Ontology for Logistics Requirements on a 4D BIM for Semi-Automatic Storage Space Planning

J. Weber[a], J. Stolipin[b], M. König[a], and S. Wenzel[b]

[a]Chair of Computing in Engineering, Ruhr-University Bochum, Germany
[b]Department of Organization of Production and Factory Planning, University of Kassel, Germany
E-mail: jan.m.weber@rub.de, jana.stolipin@uni-kassel.de, koenig@inf.bi.rub.de, s.wenzel@uni-kassel.de

Abstract –

Well-coordinated construction site logistics are important for the efficient assembly of large-scale plants. Delays in logistics have a negative impact on assembly processes and vice versa. Incorrect storage or improper transport can lead to damage to the sensitive plant components. All relevant logistical constraints must therefore be systematically analyzed, assessed and evaluated during the planning of construction site and assembly processes. For this purpose, precise knowledge of the logistical requirements of each individual component is very important. Nowadays this information is not available in digital form and must be elaborately compiled and evaluated manually. The logistical requirements are also essential for the planning of processes. So-called 4D models are already being created and used in plant construction, but storage and transport processes on the construction site are only rudimentarily taken into account. In general, the 4D models only describe the construction process. In order to better investigate and plan construction site logistics using 4D models, the logistical requirements must be identified, classified, generated for each plant component and made available digitally. Therefore, an ontology for the description of logistic boundary conditions and requirements is presented in this paper. The focus is on large-scale plant engineering and the special storage and transport conditions of the various components. The ontology is also a knowledge base to identify which information is required for the planning of construction site logistics and which may need to be added. Then, for example, semi-automatic allocation of storage space can be calculated, an analysis of the utilization of transport equipment can be carried out or the impact on the assembly processes can be determined.

Keywords –

Logistics requirements; Ontology; 4D BIM; Site layout planning; Plant construction

1 Introduction

A precisely coordinated logistics system is important for the efficient and cost-effective handling of projects in large-scale plant construction. This is particularly important as very sensitive and large components are usually transported and stored in plant construction. Planning includes the selection, design, dimensioning and optimization of processes, material flows and resources. Depending on the complexity of the large-scale plant, many different boundary conditions must be considered in the project-specific planning of construction site logistics. The planning and control of construction site logistics for such large-scale projects are not sufficiently supported by digital planning tools. Nowadays, this requires extensive project experience. If transport and storage conditions are not correctly analyzed and adhered to, this not only leads to delays in assembly, but also to damage to the sensitive system components. In the worst case, elaborate rework or complete disassembly is necessary.

Digital models have also been used for several years in large-scale plant construction for the planning and prefabrication of plant components. However, the digital models are hardly used on site. Even if system components are visualized on the construction site with the help of mobile devices, there is currently no IT-based support for planning and controlling the logistical processes on the construction site in detail. On-site transport, storage and detailed intermediate steps cannot be analyzed, checked and visualized with existing concepts and solutions. Certain information for the precise planning and control of logistics is already available based on the digital model. However, the information available is insufficient and must be systematically supplemented.

In our approach, we examine the required logistics information and describe it formally and evaluably in the Web Ontology Language (OWL) format. This ontology is linked to the information of a 3D Building Information Model (BIM) to generate logistics information for the specific component or assembly task.

2 Related Work

The planning of construction projects is generally associated with uncertainties, because the customer-specific engineering and construction of large-scale plants fundamentally differ from stationary series production. In addition to technical and structural limits, organizational project specifications, such as production steps, construction phases or resource disposition as well as logistical boundary conditions in particular are relevant aspects. Gutfeld et al. (2014) [1] describe the problems and deficits of project management in plant construction and present a method for simulation-based and logistically integrated project management in plant construction. Nowadays, the construction schedule is manually created by project managers based on their experience. The assumptions they made during the planning phase can prove to be disadvantageous in the actual construction process. This is not only due to delays in the delivery of materials, but may also be due to difficulties during assembly. A number of aspects can affect project plans, such as weather, lack of storage spaces or limited resources [2]. Therefore, a subsequent, continuous review and, if necessary, adjustment of the schedules is required. Until now, the focus of the project managers has been on the delivery dates and the duration of the assembly processes. Logistics on the construction site itself has received little attention so far. Usually, logistics processes are regulated spontaneously on site. This leads to unnecessary delays due to lack of suitable storage areas and continuous material search.

