

Ontology approach for Building Lifecycle data management

**Janakiram. Karlapudi, M.Sc.,¹ Prathap. Valluru, M.Sc.,² and
Karsten. Menzel, Professor³**

¹Institute of Construction Informatics, Department of Civil Engineering, Technische Universitaet Dresden, 01069 Dresden, Saxony, Germany; e-mail: janakiram.karlapudi@tu-dresden.de

²Institute of Construction Informatics, Department of Civil Engineering, Technische Universitaet Dresden, 01069 Dresden, Saxony, Germany; e-mail: prathap.valluru@tu-dresden.de

³Institute of Construction Informatics, Department of Civil Engineering, Technische Universitaet Dresden, 01069 Dresden, Saxony, Germany; e-mail: karsten.menzel@tu-dresden.de

ABSTRACT

The Architecture, Engineering and Construction industry involves multiple disciplines and activities throughout the Building Lifecycle Stages (BLS). To enable collaboration amongst these disciplines iterative and coordinated exchange of information is required. This improves the design process over multiple BLS. Since the last decade, BIM is a well-known approach to achieve collaboration through semantic representation and exchange of domain data. Despite the improvement, there is a lack of efficient implementation and management of building lifecycle functionalities in existing BIM solutions, because of their fundamental heterogeneity, complexity and adaptability. This research focuses on these issues and addresses a clear perception through analysis of BLS from various standards and norms. The paper concentrates on the demonstration of efficient representation of various BLS through the ontological approach and their effective involvement in BIM data management. With the validation and evaluation through SPARQL queries, this paper presents an ontological framework for building lifecycle data management.

INTRODUCTION & BACKGROUND

Efficient management, collaboration and sharing of object information throughout the BLS and among the project partners are fundamental to ensure the successful execution of a project (Mangialardi et al. 2017). The management of this project's lifecycle information ensures the reduction of error-prone operations, data communication problems, and provides significant efficiency benefits, time-saving, etc (Di Biccari et al. 2018).

The research presented in this publication starts with an ideology, how the paradigm of lifecycle data management can be introduced in the Architecture, Engineering, Construction and Operation (AECO) industry. One possible profound solution is the adoption of Building Information Modelling (BIM) into the AECO sector. BIM is an advanced technology for the development, management and usage of the 3D object and object-related data throughout the building lifecycle phases (Karlapudi and Shetty 2019; Valluru et al. 2020). This technical advancement in the AECO industry aims to increase efficiency in collaboration and data sharing between the involved stakeholders within construction projects (Zadeh et al. 2017), who in general require a diverse set of information. Apart from the data exchange, it is also a question of managing the continuous growth of the amount of data, different data structures and its management within the complete lifecycle stages of the building (Scherer and Katranuschkov 2019).

Concepts like Level of Development, Information Delivery Manual, Model View Definitions, Industry Foundation Classes, Multi-Model Containers and others were developed as part of the BIM process to address and support these diverse requirements in construction projects (Xu et al. 2020). Despite these improvements, there is a lack of efficient implementation and management of building lifecycle functionalities in existing BIM solutions. This research focuses on these issues and addresses a clear perception through effective analysis and mapping of BLS from various standards and norms. The following sections present an ontology-based BLS framework and demonstrate the management of BIM data throughout the building lifecycle stages.

RELATED RESEARCH WORK

IFC based data interoperability. The developments of the OpenBIM IFC meta-model (ISO 16739-1 2018) provide a building block for flexible interoperability of the BIM data. However, results from research on IFC-based interoperability comprehensively explains the reasons for inadequate interoperability (Karlupudi and Menzel 2020). Apart from the diversity of domain knowledge, constraints within the IFC schemas concerning the schema extendibility, and association with external data sources, the lack of data query and reasoning also make the interoperability much more complex and inefficient (Katranuschkov et al. 2014). These challenges associated with data interoperability and collaboration are posing a barrier to advances of BIM and its applicability within the building lifecycle management.

Information Containers and Web Servers. Also, parallel research on efficient linking of different data domains and data structures is carried on for the efficient exchange of data between stakeholders. The research aim leads to the development of three different approaches, the MultiModel (MM) approach (Scherer and Schapke 2011), the Dutch COINS approach (van Nederveen et al. 2010) and the Linked Building Data (LBD) approach (Beetz et al. 2009; Pauwels et al. 2017). Based on these approaches a new ISO standard – Information Container for Linked Document Delivery (ISO 21597-1 2020) is developed by combining the MM approach and LBD approach, which further enables the interlinking of heterogeneous data structures (Scherer and Katranuschkov 2019). This new development uses the concept of Linked Data and ontologies to represent the meta-data of the documents and to produce link-sets between the documents.

