Ontology Reuse in Building Permitting

Isabelle Fitkau, i.fitkau@tu-berlin.de
Department of Civil Systems Engineering, Technische Universität Berlin, Germany

Judith Fauth, jf805@cam.ac.uk
Department of Engineering, University of Cambridge, United Kingdom

Sebastian Seiß, sebastian.seiss@uni-weimar.de
Chair of Construction Engineering and Management, Bauhaus-Universität Weimar, Germany

Timo Hartmann, timo.hartmann@tu-berlin.de
Department of Civil Systems Engineering, Technische Universität Berlin, Germany

Abstract
Building permitting is a complex and often inefficient process due to limited digitalization and automation, for example, the interpretation of fire safety regulations. This research addresses these challenges by investigating the reuse of ontologies to improve the building permitting process. The study focuses on aligning domain-specific ontologies, such as the Ontology-based Building Permit Review (OntoBPR) and the Fire Safety Ontology (FiSa), using the Simple Knowledge Organization System (SKOS). The methodology involves identifying potential use cases, analyzing concept similarities, and mapping relationships with SKOS properties. Two primary use cases illustrate how FiSa can be integrated into the building permit review process and used in content checks. The findings demonstrate that a structured approach to ontology alignment can enhance communication among ontology developers and promote the reuse of concepts. This research underscores the need for further investigation to address interoperability issues in general and improve regulatory compliance in construction.

Keywords: Building Permitting, Fire Safety, Semantic Web, Ontologies

1 Introduction
Building permitting stands as a critical process within the construction domain, yet its potential is hindered by a deficiency in digitalization and automation (Noardo et al 2020). The complexity of this issue is particularly exacerbated by challenges in stakeholder involvement, underscoring the pressing need for innovative solutions to streamline and enhance the efficiency of the building permit process (Beach et al 2020). From a managerial standpoint, the engagement of various stakeholders in the building permit process remains a manual and time-consuming endeavor. This is evident in professions like fire safety engineers, where outdated practices persist. Innovative approaches are imperative to address these inefficiencies and propel the building permit process into a more streamlined and technologically advanced realm.

Fire safety requirements are described prescriptively in building regulations and are published as human-readable texts. Building regulations are legal documents written by people intended to be applied by experts (Nawari 2018). These regulations often lack clarity, which makes it necessary for experts to interpret and convert them into a machine-readable format (Hjelseth 2019) when aiming to integrate fire safety into digital building design. The process of (non-)automated compliance checking then culminates in a prescriptive fire safety certificate by the appointed fire safety engineer needed to obtain a building permit. Further, through performance-based methods, fire safety engineers can enforce and argumentatively replace prescriptive requirements, where these deviations exist within a gray area of legal documents, lacking defined definitions and relationships. When prescriptive fire safety requirements cannot be met, it necessitates a safety goal-oriented fire safety

