Application mode analysis and adaptive design exploration of BIM technology

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Abstract. Scientific and technological innovation, energy conservation and environmental protection are the theme of the development of the construction industry, as well as the goal of designing and building modern architecture. BIM is a design tool that has not been popularized in the whole process. In China, it still mostly adopts hierarchical, business object and phased transitional implementation scheme. This study focuses on the phases of BIM in domestic development goals, based on the related literature, combining with the application of BIM in architecture design phase (phase scheme and deepen), by trying to "process" and "open" the application of model analysis, studying the typical BIM technology combined with the localization design process and the architect role change; The characteristics and structural principles of the model reference adaptive design model are studied, and the simulation results show that the model reference adaptive design model with measurable state variables can not only find the adaptive law of parameter adjustment, but also ensure the stability of the system.

1. Introduction
With the introduction of domestic BIM design and construction technology and the continuous improvement of software system, as well as the continuous expansion of the construction goal of "low-carbon eco-city", the development momentum of BIM has been continuously rising in recent years [1]. Not only in the scope of design, has the construction sided, the owner of the government to its considerable evaluation and expectations [2]. The department of safety and quality supervision of the ministry of housing and urban-rural development issued the general idea for the work in 2013, saying that it will guide and promote the development of green construction, study the role of BIM technology in the construction field, study and establish the evaluation system of design know-how technology, and improve the technical capacity of survey and design industry and the level of construction industrialization [3]. In particular, the information development outline of the "twelfth five-year" construction industry proposes to "promote the application extension of BIM technology from the design stage to the construction stage, and reduce the attenuation in the information transmission process [4]. The application of 4D project management system based on BIM technology in the construction of large and complex projects is studied to realize effective visual management of construction projects. These national policies and opportunities indicate that BIM technology has been widely valued and promoted in political decision-making and development strategies, and that BIM is regarded as the core technology means to realize informatization construction in China to increase the practical driving force of BIM technology [5].

BIM technology practice is mainly driven by process and technology trends. On the one hand, based on different stages of the project, participants and model levels, the implementation content and job responsibilities are divided to adapt to the project needs and work mode customization, which is the
overall grasp of process scope. On the other hand, starting from the technology itself, the BIM tool research and development institute will explore many implementation approaches and improve the tool performance efficiency, which is the adaptive adjustment of the technical organization [6].

BIM has become a widely discussed topic in the global construction industry, especially the reform of design thinking and technological means, as well as application methods and implementation plans, which deserve to be further discussed [7-10]. The concept of BIM covers the whole cycle process of architecture, including design, construction, operation and maintenance. However, at present, there is not a whole process BIM system that can undertake all stages of application and benefit display. China's BIM promotion is mainly reflected in the application with design enterprises as the main body, that is, an application pattern of stratification and business object from design to construction. In analysis and solving the problem of BIM in the design application practice, to the application of BIM in the design phase, combing the including BIM combined with the design process and auxiliary design construction, based on its application goal and characteristics to establish adaptive and open BIM design system, combined with a large number of case analysis, project practice application way, combing the design process, to explore the adaptive design strategies and methods for BIM technologies.

2. BIM technology design application mode analysis

2.1. Application stage and design process

In theory, BIM involves the whole life cycle of a building, but the significance of combing through the design process as a technology decision-making judgment cannot be ignored. The design process involves three elements: time, space and people. People as the main body of design process, is also the BIM application of the main body, the way of thinking and the design behavior is determined by the order of the work process of decision making and promote weaving: item [fl design from planning to completion on time and space continuity, determine the design process is not linear models or simple loop, but cycle transition and has risen in a spiral pattern over and over again. Any type of building, the design stage according to the design results provided by the different times, make it as a necessity of complexity of the work. To be specific, can be divided into the following seven stages: (1) design in the early stage work: (2) the scheme design stage; (3) the preliminary design stage: (4) technical design stage: (5) construction drawing design phase: (6) phase of construction technical guidance and management; (7) after using the assessment phase. 1 so that the essence of research is to realize the rationalization and personalized full coordination. This study aimed at above be discriminating and simplify the design stage, analyzes application of BIM design process, focusing on the analysis of the scheme design and design process project design features combined with BIM application way.