Ontologies and Linked Data. To ensure the full capabilities of BIM with the efficient interoperability between the domain-specific stakeholders, researchers leveraged an ontological approach to solve interoperability issues within the AECO industry (Beetz et al. 2009; Costin and Eastman 2017). Several scientific researches, for example (Pauwels et al. 2017) were explored the potential advantages of semantic web technologies concerning data interoperability. This ontology and Linked data technologies are very high promising to reach a high level of interoperability through data integration and extraction based on complex queries across several data sources (Pauwels et al. 2017; Werbrouck et al. 2019). Furthermore, the representation of building data in ontologies enables the stakeholders to semantically interpret data for various domain-specific operations with minimal human interventions. The capabilities of linked data also ensure the linking of contextual information with the BIM data through the concept of IRI's. In the present research, the ontology and linked data concepts are used to develop the BLS framework to ensure the full potential in data management process. The BLS ontology framework is developed based on the OWL2 schema and the Protégé tool is used for the development and validation process.

ONTOLOGY-BASED BLS DATA MANAGEMENT

The scope of this research is to explicitly demonstrate the effective usage of various BLS in the building lifecycle data representation and management. As such, it aims to investigate various possibilities of BLS representation and the development of an ontology-based flexible framework to represent all these stages and enable to provide links with BIM data. The first version of this BLS ontology framework is published in (Karlupudi et al. 2020). The earlier publication is only limited to the introduction of the developed framework. But majorly, this paper's concern is to explain the applicability and adaptability of the BLS ontology framework through the demonstration and validation examples.

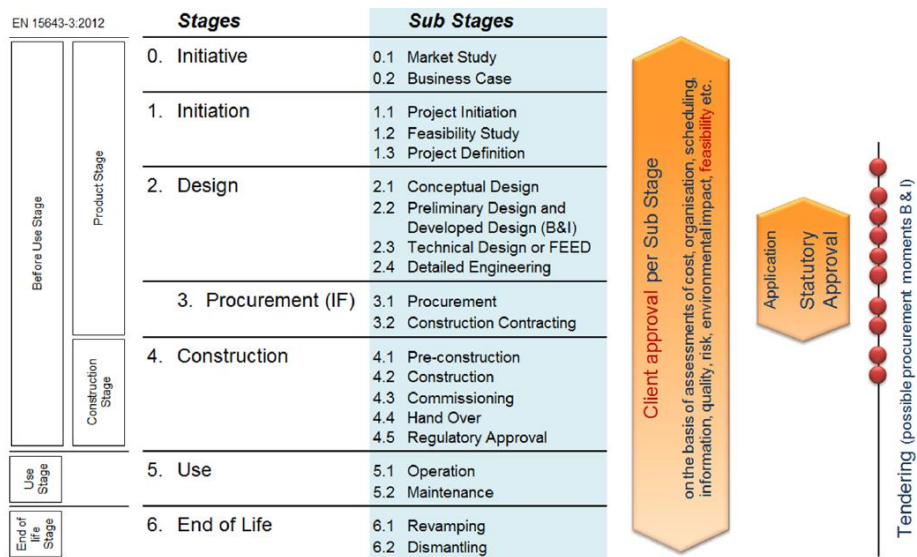


Figure 1. Stages and sub-stages in the life cycle of built assets (BS EN 16310 2013)

BLS ontology framework. BLC stages are necessary for each construction project for managing and assessment of engineering services and information. However, the standard stages in the project differ from country to country and may also be subjected to differences in legislation. An analysis is carried on the BLS frameworks according to the different standards of specifications and various practices, such as (EN 15643-3 2012), (BS EN 16310 2013), (ISO 22263 2008), (RIBA 2020), (HOAI 2001), for categorization of the building lifecycle process. Comprehensive results from this analysis are effectively illustrated in Table 2 of the publication from (Karlupudi et al. 2020) along with the resulted mappings between these stages. This analysis is considered as a basis for the BLS ontology framework definition. Figure 2 comprehensively illustrating the developed ontology framework for BLS representations. For a clear understanding of the BLS ontological framework functionality, a demonstration is considered from the analyzed BLS systems. Specifically, for the demonstration, BLS from (BS EN 16310 2013) (illustrated in Figure 1) is considered and further explained below.