certificate prepared by the fire safety engineers, which is then required for obtaining a building permit.
Integrating fire safety engineering methods within the development process of fire safety certification is challenging due to its complexity since the building permit authorities are likely not qualified to review (Athanasopoulou et al 2023). Consequently, automated content review (e.g. compliance checks) and the integration of different stakeholders remain a complex process for all parties involved, resulting in delays in obtaining building permits (Nawari 2018b, Fauth & Seiß 2022). The comprehensibility of possible fire safety solutions for authorities permitting a building project challenges discussions regarding the timing of involvement of fire safety in the design process (Athanasopoulou et al 2023b, Buchanan & Abu 2016). The challenge of organizing information for information processing stems from the heterogeneity of technical representations like vocabularies and ontologies, hindering clear semantic exchange, e.g., regarding building permits (Pauwels & McGlinn 2022). An ontology is a comprehensive classification of the entities that are assumed to exist within a specific domain of interest (Sowa 2000). Ontologies refer to a formal technical representation of knowledge within a domain, consisting of a set of concepts and the relationships between them, which can be used to organize information, as well as share and facilitate reasoning about knowledge in computer systems. To overcome interoperability issues, methods for distributed modeling and accessing information have emerged, focusing on standardizing ways to create, publish, and reuse knowledge globally (Pauwels & McGlinn 2022). For example, this involves using Uniform Resource Identifiers (URIs) for components, allowing cross-domain concept reuse through standardized vocabularies like the Simple Knowledge Organization System (SKOS) (Miles & Bechhofer 2009), which is further described in the research method. There are three types of ontology reuse: hard reuse, which involves importing the entire existing ontology (Fernández-López et al 2019); soft reuse, which involves only referencing URIs (Fernández-López et al 2019b); and direct application of an existing ontology without creating a new one (Kamdar et al 2017).
Problems can occur when ontologies do not provide a clear explanation of their licensing (Poblet et al 2018). It is important to note that just because an ontology is available online, it does not necessarily mean that it can be reused legally (Fernández-López et al 2019c). A case study using BioPortal revealed most ontologies use less than 5% of terms from a few established ones, with many having no term reuse. Ontology developers aimed to reuse terms but often used incorrect representations. Analysis showed developers commonly reuse similar terms, organizing them as sibling or parent-child nodes in the ontology hierarchy (Kamdar et al 2017b). Due to the domain-agnostic nature of ontology modelling, their findings about ontology reuse may serve as a suitable precedent in the AEC.
The lack of definitions of mapping/alignment methodologies is considered inadequate, and the throwing together of buzzwords quickly leads to incomprehensibility and a lack of reuse. Looking at examples for semantic automated code compliance checking such as Jiang et al. (2022), Zheng et al. (2022), and Zhou & El-Gohary (2021), multiple terms such as fusion or alignment are used without giving a precise definition. To investigate and overcome the problem of lacking ontology reuse in the domain of AEC, the objective of the study is to align domain ontologies that are related to the domain of building permitting. The research questions are (1) how use cases could look like from a conceptual perspective and (2) to what extent they are alignable.

2 Research Approach

The methodology is subdivided into three steps. Step 1 involves the identification of potential use cases where ontologies can be aligned from a process management perspective. In Step 2, an analysis is conducted to discern similarities among the identified concepts. Subsequently, in Step 3, the utilization of SKOS, a common data model for sharing and linking knowledge organization systems via the Web (Miles & Bechhofer 2009b), is employed to articulate and describe the relationships between concepts, contributing to a more comprehensive understanding of their interconnections.
The SKOS data model sees a knowledge organization system as a bundle of concepts, identified by URIs, while forming a concept scheme. SKOS concepts may be linked to other SKOS concepts through semantic relation properties. Therefore, the concept class serves as both the domain and range for all the semantic relation properties. A concept scheme refers to an ontology or taxonomy within the SKOS terminology. The SKOS data model offers support for hierarchical and associative links between SKOS concepts, including `skos:broader`, `skos:narrower`, and `skos:related`. SKOS concepts may be mapped to other SKOS concepts in various concept schemes. The SKOS data model offers four

fundamental mapping types where the relationships are inherent in the meanings of the linked concepts: hierarchical (`skos:broadMatch` and `skos:narrowMatch`), associative (`skos:relatedMatch`), close equivalent (`skos:closeMatch`, mapping two concepts that are sufficiently similar and can be used interchangeably), and exact equivalent (`skos:exactMatch`, mapping two concepts, indicating a high level of confidence in their interchangeability). (Miles & Bechhofer 2009c) The relation between semantic and mapping properties is illustrated in Figure 1.

```
skos:semanticRelation
 |
 +- skos:related
 |    |
 |    +- skos:relatedMatch
 |
 +- skos:broaderTransitive
 |    |
 |    +- skos:broader
 |         |
 |         +- skos:broadMatch
 |
 +- skos:narrowerTransitive
 |    |
 |    +- skos:narrower
 |         |
 |         +- skos:narrowMatch
 |
 +- skos:mappingRelation
      |
      +- skos:closeMatch
      |    |
      |    +- skos:exactMatch
      |
      +- skos:relatedMatch
      |
      +- skos:broadMatch
      |
      +- skos:narrowMatch
```

Figure 1. The full set of sub-property relationships within SKOS (Miles & Bechhofer 2009d).

