate the credibility of the survey results. In Figure 12, the simulation operated from September 1 to November 26. The working days in the period were Monday to Friday, and each working day was calculated in 6 h units.

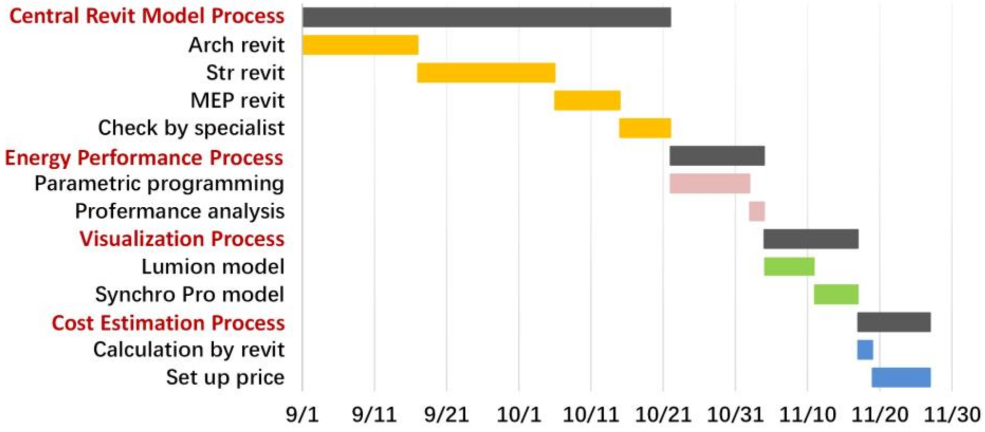


Figure 12. Period of BIM-assisted workflow simulation.

According to the operation time records of the simulation, the duration of the BIM-assisted workflow is summarized in Table 4. The central Revit model process took 222 h, the energy performance process required 54 h, the visualization process took 54 h, and the cost estimation process took 48 h. Thus, the total duration of the BIM-assisted workflow was 378 h.

Table 4. Duration results of BIM-assisted workflow simulation.

Processes of BIM-Assisted Workflow	Required Time (Hours)
Central Revit model process	**222**
Architectural Revit model	72
Structural Revit model	78
MEP Revit model	42
Specialists check the central Revit model	30
Energy performance process	**54**
Grasshopper parametric programming model	42
Energy performance analysis	12
Visualization process	**54**
Rendering image and video of Lumion	30
Construction animation video of Synchro Pro	24
Cost estimation process	**48**
Quantity calculation by Revit	12
Set up the price	36
Total	**378**

5. Discussion

5.1. Comparative Analysis of Design Approaches

Although the BIM-assisted workflow needs less time in preliminary design, the time consumption on each design activity is not all. Figure 13 illustrates the differences in the tools available to complete the preliminary design between both approaches.

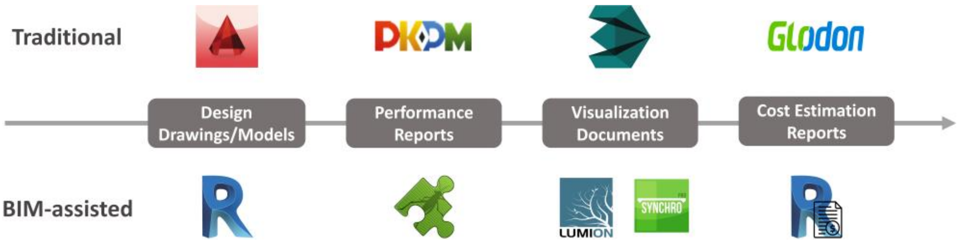


Figure 13. Approach comparison of both workflows.

Regarding the design drawings/models for preliminary design, the questionnaire results show that the traditional approach took less time, and the BIM simulation confirmed that the production of the Arch-Str-MEP Revit model lasted longer. The 2D and 3D design approaches differ in difficulty, and the traditional approach does have an advantage only in this process. On the other hand, the review time of the owner/expert is flexible, depending on its involvement. Design drawings/models are suggested in 2D to provide basic assistance for 3D to enhance the operational efficiency of the BIM-assisted preliminary design workflow.