2.2. Scheme design stage

(1) job overview and implementation role

The BIM technology platform introduces the conceptual design environment in the early stage of the scheme, enabling architects to weigh the conceptual scheme, project feasibility and BIM operability. Create and edit free 3d shapes and contours according to flexible design requirements. At the conceptual design stage, architects need to conduct conceptual analysis according to the design task book, which is to generate the architectural prototype. Architects use simple forms to interpret their ideas and display them through virtual or physical models. The core of this process is the construction of geometric logic in the form of building volume composition, featured building components, as well as the logical relationship between buildings and environment and components, etc. 2. As a key node of the design process, the proper choice of technology has a great influence on the following working mode.

(2) BIM design research

This process is mainly induced by two types of design process, including the pre-generation of architectural forms by design algorithm and the rational design adjustment of existing architectural forms based on non-parametric design methods. Provide multi-scheme technical parameters and decision reference through BIM, and analyze feasibility of implementation through parameter
information and interaction. Using virtual architectural design and automatic drawing generation and free to change management functions, BIM is optimized for complex shaped buildings, including physical and chemical surface morphology and internal streamline space integration. Meanwhile, BIM model will be used for building performance, sunshine, daylighting, energy consumption and evacuation analysis, which will provide an important overall optimization process for architectural design.

2.3. **Deepen the design stage**

(1) deepening of BIM design in localization mode:

The design basis and requirements of the concept plan make the interior of the building have a reasonable layout and functional streamline, while the exterior of the building is mostly covered by the complex shape embedded in the exterior. For the project design in the early stage, which is mainly represented by the two-dimensional design and non-parametric model, the BIM model is introduced in this stage. On the one hand, the two-dimensional design results of the scheme are verified by three-dimensional integration, and the architectural details are deepened. On the other hand, it can manage and adjust the positioning description of existing non-parametric models and non-standard components, form the "electronic sample" reference for building implementation, and integrate the process data information and transmit it to the construction drawing stage.

(2) BIM design deepening:

Based on the BIM model in the program design stage, conduct in-depth research analysis, update the parameters of the early model and refine the components according to the project design requirements and results. Many parameter information has been entered in the process of BIM model establishment, such as building components, material construction, setting of pipeline, model and installation information, etc. The in-depth design process of the project using BIM is the research focus of this paper, which will be specifically described in chapter 4.

2.4. **Data exchange mode**

The BIM software involved in the design phase is mainly composed of visual modeling software and computational and analytical software. It is related to the design habits of architects and relevant personnel, as well as the application range and docking method carried by the software. The design stage is mainly centered on the establishment of BIM model, supplemented by calculation, analysis and expansion application. Project participants involved in ahead of time, especially the design phase, in theory, promote the reasonable project cycle shortened, and the current domestic design cycle compression stress state of reality, the overall cycle has not decreased significantly, but the design phase of the work content and the results further, f chung cover some traditional processes subsequent stages of the implementation of the content, the designer early BIM for relevant analysis and detection, reduce the mapping error, decrease the cost of error correction. In addition, the design of verification has also shifted from 2d to 3d verification based on BIM model, realizing the transition from staged coordination to real-time collaborative review.

3. **Adaptive design model design**

3.1. **Characteristics of reference adaptive design model**

Model reference adaptive system is a kind of important adaptive design model, which is characterized by no need of performance index transformation, easy implementation and fast adaptive speed, and has been applied in many fields.

For systems whose mathematical models of Design objectss are difficult to know in advance or whose mathematical models often change, conventional control is often difficult to achieve better control effects, and model reference adaptive control can deal with such control problems. It does not need to identify the Design objects online. The controller parameters of the model reference adaptive system are constantly adjusted with the change of object characteristics and environment, so that the system has strong adaptability. As long as an appropriate reference model is established on the premise
of satisfying the control requirements, the time required for adaptive control can be small enough, so that the process of parameter variation of the Design objects is much slower than the time response of the reference model and the object itself.

