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Comparative Analysis of BIM-Enabled Construction Cost Estimation Practices: A Case Study of Japan and China

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Abstract: This paper presents a study that compares and analyzes the practices of utilizing BIM (Building Information Modeling) for construction cost estimation in Japan and China. The study delves into the nuanced differences and similarities in cost estimation methodologies between the two countries. The overview section explored their respective standard specifications, and the methodologies for construction quantities take-off, covering both the bottom-up estimating approach and the all-in unit rate approach. Additionally, the paper delves into the item code system used in BQ (Bills of Quantities), elaborating on its introduction and practical application. The paper meticulously breaks down the process of quantities take-off facilitated by BIM models and cost-estimating software. The study also delves into the developmental trends in comprehensive BIM standards about construction cost, coupled with the proposition of a BIM code for seamless integration into construction cost practices as part of a forward-looking research plan.
In conclusion, the paper encapsulates the comparative findings, highlighting the strengths, weaknesses, and potential areas for improvement in the BIM-enabled construction cost estimation practices of Japan and China. This study contributes to a deeper understanding of the utilization of BIM technology in the construction industry, offering valuable insights for practitioners, researchers, and policymakers alike.

Key words: BIM, construction cost estimation, quantities take-off, cost estimating software

1. INTRODUCTION

Estimating construction costs, encompassing evaluations of materials, equipment, labor, and contractor profits, constitutes a pivotal aspect of building construction. A meticulous analysis of architectural drawings and specifications is essential to delineate materials and work processes for each task, facilitating precise cost calculations. Achieving a harmonious balance between quality, progress, and cost management in quantity takeoff tasks necessitates consideration of various cost factors, underscoring the imperative understanding of quantity takeoff in construction project management.

This study undertakes a comparative analysis between China and Japan, focusing on Japan and China due to Japan's early adoption of BIM and their shared developmental trajectory in BIM integration. As the two leading economies in Asia, boasting the highest Gross Domestic Product (GDP) in the region, these countries serve as primary subjects of investigation. The central emphasis lies in a meticulous examination of the differences in construction cost management during the BIM adoption phase in Japan and China. Subsequently, the analysis extends to identifying and exploring the factors contributing to these disparities. The study aims to compare practices of quantity takeoff within BIM models in Japan and China, delving into the systems, standards, and software influencing variations in cost estimation practices. Through this comparative analysis, our research seeks to deepen the understanding of the factors causing differences in cost-related activities, ultimately contributing to more efficient and accurate quantity takeoff tasks using BIM models. In conclusion, the selection of Japan and China as research subjects provides valuable insights for future studies analyzing cost data within a broader Asian context.

2. DEVELOPMENT TRENDS OF BIM CONSTRUCTION COST

The integration of BIM technology into cost estimation processes in both Japan and China is still in progress and requires further refinement of BIM standards associated with cost estimation. Future efforts should focus on exploring more efficient BIM measurement and valuation methods.

2.1. Current BIM Standards

The survey results on BIM utilization in Japanese and Chinese companies are derived from the "Survey on the Current Status and Promotion of BIM Utilization in the Architecture Field[2]" and the "China BIM Grassroots Report 2022-2023[3]." The Japanese data was published in 2021, while the Chinese data was released in 2022. Figure 1 presents the survey results of the two cohorts. One category indicates "The situation of unachieved BIM benefits," attributed to the incomplete nature of related standards and insufficient proficiency in new technologies, resulting in disrupted workflows within companies. Challenges encompass internal management, talent development, and the assimilation of new technologies. Figure 1 illustrates that Japanese companies encounter more significant issues related to workflow and adapting to new technologies. Conversely, Chinese companies grapple with substantial challenges in internal management and aspects like profit distribution.

Another category involves "Expectations for BIM in the future." Japanese companies aspire to establish the most standardized BIM system. In contrast, Chinese companies seek more localized resources in alignment with China's construction standards. They anticipate standardized development and a reduction in the usage costs of BIM.

Figure 1. The utilization of BIM in Japanese and Chinese companies

The following are the three main BIM guidelines in Japan as of now:

(1) "Guidelines for the Creation and Use of BIM Models in Government Building Projects" issued by the Ministry of Land, Infrastructure, Transport and Tourism in 2014[4];

(2) "Guidelines for Deliverables Creation in BIM Application Projects (Draft)" issued by the Ministry of Land, Infrastructure, Transport and Tourism in2018 (revised in 2022) [5];

(3) "Guidelines on Standard Workflow and Utilization Strategies for BIM in the Field of Architecture" issued by the Ministry of Land, Infrastructure, Transport, and Tourism in 2020 (revised in 2022) [6].

