Bridging the gap between Information Management and Advanced Work Packaging: AWP Ontology

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Abstract
Construction projects face high complexity and interdependencies among involved stakeholders and their activities, ending with cost and schedule overruns and safety incidents. Several approaches have been adapted in the built environment sector to overcome these challenges, such as Advanced Work Packaging (AWP). The case studies that utilized the AWP approach show several benefits in productivity, time, cost, and safety. Also, they show that information management is a crucial factor for an effective AWP. However, there is no clear relationship in the literature between information management and AWP. Therefore, this research aim is twofold: first, to develop an ontology for the AWP including all related aspects such as Construction Work Packaging (CWP), Engineering Work Packaging (EWP) and Installation Work Packaging (IWP), and the relations between them; and second, to map the AWP classes to the required information for each work package and its sources/datasets. The developed AWP ontology fills the knowledge gap by providing a formal and shared vocabulary for the domain of AWP and associated information required. The AWP ontology can also promote the adaption of AWP and knowledge reuse and share among professional engineers. Besides, the ontology can be utilized to develop knowledge-based systems for effective AWP implementation.

Keywords: Advanced Work Packaging, Ontology, Production Control Room.

1 Introduction
The construction project to be completed on time, within the estimated budget, and with no accidents are the construction companies' core objectives. There is a movement in the construction industry to production control instead of project management to achieve that. Production control is the task of predicting, planning, and scheduling work, considering human resources, materials availability and other capacity restrictions, and cost to achieve acceptable quality and quantity when needed. Then following up the schedule to see that the plan is carried out, using whatever systems have proven satisfactory for the purpose (McKay and Wiers, 2004). Therefore, several project delivery approaches have been transformed to improve performance and reduce waste in construction projects through production control (Dave *et al.*, 2016). These approaches include Integrated Project Delivery (IPD) and Virtual Design and Construction (VDC), Lean Construction, Advanced Work Packaging (AWP). They were also armed with several technologies and techniques such as Last Planner System (LPS), Building Information Modelling (BIM), Geographic Information System (GIS), 4D, and real-time data sources such as cameras, mobile, and sensors (Hwang *et al.*, 2020).

With the increase of project complexity and uncertainties and the number of stakeholders involved in one project, integrating digital data with physical data became a critical aspect of productivity improvement (Soman *et al.*, 2020). Therefore, Digital Twin became a hot topic in the construction industry (Boje *et al.*, 2020). System engineering development in the AEC sector should now consider both the physical and the digital models for achieving the benefits of Digital Twins. In other words, the approaches for lean construction and AWP (productive physical model) should be supported by information management technologies (effective digital model). In most of the construction projects, they are working in parallel but not feeding each other effectively.

This paper aims to contribute by filling that gap by developing an ontology for the AWP requirements and mapping it to the available construction information exchange standards. The ontology would provide a semantic interoperability approach for exchanging the information from the digital model to the physical model and vice versa. This paper is organized as follows. Section 2 presents the point of departure of the AWP; it discusses the main concepts and attributes of AWP. Section 3 presents the research methods, while section 4 describes the process development of the AWP ontology. Section 5 represents the ontology and its implementation in a real case study. Finally, Section 6 summarizes the work presented and its contribution and limitations and discusses the future research areas and directions.

2 Point of Departure

The concept of WorkFace Planning (WFP) – by the Construction Owners Association of Alberta Research (COAA) – is all about getting the right things to the right people at the right time. This work has provided the foundation stone for the Construction Industry Institute (CII) to develop an executable model of enhanced work packaging (Guerra and Leite, 2020). In 2011, a research joint venture between COAA and CII worked on advanced work packaging based on WFP and other industry work packaging practices named "Advanced Work Packaging" (Halala *et al.*, 2018). As a result, AWP was announced as a best practice by CII and COAA in 2015 (Hamdi, 2013). As defined by CII, AWP is "*a planned, executable process that encompasses the work on an engineering m procurement and construction project beginning with initial planning and continuing through detailed design and construction execution*". AWP mainly is based on the three main types of work packages in construction project management: Construction Work Packages (CWP), Engineering Work Packages (EWP), and Installation Work Packages (IWP) and finally inspire by the WFP is Construction Work Areas CWA (CII/COAA, 2013).

