Ontology Construction and Intelligent Generation of Mechanized Construction Plans for Power Grid Projects

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Abstract. In the field of power infrastructure construction, the comprehensive adoption of mechanized construction has become an inevitable trend in industry development. However, traditional mechanized construction plans, which heavily rely on human resources and expert knowledge, face challenges in improving construction efficiency. To address this issue, this paper proposes an intelligent generation system for mechanized construction plans based on an ontology model combined with SPARQL query language, aiming to reduce dependence on human resources and enhance the utilization efficiency of mechanical equipment. To validate the effectiveness of the system, an application case study was conducted using overhead transmission lines as an example. The study results demonstrate that the system achieves high accuracy, significantly improves the design efficiency of mechanized construction schemes, and showcases the potential of knowledge-driven systems in optimizing construction plans. This provides strong support for a standardized pathway toward intelligent infrastructure construction.

Keywords: Mechanized Construction, Ontology Model, SPARQL Query Language, Intelligent Infrastructure Construction

1 Introduction

Traditional power grid construction primarily relies on manual labor, with mechanical equipment playing a secondary role, leading to issues such as high labor intensity, elevated safety risks, high costs, and low efficiency [1-2]. As labor costs rise and mechanization technologies advance, efficient, precise, and safe mechanized construction methods are gradually replacing traditional manual operations, shifting from a "labor-intensive" to a "technology-intensive" approach [3]. Despite the significant advantages of mechanized construction, the absence of an effective framework for designing mechanized construction plans poses several challenges in the practical application of machinery. First, designing mechanized construction plans is a knowledge-intensive task [4]. However, the required knowledge is often fragmented and scattered across various organizational databases, project logs, and complex text documents [5]. This lack of a

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structured and unified knowledge management system hinders the effective utilization of available information. Second, power grid construction is inherently complex and variable, involving numerous processes and machinery that necessitate comprehensive planning. Without systematic management, achieving optimal solutions becomes challenging. Finally, the absence of effective knowledge-sharing mechanisms directly impairs construction efficiency. For example, poor communication between designers and contractors can lead to delays and increased costs. Therefore, improving the efficiency of mechanized construction plan design for power grid projects remains a critical area for further research and development.

Ontology provides an effective framework for defining vocabulary, terms, entities, and their relationships, allowing for the formal representation of domain knowledge and promoting knowledge management, sharing, and reuse. It has been widely applied in knowledge management within the construction sector. For example, Yuan et al. [6] developed a construction process information system based on the Digital Construction Ontology (DiCon), enabling the representation and integration of domain knowledge and the formalization of construction process information. Similarly, Doukari et al. [7] combined a developed construction ontology with Building Information Modeling (BIM) and linked it to construction schedules, facilitating the automatic generation of project timelines. While ontology technology is relatively mature in traditional construction, its application in knowledge management and mechanized construction planning for power grid projects remains unexplored. This paper, therefore, adopts an ontology approach to address the challenges of mechanized construction in power grid projects and explore the potential of ontology technology in this domain.

In summary, this paper delves into the application of ontology technology for the formal representation of knowledge in mechanized construction and innovatively designs an ontology-driven automatic generation mechanism for mechanized construction plans in power grid projects. A prototype system was developed, and its practicality was demonstrated through a case study on overhead transmission line projects. Results indicate that, compared to traditional planning methods, this system significantly improves efficiency and accuracy, offering a standardized and scalable new pathway to promote intelligent mechanized construction in power grid engineering.

2 Methodology

This paper proposes to develop an ontology for power grid construction to aid in creating mechanized construction plans. The approach includes two main modules, 1) a seven-step process for ontology development and 2) an ontology-guided framework for generating mechanized construction plans._The rationale behind the method lies in the merits of ontology in supporting knowledge modeling, reasoning, and discovery. Ontology provides a robust framework for defining vocabulary, terminology, entities, and relationships, enabling the formal expression of domain knowledge. This facilitates the creation of structured knowledge systems, enhancing knowledge management, sharing, and reuse. Additionally, ontologies support rule-based logical and semantic reasoning, which aids in knowledge discovery and intelligent applications [8-9].

2.1 Ontology Development

For ontology development, the process is detailed as follows.