![Reference adaptive design model structure diagram](image)

**Figure 1.** Refer to the adaptive design model structure diagram

### 3.2. The structure of the reference adaptive design model

The typical structure of the reference adaptive design model is shown in figure 1. It mainly consists of reference model, adjustable system and adaptive mechanism, in which the adjustable system includes Design objects and adjustable controller.

The reference model is an ideal control model, which makes the reference adaptive design model different from other forms of control. Between the reference model and adjustable system performance by adaptive mechanism to ensure the consistency and performance consistency process can be adjustable system error between the reference model and the state vector or output error vector is measured, the adaptive mechanism according to reduce the deviation in the direction of the revision or update the control law, so that the performance of the system at or close to the expected performance index.

### 3.3. Reference adaptive design model of measurable state variables

Usually adopted local parameter optimization method to design the model reference adaptive design has the disadvantage of not stable, Parks, Narendra and Goodwin successively put forward using lyapunov stability theory design reference adaptive control law design model, which is both the adaptive laws of parameter adjustment, and ensure the stability of the system.

When the state variables of the Design objects are all measurable, a reference adaptive design model can be designed. Compared with the scheme of reference adaptive design model designed by gradient method, the system designed by this method can guarantee the stability of the system.

Let the object equation of state be

\[
x_p = A_p x_p + B_p u
\]  

Where, \( A_p \) and \( B_p \) are \( n \times n \) and \( n \times m \) constant matrix, \( x_p \) is \( n \)-dimensional state vector, and \( u \) is \( m \)-dimensional control (\( n \) and \( m \) are known dimensions).

Take the state equation of the reference model as:

\[
x_m = A_m x_m + B_m y_r
\]  

In the formula, \( A_m \) and \( B_m \) are the ideal constant matrix in the same row as \( A_p \) and \( B_p \), \( x_m \) is the state vector of \( n \)-dimensional model, and is the input of \( m \)-dimensional.

The adjustable state feedback controller \( F \) and feedforward controller \( K \) (as shown in figure 2) are adopted to form the adjustable system. By figure 2 know
Figure 2. Reference adaptive design model structure for measurable state variables

Where, $K$ is feedforward controller gain matrix ($m \times m$) and $F$ is feedback controller gain moment ($m \times m$).

Substitute equation (3) into equation (1)

$$x_p = (A_p + B_p F)x_p + B_p K y_r$$  \hfill (4)

When $F$ and $K$ are adjusted to make $x_p$ consistent with $x_m$, the model matches the object, so there is

$$A_m = A_p + B_p F^*$$  \hfill (5)

$$B_m = B_p K^*$$  \hfill (6)

In the formula, $F^*$ and $K^*$ respectively represent the values of $F$ and $K$ when matching, which are also the values of the stable state we want.

In order to obtain adaptive control rules, the generalized state error is defined:

$$e = x_m - x_p$$  \hfill (7)

There are

$$e = x_m - x_p$$

Substitute equations (1) and (2) into the above equation

$$e = A_m e + (A_m - A_p - B_p F)x_p + (B_m - B_p K)y_r$$

By equation (5) and equation (6), the $A_p$ and $B_p$ of above equation are eliminated

$$e = A_m e + B_m (K^*)^{-1}(F^* - F)x_p + B_m (K^*)^{-1}(K^* - K)y_r$$

Let

$$\tilde{F} = F^* - F^* \quad \tilde{K} = K^* - K$$

Then the above expression can be written as

$$e = A_m e + B_m (K^*)^{-1} x_p + B_m (K^*)^{-1} \tilde{K} y_r$$  \hfill (8)

Let the lyapunov function be

$$V = \frac{1}{2}[e^T P e + tr(\tilde{F} R_1^{-1} \tilde{F}^* + tr(K^* R_2^{-1} K^*))]$$
Where, P is positive definite symmetric \( n \times n \) matrix; Tr is a mathematical symbol trace.
\[
\frac{dV}{dt} = \frac{1}{2} [e^T Pe + e^T P e + tr(F R_1^{-1} F + F R_1^{-1} F) + tr(K R_2^{-1} K + K R_2^{-1} K)]
\]

