Enhancing Trustworthiness and Cooperation in the Construction Industry: The BuildTrust Approach

PHD FORUM SUBMISSION

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***Abstract*—The construction industry is rapidly evolving with the advent of new technologies. Despite this progress, large-scale projects remain plagued by complexity and diverse operations that hinder automation and productivity, leading to inefficiencies and lower profitability. These challenges are further amplified by traditional practices and the insufficient adoption of modern technologies. This research focuses on the adoption of Model-based System Engineering (MBSE), particularly on enriching System Modeling Language (SysML) models with ontologies. By leveraging ontologies as a comprehensive knowledge base that encapsulates essential details about the construction industry domain, providing formal support and enabling automated reasoning to verify model consistency. The proposed methodology aims at providing significant improvements in system design robustness and operational reliability, offering an effective solution for the automation and efficiency challenges in the industries. The introduction of the new SysML v2 standard promises to further enhance the integration between SysML models and ontologies, laying the groundwork for adapting the proposed methodology within the construction sector. Future research will explore the application of the methodology in the cement-based production industry, the modeling of legal contracts in SysML, and the integration of SysML models with blockchain technology to automate smart contract generation and enhance traceability in industrial operations.**

***Index Terms*—Model-based Systems Engineering, Ontologies, Knowledge Representation.**

I. Introduction

The construction industry is undergoing a significant transformation driven by technological advancements and the principles of Industry 4.0 [1]. Despite this evolution, the inherent complexity and diverse operations of large-scale construction projects continue to pose substantial challenges in terms of automation and productivity enhancement. This results in suboptimal profitability and operational inefficiencies. These issues are rooted in the industry's traditional practices and the underutilization of modern technological innovations, creating a substantial gap in the potential for innovation and improvement. This study is part of a Ph.D. program co-funded by Build Trust[1], a startup, that seeks to address these challenges by introducing innovative approaches to the construction industry. The proposed approach aims to make information across the entire value chain available on a secure and permissioned blockchain. Build Trust focuses on several key areas to enhance efficiency and transparency in large-scale construction projects by introducing Industrial Internet of Things (IIoT) sensors for monitoring the production of concrete, real-time tracking of on-site activities exploiting Building Information Modeling (BIM) models, transforming legal contracts into smart contracts for financial transparency, integrating on-site sensors for worker safety, and comprehensively tracking material usage to support sustainability goals. To complement these technological advancements in the construction industry, the application of MBSE offers a powerful methodology to support all design phases by utilizing comprehensive models of the system being engineered [2]. MBSE aids in enhancing understanding, communication, and documentation of system requirements and design, thereby improving overall system quality and efficiency. This thesis contributes to the development of some Build Trust methodology's cornerstone aspects. In particular, it focuses on creating comprehensive models written in SysML and enhancing them with the integration of formal descriptions and methods such as ontologies and semantic reasoners. Ontologies provide a formal, explicit representation of shared knowledge within a domain based on logical constructs. Ontologies allow the definition of concepts, relationships, and constraints, ensur-

[1]Build Trust S.r.l.: https://www.buildtrust.it/

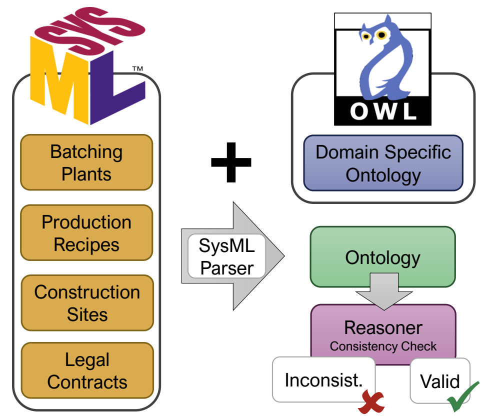

Figure 1: Overview of the proposed methodology. SysML models are paired with a *Domain Specific Ontology*. This combination is used to create a new ontology based on the SysML models. The correctness of the model is then verified by checking its consistency.

ing precise and unambiguous models. Ontology-based logical reasoning is enabled by semantic reasoner allowing the verification of model consistency. This thesis aims to explore and establish how the modeling phase of SysML could benefit from the integration of ontologies and semantic reasoners.