The list of stages from (BS EN 16310 2013) is represented as main stages and a couple of sub-stages for each main stage which is the same illustrated in Figure 1, Figure 3 and Figure 4. This representational complexity is the main reason to select this BLS framework for the example demonstration. As represented in Figure 3, the instances *inst:Initiative*, *inst:Initiation* and *inst:Design* are assigned as stages for the instance *inst:BS EN 16310* using *dicl:hasStage* object

property. Since this object property's (dicl:hasStage) domain and range are fixed to the classes dicl:BLSFramework and dicl:BLStage respectively (refer Figure 2), the inferencing engine automatically inference the new knowledge by saying the instance *inst:BS EN 16310* belongs to the class dicl:BLSFramework and the other instances are belonging to the class dicl:BLStage. This inference knowledge is illustrated in Figure 3 and Figure 4 using the grey dashed lines and the defined relationships are represented with solid black lines.

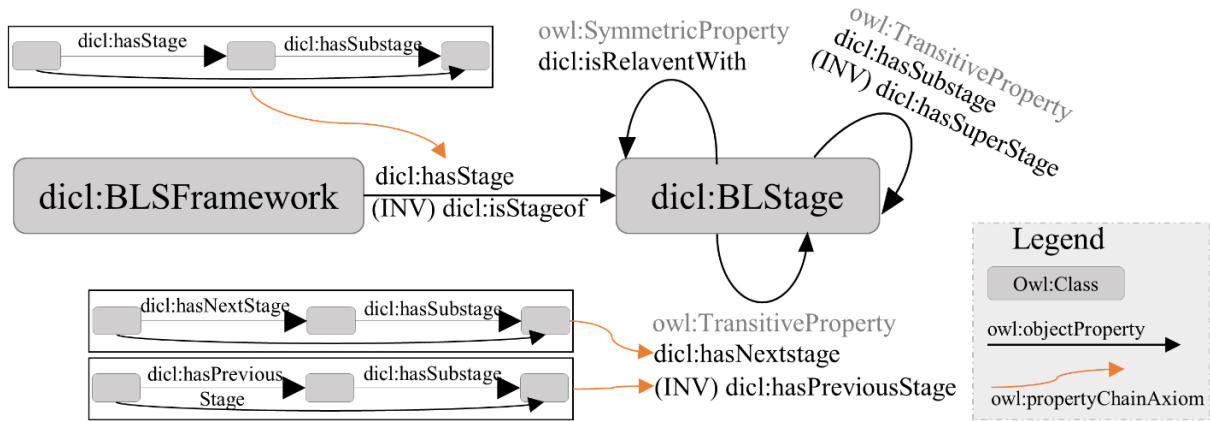


Figure 2. BLS ontology framework

Moreover, the relationship between the neighbouring instances *inst:Initiative*, *inst:Initiation* and *inst:Design* are assigned using dicl:hasNextstage transitive object property. As defined in the ontology framework, the dicl:hasNextstage object property has assigned an inverse relationship with dicl:hasPreviousStage. Which substantially generate new knowledge between the instances concerning the previous stage relationship. This inference knowledge from the inverse relationships is represented by using yellow dashed lines in Figure 3. Along with this inherited information also new relationships are generated between *inst:Initiative* and *inst:Design*, which is clearly represented with blue dashed lines in Figure 3. These generated relationships are because of the transitive property characteristic of the object properties dicl:hasNextstage and dicl:hasPreviousStage.