During the energy performance analysis production, the Grasshopper parametric programming time exceeded the PKPM modeling significantly through the comparative survey results, but the duration obtained from the practical simulation was closer to the traditional approach. The subsequent time spent on data analysis resulted in a more efficient BIM approach for survey and simulation. The parametric representation of the energy performance replaces the traditional modeling analysis with a logical algorithm to be more accurate in predicting the outcomes, even though it is slightly more time consuming.

The traditional preliminary design employed a single tool for the visualization tasks and asked for a new model to be rendered. The BIM approach applied two tools to create renderings and animations separately, but the comparative questionnaire results found that this approach took less time, and the simulation also validated this result. Repeated modeling is the key to the issue. Even though the BIM-assisted workflow requires multiapplications and the BIM flow can provide unhindered linkage to avoid duplicate modeling, this feature is particularly significant for the preliminary design of architecture.

The cost estimation through questionnaire results comparison can determine that the BIM approach benefits the preliminary design. After the practical simulation, it was found that the BIM approach applied to the appraisal brought the potential for more time saving. It was not only the efficiency that could be improved by reducing Repetitive modeling but also by generating QTO based on the Revit model to achieve bidirectional connection. Therefore, the approach is suggested to be strongly promoted for the preliminary design.

5.2. Duration Influencing Factors

There was a time discrepancy between both workflows, and this research further evaluated the influencing factors. The specific analyses of the influencing factors are listed below:

Repetitive 3D modeling: Repetitive 3D modeling means that a significant amount of time is devoted to performing the same tasks. The traditional workflow involved transferring CAD drawings to other design phases and stakeholders building 3D models to fit the corresponding analysis software or post-design software. In contrast, stakeholders in the BIM-assisted workflow could complete design requirements directly based on the central Revit model, thereby increasing design efficiency.

Incompatible format: The data transfer in the traditional workflow could not be operated by stakeholders promptly due to incompatible file formats. For instance, when clients checked multiple design outputs, there was no possibility to compare because of different formats. Even though the BIM-assisted workflow involved various design software, the incompatible file formats could be solved without any obstacles by installing the corresponding plug-ins in Revit, thus alleviating the problem of poor design connections.

Manual calculation: Given companies' gradual acceptance and stabilization of existing traditional workflow, this situation makes a leapfrog upgrade in technology impossible, resulting in continued reliance on manual work. In particular, although the budget report was completed with Glodon, the quantity calculation remained dependent on manual calculation. The central Revit model in the BIM-assisted workflow could automatically calculate the usage of each type of component, which enhanced the efficiency and reduced the cost deviation caused by manual errors.

Communication platform: The lack of a unified platform in the preliminary design process affects the communication among relevant stakeholders. Task activities in the traditional workflow were more independent than those in the BIM-assisted workflow, and the non-uniform data exchange feature might cause delays in communication between stakeholders. However, the BIM-assisted workflow depended on BIM to enhance the real-time data sharing among the stakeholders involved, replacing batch processing with continuous information flow.

Idle time: Idle time generated in the data exchange between design activities is one of the significant causes of time wastage. The process model in this study indicated that the traditional workflow had more idle time than the BIM-assisted workflow because no standardized communication pattern was defined. The BIM system could minimize the generation of idle time to prevent schedule delays.

Client involvement: The long interval between clients' feedback in the preliminary design affects the efficiency. The client reviewed the CAD drawings in the traditional workflow in multiple sections in sequence, and such a mechanism hindered the coherence of the design workflow. However, the BIM-assisted workflow completed the various sections through the Revit model and allowed the client to review the model in parallel, increasing operational flexibility and efficiency.