A construction work package (CWP) is a unit of the first level of a project's scope breakdown. It defines a logical and manageable division of work within the construction scope. An engineering work package (EWP) is an engineering and procurement deliverable that is used to form Construction Work Packages (CWP). The EWP is generally aligned with the construction sequence and priorities. An installation work package (IWP) is the deliverable to a construction work crew that enables a crew to perform quality work in a safe, predictable, measurable, and efficient manner. An IWP is defined to be manageable, typically of a limited size, such that a crew can complete the work in about a week. In 2020, the CII published a data requirement index for AWP. This document has been the point of the departure for this research as it includes the required data to be integrated, collected, and shared for the successful implementation of AWP in construction projects. The data requirements are divided based on four main stages of the project: stage 1 – preliminary planning/design, stage 2 – detailed engineering, stage 3 – construction, and finally, stage 4 – operation. Figure 1 illustrates a screenshot for the index of the data requirement spreadsheet published by the CII, and the colored rows are the ones extracted to develop the proposed ontology.

The main contribution of this ongoing study is that it takes the human-readable AWP into a machine-readable form so that state-of-the-art artificial intelligence can be applied on it to support decision making in complex projects, thereby increasing productivity, reducing cost overruns, schedule delays and carbon emisssions .

AWP Requirement Index				
DR00-01 Requirement List				
Data Requirement Number	Requirement Name	Data Table	Table Name	Directory Name
DR010	AWP Master Index	01	Project Information	DR010-01 Project Information
DR010	AWP Master Index	02	CWAs	DR010-02 CWAs
DR010	AWP Master Index	03	CWPs	DR010-03 CWPs
DR010	AWP Master Index	04	EWPs	DR010-04 EWPs
DR010	AWP Master Index	05	IWPs	DR010-05 IWPs
DR020	Project Schedule	01	Schedule Activities	DR020-01 Schedule Activities
DR050	Equipment Design	01	Equipment List	DR050-01 Equipment List
DR070	Piping Design	01	Line List	DR070-01 Line List
DR070	Piping Design	02	Isometric List	DR070-02 Isometric List
DR070	Piping Design	03	Tie-in List	DR070-03 Tie-in List
DR080	3D Modeling	01	Pipe Components	DR080-01 Pipe Components
DR080	3D Modeling	02	Equipment Components	DR080-02 Equipment Components
DR080	3D Modeling	03	Generic Components	DR080-03 Generic Components
DR090	Structural Design	01	Structures List	DR090-01 Structures List
DR100	Electrical & Instrumentatio	01	Cable Schedule	DR100-01 Cable Schedule
DR100	Electrical & Instrumentatio	02	Electrical Equipment	DR100-02 Electrical Equipment
DR100	Electrical & Instrumentatio	03	Instrument Index	DR100-03 Instrument Index
DR100	Electrical & Instrumentatio	04	Conduit	DR100-04 Conduit
DR100	Electrical & Instrumentatio	05	Cable Tray	DR100-05 Cable Tray
DR100	Electrical & Instrumentatio	06	Lighting & Devices	DR100-06 Lighting & Devices
DR100	Electrical & Instrumentatio	07	Electrical Heat Tracing	DR100-07 Electrical Heat Tracing
DR120	Document Control	01	Document Register	DR120-01 Document Register
DR120	Document Control	02	Document to Entity	DR120-02 Document to Entity

Figure 1: Screenshot of the index of the data requirement spreadsheet.

3 Research Methods

Ontological modeling is a well-suited approach to model AWP data requirements for two main reasons. First, AWP concepts and their semantic relationships can be effectively represented in the form of classes and properties in an ontology. Second, the development of AWP can enhance the applicability of AWP and its integration with the digital transformation technologies and standards. For developing a domain or upper ontology, it is necessary to follow a set of defined and ordered steps. After the analysis of various methods for ontology buildings such as Uschold and Gruninger's (1996) approach, METHONTOLOGY (Fernández-López *et al.*, 1997), SKEM (Noy and McGuinness, 2001), and NeOn (Suárez-Figueroa *et al.*, 2012). The Uschold and Gruninger (1996) approach is used to build the AWP ontology and map it to existing ontologies. The approach consists of five main steps: identifying purpose and scope, building ontology, integrating existing ontologies, evaluating the ontology and documentation. For the second step – building ontology, the SKEM (Noy and McGuinness, 2001) ontology development is adapted in this research. In addition, other steps were added, such as identifying the ontology description language, ontology editing tool, and process of reasoning. In this research, OWL is the selected language, protégé is the editing tool, and finally, SWRL is selected as the reasoning rules of ontology as it allows adding and modifying rule restraints flexibly. All the steps of ontology development and their main deliverables are shown in Figure 2. The steps by which the AWP ontology was achieved are discussed in the following section.

