Technische Universität Darmstadt

Institut für Numerische Methoden
und Informatik im Bauwesen

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Linked Product Data

Describing Multi-Functional and Parametric Building Products using Semantic Web Technologies

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Linked Product Data: Describing Multi-Functional, Parametric Building Products using Semantic Web Technologies

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Everything is connected. And nothing. Nothing is also connected.
— Dirk Gently

Preface

The thesis at hand was created during my employment at the Institute of Numerical Methods and Informatics in Civil Engineering from the Technische Universität Darmstadt. In that time, the research projects SolConPro and SCOPE, in collaboration with the Fraunhofer Institute for Solar Energy (ISE) and Ed. Züblin AG, had an impact on this work.

I thank Prof. Dr.-Ing. Rüppel for supporting me on my endeavours that led me to this point and assuming his role as first referent, for his encouragement to discover new areas of interest, counsel in the scientific environment, and endorsement to participate actively in research communities. I extend my gratitude to Prof. Dr. Jakob Beetz for being interested in my work, hosting me at his chair, and accepting the role as second referent.

Furthermore, I wish to thank Dr. Uwe Zwinger, who led me to the area of computer science in civil engineering, as well as Drs. Kristian Schatz and Christian Schwöbel for supervising my Bachelor's and Master's thesis. Their guidance woke my interest in research and teaching activities.

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Anna Wagner

Abstract

The digitisation in the domain of Architecture, Engineering and Construction (AEC) results in a variety of software tools with different requirements. Especially from the perspective of product descriptions, this heterogeneity is troublesome, as they should suit each potential use case and involved software application. Product descriptions, therefore, either cause information overflow for singular use cases, or hold redundant information within multiple, differently focused descriptions of the same product. Considering innovative, multi-functional and parametric products, further questions arise, e.g. how to model their uncommon structure, innovative technologies, and priorly unknown properties. Even if those unusual characteristics can be described, additional domains are involved during the building and product lifecycle. In the case of energy active façade components, for example, heating, electricity, design, structure, and building physics must be addressed. Thus, descriptions of innovative and multi-functional product reach higher complexities than common product descriptions.

In order to sufficiently describe building products in the digital world of AEC, open and vendor-neutral product description schemes are needed. Current open product description schemes include the template-driven directive VDI 3805 from the *Verein Deutscher Ingenieure* and the Industry Foundation Classes (IFC) schema that is originally introduced for entire building models. As neither of these schemes support the use case of innovative, multi-functional and parametric products, a novel product description schema is needed. Such a new schema needs to be flexible to allow semantically meaningful descriptions and fast integration of innovative and multi-functional products. Furthermore, the schema should be modular to avoid information or schema overhead, and subsequent performance-loss. To ensure common understanding of the parametric dependencies of the product, the dependencies also need to be part of the neutral and open description and separated from proprietary software applications.

In this thesis, an analysis of the current state is conducted, and suitable technologies, i.e. the Semantic Web and Linked Data, are evaluated. With this analysis in mind, two concepts for product descriptions using Semantic Web technologies are presented: Linked

Product Data, aiming to serve as a generic product description schema, and Linked Building Product Data, its implementation for the AEC domain. This thesis, hence, discusses the suitability of the Semantic Web and Linked Data as product description framework and introduces a novel methodology to create Linked Product Data, which is evaluated on the implementation of Linked Building Product Data.

Based on the Semantic Web, the concept of Linked Product Data stands as a flexible, modular, and machine-readable product description schema that can be adapted for any use case or domain. The AEC adaptation, Linked Building Product Data, is demonstrated with an example configuration for innovative, multi-functional and parametric products. As generic core for Linked Building Product Data, the *Building Product Ontology* (BPO) for defining product compositions, component interconnections, and product attributes is introduced. The extension of Linked Building Product Data and its core is shown on the example of geometry descriptions, wherefore the *Ontology for Managing Geometry* (OMG) is proposed and applied. A third ontology, the *Ontology for Parametric Systems* (OPS) is created to indicate how interconnections between multiple domains and ontologies can be realised within Linked Building Product Data on the example of parametric product descriptions.

The configuration of Linked Building Product Data is evaluated for the use case of energy active façade components. The evaluation results show overall benefits of the novel approach over the established VDI 3805 and IFC schemes regarding modularity, flexibility, parametric modelling, and machine readability. Concluding, Linked Building Product Data poses as a neutral, flexible and modular product description schema. Its functionality and potential are shown by the application of Linked Building Product Data to innovative, multi-functional and parametric products, and a generalisation of Linked Building Product Data to Linked Product Data seems easily conceivable.