- Step 1 - Determine the domain and scope of the ontology. The ontology is designed to aid in creating mechanized construction plans for power grid construction projects. Thus, it should encompass concepts related to power grid construction, particularly within the context of mechanized construction.
- Step 2 - Consider reusing existing ontologies. The ontological model proposed by EI-Diraby and Osman [10], which assumes that a project consists of a set of processes where various actors control resources to produce products is suitable existing reference. This paper expands on the aforementioned model to develop a specialized ontology for power grid construction.
- Step 3 - Enumerate important terms in the ontology. In developing the ontology for power grid construction, it is essential to enumerate important terms that will form its foundation. This step involves identifying and listing all relevant concepts, entities, attributes, and relationships specific to power grid construction and mechanized construction processes through literature review and expert interviews.
- Step 4 - Define the classes and the class hierarchy. This step involves organizing the enumerated terms from the previous step into a structured framework, where classes represent key concepts and their hierarchy reflects the relationships and generalizations among these concepts.
- Step 5 - Define the properties (slots) of classes. This step involves defining properties, also known as slots or attributes, for each class within the ontology. These properties can include data properties, which describe data values (e.g., numerical, textual), and object properties, which define relationships between different classes.
- Step 6 - Define the facets of the properties. This step involves specifying the characteristics of each property, including the domain (the class to which the property belongs), range (the type of value or class the property can take), cardinality (the number of values a property can have, e.g., single, multiple), and constraints (any limitations or conditions on the property values).
- Step 7 - Create instances. Creating instances, or individuals, is the process of populating the ontology with specific examples of the classes and their properties defined in previous steps.

Following the seven-step procedure, the resulting ontology, shown in Figure 1, consists of six core classes: Project, Process, Actor, Resource, Product, and Mechanism. These core classes are expanded with hierarchies specific to the domain of power grid construction. For instance, under the Process class, subclasses represent the main processes for a power grid project, such as design, construction, operation and maintenance. Using the overhead transmission line construction process as an example, it includes subprocesses such as temporary road preparation and construction, material transportation, foundation construction, tower assembly, and line stringing, each of which can be further specialized. Also presented in Figure 1 are the defined object properties and data properties.