In China, BIM-related standards are divided into basic standards and application standards.

The basic standards include:

(1) "Standard for Storage of Building Information Model" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2021[7];

(2) "Standard for Classification and Coding of Building Information Model" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2017[8].

The application standards consist of:

(3) "Standard for Design Delivery of Building Information Modeling" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2018[9];

(4) "Standard for Building Information Modeling in Construction" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2017[10];

(5) "Unified Standard for Building Information Modeling" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2016[11];

(6) "Standard for Graphic Expression of Building Information Modeling issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2018[12]" and

(7) "Application Standard for Manufacturing Industry Design Information Modeling" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2019[13].

Among these standards, there are currently no specifications governing the pricing process during the investment estimation, conceptual estimation, bidding, and completion settlement stages based on BIM. Additionally, there is an absence of guidelines for data exchange methods during bill of quantities preparation, standards for delivering measurement and valuation results, storage standards for cost data at each stage, and interaction methods between valuation results and other hardware or software systems. The development of pertinent standards has the potential to standardize BIM cost estimation operational processes, yielding high-quality outcomes and enhancing practitioner efficiency.

2.2. Methodologies for BIM-Based Cost Estimation

The inclination toward utilizing estimating software for quantity calculations and the widespread practice of cost calculation using such software has been brought to light. While estimating software can read and analyze BIM models, its ability to recognize data is constrained. Consequently, when reintegrating BIM models into estimating and takeoff software, manual adjustments become imperative. In instances of engineering design changes, BIM models necessitate repetitive modifications and reintegration into estimating and takeoff software, resulting in diminished efficiency and an augmented demand for estimator skills. Therefore, the development of cost calculation methods within BIM software plays a pivotal role in significantly enhancing the efficiency of quantity takeoff and estimation processes.

The future research objectives aim to revolutionize traditional quantity takeoff and estimation methods. This involves achieving seamless information sharing among design, quantity takeoff, and estimation, ultimately improving the efficiency of cost calculation tasks. The focus is on calculating the quantities and costs of construction projects using Autodesk Revit. The effectiveness of this method will be validated by implementing changes within the BIM model. The overarching goal of future research is to overhaul traditional quantity takeoff and estimation methods, fostering information exchange among design, quantity takeoff, and estimation, with a particular emphasis on enhancing the efficiency of cost calculation tasks. This entails calculating construction quantities and costs in Revit, along with validating the efficacy of this approach through model-based modifications.

2.3. Optimizing Cost Data Utilization

In the future evolution of applying cost data in Building Information Modeling (BIM), the effective utilization of cost information will increasingly revolve around integration and intelligence. Firstly, this involves further optimizing the BIM platform to enhance collaboration among cost estimation, design, and cost management. Secondly, future developments will emphasize real-time collaboration and interactivity. Stakeholders can flexibly collaborate and process information in real-time within the same system to adapt to dynamic changes in project requirements. Additionally, the future application of BIM cost data will focus more on intelligent analysis and utilization of data, enabling project teams to more accurately predict potential cost trends and formulate effective cost management strategies.

The trend toward using estimating software for quantity calculations and the prevalent practice of cost calculation using such software have come to the forefront. While estimating software can read and analyze BIM models, its ability to recognize data is limited. Consequently, when reintegrating BIM models into estimating and takeoff software, manual adjustments become imperative. In cases of construction changes, BIM models require repetitive modifications and reintegration into estimating and takeoff software, leading to decreased efficiency and an increased demand for estimator skills. Therefore, the development of cost calculation methods within BIM software plays a pivotal role in significantly enhancing the efficiency of quantity takeoff and estimation processes.

The future research objectives aim to transform traditional quantity takeoff and estimation methods by achieving seamless information sharing among design, quantity takeoff, and estimation, ultimately enhancing the efficiency of cost calculation tasks. The focus is on computing the quantities and costs of construction projects using Revit. The effectiveness of this method will be validated by implementing changes within the BIM model. The overarching goal of future research is to revamp traditional quantity takeoff and estimation methods, fostering information exchange among design, quantity takeoff, and estimation, with a particular emphasis on improving the efficiency of cost calculation tasks. This involves calculating construction quantities and costs in Revit, along with validating the efficacy of this approach through model-based modifications.