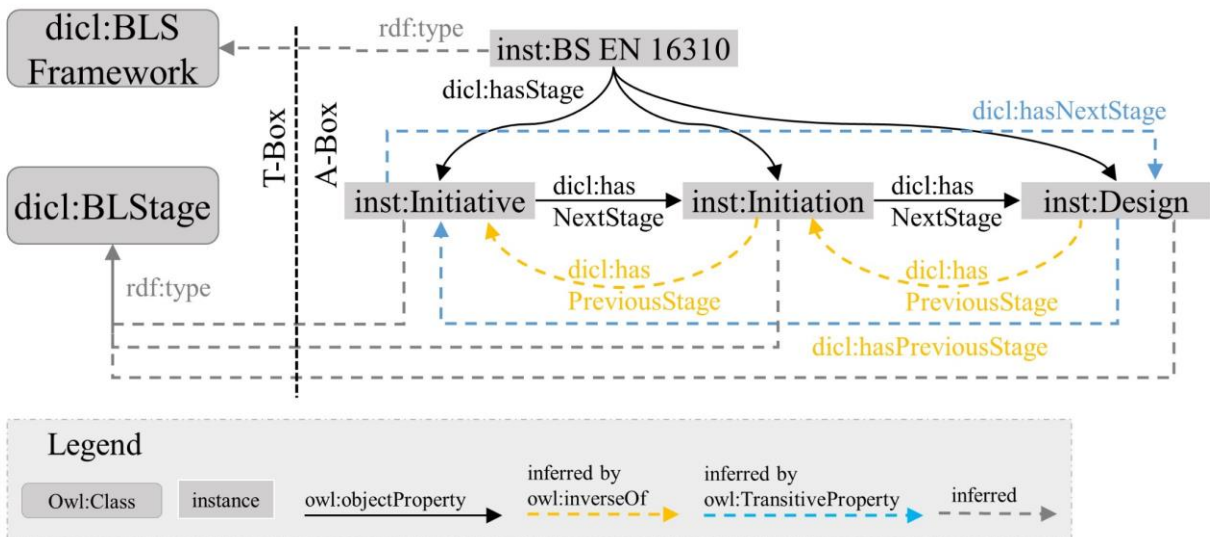


Figure 3. Demo1 – Relation between main stages of (BS EN 16310 2013) BLS framework

Furtherly, the sub-stage information regarding each main-stage is defined by using transverse object property called `dicl:hasSubstage` and its inverse property `dicl:isSuperStage`. Because of the transverse property nature of these object properties, any sub-levels of a mainstage is considered as a sub-stage to the mainstage. Similarly, due to the defined axiom to `dicl:hasStage` property, all these sub-stages are inferred as stages (`dicl:BLStages`) to the `dicl:BLSframework` (*inst:BS EN 16310*). Furthermore, the relationship between the sub-stages of a mainstage is developed by using `dicl:hasNextstage` and also the inference relations from its inverse property and the transitive property characteristic are illustrated in Figure 4. But the complexity is to inference the relationship between the main-stage (*inst:Initiative*) and a sub-stage (*inst:ProjectInitiation*) of another mainstage (*inst:Initiation*), similarly between the sub-stage (*inst:BusinessCase*) of a mainstage (*inst:Initiative*) and the sub-stage (*inst:ProjectInitiation*) of another mainstage (*inst:Initiation*). This complexity of inferencing the new knowledge is resolved eventually by creating property axioms to `dicl:hasNextstage` and `dicl:hasPreviousStage` as represented in Figure 2.