The construction industry is currently experiencing a change to a digital construction planning process mainly with the help of BIM. The BIM method is used to provide necessary information of a specific building project starting from the planning phase up to facility maintenance with the help of an intelligent 3D-Model. This is achieved by expanding the geometrical information (3D) of the model with additional information. A BIM-model can be used for visualization, fabrication drawings, code reviews, forensic analysis, facilities management, cost estimating, conflict, interference and collision detection and construction sequencing. During the whole construction process, an up-to-date as-built BIM-model helps keep an overview of the construction site and to avoid incorrect planning that may cause interferences of different trades. These interferences generally cost time, which leads to higher costs due to additional wage costs or contractual fines because of delay [3]. The Industry Foundation Classes (IFC) provide a comprehensive and standardized data model for the vendor-neutral exchange of digital building models. A significant advantage of IFC is that digital model objects can be dynamically extended by any additional information [4].

To implement an integrated digital planning, the site layout also needs to be integrated into BIM-models. A BIM-based site layout planning not only provides 3D models of site equipment, where 2D site layout plans can easily be derived from, but also considers scheduling information. The linking of building elements or construction equipment with activities of a time schedule is called a 4D model. The main purpose is the visualization and analysis of the construction processes and the temporally variable construction site equipment [5]. The use of 4D-BIM promotes communication and enables a uniform understanding between all project participants. Variant assessment tests provide support in procurement with material lists and material calculations. The planned progress can be represented at any time during the construction project and delays can be seen by comparison with an as-built model. This also supports the analysis of work processes.

An essential aspect of BIM is the linking of building elements with other external information for a certain application. Which information is linked or added under which conditions can be defined using a higher-level ontology. An ontology describes a hierarchy of concepts (class and subclass) linked by relationships, adding appropriate axioms to express relationships between concepts and limit their interpretation. Furthermore, ontologies can be used to describe a common vocabulary of terms and the specification of their meaning for the knowledge area [6]. Special ontologies have already been developed in various research approaches in the construction industry. Zhang and Issa (2012) use an ontology to extract specific information from a BIM-model [7]. El-Gohary et al. (2010) show a concept of a domain ontology for supporting knowledge-enabled process management and coordination across various stakeholders, disciplines, and projects [8]. Kim et al. (2009) use an ontological consistency checking for design coordination in BIM [9]. Lee et al. (2015) create an ontology model for supporting information handling of off-site automatic prefabrication and on-site assembly [10]. In order to achieve the target of just-in-time (JIT) production and lean construction, Xiong et al. (2018) use the Process Specification Language (PSL) based ontology to unify the process information from multiple planning software applications [11]. Pedro et al. (2017) use an ontology for linking and sharing Job Hazard Analyses (JSA), safety rules and training contents for construction safety [12]. For the controlling of construction site logistics, it is important to have (near) real-time data to confirm the planned schedule. Therefore, Isaac (2016) reviewed existing scheduling methods and compared their outputs with the data provided by automated monitoring technologies. He proposes ways in which scheduling methods can be enriched in order to better support real-time monitoring and control processes [13]. One of the key integration gateways between BIM and ontology is represented by the ifcOWL and ifcWoD [14]. These ontologies allow the publication of IFC-based building models using the Resource Description Framework (RDF) data model.