3. CONSTRUCTION COST LANDSCAPE: JAPAN AND CHINA

The quantity data generated by Autodesk Revit cannot be directly applied as construction quantities. Consequently, both Japan and China have devised and introduced estimation software aligned with their respective national measurement standards. In China, as depicted in Figure 2, domestic estimating software is used in many cases for both quantity take-off and cost estimation. Japanese general contractors and design farm, employ diverse approaches, including the utilization of estimation software for quantity calculations, quantity take-off in BIM authoring tools, manual computations, the adoption of alternative software for example specialising in construction drawings for specialised works for cost estimation, and processing output files with distinct software for example spreadsheet[14].

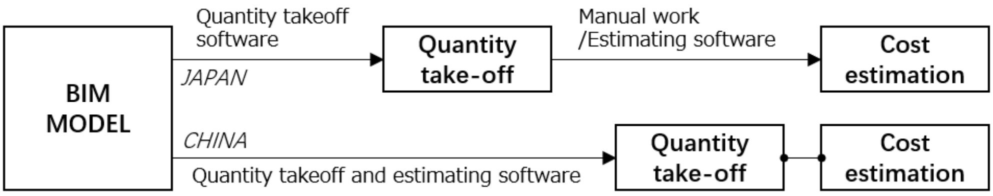

Figure 2. Comparison of Quantity Takeoff Procedures in BIM Models between Japan and China

3.1. Current Research Status

Fujiki Architects studied the "Verification of Preliminary Cost Calculation Method Using Implementation Design BIM Models with Assigned Uniclass Codes[15]." The research assigned Uniclass codes to BIM models, linking them with RIBC2 codes for building unit prices. Results showed over 70% assignment rate of Uniclass codes to BIM objects, reducing estimating duration by over 20%. Challenges included significant workload in code assignment and lack of criteria, relying on operators' judgment. Lin Hanhan and Zhou Hongbo integrated calculation plugins into Revit, modifying quantity calculation rules to generate compliant construction quantities for China's settlement regulations [16].The study concludes that the feasibility of generating quantity takeoffs from BIM design software has been substantiated. This capability contributes to facilitating the integration and mutual utilization of design and cost-related BIM information. Anpei et al. introduced and applied a rapid quantity takeoff method based on BIM models, establishing Revit modeling specifications that comply with the requirements of quantity calculations. Through the development of a specialized software plugin (Revit Model Import Plugin for GCL Quantity Software), they facilitated the importation of Revit models, created according to the specified modeling standards, into the GCL quantity software for engineering measurement and cost estimation[17].

3.2. Cost Estimation Methodologies

In Japan, the bottom-up estimating method is a prevalent approach for quantity calculation. This method involves breaking down projects or tasks into detailed elements, with the costs and resources for each element accumulated to estimate the overall cost. In China, the widely adopted method is the all-in unit rate method. This approach calculates the unit cost for each task based on the quantities and costs of associated resources, then multiplies the unit price by the actual work quantity to determine the total project cost.

The commonality between the bottom-up estimating method and the all-in unit method lies in their approach to breaking down projects or tasks into smaller components for detailed estimation and calculation. Regardless of the chosen method, it is crucial to evaluate the necessary resources (such as labor, materials, and machinery) for each component and determine the corresponding costs. The total estimate is obtained by summing up the costs of individual components. The key difference lies in the approach to cost calculation.

The all-in unit method emphasizes establishing a uniform standard unit price for calculating project costs. Unit prices are typically determined using cost tables or wage charts, and costs are obtained by multiplying these prices by quantities. In contrast, the bottom-up estimating method emphasizes breaking down projects or tasks into multiple components and calculating each independently before adding up the total cost. The all-in unit method is commonly applied to general and standardized project tasks, where most activities can be calculated using standard unit prices. In contrast, the bottom-up estimating method is suited for complex, specialized, or non-standardized project tasks, wherein calculations are based on the tasks themselves, whereas the all-in unit method involves partitioning tasks into independent units of work.

While the bottom-up estimating method provides more detailed calculations, leading to more accurate and precise estimates, it demands additional time and effort due to the detailed breakdown and calculations. The all-in unit method includes instructions on calculating bid prices and final settlement prices, outlining methods for adjusting costs in case of changes and considering unpredictable future items. This comprehensive approach allows for a more thorough price evaluation that accommodates unknown factors. In contrast, the all-in unit method is generally simpler.