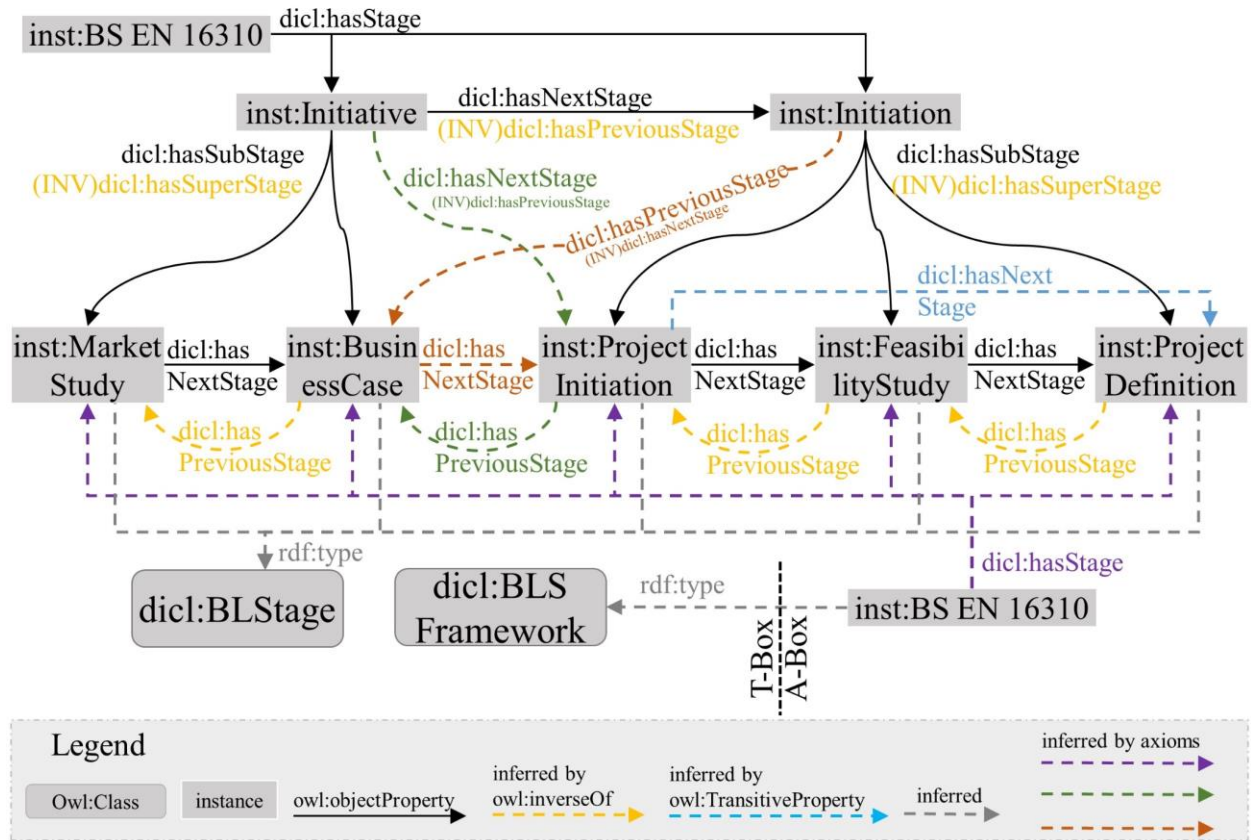


Figure 4. Demo2 – Relation between sub-stages of (BS EN 16310 2013) BLS framework

The understanding of the inference relationship between the main stage and the sub-stages of another main stage is pretty straightforward from the assigned axioms but the generated links between sub-stages of different mainstages are quite complex to understand. The assigned axiom to `dicl:hasNextstage` generates the next-stage relationship between *inst:Initiative* and *inst:ProjectInitiation*. It also means that *inst:Initiative* is a previous-stage to *inst:ProjectInitiation* and this information generated based on the inverse property of `dicl:hasNextstage`, which is `dicl:hasPreviousStage`. Now the axioms assigned to `dicl:hasPreviousStage` further inherits the previous-stage relationship between *inst:ProjectInitiation* and *inst:BusinessCase*. These inherited

relationships clearly represented and distinguished based on the coloured dashed lines within Figure 4. Additionally, a symmetric property called `dicl:isRelaventWith` is introduced to allows the representation of interrelation between the stages from different standards or publications.

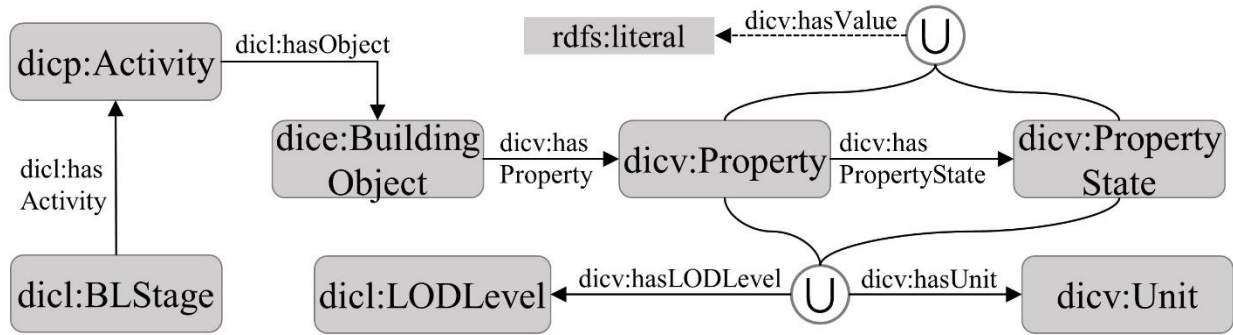


Figure 5. BIM data representation and management according to BLS

The next step in the process is the representation and management of Building data according to the different BLS. For this process, a simple use case scenario is considered and represented in Figure 5. The example scenario focused on the representation of building object properties according to different building lifecycle stages. Apart from the representation the data can also be queried and transferred to the relevant applications in the AECO industry. A similar approach can also be used to represent different kinds of building-related data, for example, the data regarding construction details, sensor data, facility management data, simulation data, etc. The complete set of developed ontology frameworks is presented in BIM4EEB [Digital Construction Ontology \(DiCon\)](#) suite and published under the [Digital Construction Lifecycle](#) webpage. The DiCon webpage also comprehensively explains the details of the prefixes used in the above images.