5.3. Limitations

The integrated application of a multi-BIM-assisted workflow plays a critical role in improving the preliminary design efficiency. The study employed traditional and BIM-assisted methods and evaluated the entire cycle data to demonstrate the efficiency gains of BIM tools for preliminary design. However, some limitations may have implications for further research.

BIM limitations: BIM technology serves an enhanced role in preliminary design, but the tool still has inaccuracies. For instance, Grasshopper, the energy performance analysis application in the research, was helpful for fenestration and apertures of the building complex but lacked in-depth and direct impact, recommending the introduction of more effective tools, such as Autodesk Insight [61]. In addition, the investment in hardware equipment and software licenses required for BIM is relatively high [62]. Architectural design firms may not adopt the increased initial investment, preferring traditional design methods with lower initial costs. In addition, decision-makers steadily apply conventional methods and are conservative about introducing new technologies, making it difficult for BIM-assisted workflow to be widely used [63].

Case scope: The case and industry regulations were based on the China region, but this paper only focused on Shanghai as the research object, which would not fully reflect the application of preliminary design in China. Therefore, it is necessary to introduce multiple locations in China as objects in subsequent studies to improve the result accuracy. Additionally, it is suggested that future work could be conducted to explore the differences between China and East Asia to expand the research scope.

Survey amount: Both workflows adopted a questionnaire with a valid number of 85. Although the AEC industry provided the survey responses, the current survey amount may be inadequate to achieve comprehensive results. The survey amount needs to be expanded in subsequent research to improve the data's reliability.

6. Conclusions

This research demonstrates that the BIM-assisted workflow enhances the preliminary design efficiency of architecture. This study has successfully established process models to define traditional and BIM-assisted workflows to produce design drawings/models, performance reports, visualization documents, and cost estimation reports. The actual design efficiency discrepancy was measured by comparing the time required to implement both workflows. Both workflows adopted a questionnaire to collect duration data from the target group. The BIM-assisted workflow then validated the credibility of the survey results by the simulation. The survey data results of both workflows presented 462 h for the traditional workflow and 402 h for the BIM-assisted workflow. The implementation time for the BIM-assisted workflow was 378 h, which indicates that the BIM-assisted workflow is significantly more efficient than the traditional workflow.

This study reveals the potential implications of BIM tools for preliminary design. BIM for energy performance analysis, visualization, and cost estimation demonstrated absolute advantages over preliminary design, strengthening design efficiency and improving its quality. Although design drawings/models were more time consuming than the traditional approach, BIM could cover the whole design process, leading to an overall efficient design. It implies that the study validates the efficiency of single-function BIM for each preliminary design activity. Furthermore, it fills the current research gap on the practical efficiency impact of full BIM flow on the preliminary design. The industry has neglected BIM application in the preliminary design of architecture in the past, and the research findings can facilitate construction companies to enhance the involvement of BIM in the preliminary design. The study results also show that 2D took less time, but 3D allows for direct extensions to subsequent design activities, and it fulfills the needs of the e-tendering trend, for which 3D still benefits. Therefore, the entire BIM workflow for preliminary design deserves to be further promoted in the Chinese AEC industry.

The BIM-assisted workflow in this research utilized several BIM software to perform preliminary design using the Revit model as the design basis with plug-ins to achieve a joint operation with other design activities to reduce design time. Based on the comparison of the characteristics of both workflows, several factors were analyzed for the BIM-assisted workflow to improve efficiency: (1) no duplicate modeling, (2) good format compatibility, (3) automatic calculation, (4) data integration platform, (5) low idle time, and (6) high client involvement. Limitations in the study have hindered the research findings. BIM shortcomings affect the practical simulation steps, resulting in data not reaching the desired state. The case scope limits the study to one region or building type, influencing the adaptability of the findings to particular situations. The insufficient survey amount also affects the survey accuracy. Given the current research limitations, the implications for future research are introducing advanced technology optimization in the BIM flow and analyzing other countries for preliminary design applications, thus exploring more efficient preliminary design solutions for the development of the AEC industry in China.

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