The BIM Lifecycle Management of Manufacturing Cultural Heritage Projects

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Abstract. As a popular cultural heritage in China, the Lingnan architecture is increasingly adopting prefabricated construction to meet the growing need in building projects exhibiting the unique culture of the region, which can be enhanced by BIM technology. As most BIM related research focuses on particular phases of a project, there lacks of a study on the BIM lifecycle management, particularly on manufacturing cultural heritage projects. Hence, this research analogizes the BIM lifecycle management to the evolution of biological agents, and constructs the self-organizing relationship complex of BIM application key items and BIM application technology prototype, taking this as the cornerstone to develop a lifecycle BIM management framework and form an operation theory for manufactured heritage buildings, which are verified through a case study.

1. Introduction

As one of the traditional Chinese architecture, Lingnan heritage buildings are characterized by exquisite outlook, flexible spatial organization, harmonious decoration with folk customs and the natural environment. Over a long history, they have absorbed the excellent space and decorative elements of China and the West, and have evolved to a form with great vitality. Lately, under the vigorous promotion of traditional culture, Lingnan's architectural style has become a symbolic element in many places of interest and urban areas to exhibit the unique culture of the region.

The traditional construction method has many drawbacks, including severe environmental pollution, long construction duration, and inconsistent quality, etc. Due to the requirement of stable characteristics of heritage buildings, prefabricated construction is increasingly adopted in practice. Nonetheless, manufacturing requires an integrated industrial supporting system, and the key lies in the application of digital technologies (e.g., BIM) in the project lifecycle.

A few researchers explored the integration of manufacturing with digital technology on heritage projects. For instance, Sun et al. used a BIM model for traditional Lingnan residential buildings, and found several advantages due to its information storage [1]. Liu built a BIM model based on a point cloud for heritage buildings [2]. Liu proposed the integration of 3D laser scanning with BIM technology to assist prefabrication product control from production to installation process [3]. Sun proposed a solution to the management challenges with prefabrication products using BIM and internet [4]. Hu et al. established a procedural modeling method for Chinese heritage buildings to quickly built the model structure [5]. Ramaji et al. proposed a modular information transmission framework for BIM to improve the system of industrialized building products [6]. Ke et al. developed a BIM system to collect
information about the manufacturing process and improve the efficiency of assembly of the components [7].

To sum up, the existing research focused on particular phases of a project, there is little research in the lifecycle management of the manufacturing project with digital technology support, and there are even fewer studies in heritage architecture. Hence, this paper proposes a BIM lifecycle management framework for the manufacturing construction of Lingnan heritage buildings, aiming to solve the problems associated with information fusion and model management in the lifecycle of heritage building projects.

2. Theoretical Basis
The Lingnan heritage buildings contain the characteristics of many architectural styles and their components can be flexibly combined to have various forms. For this particular type of prefabricated construction, it is important to consider the engineering needs of different stages, the linkage, and transmission of information between the stages, requirement changes, and workload of model changes in the process. The construction process of manufacturing buildings generally consists of five stages: planning, design, production, on-site assembly/installation, and operation and maintenance (O&M). In the early planning and design stages, it faces the problem with component selection, and later processing and on-site assembly due to the defective manufacturing collaboration and the frequent change of manufacturers and installation teams. Facing this complex situation, the viable solution is to integrate digital carriers with agile management of the related technologies.

Most engineering management adopted top-down and static control methods, which is not suitable for prefabricated construction. It is shown that the operation and development process of engineering projects can be analogized to the evolution of biological agents [8]. As the environment changes, biological agents can achieve intergenerational selection, inheritance, and reproduction according to the principle of "survival of the fittest". Biological agents control the generational inheritance and evolutionary variation of biological populations through genes. Engineering projects from project conception to design and construction, as well as the O&M, are actually in an iterative process of planning and implementation guided by the requirements of the project owner and user. Therefore, engineering projects can also use bionic principles to restrict the orderly operation and development of projects through stable core technical elements. Furthermore, as the main digital carrier of manufacturing projects, BIM models act similar to biological agents. The continuous deepening and changes of its models with project requirements are analogous to the natural selection process of biological agents. The evolution of biological agents revolves around the two core elements: environmental action and biological genes, which form an orderly and constrained self-organizing system relationship. The management of the BIM model also revolves around similar elements, namely project requirements and model constraints.