Due to its flexibility, Linked Building Product Data allows manufacturers to exhaustively model their products and offer the resulting product descriptions, which they can enrich with multiple geometry descriptions for diverse use cases and software applications. Users can easily filter relevant information and geometry descriptions for their individual use cases and software applications. With Linked Building Product Data and Linked Building Data, error-prone file-based data exchange can be renounced. Instead, products can be offered distributively, applying Linked Data methods to include product descriptions into Linked Building Data models. Consequently, a common, machine-understandable data source based on Linked Building (Product) Data can serve as anchor for the heterogeneous software applications, replacing data exchange with automated synchronisation.

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List of Abbreviations

Abox *Assertion Box* xiii, 12–14, 18, 23, 51, 71, 76, *Glossary:* Assertion Box (Abox)

AEC *Architecture, Engineering and Construction* 1, 7, 8, 26, 31, 34, 35, 37, 38, 41–43, 47, 53, 58, 59, 78, 79, 81, 82, 98, 102, 106, 132, 144, 145, 147, 149–159, 162, 163

BIM *Building Information Modelling* 1–4, 32–36, 41, 54, 142, 146, 147, 150, 153, *Glossary:* Building Information Modelling (BIM)

BIPV *Building Integrated Photovoltaic* 5, 7, 8, 32, 55, 133, 134, 140, 191

BIST *Building Integrated Solar Thermal* 5, 7, 8, 32, 55, 133, 134, 191

BOT *Building Topology Ontology* 38, 39, 74, 99, 150, 155, *Glossary:* Building Topology Ontology (BOT)

BPO *Building Product Ontology* 7, 8, 78, 79, 81–86, 88, 90, 91, 93, 97–100, 103, 108, 123, 131, 133–135, 137, 138, 141, 147, 149–151, 153–156

bSDD *buildingSMART Data Dictionary* 34, 43, 58, 78, 81, 100–102, 104, 135, 151, 153, 155, 156, *Glossary:* buildingSMART Data Dictionary (bSDD)

CAD *Computer Aided Design* 1, 44, 46, 48, 69

CPU *Central Processing Unit* 13, 14

CSP *Constraint Satisfaction Problem* 27, 37, 49, 69, 71, 121–123, 126, 156, *Glossary:* Constraint Satisfaction Problem (CSP)

CSV *Comma-Separated Values* 34, 134

FOG *File Ontology for Geometry formats* 105, 118, 119, 136, 154

OPS *Ontology for Parametric Systems* 7, 8, 79, 121, 123, 126, 129, 131, 139, 140, 147, 149–151, 153–156

OWL *Web Ontology Language* 12, 14–17, 21, 38, 40, 41, 49, 65, *Glossary:* Web Ontology Language (OWL)

PDF *Portable Document Format* 1, 3, 133

PROV-O *Provenance Ontology* 51, 102, 108, 112, 150, *Glossary:* Provenance Ontology (PROV-O)

PV *Photovoltaic* 135, 137, 139, 140, 191

QUDT *Quantities, Units, Dimensions, and Data Types* 43, 91, 92, 96, *Glossary:* QUDT

Rbox *Role Box* 12, 14, 26, 70, 162, *Glossary:* Role Box (Rbox)

RDF *Resource Description Framework* xiii, 11–13, 17, 18, 20, 22, 38, 39, 41–44, 46–50, 57–70, 79, 82, 93, 100–102, 105, 106, 109, 112, 113, 115–119, 123, 124, 126, 127, 129, 136, 144, 146, 151, 152, 155–163, *Glossary:* Resource Description Framework (RDF)

RDFS *Resource Description Framework Schema* 12–14, 102, *Glossary:* RDF schema (RDFS)

RFA *Revit Family File* 2, 33, 57–59

SCOPE *Semantic Construction Project Engineering* 4, 56, 77, 131, 136, 153

SEAS *Smart Energy Aware Systems Ontology* 39, 98, 99, 108, 114, 117, *Glossary:* Smart Energy Aware Systems Ontology (SEAS)

SHACL *Shapes Constraint Language* 18, 49, 71, 153, 156, *Glossary:* Shapes Constraint Language (SHACL)

SolConPro *Solar Construction Processes* 4, 56, 81, 121, 131, 153

SPARQL *SPARQL Protocol And RDF Query Language* 12, 17, 48, 49, 58, 64, 65, 70, 100, 101, 125, 141, 146, 147, 153, 154, 161, 162, *Glossary:* SPARQL Protocol and RDF Query Language(SPARQL)