In addition, the Chinese estimate document must incorporate item codes, such as the coding method illustrated in Table 1 for the item code "010502001," referring to in-situ concrete rectangular columns. These item codes adhere to the specifications outlined in the national standard "Specification for Quantities Calculation of Building Construction and Decoration Engineering[6]." Each component is identified by a 12-digit code, with the first 9 digits defined by the standard and the last 3 digits assigned by the quantity surveyor based on the project's specifics. The initial 2 digits denote the project category, followed by 2 digits indicating the construction type, the subsequent 2 digits representing the component type, and concluding with the classification of that component. This structure is exemplified below using a rectangular column.

Compared to BIM codes, this coding system captures less detailed information but is meticulously crafted for quantity surveying tasks, facilitating the classification and analysis of data for workers. Although it provides less granularity, it streamlines the quantity surveying process within construction projects by incorporating fundamental information about components through this coding system. Although Japan also has RIBC codes related to quantities, there is no requirement for them to be filled out in quotations, and their usage is not widespread.

Table 1. Extraction method for item code

Level 1 Category		**Level 2 Category**		**Level 3 Category**		**Level 4 Category**		**Level 5 Category**	
01	**Construction Engineering**	01	Earthworks	01	In-situ concrete foundation	**01**	**Rectangular column**	**001**	**<Self-set>**
02	Decorative Engineering	02	Foundation and Shoring	**02**	**In-situ concrete column**	02	Structural column	002	<Self-set>
03	Equipment Engineering	03	Piling Works	03	In-situ concrete beam	03	Irregular column	003	<Self-set>
04	Municipal Engineering	04	Masonry	04	In-situ concrete wall				…
05	Landscape Engineering	**05**	**Concrete Works**	05	In-situ concrete slab				
		07	Structural Timber Works	07	Other in-situ concrete elements				
			…		…				

4. BIM-ENABLED QUANTITIES TAKE-OFF: A COMPARATIVE STUDY

The rules for quantity calculation in BIM software do not align with standards in all countries. As a result, countries have developed specialized cost estimation software connected to BIM tools and national databases. Our research utilized Japan's "Helios" and China's "Luban," integrating a consistent Revit BIM model. Comparative analysis of the calculated quantities and breakdowns in both applications revealed differences in approach and outcomes, underscoring the necessity for country-specific adaptations.

4.1. Quantities take-off based on the BIM model using cost-estimating software

・Introduction of cost estimating software

In this study, we employ Japan's leading quantity surveying software, "Helios," and China's representative quantity surveying software, "Luban." A common Revit model is introduced into each of the two quantity surveying applications. Subsequently, a comparative analysis of the resulting quantity calculation outcomes and detailed breakdowns is conducted.

The workflow of quantity surveying is as follows:

(1) Import the Revit model into the quantity surveying software.

(2) Since not all objects have corresponding objects in the quantity surveying software, change unsupported parts to objects compatible with the quantity surveying software.

(3) Check the placement of changed objects and make corrections if there are any discrepancies.

(4) Finally, review the calculated results and make necessary modifications.

・Analysis of Quantity Results

Table 2 compares the construction quantities generated by both quantity surveying software and Revit (limited to structural concrete). The variances in construction quantities are elucidated as follows:

Table 2. Quantity results output by each software

Components	Helios	Luban	Unit
Total	1139.61	1058.44	m^3
Column	98.63	97.6	m^3
Beam	262.03	234.72	m^3
Slab	347.79	333.22	m^3
Wall	342.19	327.14	m^3
Stair	-	78.62	m^3
Concrete shutter	8864	8199	㎡
Baseboard	555.97	546.93	m
Interior flooring	1692.2	1715.6	㎡
Interior wall	2119.7	2215	㎡
Ceiling	2237.8	2113.4	㎡
Exterior wall	-	1331.79	㎡

(1)Calculation Priority in Software:

Revit defaults to calculating slabs, columns, beams, and walls with the highest priority, leading to a greater quantity of slabs. Helios and Luban, on the other hand, prioritize elements such as foundations, columns, beams, slabs, walls, stairs, and others.