2.1 The Domain-Ontologies

Ontologies have been scientifically discussed in relation to building permits, with the following four approaches presented and examined as examples. The concept of the Ontology-based Building Permit Review (OntoBPR) (Zentgraf et al 2023) has been developed to cover the process steps involved in building permit reviews within authorities. Consequently, OntoBPR aligns different ontologies that cover the subprocesses of the building permit process. The representation of knowledge and information covering the administrative structure and workflows of building permit authorities is provided by the Ontology for Building Permit Authorities (OBPA) (Fauth & Seiß 2023, Fauth et al 2022). The OBPA is designed as a flexible and extendable system to represent country-specific building permitting processes of building permit authorities. In addition to the OBPA, the Interconnected Data Dictionary Ontology (IDDO) is aligned with the OntoBPR ontology. The IDDO (now known as ISOProps (Mellenthin Filardo et al 2024)) covers the content-specific review of building permits by providing digitized knowledge from building codes in a hierarchically structured tree of properties referenced in a dictionary (Zentgraf et al 2022).
As the fire safety certificate is crucial documentation required for building permits, the Fire Safety Ontology (FiSa) (Fitkau & Hartmann 2024) can be regarded as a domain ontology. FiSa represents fire safety requirements of building regulations in a machine-readable format, enabling automatic compliance checking. Integrating fire safety experts into the ontology's development fostered a shared understanding aiming to guarantee the encompassment of concepts required for the representation of fire safety requirements. The ontological knowledge formalization describes building structures from the perspective of fire safety, covering preventive requirements, building classification, materials, and components. FiSa addresses communication gaps among stakeholders that arise from building designs developed without a comprehensive understanding of the necessary fire safety requirements.

3 Key Findings

To align the domain ontologies, use cases are described to evaluate the possibility of integrating OntoBPR and FiSa from a management perspective. Later, the mapping of similar concepts is shown using the example of the alignment of OBPA and FiSa.

3.1 Use Cases

The use cases describe different scenarios how FiSa can be integrated into OntoBPR in a processual manner.

3.1.1 Use Case 1

The first use case is intended to integrate FiSa in the participation process of the building permit review within OntoBPR (see Figure 2). In the participation process, multiple other stakeholders are involved and are asked to give statements. The participation applies to other authorities, private agencies, but also fire safety engineers under specific circumstances (e.g., public building) as explained in the introduction. In this use case, FiSa can be implemented to serve the fire safety engineer in his role as an external stakeholder to check the project in the context of the OBPA.

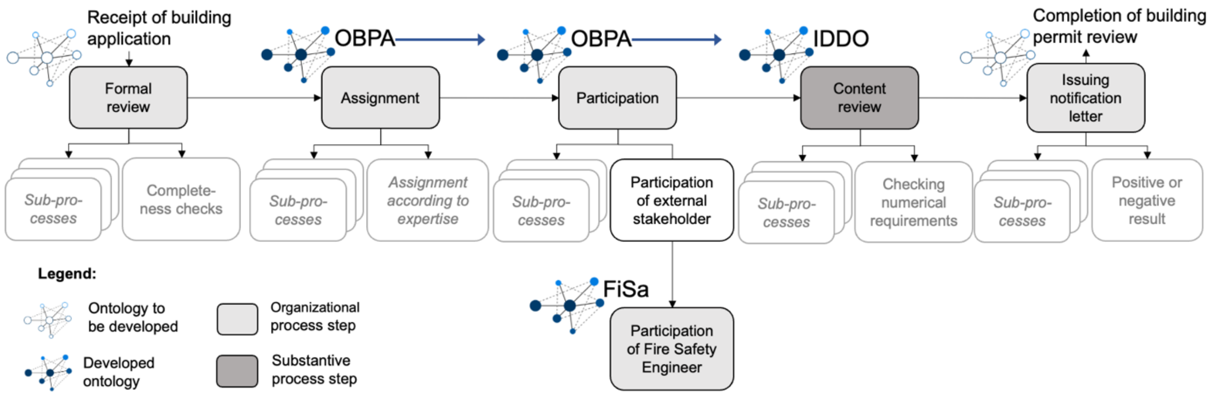

Figure 2. Building permit process: participation of external stakeholders, such as fire safety engineers (Use Case 1) (extended (Zentgraf et al 2023)).