VALIDATION

The validation of the developed framework is performed by running the SPARQL queries on the demonstrated example. As represented in the above figures, the information related to instances and relations (solid black lines) is developed to the main default framework ontology.

Table 1. Queries and their results

Query 1:- What is the relationship between <i>inst:ProjectDefinition</i> and <i>inst:MarketStudy</i> ?			
SPARQL Profile	Query Results		
SELECT Distinct ?Stage1 ?relation ?Stage2 WHERE { ?Stage1 ?relation ?Stage2 . Filter(?Stage1=:1.3.BS_EN_Project_definition && ?Stage2=:0.1.BS_EN_Market_study). }	?Stage1	?relation	?Stage2
	:1.3.BS_EN_Pro ject_definition	:hasPreviousSt age	:0.1.BS_EN_ Market_study
Query 2:- What is the relationship between <i>inst:ProjectDefinition</i> and <i>inst:Initiative</i> ?			
SPARQL Profile	Query Results		
SELECT Distinct ?Stage1 ?relation ?Stage2 WHERE { ?Stage1 ?relation ?Stage2 . Filter(?Stage1=:1.3.BS_EN_Project_definition && ?Stage2=:0.BS_EN_Initiative). }	?Stage1	?relation	?Stage2
	:1.3.BS_EN_Pro ject_definition	:hasPreviousSt age	:0.BS_EN_In itiative

After the population of A-Box instances, a reasoner called Pellet is used to inference the new knowledge and to check the consistency, correctness of the ontology. Thereafter performed several queries to extract the generated information to check the consistency and quality by comparing it with the original information from the standards. Within this paper, simple queries and their results regarding the relationship between the stages is presented in Table 1.

CONCLUSION

The paper explains an ontological framework for BLS representations through the demonstration example. With the defined and inherited knowledge capabilities of the developed ontology framework evidently represents its applicability and functionalities in terms of capturing the building lifecycle data. This ontological representation of the BLS frameworks brings flexibility, compliance and alignment capabilities through logical reasoning and knowledge inferencing. The framework is also adaptable and applicable to the present BIM process since the representation of BIM data in different ontologies (BOT, ifcOWL, etc.) are within reach. Finally, the validation and evaluation of the developed framework were performed based on the SPARQL queries.

ACKNOWLEDGEMENT

This research is part of the EU project entitled “BIM4EEB – BIM-based fast toolkit for the Efficient rEnovation in Buildings” which is supported and funded by European Union’s H2020 research and innovation program under grant agreement No 820660. The authors gratefully acknowledge the support and funding from the European Union.

REFERENCES

- Beetz, J., van Leeuwen, J., and Vries, B. de (2009). "IfcOWL: A case of transforming EXPRESS schemas into ontologies." *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 23(1), 89–101.
- BS EN 16310. (2013). "Engineering services — Terminology to describe engineering services for buildings, infrastructure and industrial facilities." *BS EN 16310:2013*.
- Costin, A., and Eastman, C. (2017). "Requirements for Ontology Development in the AECO Industry." *Lean and Computing in Construction Congress (LC3)*, 1(JC3 2017), 533–540.
- Di Biccari, C., Mangialardi, G., Lazoi, M., and Corallo, A. (2018). "Configuration Views from PLM to Building Lifecycle Management." *Product lifecycle management to support industry 4.0: 15th IFIP WG 5.1 International Conference, PLM 2018, Turin, Italy, July 2-4, 2018 : proceedings*, P. Chiabert, ed., Springer, Cham, 69–79.
- EN 15643-3. (2012). "Sustainability of construction works - Assessment of buildings - Part 3: Framework for the assessment of social performance." *15643-3*.
- HOAI. (2001). "Honorarordnung für Architekten und Ingenieure." *HOAI*, Germany.
- ISO 16739-1. (2018). "Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema." *16739-1:2018*, Switzerland.
- ISO 21597-1. (2020). "Information container for linked document delivery — Exchange specification — Part 1: Container." *ISO 21597*, Switzerland.
- ISO 22263. (2008). "Organization of information about construction works — Framework for management of project information." *ISO 22263:2008*, Switzerland.