Therefore, this paper focuses on the manufacturing Lingnan heritage buildings by analogizing to the evolution of biological agents and constructs the core elements for the BIM model management, that is, BIM application key items (i.e., projects requirements) and BIM application technology prototype (i.e., model construction constraint elements), and then interprets the self-organizing constraint relationship formed by the two throughout the project lifecycle [9].

3. Conceptual Framework
BIM application key items in this study refers to the standardized expression of BIM requirements for each stage of the manufacturing construction project lifecycle. It comes from project engineering requirements and is presented in a list of BIM requirements or project constraints posed by external factors. BIM technology prototype is the most simplified expression of the project's BIM construction and management scheme, which is equivalent to the genetic prototype of a biological agent. It is specifically manifested as the six core elements restricting the standardization of the BIM application. To make it self-organizing with the progress of the project, these elements are classified into two categories: modeling rules and model application rule. Hence, the project modeling and model operations rules are formed accordingly to guide the standardization of BIM applications. Figure 1 is an evolutionary analogy of the relationship between biological agents and BIM technology prototypes.
When the requirements of BIM application key items change, they can affect the model through BIM technology prototypes, so that the model will be changed accordingly, indicating an inevitable self-organizing relationship between BIM application key items and BIM technology prototype. Through the design of these organizational relationships, the construction and application of the BIM model can not only meet the needs of the project at each stage but also can be passed to the model control rules when the project needs change so that the model iteratively updates according to the project needs [9].

3.1. BIM application guidelines
The BIM application key items are based on the needs of the project stakeholders, combined with the project engineering logic and BIM technical characteristics, which form a tabulated list of critical points at each stage. This list serves as an important basis for project BIM application and also serves as a basic reference for cost estimation. Table 1 is the main list of BIM applications for manufacturing projects, which can meet the requirements of most projects.

3.2. BIM technology prototype
The BIM Technology Prototype consists of two categories with six elements. The modeling rules include classification and coding rules, modeling rules and model split rules. The model application rules include the collaboration mode of participants and model detail and function, and software platform and data exchange standards. These two interact to form a uniformed model management system. In practice, the generation or change of these rules is mainly caused by the BIM application key items, that is, the process operation elements are deduced from the project objectives.

3.2.1. Modelling rules. (1) Classification and coding rules: mainly refer to the classification and coding rules of components, that is, the division methods and coding regulations of various components. Components are generally divided into nine categories: foundation, platform foundation, ground, column, bucket arch, beam frame, roof, enclosure, decoration, etc., which have sub-categories. A reasonable classification is not only critical to the parametric reuse of components but also product processing and tracking. For manufacturing buildings, codes are mainly used for quantity takeoff, component production, installation, and O&M. Generally, three types of codes are used: project, production, and installation codes. (2) Modeling rules: refer to the construction relationship and methods of components. Taking fabricated columns as an example, they are generally divided into column footing, column body, and column cap. An integrated method is adopted in practice, but the corresponding BIM family model adopts the nested method for the sake of convenient parameter change and manufacturing combination adjustment. (3) Model split rules: based on the functional division of the building and the performance constraints of computer hardware, the building is properly split and managed according to needs, and the division method is generally divided by zone and layer. Heritage buildings are divided based on rooms. Generally, the number of floors of heritage buildings is small, and the area of single units is limited. Hence, most of them are split into single units. However, the new
heritage-style buildings can adopt a layering system and have modern and large spaces. Figure 2 is an illustration of the modeling rules.