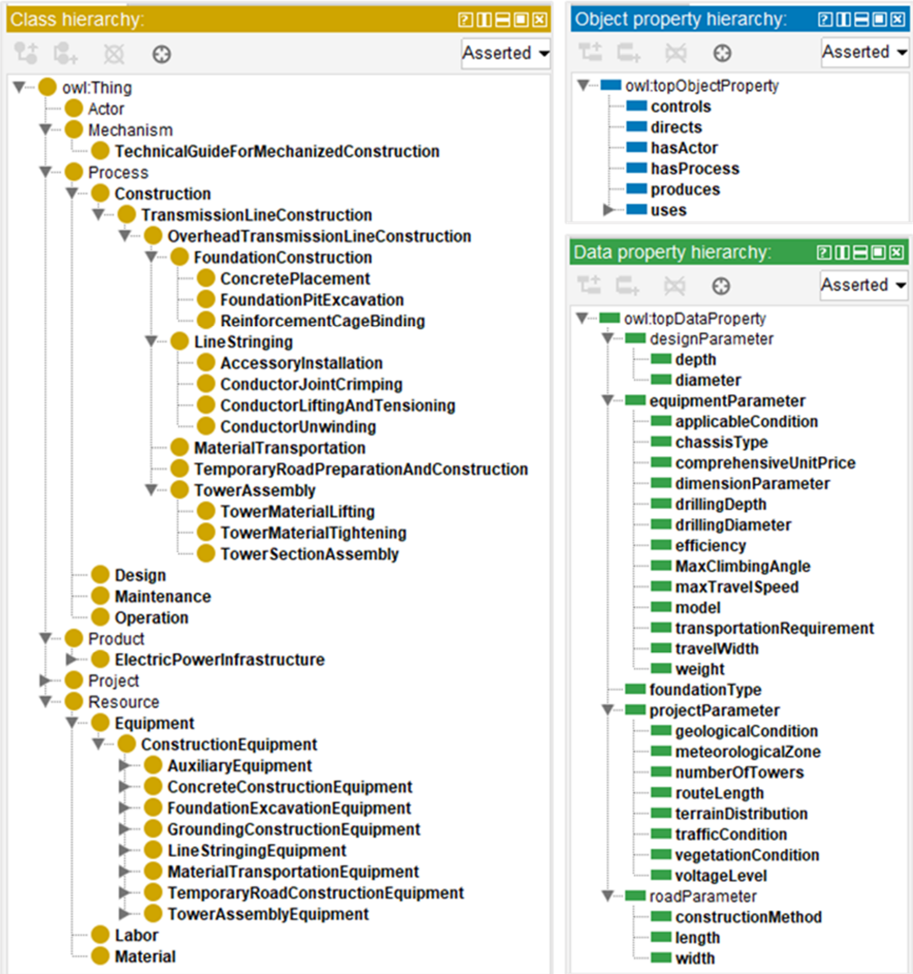

Fig. 1. The defined ontology classes, object properties, and data properties for power grid construction

2.2 Ontology-Guided Framework for Mechanized Construction Planning

To generate mechanized construction plans, an ontology-guided workflow is proposed. The process begins by collecting case-specific information to populate the ontology and build a comprehensive knowledge base. In addition to this, construction equipment data, unit price data, and specification data must also be pre-loaded into the ontology to form an integral part of the knowledge base. Subsequently, the ontology guides the identification of key construction processes for mechanization, the design of corresponding mechanized construction plans, and the calculation of associated costs. The design of the mechanized construction plan involves five further steps: determining equipment type and model, configuring equipment and personnel, designing the construction site layout, specifying mechanized construction procedures, and developing corresponding quality, safety, and environmental protection measures. These steps ensure that the designed plan is practically applicable. Figure 2 illustrates the inner mechanism for ontology guidance for generating mechanized construction plans for power grid construction projects. The core technology underlying this process is reasoning with the RDFS/OWL ontology and RDF data. The ontology for power grid construction is expressed using RDFS/OWL, which serves as the semantic schema for modeling and organizing specific instances in RDF format based on real-life case projects. Both the RDFS/OWL ontology and the RDF instances are loaded into an inference engine, also known as a reasoner. This reasoner enables logical inferencing, allowing for the automatic deduction of additional knowledge from the given data. SPARQL queries are then executed on top of this reasoning layer to extract, manipulate, and analyze the data stored in RDF format, facilitating the generation of accurate and efficient mechanized construction plans.

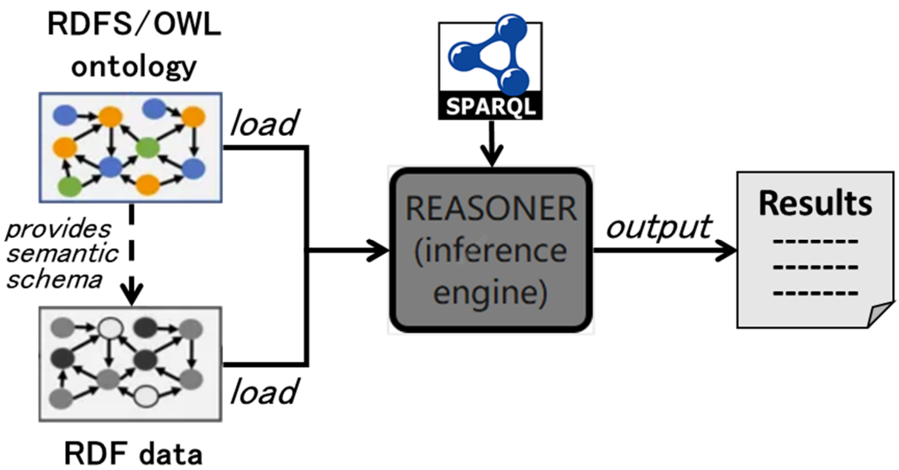

Fig. 2. The inner mechanism for ontology guidance

For illustration purpose, the following only demonstrates the ontology-guided process for identifying key construction processes for mechanization. For a case involving an overhead transmission project, once all case-specific data are converted into ontology-compliant RDF instances, the main construction processes for mechanization can be identified using a SPARQL SELECT query. Figure 3 presents the SPARQL query designed to retrieve the foundation pit excavation activity from the case project, returning the specific instance case1_FoundationPitExcavationT12.