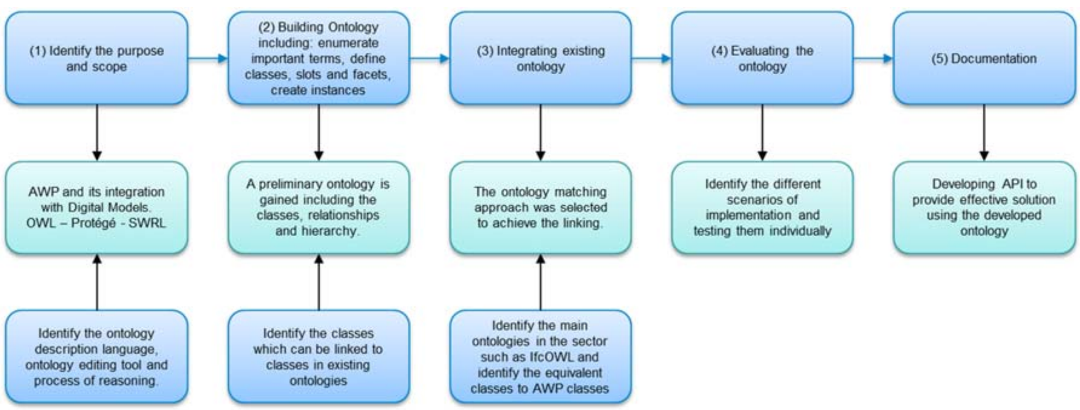

Figure 2: The steps for the ontology development and the related deliverables

4 AWP Ontology Development

The ontology development includes five main steps, as mentioned in the methods section. Step 1 includes identifying the domain and purpose and defining the scope. That step plays a significant role in ontology development and has a significant influence on its quality. As such, answering competency questions acts as a practical approach so that the authors can know the scope of the ontology and how it would be achieved. Some of the questions asked in the early stage of this research, together with the respective answers, were: 1) Why develop AWP ontology? To better control and monitor the Programme and Production Control during the pre-construction and construction stage. This could be achieved by effective integration between the different datasets through the developed Linked Data environment using AWP ontology. 2) What domain the AWP ontology would cover? In the piece of work, it would only cover monitoring and controlling the document deliverables such as drawings, models, inspections, signoffs, and reports. It will be extended in further work to cover also 3 and 8 weeks look-ahead and site delivers and labors. 3)Who is going to use the AWP ontology? It is mainly contractors and sub-contractors; however, the use cases can be extended to include designers and owners too. 4) What is the source for the ontology? The AWP Requirement Index was published by CII (2020). 5) How would the ontology be developed? Protégé, which Stanford University developed, will be used to load and save the OWL ontologies. Protégé supports modeling ontologies, is compatible with most OWL syntax validators, and includes various plugins that can be used for visualization and queries.

Step 2 involves the preliminary development of the ontology components. This starts with identifying any existing ontology related which can be reused or extended. In the literature, we have found several ontologies representing the construction information, such as IFCOWL and BOT for BIM models and others for activities (Koo *et al.*, 2007), cost (Lee *et al.*, 2014), and maintenance of building assets (Farghaly *et al.*, 2019). However, there is no existing ontology for the AWP. Therefore, a new ontology has been developed. As mentioned before, a glossary of essential terms was generated from the AWP requirement index published by CII. The key concepts only related to the different work packaging and representation of documents and their relationships with entities were extracted and developed as classes and relationships in the proposed ontology.