3.1.2 Use Case 2

In the second use case, the fire safety aspects (represented by FiSa) are checked as part of the content check (see Figure 3). The content check refers to checking of substantive information (in comparison to formal information) processed by the building permit authority. Besides other substantive information such as accessibility or energy, fire safety regulations are considered here. As presented in OntoBPR, IDDO runs in parallel to FiSa, meaning that FiSa covers the checking of fire safety regulations by the building permit authority while IDDO covers other relevant substantive compliance checks.

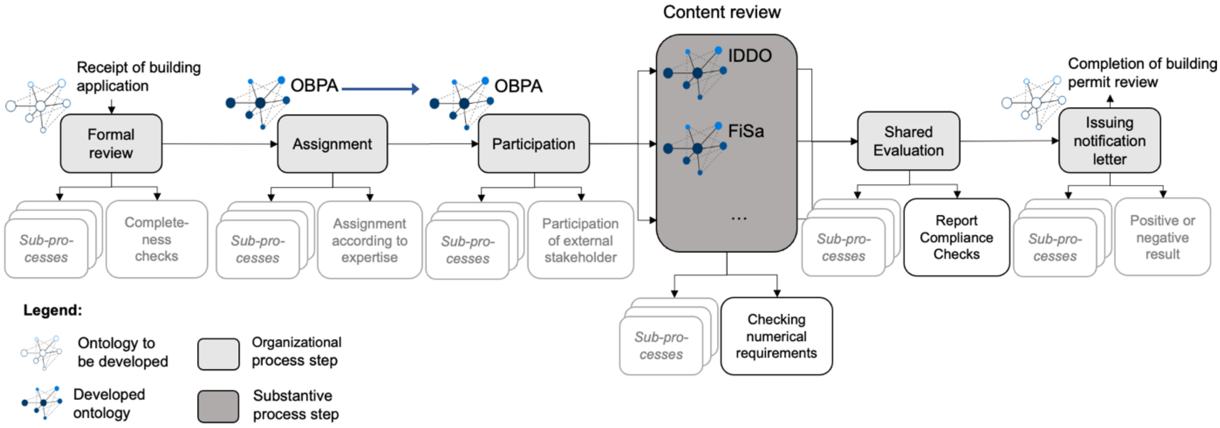

Figure 3. Building permit process: mapping compliance checking ontological schemas within content review (Use Case 2) (extended (Zentgraf et al 2023)).

3.2 Alignment and Reuse

With regard to the alignment of OBPA and FiSa, using the SKOS properties, the concepts listed in Table 1 are suitable for reuse while being mapped using one or more of the four SKOS mapping types. This mainly concerns higher-level concepts such as the taxonomy of buildings and the certificates required for a building permit, where e.g. the fire safety certificate is a sub-concept of `fisa:TechnicalStructuralCertificate` in FiSa, but does not exist in OBPA, requiring the use of general semantic relations rather than the discrete set of mapping properties of SKOS.

The determination is based on a pure direct exchange between the developers of both ontologies. Therefore, we went by whether the respective concepts are similar in their use and their sub-concepts (whether exactly, somewhat distant, or far away). That means, the less precise the match was defined by the developers (qualitatively in the exchange), the further away from ‘exact affiliation’ the SKOS attribute was used. For example, this may result in the use of 'hasRelatedMatch' or 'hasCloseMatch' rather than 'hasExactMatch' (for a complete exact match).

Table 1. Mapping of OBPA and FiSa through SKOS-Concepts.