3 Methodology

An essential requirement for planning and control in large-scale plant construction is the systematical description of all logistical constraints according to the specific project. There are different requirements for different plant components and parts. Certain components must be specially stored and transported. Suitable storage areas and transport aids have to be available for this purpose. This information must be systematically recorded, documented and made available digitally in advance. In our concept describes below, the logistical requirements are described flexibly and they are reusable with the help of an ontology. In large-scale plant construction, the focus lies on sensitive and costly plant components. The components are usually prefabricated and partly pre-assembled. Afterwards, the components are transported to the construction site. The next step is often an intermediate storage. On international construction sites, most problems arise during this intermediate storage and corresponding transport.

For typical plant components and projects in large-scale plant construction, our ontology covers all essential logistical boundary conditions. Complex dependencies between the components, means of transport and logistic influencing variables are modelled. The ontology is thus a formally ordered representation of a set of concepts and the relationships between them. The ontology is used to provide expert knowledge on logistic processes on construction sites in a digitized and formal form for planning and control. Furthermore, ontologies contain inference and integrity rules, i.e. rules on conclusions and on ensuring compliance.

We worked out company-specific requirements by analyzing the results of surveys on the topic of logistics and assembly planning for small medium-sized (SME) companies by means of expert interviews and case study analyzes. Here, other companies were also involved in individual discussions in order to record project and product-specific boundary conditions regarding organization, technology, personnel, quality and safety measures and country-specific regulations to be observed. In addition, requirements regarding the content of a digital planning and management of the construction logistics are included. At the same time, it is being examined how and to what extent product-specific restrictions must be formulated.

It is assumed that a digital model of the plant and the site equipment as well as associated and linked assembly processes for the individual components are available (see Figure 1). The existing digital models (4D-BIM including construction site layout) are imported and evaluated. This means that the components, storage areas, transport aids, processes and other boundary conditions are extracted. The ontology is used to classify the various objects and to conclude the associated logistical requirements. Therefore, every object needs to provide the standard properties, inter alia, family, type, identifier and dimensions. With the help of manual inputs via a user interface, logistics information, respectively logistics requirements per component, can be edited as well as extended and later used for planning and controlling on-site logistics.

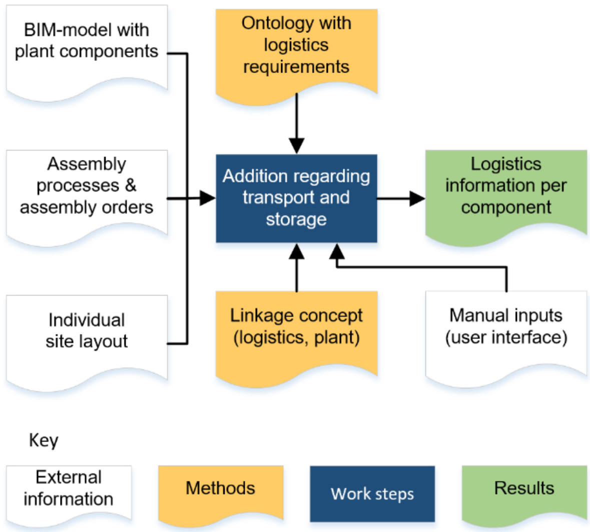

Figure 1. Methodology overview

4 Ontology for Logistics Requirements

When planning onsite-logistics, it is important to consider the specific requirements of the plant components. For space and cost reasons, not all components can be stored in secure areas. Therefore, the use of different types of storage areas is appropriate. Secure areas should be provided for very sensitive or very valuable components. Such components are typically present particularly in large-scale plant construction. Components that cannot be mounted directly after delivery (e.g. due to delays in the assembly of previous components) must be secured accordingly. Other components, which are sensitive to environmental influences such as dust, sunlight, cold or moisture, must be stored in closed storage areas. However, if components are to be protected from rain and direct sunlight only, a covered area will be a sufficient storage location.

If components react very sensitively to external influences, they will be specially packaged. The disadvantage of packaging is that often special transport aids are requires and more waste is produced. In this case, the disposal areas must be enlarged or reorganized accordingly. The construction site layout must also be analysed and taken into account in detail. For example, it must be determined which transport routes and areas are available. Figure 2 shows a typical layout of a construction site in large-scale plant construction.