Figure 3 demonstrates the main five terms and crucial associated information. They are color-coded based on what property is between them. There are three main kinds of properties are utilized in ontology development: object properties (green), data properties (Blue and Orange) and annotation properties. The object properties explain relation between class and another. For instance, in the proposed ontology, *HasCWA*. Using this object properties can connect the classes and provide semantic alignment with existing information management ontologies. Figure presents the main classes of AWP and other main classes in information management and the object relationships. The data properties present the characteristics of various instances such as description and status. Once classes and relationships were developed, instances were added from a pilot study and SWRL rules were created (Discussed in the next section).

Step 3 aims to achieve effective integration by linking across domains and making logical inferences to perform constraint checking on construction process information. This is achieved through reusing existing ontologies (BOT ontology and Time ontology). In addition, other small ontologies were built for semantic enrichment includes classes such as activity, contractor, shipment. These classes are discussed in future work as they are out of the scope of the paper, which concentrates on deliverables. The class related to deliverables is built based on the data requirements and includes four sub-classes, namely, document file type, document number, which is samaAs document ID, document status, and document type. Step 4 is discussed in the next section, while step 5 is ongoing work that will be published in the future.

Property	PI	CWA	EWP	CWP	IWP
Project Name					
Project Description					
Location					
Project ID					
CWA Description					
GIS Boundary					
Zone					
Plot Plan Drawing ID					
Discpline					
Trade					
CWA					
EWP Description					
EWP Status					
Owner					
Revision					
EWP					
CWP Description					
CWP Status					
CWP Type					
Esitmate Hours					
Revision					
Sequence					
CWP					
Trade					
IWP Description					
EWP Status					
Planner					
Foreman					
General Foreman					
Superintendent					
Esitmate Hours					
Revision					
Sequence					
Type					

	Class has a direct relationship (Object Property)
	Data Property
	Data Property Optional
	Second relationship based on first relationship property

Figure 3: Matrix for the main classes of AWP and required data

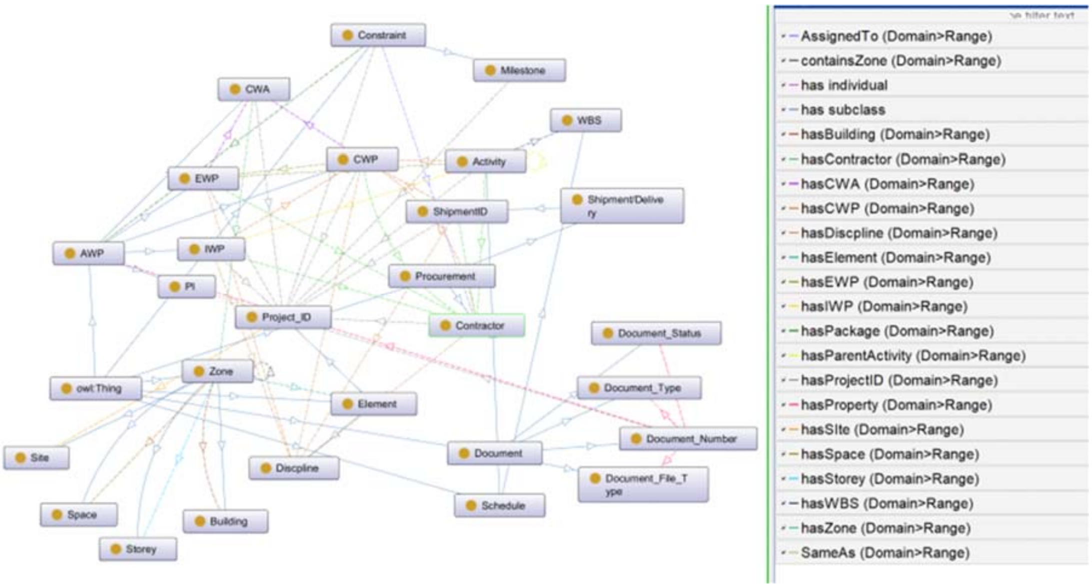

Figure 4: The developed ontology and external classes required for semantic alignment.