	Related Concepts		
	FiSa	OBPA	SKOS
1	bot:Building	bot:Building	`hasCloseMatch`
2	fisa:SpecialPurposeConstruction	obpa:SpecialConstruction	`hasExactMatch`
3	fisa:RuleOfApplication	obpa:Regulations	`hasRelatedMatch`
4	fisa:TechnicalStructuralCertificate	obpa:BuildingApplication	`related`
5	fisa:Surrounding	obpa:PlotOfLand	`hasExactMatch`

4 Discussion and Implications

Reusing ontology concepts faces challenges due to a lack of organized views across domains. In particular, finding and understanding relevant ontologies for reuse requires extensive research. When reusing ontology concepts, developers must ensure the consistency of the ontology scheme, addressing the fact that the reused ontology scheme may also include other reused ontologies. Furthermore, importing entire ontologies for a hard reuse is time-consuming and often results in limited suitable concepts for modeling. Developers seek similar concept meanings across domains rather than a database of numerous ontologies for inspiration. Clear definitions in a thesaurus are crucial to provide ontology (re-)users with dedicated information about the meaning and existing reuses of the ontology. Rather than enforcing naming conventions, the focus could be on facilitating understanding and explaining differences in meaning. This may also support the documentation of reuses and illustrate the reuse of an ontology in a separated view. The buildingSMART Data Dictionary (bSDD) (buildingSMART International n.d.) offers comprehensive features promoting data quality, consistency, and interoperability, enhancing granularity through its terminology approach.

Further practical research must show whether the granularity of an ontology can be addressed not only by terminology work but also by an overall mapping approach as described using the following workflow. A thesaurus could effectively combine similar concepts within the built environment domain through the use of SKOS concepts. This will allow for a direct search query by including similar concepts that are defined, commonly understood, and categorically organized. The thesaurus will be accessible on the web, providing an organized collection of terms and a linked database for researchers to use. Technically, the Built-Environment-Thesauri (BEssi)-Ontology can serve as a distinct ontology in the backend. The BEssi data model then includes the interchangeable concepts that can be mapped using SKOS properties, as shown in Table 1. Such selections are made by the ontology modeler using a specially designed input mask. In this input mask, similar concepts are mapped to existing thesaurus concepts using BEssi via SKOS object attributes. A background process checks the mapping entries before displaying them in the thesaurus. The thesaurus itself will promote the reuse of concepts by providing the possibility to search for similar concepts in the first place. The process of mapping for ontology modelers is illustrated as a flowchart in Figure 4.