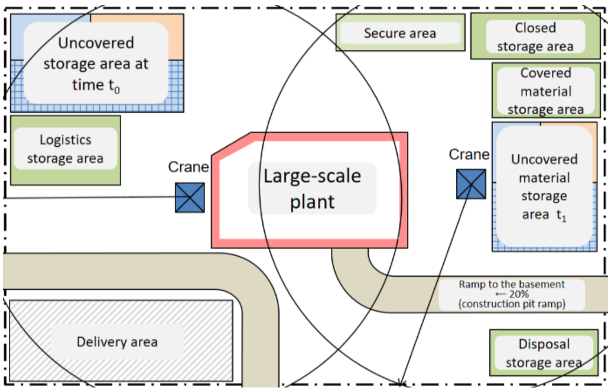

Figure 2. Construction site layout with typical logistical elements

In connection with the storage location, the logistical requirements of the components must also consider that they can be reached and equipped in a time-effective manner (e.g., only components of the same type may be stacked). The range of the cranes must also be taken into account. It should be noted, for example, that a direct crane operation from the truck to the covered storage areas might not be possible due to the roofing. For the affected components, lift trucks, or forklifts must be available on delivery, as well as suitably qualified personnel.

In some cases, roof elements of the storage areas must also be removed for the delivery of large, heavy equipment requiring appropriate storage. JIT delivery should be preferred for such components.

During transport and storage of components on the construction site, the following information must be observed:

- package size (number of components per package),
- weight,
- packaging dimensions,
- permissible temperature range,
- permissible (air) humidity range,
- shock sensitivity,
- permitted change of position,
- stackability,
- fragility,
- legal requirements,
- hazardous content,
- just-in-time priority,
- assembly order.

For a valid planning of logistics processes, it is important to have the necessary project-relevant information available. This information can also be used to optimize logistics processes on the construction site. The logistical requirements should therefore be known at an early stage. The exact definition of the logistics processes (transport and storage at the construction site) depends not only on the components of the large-scale plant, but also on the delivery dates, assembly processes and other conditions at the construction site. In order to optimize assembly and logistics processes, planners must be provided with project-relevant information in the right quality at the right time. BIM is a suitable method for storing