### Table 1. BIM application key items of manufacturing projects.

| Project Phase   | Task Category          | BIM Technology Application Focus                                                                 |
|-----------------|------------------------|----------------------------------------------------------------------------------------------------|
| 1. Planning     | 1. Architectural planning | 1) Architectural style and style; 2) Factory component style; 3) Site construction and layout; 4) Scheme indicators; 5) Site engineering quantity statistics |
|                 | 2. Craftsmanship planning | 1) Project model construction; 2) Key component design; 3) Combination design of fabricated technology and model components; 4) Preliminary estimation of engineering quantity and cost; 4) Building green analysis; 5) Project rendering and drawing |
|                 | 3. Construction planning | 1) Architectural style and style; 2) Factory component style; 3) Site construction and layout; 4) Scheme indicators; 5) Site engineering quantity statistics |
| 2. Design       | 1. Schematic design     | 1) Export of design drawings; 2) Material cost budget; 3) Factory production model clarification; 4) Outer packaging coding design |
|                 | 2. Assembled design     | 1) Construction schedule and simulation; 2) Construction communication and coordination; 3) BIM animation assisted installation; 4) Site layout of on-site materials |
|                 | 3. Sustainability analysis | 1) Construction schedule and simulation; 2) Construction communication and coordination; 3) BIM animation assisted installation; 4) Site layout of on-site materials |
|                 | 4. Drawing              | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
| 3. Production   | 1. Engineering bill of materials | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 2. Coding for package design | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
| 4. Assembly/Installation | 1. On-site management of installers | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 2. Work together        | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 3. BIM site assistance  | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 1. Component information collection | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 2. O&M intelligent platform | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |
|                 | 3. Property Information Management | 1) Complete completion model; 2) Supplement necessary attribute information; 3) Intelligent platform operation; 4) Property information management and maintenance |

**Figure 2.** An illustration of the modeling rules.

3.2.2. **Model application rules.** (1) Participants and coordination methods: Participants refer to different entities involved in the production or use of BIM projects, and the rights and restrictions of model operation are based upon permissions. The collaboration method refers to the platform and working methods used by all parties in collaboration. The prefabrication of Lingnan heritage buildings involves multiple steps, such as design, production and processing, and on-site installation. Facing the same digital model carrier, if the authority and cooperation protocols are not clear, it will cause confusion in the process and seriously affect project implementation. (2) Model details and usage: Model details refer to the amount of information of the model at different stages, and the industry generally defines it based on the model's LOD depth level. Model usage refers to how the model is used at different stages. The assembly of Lingnan heritage buildings has different requirements about model details from schematic design to assembly design, and even the later processing of complex connections. Even if the depth levels are the same, the accuracy of different parts is deleted according to the requirements to reduce
unnecessary waste in the modeling work. For example, it only needs a contour model for components produced by quantity takeoff and non-detailed drawings. (3) Software platform and data exchange standards: Software platform refers to the software platform and tools used for modeling. Data exchange standard refers to the standard of model format and data conversion between different tools. The industry has two main technical solutions for data interoperability problems. One is to adopt a common data exchange standard (such as IFC), and the other is to use the same software ecosystems with core model categories, such as Revit, to take advantage of its high compatibility with other programs in the ecosystem [9]. Figure 3 is an illustration of the modeling application rules.

Figure 3. An illustration of the modeling application rules.

3.3. Project implementation steps. The manufacturing Lingnan heritage buildings is a highly industrialized and collaborative operation system, including the system for the selection of project plan and components, the establishment of component family libraries, and the digital technology system for later assembly line production, as well as design, production, processing, and on-site assembly. The integrated and seamless connection of the collaborative system is the core feature of the high-quality operation of these two systems. In the context of this system, the implementation of such projects is generally divided into the following three steps:

- According to the task list, the BIM application key items of this project are defined;
- It searches the BIM technology prototype from similar projects according to the BIM application key items by iterating the six elements of the prototype to form a BIM technology prototype that meets the requirements of this project. Based on this, the project BIM modeling standards and operating procedures are formed to guide the process.

When the project requirements change, the BIM application key items change accordingly, and the six elements of the BIM technology prototype will be iterated, and the resulting changes in modeling standards and operating rules will have an effect on the procedure.

Figure 4 is the BIM management flow chart. It is shown that according to this BIM management framework, the BIM application key items and the BIM technology prototype form a closely related and self-organizing consortium to establish an adaptive and iterative relationship according to project needs and progress, which then guides the model development and modification iterations. Due to the stability and strong adaptability of the entire structure, even if the project is modified, the cost of work is greatly reduced compared to the previous irregular management.

Figure 4. The BIM management flow chart.