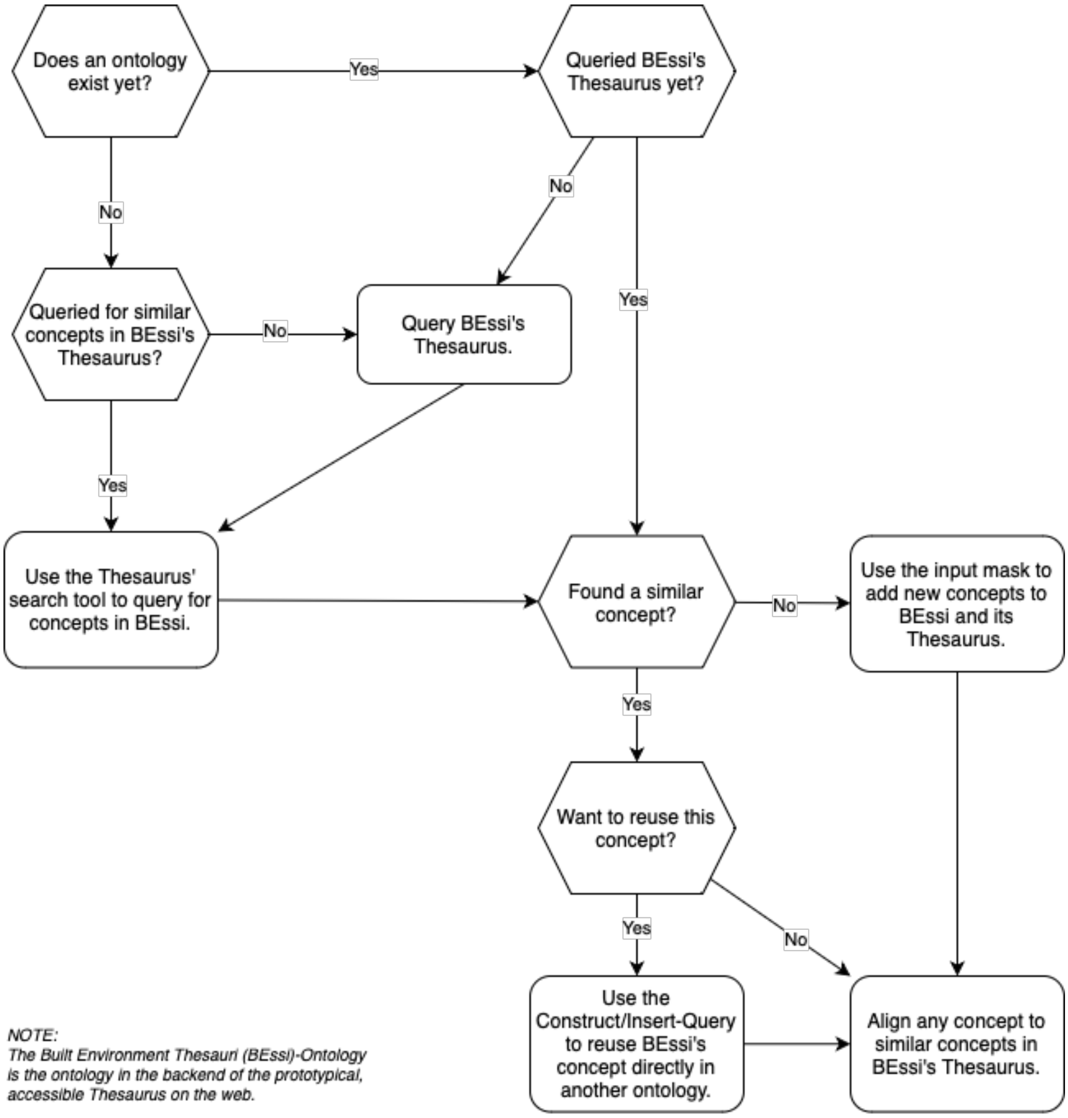

Figure 4. Mapping-Workflow of ontology modelers to support the reuse of similar domain concepts.

In the course of content discussions, pivotal questions emerge: Firstly, would the engagement of stakeholders beyond fire safety engineers exhibit similar dynamics? Secondly, what potential alterations could manifest in the review process with the practical implementation of ontologies? These inquiries underscore the need for a nuanced exploration of stakeholder roles and the transformative impact of ontologies on the review procedures. Notably, the identified use cases, though indicative, may not provide a comprehensive overview, suggesting the possibility of additional scenarios, such as the amalgamation of Use Case 1 and Use Case 2, that warrant exploration and analysis.

This study aims to stimulate discourse on how tracking could be significantly improved in the future by unifying ontologies within a single terminology. Currently, a human with a subjective perspective is responsible for merging requests from ontology creators into the terminology database. This presents a challenge, especially when dealing with vocabulary in different languages, among other complexities. The question remains: who ultimately serves as the qualitative authority in this process?

Further limitations concern the missing defined rationalization, as mentioned in section 3.2. Future work could focus on approaches, for example, on how this can be quantified in the future (e.g., 20 matching sub-concepts equals 'CloseMatch' or rather rule-based arguments infer the same concepts, hence 'CloseMatch').

5 Conclusion

In conclusion, our study explores the critical role of ontology reuse in the context of building permitting. Through the alignment of FiSa and OPBA using SKOS, we pathed the novel mapping approach, providing a structured and query-ready schema (BEssi) to enhance future reuse of concepts and communication among stakeholders. Our key findings encompass two distinct use cases that illustrate the possible integration of domain ontologies using the example of FiSa in the participation process of building permit reviews and its application in content checks. The identified use cases, while indicative, suggest the need for further exploration and analysis, pointing towards future research directions in ontology reuse for improved building permitting processes.