(2)Compliance with National Standard Formats:

The quantity surveying standards in both countries adhere to the "Architectural Quantity Calculation Standards" issued by the Building Cost Management System Research Institute in Japan and the "Specification for Quantities Calculation of Building Construction and Decoration Engineering" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China. These standards outline variations in structural works:

① Columns: In Japan, column quantities are determined by factors such as foundation columns, each-floor columns, and top-floor columns. In China, quantities are calculated based on columns under

slabs with beams, columns under slabs without beams, frame columns, and structural columns.
② Walls and Slabs: According to China's standards, deductions are required for walls and slabs with openings larger than 0.3 square meters, encompassing deductions for intersecting parts with columns and beams. Conversely, Japan's standards stipulate deductions for openings larger than 0.5 square meters, including those for intersecting parts with columns and beams.
(3) Analysis of Calculation Formulas in Software:
① Stairs: Revit calculates only the tread area of stairs, whereas Luban software computes the entire staircase, encompassing landings, landing beams, and staircase beams.
② Beams: Concerning beam calculations, as evidenced by the formulas in the output of quantity surveying software, Helios calculates based on the length of the red part of the beam shown in Figure 2, whereas Luban calculates the entire volume of the beam and then deducts the overlapping volume with columns. Consequently, modeling discrepancies in Revit, such as beam start and end points not aligning with the center axis of columns, can be challenging to visualize directly in Revit but impact the calculation results in both quantity surveying software.

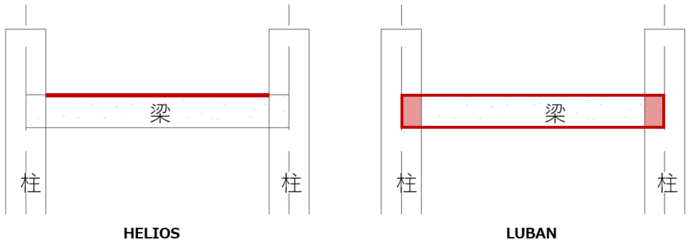

Figure 2. Calculation rules for beams

4.2. Feature of cost estimation software

The procedures for importing Revit data in Helios and Luban are generally consistent. In Helios, export settings include component mappings, while Luban's settings are straightforward, requiring confirmation of accurate floor, output settings, category, and material strength. Any inaccuracies can be directly modified in export settings. Although both quantity surveying software have similar functionalities, disparities arise due to variations in surveying methods and standards between Japan and China. Japan follows a unified national standard, aligning Helios' rules with it. In China, there's a unified standard, but methods for decomposing composite unit prices vary by region, allowing Luban to import multiple standards.
Results indicate that in Helios, Revit data can be displayed more comprehensively, whereas Luban struggles with finishing details. Data from Helios integrates more easily with other BIM tools. Luban requires substantial modification based on project conditions and allows output of composite unit prices. Helios can also output composite unit prices, but in China, bidders must submit them during the bidding process. Thus, Luban has a higher usage rate for composite unit price output, resulting in longer calculation times, a complex interface, and greater complexity for users.

5. DISCUSSION

This study thoroughly investigates the current landscape of BIM technology utilization for quantity surveying and cost estimation in both Japan and China. The examination encompasses an in-depth analysis of national standards governing BIM implementation in construction activities within each country. In the realm of architectural quantity surveying, Japan, an advanced nation, has witnessed early development and standardization. The impetus behind BIM technology adoption in Japan primarily stems from the private sector, whereas in China, governmental mandates have accelerated the proliferation of BIM, particularly for projects of significant scale. Residential projects in Japan typically entail individual houses, resulting in modest data volumes and the prevalent use of takeoff methods. Conversely, Chinese residential construction predominantly comprises housing complexes, with each project encompassing approximately 20 to 30 units, thus generating substantial surveying data. Consequently, China has formulated quantity surveying codes, predominantly favoring the comprehensive unit price method. In terms of quantity surveying software, Chinese standards necessitate finer data categorization within estimate sheets, resulting in Luban requiring more extensive setup procedures and offering fewer editable data points compared to Helios. To advance future quantity surveying tasks involving BIM technology, establishing BIM standards is imperative, including the development of a coding system for BIM models and optimizing BIM coding integration within quantity surveying software to enhance computational efficiency.

In conclusion, the paper presents strategic recommendations for the future evolution of BIM-enabled quantity surveying and costing practices in Japan and China. These proposals encompass the refinement of existing BIM standards, the establishment of a comprehensive BIM engineering quantity system, and the facilitation of data sharing across design, quantity calculation, and cost calculation stages. Such integration is envisioned to address issues related to BIM-based dynamic estimation. As the current state of BIM-based lifecycle cost management is in its early stages, this study advocates for the development of estimation methods grounded in BIM, highlighting their potential to enhance work efficiency and foster the growth of lifecycle cost management using BIM.

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