Given that a case project may involve the construction of numerous towers, the SPARQL query can be refined to retrieve all relevant construction processes. This can be organized according to the class hierarchy defined in the ontology and neatly grouped by tower IDs, ensuring comprehensive process identification across the entire project.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX pgcp: <http://www.semanticweb.org/PGCP_Ontology#>
SELECT ?constructionProcess
WHERE {
  ?constructionProcess rdf:type ?unknownClass .
  ?unknownClass rdfs:subClassOf pgcp:FoundationConstruction .
}
```

Fig. 3. Example SPARQL QUERY

3 Case Application

An overhead transmission line construction project is selected as the case study. This paper designed an intelligent system based on the ontology-guided framework for generating mechanized construction plans for power grid construction projects. Figure 4 shows the system's starting page. The system integrates multi-source heterogeneous data (such as construction equipment data, specification data, cost data, and case project data) with the developed ontology through semantic mapping, resulting in the creation of a comprehensive knowledge base. Based on this integrated knowledge base, the system offers functionalities such as target data retrieval, mechanized construction plan design, and corresponding cost calculations.

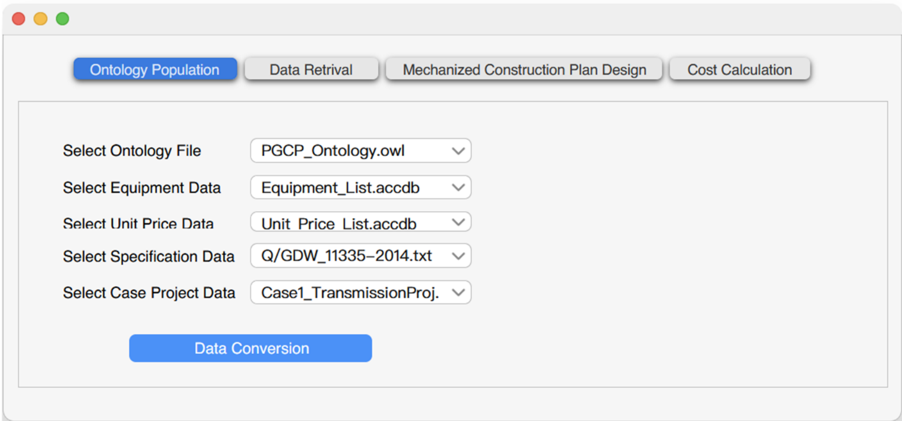

Fig. 4. The starting page of the developed system.

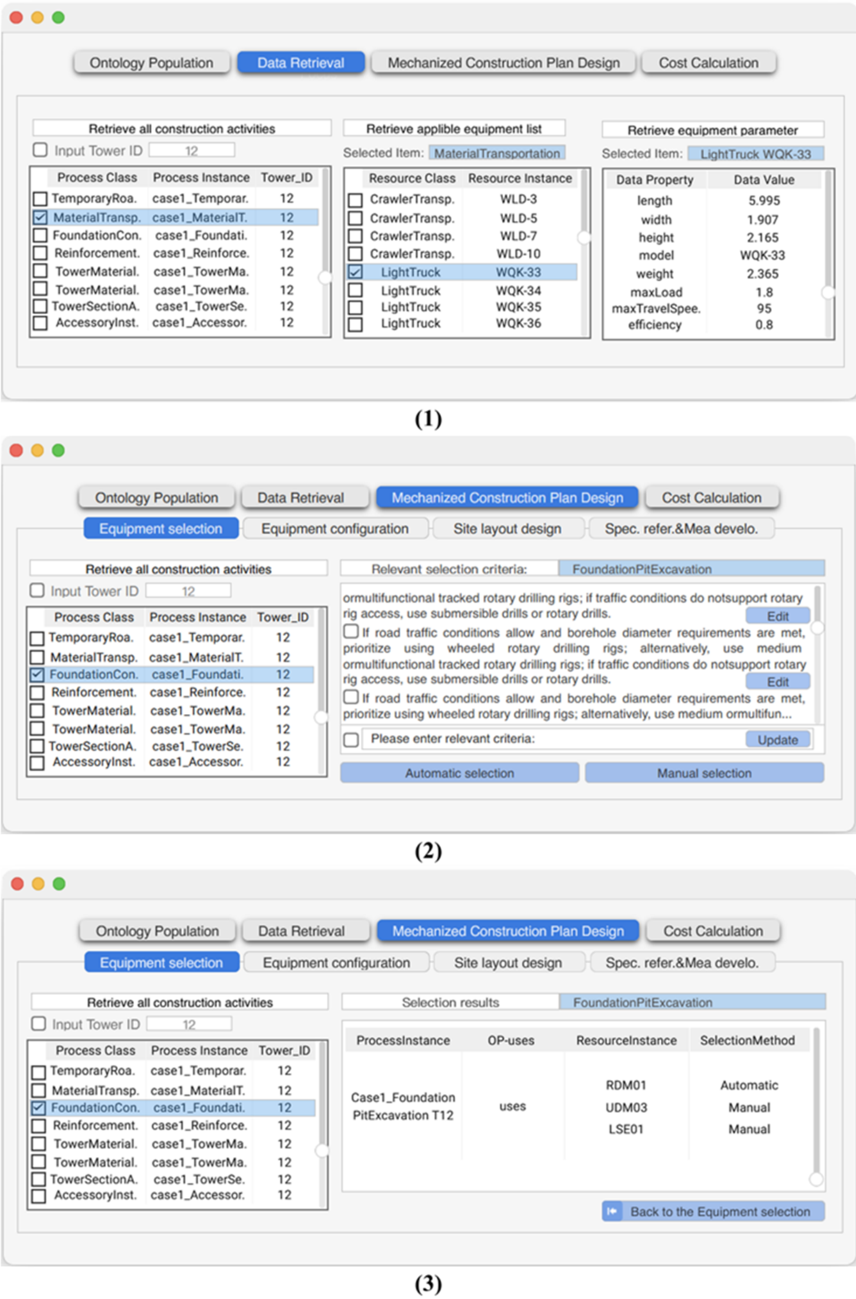

Fig. 5. Use illustration of the developed system.

An example of the system's functionality for equipment selection is shown in Figure 5. Figure 5 (1) illustrates the system's data retrieval capability, where SPARQL queries are used to identify construction activities requiring mechanization and their corresponding lists of equipment from the RDF triple store. Figures 5 (2) and (3) demonstrate the system's equipment selection features, allowing users to choose equipment either automatically or manually. For automatic selection, the system generates SPARQL queries based on predefined criteria. For manual selection, the system enables users to display, edit, or update relevant selection criteria and knowledge to facilitate the manual selection of specific construction equipment. Beyond these examples, the system includes equipment configuration capabilities, where it calculates the required quantities of equipment and personnel for specific construction activities based on SPARQL query results. The system also supports site layout design, allowing users to upload base layouts created in other software environments (e.g., AutoCAD) and make adjustments according to specific construction needs. Additionally, the system offers functionality for retrieving specification information and developing assurance measures through SPARQL queries, providing relevant construction specifications and measures. Finally, the system includes cost calculation and plan generation features, where it retrieves unit prices for equipment and personnel via SPARQL queries, calculates the total costs, and ultimately generates a comprehensive mechanized construction plan.

