Research on the Integrated Application of 3D Design and Project Cost based on Digital Power Grid

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Abstract. In order to enhance the digitization and intelligence of the field of power grid, this paper presents an integration theory between 3D design and the project cost. Based on the standard of the digitization power grid 3D design model, this paper researches on the standard quota and list in the field of budget, and puts forward a set of mapping rules between them. Then, the paper develops a 3D design intelligent computing application platform integrating 3D design model data analysis and storage, lightweight 3D visualization, quantity analysis and project quantity output. Taking the actual line project and substation project in Hunan province of China as examples, the extraction process of substation and line quantity is realized respectively, and the computability of the extraction results is deeply analyzed. The experiments reveal the practical significance of the integration theory between 3D design and project cost.

1. Introduction
In the process of the smart city, people gain in-depth understanding of 3D models. 3D design enables structured storage of design data by object-oriented and parameterized technology, which makes it feasible to generate Technical and Economic (later referred to as T&E) items automatically from design data. From the perspective of information technology and engineering technology, the Research Institute of State Grid of China puts forward the concept of Grid Information Model (GIM). Based on the Geographic Information System (GIS), GIM digitizes the power grid components, integrates information within the life cycle with information model as the carrier, to realize efficient, accurate and comprehensive application of information. However, there are many drawbacks in the current 2D-based construction economic field. The company’s system cost preparation relies heavily on manual work, leading to a low degree of automation. Due to the lack of support of big data and professional software, the evaluation is biased. In addition, the current construction cost data is scattered and stored in various application systems, causing weak data correlation, lacking authenticity and quality.

Furthermore, in the phase of 3D design, the paperwork of the grid project design company transferred from 2D drawings to 3D models, leading to the failure of the T&E quantity compilation. In recent years, 3D digital design technology has developed from display level to design level. Building Information Modeling (BIM) is an important technology in the design of 3D solid model. BIM technology realizes the whole life cycle project management and information sharing as an advanced digital information technology [1]. At present, BIM technology is widely used in most developed countries. Kwak, Seong Mo’s invention receives a building drawing and a selected construction area from the outside and outputs
the calculated necessary quantities [2]. Fenato et al. develop a method to prepare the operational bill of quantities through BIM that allows clarification of the calculation considerations and automation of the takeoff process [3].

The application subjects of BIM in China are mainly design departments and construction departments. In the 1990s, China developed the application of 3D design technology in the field of thermal power plant design, to solve the 3D space distribution in the workshop and reduce the collision errors in the design [4]. BIM tools can also realize 3D design model identification, automatic extraction of evaluation index data, spatial measurement, automatic generation of detection report and other functions [5]. The civil engineering calculation software Guanglianda can deal with complex model quickly and accurately, reuse multiple design model to realize efficient modeling [6]. In the process of building water supply and drainage system, the application of Lubang software provides effective approaches and methods for pipeline collision, quantity statistics and other links [7].

Existing researches utilized BIM are based mainly on 2D drawings, where 3D model-aided calculation output covers only several particular materials (such as ceiling, rails, housing). Moreover, the application of BIM model in T&E management of power transmission and transformation engineering is still theoretical, with few practical applications. This paper studied existing 3D design standards and sorted out the hierarchical relationship and properties of 3D design model (GIM) data. The rules of the quota and list standard valuation systems are sorted out. Besides, by comparing the information requirements of the T&E quantity system with the information provided in the existing 3D design model specifications, the mapping rules of the 3D model and the two evaluation systems are established. On this basis, this paper completes the experiment based on the project example of Hunan power grid, studies the integration application of 3D design model and engineering cost, respectively demonstrates the computability analysis of engineering quantity extraction, and improves the efficiency and accuracy of engineering cost.

2. Mapping Theoretical Method of the 3D Design and Engineering Cost

2.1. Technical Route
Based on the basic framework and existing specifications of digital power grid, the theoretical method of 3D design and engineering cost mapping is studied. The technical route is shown in Figure 1 below. The research involves three aspects, namely the lightweight 3D visualization, analysis of 3D design model data and conversion into computational components, as well as output in the form of list summary sheet and quota summary sheet.