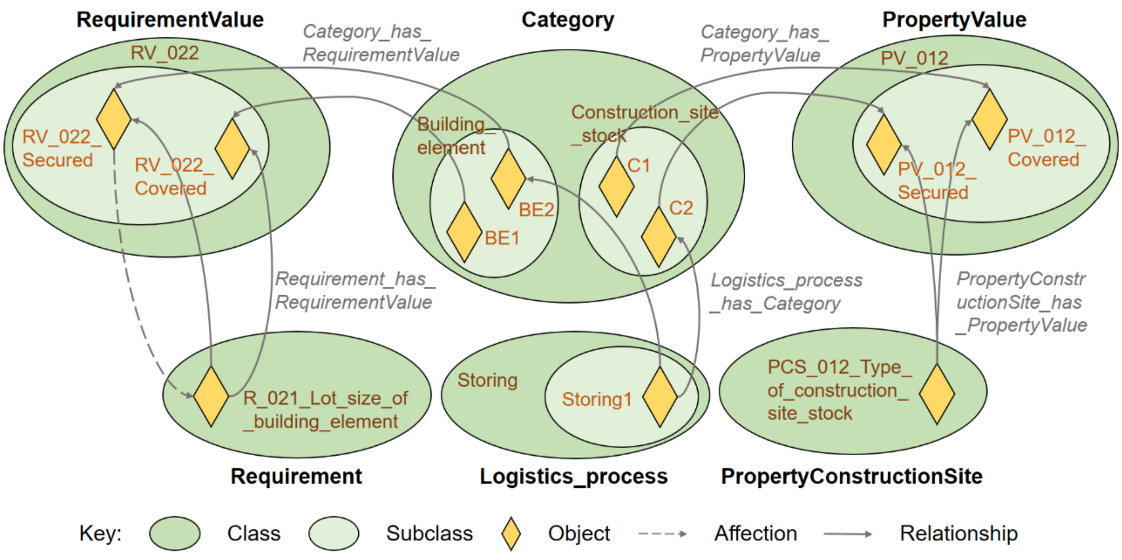

Figure 3. Detail of the basic structure of the developed ontology

this information and making it available to all parties involved. For the planning of logistics processes in large-scale plant construction, requirements for components, construction site equipment, etc. were examined and confirmed with the help of an interview study.

The ontology is mainly designed to support the planning of construction site logistics. For this purpose, existing information in the form of BIM-models of the objects of the plant to be built, the necessary assembly processes and scheduled resources are analyzed based on the ontology and are supplemented by necessary logistical information. The ontology provides a basis for summarizing requirements for the planning of logistics processes on the construction site in large-scale plant construction. In its semantic structure, the planning-relevant information on requirements, prerequisites for site equipment and planning objects (see Figure 3, class *Category* with *Construction_site_stock*, *Building_element* etc.) can be linked, represented and saved. The class *Requirement* contains a list of possible logistical requirements.

Currently ca. 20 pre-defined requirements are available. The characteristics of these requirements are described in the *RequirementValue* class. The individual components relevant to planning (such as *Assembly_group*, *Assisting_tool*, *Building_element*, *Construction_site_stock*, *Control*, *Data*, *Means_of_transport*, *Staff*, *Structure*, *and Working_environment*) are described in the *Category* class. The processes to be planned (*Assembly_process* and *Logistics_process* with *Search*, *Storing* and *Transport* subclasses) are defined in the *Process* class. They are assigned to certain properties in relation to the construction site facilities (*PropertyConstructionSite*), whereby the values of these properties are also assigned in a class called *PropertyValue* is defined. The list *PropertyConstructionSite* with the properties and their characteristics can also be extended. To compare the requirements with a digital model, the class *Sources* is defined with subclasses *BIM* and *Calculations*.

The ontology editor *Protégé 5.2* [15] was used to develop the ontology. The hierarchy of the ontology is shown in Figure 4. The *RequirementValue* and *PropertyValue* classes were created to group the possible characteristics of the properties and requirements. They group the values into individual numbered types (subclasses) and display their possible values in the form of objects (see Figure 4).

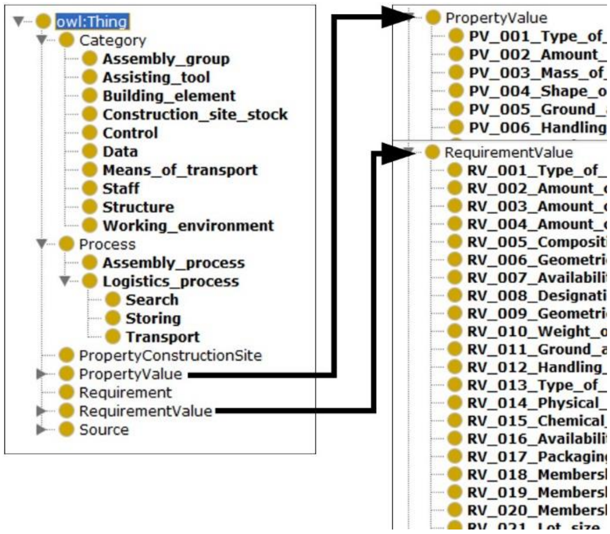

Figure 4. Classes *RequirementValue* and *PropertyValue*

With the help of the proposed ontology, the information relevant for planning can be linked and visualized in the *Protégé* editor with the help of *OntoGraf* (see Figure 5). This visualization helps to understand and verify the ontology.