To evaluate the system's effectiveness in generating mechanized construction plans, six industry experts were engaged to review the plans, focusing specifically on the suitability of equipment selection for key construction processes. The experts based their assessments on four primary criteria: efficiency, cost, quality, and safety. In the case study involving 27 towers, each with eleven construction processes requiring mechanization, the evaluation indicated that 31 construction processes required adjustments in the final equipment selections, while 54 processes—mainly related to reinforcement cage binding and conductor joint crimping—needed completely new equipment. This led to an accuracy rate of 71.38%. Compared to manual selection, the designed system has proven effective in generating mechanized construction plans. With the integration of more complex domain knowledge into the system, it is anticipated that full automation with advanced intelligence can be achieved, enhancing the system's overall capabilities.

4 Summary and Conclusions

This paper presents the development and application of an ontology-guided system designed to automate the generation of mechanized construction plans for power grid projects. The key findings demonstrate that the developed ontology effectively models and organizes a wide range of domain knowledge, enabling automated equipment selection and mechanized construction planning. The ontology-guided system successfully integrates knowledge reasoning capabilities via SPARQL queries, allowing for more efficient and accurate decision-making compared to traditional methods. Ontology-guided systems represent a transformative step in automating construction planning, offering a structured and scalable approach to managing complex knowledge in the construction industry. By enabling more efficient and accurate decision-making, these systems not only streamline the planning process but also support the broader goals of sustainability and innovation in infrastructure development. As the construction industry continues to evolve, the integration of advanced technologies such as ontology-guided systems and Large Language Models (LLMs) will be critical in meeting the demands of increasingly complex projects while maintaining high standards of quality, safety, and efficiency.

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