**Figure 1.** Technology route.

2.2. Research on the Standard of 3D Design Model
This section studies 3D design model architecture, file storage structure, and hierarchical management. In order to meet the needs of 3D design of power transmission and Transformation projects, unify the model framework and data interaction format, and realize the data sharing of the whole life cycle of the
project, the State Grid has compiled *Interaction Specification for Three-dimensional Design Model of Power Transmission and Transformation Engineering* (hereinafter referred to as the *Specification*).

Considering that the fineness of the 3D design model affects the accuracy of the project quantity calculation, this section combs the hierarchical relationship and properties of the 3D model data to form the result of *Specification*. The result is shown in Figure 2.

![Diagram](image)

**Figure 2.** An example of the interaction specifications of a 3D transformer unit model.

### 2.3. Mapping Rules between 3D Design Model Component and Cost Quantity Component

To meet the needs of the application of 3D design model in engineering cost compilation, according to *Specification*, T&E quota valuation system and list valuation system, the extraction mapping of 3D design result model to T&E cost and engineering quantity is formed. In this paper, the *Mapping Rules between 3D Design Model Component and Cost Quantity Component* are compiled (hereinafter referred to as the *Mapping Rules*).

*Mapping Rules* are divided into two parts: line rules and transformer installation rules. The rule carves out the property mapping relation of the quantity extracted from the 3D project model documents to the project cost quota valuation system and the list valuation system, which is applicable to the design of voltage class 110 (66) kV and above.

#### 2.3.1. Theory and examples of line rules

The project model of overhead transmission lines includes tower group, conductor group and crossing group, device components can correspond to T&E components and property items by means of property one-to-one mapping, constraint mapping, combination mapping and indirect calculation. The overall matching is shown in the table below.

**Table 1.** Matching between overhead transmission line models and T&E computational components.

| Device level(F4System) | Component         | Matching case(Y/N) | Total number | Matching number |
|------------------------|-------------------|--------------------|--------------|----------------|
| Tower Group            | Pole and Tower    | Y                  | 3            | 3              |
|                        | Base              | Y                  |              |                |
|                        | Insulator chain   | Y                  |              |                |
| Conductor Group        | Wire              | Y                  | 6            | 5              |
|                        | Ground wire       | Y                  |              |                |
|                        | Jumper            | Y                  |              |                |
|                        | Spacer            | Y                  |              |                |
|                        | Anti-vibe hammer  | Y                  |              |                |
|                        | Conductor and Metal fittings | N | | |
| Crossing Group         | Crossing items    | Y                  | 1            | 1              |
|                        | Summarize         |                    | 10           | 9              |
2.3.2. Theory and examples of substation installation rules. This part defines the mapping relationship of substation installation project, which is dominated by electrical equipment. Equipment components involved can correspond to T&E quantity through one-to-one mapping of model properties and combination mapping. The substation commissioning project and other T&E quantities are not in the range of 3D design, and thus, not discussed here.

Table 2. Mapping rules of electric reactor.

| Property items          | Property type | Enumeration                  | Mapping rules                                      |
|-------------------------|---------------|------------------------------|---------------------------------------------------|
| Component type          |               | Name                         | Reactor, Group level coding = G_N_1                |
| Name                    | String        | Name in the project          |                                                   |
| Classification          | Enumerate (store as string) | Dry-type                     | Equipment type = single-phase dry hollow          |
|                         |               | Oil-immersed                 | Type of equipment = Oil-immersed core             |
| Rated voltage (KV)      | Int           | Voltage class                |                                                   |
| Rated capacity (KVA)    | Int           | Rated capacity               |                                                   |
| Installation method     | String        | Indoor/outdoor               | /                                                 |
| Corrosion preventive request | String   | /                            | /                                                 |

3. 3D Model Intelligent Computing Application Platform

3.1. System Framework

This paper builds a 3D model intelligent computing application platform. The business logic layer uses the SpringBoot development framework belonging to Java, combines with the Spring Cloud micro-service architecture to realize the application data access of the whole construction process integrated digital management platform. The business presentation layer is realized by React and H5, and the 3D visualization lightweight engine, HTML, ReactJS and CSS technology are utilized. The data interaction is realized by calling RESTful services. The system adopts B/S architecture, which can directly view the application of 3D intelligent computational cost on the web page. The technical framework of the platform is illustrated in Figure 3.