As depicted in Figure 1, the system under analysis is initially modeled in SysML. The resultant model is then paired with a *Domain Specific Ontology*, which encapsulates all the relevant knowledge within that domain. We are developing a toolchain able to parse SysML models and encode them into ontologies, which are described using the Web Ontology Language (OWL). The parser takes as input a SysML model and the corresponding *Domain Specific Ontology*; then, it generates a new ontology that combines the information from both sources. The newly generated ontology is then used to verify the consistency of the model. A semantic reasoner verifies the ontology consistency by checking logical inconsistencies.

The proposed methodology has been validated through its application to a fully operational manufacturing line within a research facility, showing its applicability in real-world scenarios.

II. Preliminary Results

Our preliminary work focuses on creating a first methodology combining SysML with ontology reasoning. The work aims to enhance the modeling and verification processes of manufacturing systems within the context of Industry 4.0. The approach we presented in [3] involves creating a *Production Plant Ontology* that integrates the information contained in the SysML models with a *Foundational Ontology* acting as the *Domain Specific Ontology*. The *Foundational Ontology*, based on industrial standards, e.g., DIN 8580, contains all the necessary knowledge to describe production plants, including concepts such as physical machines, manufacturing operations, and their relationships. By mapping the SysML models onto the classes and relationships defined by the *Foundational Ontology*, we facilitate a formal representation of manufacturing knowledge. The resultant formalization enables automated reasoning to verify the consistency and correctness of the models. The methodology relies on SysML to provide a structured representation of the production system and its machinery using Block Definition Diagrams (BDDs) according to the modeling approach described in [4]. Additionally, SysML Activity Diagrams are employed to model manufacturing operations and material transformations. Each manufacturing action performed by machines is represented by an Activity Diagram, which details the step-by-step process of transforming input materials into output products. Activity diagrams capture the sequence of operations, the flow of materials, and the interactions between different components of the system.

Consistency verification is a critical component of the methodology. An automated reasoner, i.e., Pellet, is used to verify the consistency of the *Production Plant Ontology*. The verification process ensures that the models are not only consistent but also that the production recipes being modeled are coherent and executable within the specified production environment. The automatic generation of the ontology from SysML models is facilitated by a parser, which converts the SysML representations into OWL ontologies.

The methodology in [3] has been validated in the Industrial Computer Engineering (ICE) Laboratory: a research facility equipped with a fully-fledged reconfigurable manufacturing line. Specifically, a production recipe for engraving a plastic piece with a milling machine was modeled using SysML and subsequently encoded into an ontology. The consistency of the generated ontology was then verified using the reasoner, which ensured the correctness of the SysML model and the feasibility of the production recipe. Integrating SysML with ontologies offers several benefits. Firstly, it provides formal support to SysML models, ensuring precise and unambiguous representations of manufacturing systems. Thus, enhancing formalization enhances the reliability of the models by enabling automated verification processes that reduce manual effort and the likelihood of errors. Additionally, combining SysML with ontologies enriches the models with rigorous semantics, improving the overall reliability of the system design process.

III. Future Work

In this work, we explored the integration of SysML models with domain-specific ontologies. The approach facilitates precise knowledge representation and automated reasoning, ensuring model consistency and improving system reliability. Looking forward, the forthcoming transition to SysML v2, with its enhanced capabilities such as a standardized Application Programming Interface (API) and more flexible language extension, will enable us to further refine and extend the proposed methodology. This will facilitate more seamless integration between SysML models and ontologies, making the approach even more effective and scalable across different industrial domains. Future research will focus on expanding the application of this methodology to other areas, including the modeling of legal contracts and the automatic generation of smart contracts from SysML models. These efforts are aimed at further enhancing transparency, traceability, and operational efficiency in the construction industry, ultimately contributing to its transformation into a more innovative and sustainable sector.

References

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