- Karlapudi, J., and Shetty, S. (2019). "A methodology to determine and classify data sharing requirements between OpenBIM models and energy simulation models." *31. Forum Bauinformatik: 11. bis 13. September 2019 in Berlin : proceedings*, M. Sternal, L.-C. Ungureanu, L. Böger, and C. Bindal-Gutsche, eds., Universitätsverlag der TU Berlin, Berlin, 331–338.
- Karlapudi, J., and Menzel, K. (2020). "Analysis on automatic generation of BEPS models from BIM model." *BauSIM 2020 - 8th Conference of IBPSA Germany and Austria*, M. Monsberger, C. J. Hopfe, M. Krüger, and A. Passer, eds., Verlag der Technischen Universität Graz, Austria, 535–542.
- Karlapudi, J., Menzel, K., Törmä, S., Hryshchenko, A., and Valluru, P. (2020). "Enhancement of BIM Data Representation in Product-Process Modelling for Building Renovation." *Product Lifecycle Management Enabling Smart: 17th ifip wg 5.1*, F. Nyffenegger, J. Ríos, L. Rivest, and A. Bouras, eds., Springer, [S.l.], 738–752.
- Katranuschkov, P., Scherer, R. J., Weise, M., and Liebich, T. (2014). "Extending BIM for Energy Simulation and Design Tasks." *Proc., 2014 International Conference on Computing in Civil and Building Engineering*, R. I. Issa, and I. Flood, eds., [Place of publication not identified], 625–632.
- Mangialardi, G., Di Biccari, C., Pascarelli, C., Lazoi, M., and Corallo, A. (2017). "BIM and PLM Associations in Current Literature." *Product lifecycle management and industry of the future: 14th IFIP WG 5.1 international conference, PLM 2017, Seville, Spain, July 10-12, 2017*, J. Ríos, A. Bernard, A. Bouras, and S. Foufou, eds., Springer, Cham, 345–357.
- Pauwels, P., Zhang, S., and Lee, Y.-C. (2017). "Semantic web technologies in AEC industry: A literature overview." *Automation in Construction*, 73, 145–165.
- RIBA. (2020). "RIBA Plan of Work 2020 Overview." *RIBA 2020*, London.
- Scherer, R. J., and Katranuschkov, P. (2019). "Context capturing of multi-information resources for the data exchange in collaborative project environments." *Proc., 2019 European Conference on Computing in Construction*, Computing in Construction, 359–366.
- Scherer, R. J., and Schapke, S.-E. (2011). "A distributed multi-model-based Management Information System for simulation and decision-making on construction projects." *Advanced Engineering Informatics*, 25(4), 582–599.
- Valluru, P., Karlapudi, J., Menzel, K., Mätäsniemi, T., and Shemeika, J. (2020). "A Semantic Data Model to Represent Building Material Data in AEC Collaborative Workflows." *Boosting Collaborative Networks 4.0: 21st ifip wg 5.5 working*, L. M. Camarinha-Matos, H. Afsarmanesh, and A. Ortiz, eds., Springer International Publishing, Cham.
- van Nederveen, S., Beheshti, R., and Willems, P. (2010). "Building Information Modelling in the Netherlands: A Status Report." *Proc., CIB W078 - Information Technology for Construction*, D. Amaratunga, R. Haigh, K. Keraminiyage, and C. Pathirage, eds., 28–40.
- Werbrouck, J., Pauwels, P., Beetz, J., and Berlo, L. v. (2019). "Towards a decentralised common data environment using linked building data and the solid ecosystem.", Bimal Kumar, Farzad Rahimian, David Greenwood, and Timo Hartmann, eds., 113–123.
- Xu, Z., Abualdenien, J., Liu, H., and Kang, R. (2020). "An IDM-Based Approach for Information Requirement in Prefabricated Construction." *Advances in Civil Engineering*, 2020, 1–21.
- Zadeh, P. A., Wang, G., Cavka, H. B., Staub-French, S., and Pottinger, R. (2017). "Information Quality Assessment for Facility Management." *Advanced Engineering Informatics*, 33, 181–205.