![Figure 3. The technical framework of the platform.](image)
relational data structure, which can guarantee data security, understandability, convenience to use and easy to maintain.

3.1.2. Business logic layer. This layer is responsible for the maintenance of rules, the storage of calculation rules based on quota and list rules, and corresponding programming. It stores the 3D design model files uploaded by users to form user folders, and manages the 3D design models of substation and line project. At the same time, the layer transforms and encapsulates the 3D model into a computational component (a basic data unit for intelligent calculation), thus, makes it analyzable by computer and promotes the calculation of the 3D model. In addition, the business logic layer also extracts and calculates the project quantity automatically.

3.1.3. Business display layer. This layer integrates data and computational analysis results, supports lightweight 3D model visualization and Web browsing, which is convenient for online view. Example figures are given below in Figure 4.

![Figure 4. Lightweight visualization of the 3D model.](image)

3.2. Quantity Extraction and Summary Sheet Output
The platform extracts project quantity. The user inputs the corresponding 3D design file, the file is then analyzed by the platform, transferred into calculation components and extracted the quantity. The platform page is exhibited in Figure 5. After the deconstruction of the input project, the user can preview and export the corresponding quota and list summary summaries, as represented in Figure 6.

![Figure 5. The main page of the 3D design intelligent computing application platform.](image)
4. Application and Analysis

4.1. Experimental Design and Results
This report was based on existing mapping rules and operating platforms, applied the "Guting - Hengdian Village 220kV Line Project" as the pilot line project and the "Xiangtan - Xuechu 110kV Substation Construction Project" as the pilot substation project. The pilot project design files were provided by Hunan Power Transmission Survey and Design Consulting Co., LTD., retained the newly built facilities for calculation purposes. The 3D design software company (Beijing Daoheng Time Co., LTD.) provided the optimized final model and the supplementary material list. The result of the project quantity is summary sheets of quota and list, respectively.

Figure 6. The preview of the exported summaries of quota and list.
4.1.1. Result of line project. After the operation, the platform exported one list summary table and one quota summary table. It generated 40 quota items, including 10 basic projects and 9 tower projects. There were 36 list items, including 13 basic projects and 1 electric pole and tower project.

4.1.2. Result of substation installation project. After the operation, the platform exported one list summary table and one quota summary table. A total of 19 quota items were generated, including 1 main transformer and 6 indoor power distribution devices. There were 22 items on the list table, including 4 items of main transformer system and 7 items of indoor power distribution device.
4.2. Analysis of Experimental Results

4.2.1. Line project analysis report. According to the pilot project, the outcome can be divided into 7 different situations, namely computable by 3D design model, provided by the supplementary material list, unknown or can’t correspond at the design stage, no design-model, the excavation quota, the transport quota, the cable engineering quota. The statistical analysis result based on 6 project dimensions is listed in Table 3.

Table 3. Statistical analysis result of the line project.

| Project Name       | Computable | Provided by the supplementary material list | Unknown or can’t correspond at the design stage | No design-model | The excavation quota | The transport quota | The cable engineering quota | Total |
|--------------------|------------|---------------------------------------------|-----------------------------------------------|----------------|----------------------|---------------------|---------------------------|-------|
| 1.Basic project    | 28         | 1                                           | 3                                             | 18             | 6                    | 3                   | 24                        | 56    |
| 2.Tower project    | 7          | 1                                           |                                               | 1              |                      |                     |                           | 11    |
| 3.Grounding project| 1          | 4                                           | 1                                             | 3              |                      |                     |                           | 12    |
| 4.Wiring project   | 21         | 6                                           |                                               | 6              |                      |                     |                           | 33    |
| 5.Installation of accessories | 10 | 1                                           |                                               | 3              | 1                    |                     |                           | 15    |
| 6.Auxiliary project| 67         | 5                                           | 10                                            | 4              | 24                   | 24                  | 1                         | 9     |
| Total              | 67         | 5                                           | 10                                            | 4              | 24                   | 24                  | 1                         | 136   |
| Percentage (%)     | 49.26%     | 3.68%                                       | 7.35%                                         | 2.94%          | 17.65%               | 17.65%              | 1.47%                     | 100.00%|

There were 136 items of the pilot project budget quota, among which 67 items can be calculated by the 3D design model, accounting for 49.26%. 5 items (3.68%) can be provided in the supplementary material list. 10 items cannot be corresponding or determined in the design stage (7.35%). There were 4 models that did not belong to 3D design (2.94%). 24 items belonged to the excavation quota (17.65%). Transport quota has 24 items (17.65%). There were 2 items of cable engineering quota (1.47%).