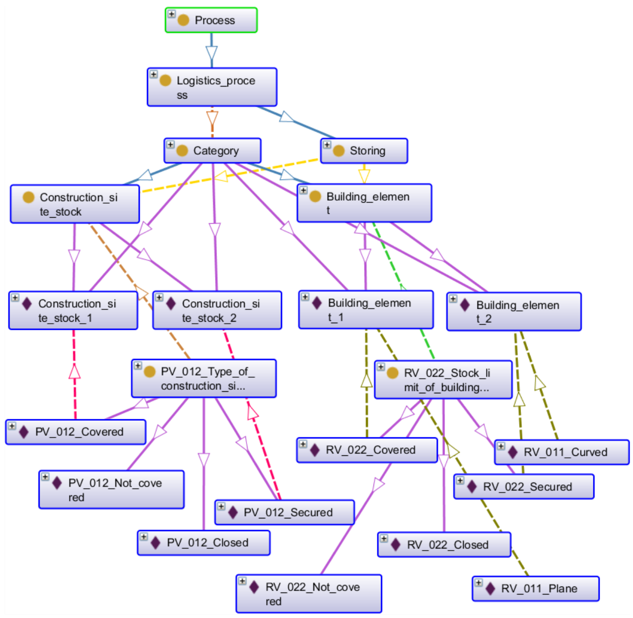

Figure 5. Graphical representation of the ontology in OntoGraf

Figure 6 shows how the limitations of a component (to be stored only in a covered place) influence the storage process. The associated storage process can therefore only be planned considering this requirement. For this purpose, the conditions on the construction site must be examined with regard to a covered storage area and the storage of the component in such a storage area must be planned. Afterwards, the corresponding relationship is set according to this relationship.

Figure 6. Classes *Requirement* and *PropertyConstructionSite*

5 Evaluation of the Ontology

The proposed ontology can be used in the BIM-based planning of site logistics processes to share knowledge about site logistics. This ontology will assist project participants in two areas. First, it will help to identify and classify the requirements for planning individual processes, as the user may not have enough logistics knowledge to fully incorporate this information into BIM-models. Second, it will help to analyze the information from a BIM-model in relation to logistics planning and assign it to the processes to be planned. These two cases are explained in the following sections using the proposed ontology. The queries are created with the *Protégé 5.2* tool.

5.1 Case 1 - Ontology to Read the Requirements for Planning the Individual Processes

When creating BIM-models, these requirements can be incorporated into the model in the form of planning-relevant information. For this purpose, a checklist can be created using the ontology in order to check such planning-relevant information in the model.

Simple ontology queries can be performed in *Protégé 5.2* using either a DL query or a SPARQL query. SPARQL is a query language for RDF, i.e. a query language for databases capable of retrieving and editing data stored in RDF format [16]. Table 2 shows an extract of the result of the SPARQL query shown in Table 1 that retrieves *Requirements* relevant to logistics planning. This list of planning-relevant information can be used as a checklist.

Table 1. SPARQL query for requirements

```
PREFIX bimlog: <http://www.semantic-web.org/user/ontologies/2018/12/bimlog#>
SELECT ?Requirement
WHERE { ?Requirement a bimlog:Requirement}
order by asc(str(?Requirement))
```

Table 2. Results of SPARQL query for requirements

Requirement
R_001_Type_of_assembly_group
…
R_008_Designation_of_building_element
…
R_010_Weight_of_building_element
…
R_039_Transmission_speed
…
R_051_Priority_of_task
…
R_060_Lot_size_of_building_element
…

5.2 Case 2 - Analysis of Information from BIM-Models in Relation to logistics Planning

If the information on the individual category classes (e.g. *Building_element*) from BIM-models is integrated into the ontology, the missing information can be analyzed and supplemented.

Table 3 shows the SPARQL query where components are retrieved, their requirement values are queried and restricted to the referring requirements of warehouse or transport restrictions (see Table 4).