Substitute equation (5) into the above formula
\[
\frac{dV}{dt} = \frac{1}{2} [e^T (A_m^T P + PA_m) e] + e^T PB_m (K^*)^{-1} F x_p + e^T PB_m (K^*)^{-1} K y_r +
\]
\[
\frac{1}{2} tr(F R_1^{-1} F + F R_1^{-1} F) + \frac{1}{2} tr(K R_2^{-1} K + K R_2^{-1} K)
\]

The second and third terms on the right side of the above equation are both scalar quantities, according to the property of the matrix trace: \( x^T Ax = tr(xx^T A) \) \( \Rightarrow trA = trA^T \),
\[
e^T PB_m (K^*)^{-1} F x_p = tr(e^T PB_m (K^*)^{-1} F x_p) = tr(x_p e^T PB_m (K^*)^{-1} F)
\]
\[
e^T PB_m (K^*)^{-1} K x_p = tr(e^T PB_m (K^*)^{-1} K x_p) = tr(x_p e^T PB_m (K^*)^{-1} K)
\]
\[
tr(F R_1^{-1} F) = tr(F R_1^{-1} F) \quad tr(K R_2^{-1} K) = tr(K R_2^{-1} K)
\]

Since \( A_m \) is a stable matrix, the positive definite symmetric matrix Q can be selected, which makes the following formula true:
\[
A_m^T P + PA_m = -Q
\]
Q is a positive definite symmetric matrix, and equation (9) can be written as
\[
\frac{dV}{dt} = \frac{1}{2} e^T Q e + tr(x_p e^T PB_m (K^*)^{-1} F + F R_1^{-1} F) + tr(y_r e^T PB_m (K^*)^{-1} K + K R_2^{-1} K)
\]

If the second and third terms on the right end of the above equation are both zero, then there are
\[
\tilde{F} = -R_1 [B_m (K^*)^{-1}]^T P e_{x_p}^T, \quad \tilde{K} = -R_2 [B_m (K^*)^{-1}]^T P e_{y_r}^T
\]
According to the definition of F and K, there are
\[
\tilde{F} = -\tilde{F} = R_1 [B_m (K^*)^{-1}]^T P e_{x_p}^T, \quad \tilde{K} = -\tilde{K} = R_2 [B_m (K^*)^{-1}]^T P e_{y_r}^T
\]
Or write it as an integral
\[
F(t) = \int_0^t R_1 [B_m (K^*)^{-1}]^T P e_{x_p}^T dt + F(0)
\]
\[
K(t) = \int_0^t R_2 [B_m (K^*)^{-1}]^T P e_{y_r}^T dt + K(0)
\]
In the formula, F (0) and K (0) are the initial values.
Given that R1 and R2 are somewhat arbitrary, write
\[
\tilde{R}_1 = R_1 ((K^*)^{-1})^T, \quad \tilde{R}_2 = R_2 ((K^*)^{-1})^T
\]
At this point, equation (10) becomes
\[
\frac{dV}{dt} = \frac{1}{2} e^T Q e^{-1} < 0
\]
The adaptive control law determined by equation (11) or equation (12) is globally asymptotically stable when input is continuous

\[ \lim_{t \to \infty} e(t) = 0 \]

From (11) or (12), to calculate \( F(t) \) and \( K(t) \) expression, must know \( t \) information, all of the information the state variables of the object, which is difficult in many occasions, unless with state observer, so this method is only applicable to all state variables can be measured, or with the aid of observer to achieve control.

4. Conclusion

BIM is a new working mode, which can obtain correct, unique, continuous and consistent information through close cooperation and smooth communication. Aiming at the application status of BIM in the design stage at home and abroad, this paper focuses on discussing the localized design application patterns of hierarchical, staged and business objects by combing the design process and project features. BIM is a design tool that has not been popularized in the whole process. In China, it still mostly adopts hierarchical, business object and phased transitional implementation scheme. This study focuses on the phases of BIM in domestic development goals, based on the related literature, combining with the application of BIM in architecture design phase (phase scheme and deepen), by trying to "process" and "open" the application of model analysis, studying the typical BIM technology combined with the localization design process and the architect role change; The characteristics and structural principles of the model reference adaptive design model are studied, and the simulation results show that the model reference adaptive design model with measurable state variables can not only find the adaptive law of parameter adjustment, but also ensure the stability of the system.

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