5 AWP Ontology Implementation and Ongoing work

AWP ontology and its integration with other ontologies can be valuable in several AEC production control scenarios. However, each scenario would need particular attention to understand what the end-users want and which datasets should be integrated and visualized to achieve that. This research is a part of ongoing research funded by Innovate UK named: AEC Production Control Room. The project proposes to build a scalable and repeatable 'plug-and-play' construction management and reporting platform that will be tested on three significant projects in the UK. This digital project management platform will be accessible via physical site-mounted 'AEC Production Control Rooms' that will display a suite of preconfigured performance metrics using real-time data, facilitating planning and collaborative decision-making at the team, project, and portfolio level. One of the main reasons for implementing the AEC production control room in the demonstrator projects is monitoring and managing the Programme and Production Control (PPC) deliverables. Interviews with experts have emphasized that it is hard to control the deliverables such as drawings, reports, schedules, inspection reports, and quality signoff reports. Despite the available tools for document management, they found it hard to manage it as there are usually around 10-15 different subcontractors on site every day, and their deliverables are not linked to other deliverables. In other words, it is hard to find the root cause of the delay of a specific delivery if it is because of another work package. We realized that AWP could help in achieving effective PPC, so we implemented it as the first scenario to prototype the AWP ontology.

With AWP ontology, it is easy to integrate data that comes from different systems. For instance, listing 1 gives a SPARQL query to show all the deliverables related to a certain CWA. Here the documents are not related directly to a CWA however have a second-order relation through CWP and EWP. Similarly, listing 2 shows the deliverables that have a planned submission date such that the IWP may be delayed. Here, the deliverables are not directly related to sequence; rather, they have a second-order relation through the EWP relations. The knowledge within the AWP ontology allows us to exploit these second-order relations to provide insights and understanding these insights are critical for efficient PPC.

```
PREFIX inst: <http://www.exampleproject.com/AWPProject#>
PREFIX awpont: <http://www.exampleproject.com/AWPOntology#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?DocumentID ?PlannedSubmissionDate
WHERE {
        ?DocumentID awpont:RelatedID ?CWP.
        ?CWP awpont:hasEWP ?EWP.
        ?EWP awpont:hasCWA inst:CWA_Zone_2A.
    }

```

Listing 1: SPARQL query to list all the documents to a CWA

```
PREFIX inst: <http://www.exampleproject.com/AWPProject#>
PREFIX awpont: <http://www.exampleproject.com/AWPOntology#>
PREFIX time: <http://www.w3.org/2006/time#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?DocumentID ?PlannedDate ?IWP ?
WHERE {
        ?DocumentID awpont:RelatedID ?IWP.
        ?DocumentID awpont:hasPlannedSubmissionDate ?PlannedDate.
        ?IWP awpont:hasSequence ?Sequence.
        ?Sequence awpont:hasTimeInterval ?S1.
        ?S1 time:hasBeginning ?S1Start.
        ?slack a time:Interval.
        ?slack time:hasDurationDescription ?slackduration.
        ?slackduration a time:DurationDescription.
        ?slackduration time:days 7.
        ?slack time:hasEnd ?S1Start.
        ?slack time:hasBeginning ?slackstart.

        FILTER (?PlannedDate time:after ?slackstart).

    }

```

Listing 2: SPARQL query to list all documents that have a late submission. Query displays document, IWP associated, and planned submission date

6 Conclusion

The whole goal of AWP is to make sure that the crews can execute their work without any constraints and without dependencies that have not been fulfilled. This could be translated to shorter durations, better schedule, safer environment, lower overall cost of the project, and higher productivity. For an effective AWP, a process should be implemented where resources, processes, and data are aligned, and an environment should be developed where the right stakeholders get the right stuff at the right time. Therefore, the data integration from the different data sources is vital for an effective AWP. As an initial attempt, this paper discusses how to utilize ontology and SWRL rules to support a more comprehensive implementation of AWP. It introduces an AWP ontology based on the CII AWP data requirements. The ontology consists of the main classes of AWP, which are the construction work packages (CWP), Construction Work Areas (CWA), Engineering Work Packages (EWP), Installation Work Packaging (IWP) associated with other classes and relationships important for presenting the AWP ontology. In this paper, one use case was tested, related to control and to monitor PPC deliverables. The results showed that AWP ontology was validated against its purpose. Two main functions have been achieved: 1) sorting and providing information about the deliverables planned and actual schedules. 2)assisting in arranging the deliverables based on the IWP sequences. Although these outcomes are promising, it is just the beginning of ongoing work. The proposed ontology aims to achieve more by linking diverse datasets related to deliverables, activities, and real-time data from site related to labor presence, material delivery, and crane operation and deriving data driven insights for decision making. The integrated data and the insights derived from it will be visualized in control rooms on ongoing mega projects to enable data-driven collaborative decision making. The future work will include: 1) Investigating more construction datasets and semantically enriching them so that it be easily linked to the AWP ontology, 2) develop and examine more domain specific functional queries using SPARQL , and 3) Investigate the opportunies for automatiion workflows for the semantic enrichment and data integration, and 4) Publishing the ontology and the mapping with the OpenBIM Standards such as IfcOWL and BOT.