Table 3. SPARQL query for Building_element and RequirementValue

```
PREFIX bimlog: <http://www.semantic-web.org/user/ontologies/2018/12/bimlog#>
SELECT ?Building_element ?Stock_limit
WHERE {
?Building_element a bimlog:Building_element.
?Building_element bimlog:Category_has_requirementValue ?Stock_limit.
?Stock_limit a bimlog:RV_022_Stock_limit_of_building_element}
```

Table 4. Results of SPARQL query for Building_element and RequirementValue

Building_element	Stock_limit
Building_element_2	RV_022_Secured
Building_element_1	RV_022_Covered

Queries can be carried out to obtain further information on transport and storage on the construction site, to find out where the construction elements are stored on the construction site and by which means of transport they can be transported. It is also possible to add new recommendations to the requirements according to use. For example, it is also possible to define automatic recommendations to support the decisions of project planners.

In our approach, we used the 4D-BIM software ceapoint desiteMD to import an IFC-format building model. As shown in Figure 7 information based on the developed ontology can help to visualize specific elements for the logistics planning.

Figure 7 shows two states of the visualization. In the upper screenshot, the entire plant is shown at the time t_1, in the lower screenshot, however, the object properties are used to highlight and to show only all the components in question. In this sample model, these are the bolts, queried by their amount and *Weight_of_building_element*. The advantage of the visualization in this example is the quick recognition of a possible storage position for short transportation paths of these small but numerous elements. Furthermore, possible logistical problems or potentially vulnerable components can be identified. For each element, IFC 3D Models only provide standard properties e.g. name, dimensions, material and identifier, while the ontology database only provides general logistics information, independent of individual elements.

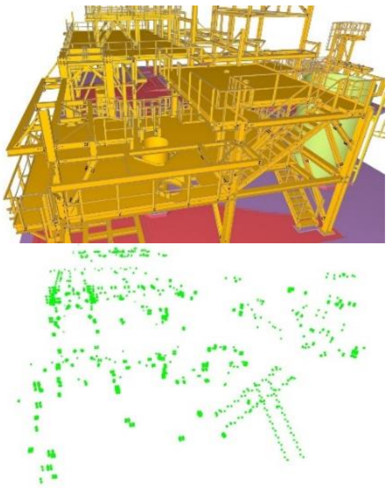

Figure 7. Highlighted consumable building components

To receive the specific logistics information for each element the information of the ontology database and the IFC 3D-model need to be linked as shown in Figure 8.

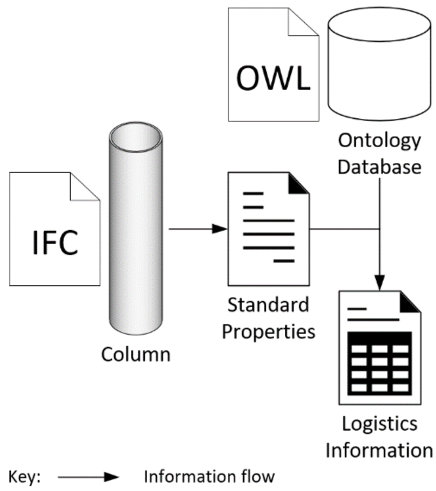

Figure 8. Receiving and linking logistics information

The link between the IFC and the OWL format may be established e.g. with the software *ceapoint desiteMD* via JavaScript and the help of the *Apache Jena RDF API* (Application Programming Interface).

6 Conclusion & Outlook

The definition of the specific requirements and the development of the ontology with the support of the surveyed companies creates the methodical prerequisite for semantically combining logistics, assembly and product descriptions to ensure a standardization and transferability of the results. This approach enables companies to identify gaps in their planning to ensure smoother operation, to improve processes to reduce costs and save time on the job site.