4. Case Study
The Zengcheng Campus of Guangzhou Zhixin Middle School integrates the Lingnan architecture style and local culture with its buildings. The classroom buildings, student and teacher dormitories adopted prefabricated construction, accounting for 68% of the total area. The prefabrication scenario includes prefabricated columns; the enclosure wall and the inner partition wall with integrated pipeline and decoration. In this project, BIM was used in the project lifecycle. The main contents include:
4.1. Development of BIM application key items.

According to the requirements of the owner and the needs of project development, the project is drawn by the design unit, and the entire component processing and on-site installation process are controlled with the assistance of the owner and the participating construction parties. Based on this, the main content of the BIM application is drawn up. The main content is included in the planning Auxiliary project architectural style positioning, ancient building shape and assembly technology system selection, preliminary evaluation of cost; auxiliary ancient building single plan design, assembly deepening design, component and process method selection, project drawing, and project in the design stage Output various component processing lists; provide corresponding component processing BIM models, drawings and lists in the production and processing stage, BIM auxiliary technical disclosure, including component product coding, packaging, and transportation; BIM auxiliary in the on-site installation stage, including material entry and exit timing and location planning, overall construction and installation simulation of important components, and results acceptance; overall project information storage and component information tracking in the operation and maintenance phase.

4.2. BIM technology prototype generation.

4.2.1. Classification code. This project belongs to the "modern space + traditional style", which is classified according to conventional components. The typical components include columns, railings, purlins, roof ridges, and trims, etc. The component codes are mainly production codes and installation codes. For instance, if the product information is “Columns-Eaves Columns-Brown-Stone Finishes-600X600X3200”, the production code is “Z-YZ-RE-SSM-600X600X3200”; if the column is installed on the 3rd floor, at the intersection of the axis A and axes 2, then the installation code is "Z-3F-A/2".

4.2.2. Modeling rules. It is divided into two stages. In the design stage, various components are divided into major categories (i.e. rigid code segments) based on the principles of intuitive visualization and convenient modeling and adjustment; and the design process is accommodated to component selection. In the detailed design stage, standard components, such as columns, railings, etc., are divided and refined according to the assembly type component classification and structure installation method. The library does not yet exist or is non-standard, such as decorative stone beasts, which are constructed according to modeling standards. The model in the design stage requires the output of assembly drawings and quantity takeoff.

4.2.3. Overall model split. The project units are modeled in a hierarchical manner, which is linked to form the whole model to assist modification and quantity takeoff in the later stages. Hence, a combined file is added and managed in the form of a model group.

4.2.4. Collaboration. The project is led by the owner and the designer, and the component processing and on-site work teams are involved through workplan discussion, based on the Revit model, the Enscape light model, and the WeChat group chat.

4.2.5. Model detail and functions. The model details of LOD1.0 and 2.0 is adopted in the plan design stage, and LOD3.0 is adopted in the deepening design stage, but the detail of the components is strictly controlled to meet the quantity takeoff and the output of the main construction drawings. The accuracy of detailed drawings of prefabrication components can be appropriately increased.

4.2.6. Software platform and data exchange. Revit modeling software is used, combined with Enscape rendering and light browsing, and Navisworks is also used for installation simulation of the nodes and overall project, as well as construction and material entry and exit plans. Due to the same manufacturer series, the data exchange is seamlessly connected internally.

This case project has started the on-site assembly. Figure 5 shows some scenes of component production, processing, and on-site installation. Because the participating party lack experience in
assembly and BIM application, the education to the process and the docking of various technical systems are time-consuming. However, due to the BIM management method, it has connected various steps and participating parties. The accuracy of data and the efficiency of on-site information docking have been greatly improved, which verifies the effectiveness of the method.

![Image of construction process]

**Figure 5.** The component production and on-site installation.

### 5. Conclusion

The design and construction of heritage buildings is an ancient and original assembly and production method. How to inherit the ancient charm by using modern materials and industrialized methods in the new type of heritage buildings to achieve high-quality with short duration is an important problem for the continuation of the vitality of ancient buildings, and digital integrated carrier technology becomes one of the core links for the effective solution of this challenge. Lately, manufacturing design and smart construction assisted by BIM have become a hot topic in the construction community. However, due to the long construction period and a large number of participants, there are still few relevant discussions on the use of BIM technology throughout the project lifecycle. Based on preliminary research and practical experience, this article explored this territory, aiming to stimulate more discussion and thinking in the industry.

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