7 Acknowledgment

Innovate UK has kindly sponsored the project grants AEC Production Control Rooms No. 106169.

References

Boje, C., Guerriero, A., Kubicki, S. and Rezgui, Y. (2020), “Towards a semantic Construction Digital Twin: Directions for future research”, *Automation in Construction*, Elsevier BV, Vol. 114, p. 103179.

Dave, B., Kubler, S., Främling, K. and Koskela, L. (2016), “Opportunities for enhanced lean construction management using Internet of Things standards”, *Automation in Construction*, Elsevier B.V., Vol. 61, pp. 86–97.

Farghaly, K., Abanda, F.H., Vidalakis, C. and Wood, G. (2019), “BIM-linked data integration for asset management”, *Built Environment Project and Asset Management*, Emerald, Vol. 9 No. 4, pp. 489–502.

Fernández-López, M., Gómez-Pérez, A. and Juristo, N. (1997), “Methontology: from ontological art towards ontological engineering”, American Asociation for Artificial Intelligence.

Guerra, B.C. and Leite, F. (2020), “Bridging the Gap between Engineering and Construction 3D Models in Support of Advanced Work Packaging”, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, American Society of Civil Engineers, Vol. 12 No. 3, p. 4520029.

Halala, Y., Fayek, A.R. and Eng, P. (2018), “Framework to Assess Impacts of Advanced Work Packaging on Work Package and Project Performance: Construction Owners Association of Alberta”.

Hamdi, O. (2013), *Advanced Work Packaging from Project Definition through Site Execution: Driving Successful Implementation of WorkFace Planning*, available at: http://repositories.lib.utexas.edu/handle/2152/21384.

Hwang, B.G., Ngo, J. and Her, P.W.Y. (2020), “Integrated Digital Delivery: Implementation status and project performance in the Singapore construction industry”, *Journal of Cleaner Production*, Elsevier Ltd, Vol. 262, p. 121396.

Koo, B., Fischer, M. and Kunz, J. (2007), “A formal identification and re-sequencing process for developing sequencing alternatives in CPM schedules”, *Automation in Construction*, Elsevier BV, Vol. 17 No. 1, pp. 75–89.

Lee, S.K., Kim, K.R. and Yu, J.H. (2014), “BIM and ontology-based approach for building cost estimation”, *Automation in Construction*, Vol. 41, pp. 96–105.

McKay, K.N. and Wiers, V.C.S. (2004), *Practical Production Control: A Survival Guide for Planners and Schedulers*, J. Ross Publishing.

Noy, N.F. and McGuinness, D.L. (2001), “Ontology development 101: A guide to creating your first ontology”, Stanford knowledge systems laboratory technical report KSL-01-05 and ….

Soman, R.K., Molina-Solana, M. and Whyte, J.K. (2020), “Linked-Data based Constraint-Checking (LDCC) to support look-ahead planning in construction”, *Automation in Construction*, Elsevier BV, Vol. 120, p. 103369.

Suárez-Figueroa, M.C., Gómez-Pérez, A. and Fernández-López, M. (2012), “The NeOn methodology for ontology engineering”, *Ontology Engineering in a Networked World*, Springer, pp. 9–34.

Uschold, M. and Gruninger, M. (1996), “Ontologies: Principles, methods and applications”, *TECHNICAL REPORT-UNIVERSITY OF EDINBURGH ARTIFICIAL INTELLIGENCE APPLICATIONS INSTITUTE AIAI TR*, Citeseer.