Today, there are no commercial solutions on the market or scientific approaches available to implement a BIM-based logistics model. Therefore, new ground is broken with the conceptual work carried out in our approach. Based on the results of this work, software solutions can be developed for the coupling of IFC models and OWL ontologies. Based on our methodology, comprehensive databases can be created and will support project managers and planners to plan their construction schedules and to ensure a smoother progress of the projects. These databases can be continually supplemented, so that these knowledge bases grow gradually and require only fewer adjustments in future projects. Furthermore, the component information could also be extended by empirical values for the assembly time, thus ultimately enabling semi-automatic scheduling, taking into account all logistical requirements on the construction site.

Acknowledgements

The results presented in this paper originated in the joint research project "BIMLog - BIM-Based Logistics Planning and Control in Large-Scale Plant Construction" of the University of Kassel and the Ruhr University Bochum. The Industrial Collective Research (IGF) Operation (19720 N) of the Bundesvereinigung Logistik e.V. (BVL) was funded via the Industrial Research Associations (AiF) under the program for the promotion of the IGF by the German Federal Ministry for Economic Affairs and Energy (BMWi) based on a resolution by the German Bundestag.

References

[1] Gutfeld T., Jessen U., Wenzel S., Laroque C. and Weber J. A technical concept for plant engineering by simulation-based and logistic-integrated project management. In *Proceedings of the Winter Simulation Conference,* Savanah, GA, USA, 2014.

[2] Castro-Lacouture D., Süer G. A., Gonzalez-Joaqui J. and Yates J. K. Construction Project Scheduling with Time, Cost, and Material Restrictions Using Fuzzy Mathematical Models and Critical Path Method. *Journal of Construction Engineering and Management,* (10):1096–1104, 2009.

[3] Khoshnava S. M., Ahankoob A., Preece C. and Rostami R. Potential application of BIM in construction dispute and conflict. In *Management in Construction Research Association Postgraduate Conference,* Universiti Teknologi Malaysia Kuala Lumpur, 2012.

[4] buildingSMART e.V. IFC Introducion. Online: https://www.buildingsmart.org/about/what-is-openbim/ifc-introduction/, Accessed: 28/01/2019.

[5] Borrmann A., König M., Koch C. and Beetz J. *Building Information Modeling: Technology Foundations and Industry Practice*. Springer Vieweg, Wiesbaden, 2015.

[6] Guarino N. Formal ontology in information systems. In *Proceedings of the first international conference,* Trento, Italy, 1998.

[7] Zhang L. and Issa R. R. Ontology-based partial building information model extraction. *Journal of computing in civil engineering,* (6):576–584, 2012.

[8] El-Gohary N. M. and El-Diraby T. E. Domain ontology for processes in infrastructure and construction. *Journal of Construction Engineering and Management,* (7):730–744, 2010.

[9] Kim H. and Grobler F. Design coordination in building information modeling (BIM) using ontological consistency checking. *Journal of computing in civil engineering,* (27):410–420, 2013.

[10] Lee S., Isaac S. and Bock T. An Ontology for Process Information Modeling. In *Proceedings of the 32nd ISARC,* Oulu, Finland, 2015.

[11] Xiong W., Yang J., Wang Z., Hu H., Xu F. and Zhang J. Improving Supply Chain Communications for Off-Site Construction Using Process Specification Language. In *Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC),* Taipei, Taiwan, 2018.

[12] Pedro A., Lee D. Y., Hussain R. and Park C. S. Linked Data System for Sharing Construction Safety Information. In *Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC),* Taipei, Taiwan, 2018.

[13] Isaac S. Real-time Schedule Control. In *Proceedings of the 33rd International Symposium on Automation and Robotics in Construction (ISARC),* Auburn, AL, USA, 2016.

[14] Pauwels P. and Terkaj W. EXPRESS to OWL for construction industry: Towards a recommendable and usable ifcOWL ontology. *Automation in construction,* (63):100–133, 2016.

[15] Stanford. The Protégé Ontology Editor and Knowledge Acquisition System. Online: http://protege.stanford.edu/index.html, Accessed: 04/01/2019.

[16] W3C. SPARQL Query Language for RDF. Online: https://www.w3.org/TR/rdf-sparql-query, Accessed: 04/01/2019.