4.2.2. Substation installation project analysis report. According to the pilot substation project, substation installation part of the estimated quota project was analyzed. The result can be divided into three catalogs: computable by the current 3D design model (corresponding to the budget items), can be supplemented by the 3D design model (by improving the model precision), and not supported by the 3D design model (required further information). The result is demonstrated in Table 4.
Table 4. Statistical analysis result of the substation installation project.

| Estimated quota item                   | Computable | Can be supplemented | Not supported | Total |
|----------------------------------------|------------|---------------------|---------------|-------|
| 1. Main transformer system             | 5          | 1                   | 0             | 6     |
| 2. Power distribution unit             | 7          | 0                   | 0             | 7     |
| 3. Reactive compensation               | 2          | 0                   | 0             | 2     |
| 4. Control and DC system               | 2          | 7                   | 0             | 9     |
| 5. Station electricity system          | 4          | 0                   | 0             | 4     |
| 6. Cables and grounding                | 3          | 8                   | 9             | 20    |
| 7. Communication and remote operation system | 0          | 7                   | 8             | 15    |
| 8. Debugging of the whole station      | 3          | 13                  | 41            | 57    |
| 9. Off-site power supply               | 0          | 3                   | 0             | 3     |
| Total                                  | 26         | 39                  | 58            | 123   |
| Percentage (%)                         | 21.14%     | 31.70%              | 47.16%        | 100.00%|

There were 123 items in the estimated quota of substation installation pilot project, among which 26 items can be calculated from the current 3D design model (21.14%). After the supplementary 3D design model, 39 items can be calculated (31.70%). There were 58 non-calculated quota items of 3D design model data (47.16%).

4.2.3. Analysis and Summary. Based on the practical analysis of the pilot project, the computability of the 3D design model of the line project is about 50%, and that of the substation (substation installation) is about 20%. In order to further improve the calculation coverage of 3D design model, this paper offers some suggestions.

1. Optimize suggestions for line projects
   1) Design models, such as drainage ditches and slope protection, can be added relatively.
   2) The parameters of the design model can be appropriately improved. Figure 11 illustrates the properties of the cushion.
   3) Design and T&E soil classification can be integrated, classification standards should be developed and support the design of geological models in the design platform.
   4) A supplementary material list should be provided by the design platform as a supplement to the 3D design model to fill in the missing contents.

2. Optimize suggestions for substation projects
   Firstly, improve the fineness of the model for the small size and subtle structure components. Secondly, for non-major electrical units and construction components, expand the scope of 3D modeling, whether to add a specific equipment can be decided from the perspective of T&E. Third, for quota equipment that cannot be classified, add the name items as property of the higher level or associated components to help classify the belonging and improve the mapping rules. Fourth, calculations that are not supported by the 3D design model can be supplemented according to the material sheet provided by the design and by technicians in accordance with the general calculation method.
Based on the practical application of the pilot project, the computational quantity reports are achieved respectively. Moreover, this paper completed the mapping rules of 3D design model and calculation components, further promoted the fusion application of 3D design model and engineering cost.

5. Conclusions
Based on the project example of Hunan power grid, this paper studies the integration application of 3D design model and engineering cost, and demonstrates the computability analysis of engineering quantity extraction. The intelligent generation of engineering quantity based on 3D models can greatly reduce the work burden of technical and economic personnel, ensure the authenticity of engineering cost, and enhance the precision level of engineering budget. The penetration of two modes, quota valuation and list valuation, can break the data barrier, realize the intelligence of technical and economic compilation. For the purpose of supporting T&E estimates, the scope of visual equipment should be expanded, the precision of modeling should be increased, and property items should be added according to technical specifications. Comprehensive digitization of engineering will become the future trend, from the visualization of 3D design model to the application of actual extraction of engineering quantity, the big data center of T&E will gradually be formed to create a data sharing ecosystem.

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