References

Athanasopoulou, A., Sciarretta, F., Sousa, L. & Dimova, S. (2023). The status and needs for implementation of Fire Safety Engineering approach in Europe, EUR 31383 EN, *Publications Office of the European Union*, Luxembourg, 2023, ISBN 978-92-76-61624-5, doi:10.2760/031591, JRC131689.

Beach, T. H., Hippolyte, J. & Rezgui, Y. (2020). Towards the adoption of automated regulatory compliance checking in the built environment. *Automation in Construction*, 118, p.103285.

Buchanan, A.H. & Abu, A.K. (2016). Structural Design for Fire Safety: Second Edition. *John Wiley & Sons*, Ltd. https://doi.org/10.1002/9781118700402.ch2.

buildingSMART International. (n.d.) buildingSMART Data Dictionary. Available at: https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/. Accessed: May 30, 2024.

Fauth, J. & Seiß, S. (2022). A Decision Support System for the Building Permit Review Process. *International Journal of Innovation Management and Technology*, 13(3), pp. 51–57. DOI:10.18178/ijimt.2022.13.3.921

Fauth, J., Müller, W. and Seiß, S., (2023). Process-based building permit review – A knowledge engineering approach. In: *ECPPM 2022 - eWork and eBusiness in Architecture, Engineering and Construction 2022*, 1st ed. CRC Press, pp. 7. eBook ISBN 9781003354222.

Fauth, J. & Seiß, S. (2023). Ontology for building permit authorities (OBPA) for advanced building permit processes. *Advanced Engineering Informatics*, 58, p.102216. DOI: 10.1016/j.aei.2023.102216.

Fernández-López, M., Poveda-Villalón, M., Suárez-Figueroa, M. C., & Gómez-Pérez, A. (2019). Why are ontologies not reused across the same domain? *Journal of Web Semantics*, 57, p.100492. DOI: https://doi.org/10.1016/j.websem.2018.12.010.

Fitkau, I. & Hartmann, T. (2024). An ontology-based approach of automatic compliance checking for structural fire safety requirements. *Advanced Engineering Informatics.* 59, 102314. https://doi.org/10.1016/j.aei.2023.102314.

Hjelseth, E. (2019). Foundations for BIM-based model checking systems: transforming regulations into computable rules in BIM-based model checking systems. *Doctoral thesis*, Norwegian University of Life Sciences, Ås, 2019. Accessed: Aug. 15, 2024. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2579671.

Jiang, L., Shi, J. & Wang, C. (2022). Multi-ontology fusion and rule development to facilitate automated code compliance checking using BIM and rule-based reasoning. *Advanced Engineering Informatics*, 51, p.101449. DOI: 10.1016/j.aei.2021.101449.

Kamdar, M. R., Tudorache, T. & Musen, M. A. (2017). A systematic analysis of term reuse and term overlap across biomedical ontologies. *Semantic Web*, 8(6), pp. 853–871. DOI: 10.3233/SW-160238.

Miles, A. & Bechhofer, S. (Eds.). (2009). SKOS Simple Knowledge Organization System Reference. *W3C Recommendation*, August 18, 2009. Available at: http://www.w3.org/TR/2009/REC-skos-reference-20090818/. Latest version available at: http://www.w3.org/TR/skos-reference/.

Mellenthin Filardo, M., Liu, L., Hagedorn, P., Zentgraf, S., Melzner, J. & König, M. (2024). A standard-based ontology network for information requirements in digital construction projects. *LDAC2024: Linked Data in Architecture and Construction Workshop*, June 13–14, 2024, Bochum, Germany.

Nawari, N.O. (2018). Building Information Modeling: Automated Code Checking and Compliance Processes. Boca Raton: *CRC Press.* DOI: 10.1201/9781351200998.

Noardo, F., Ellul, C., Harrie, L., Overland, I., Shariat, M., Ohori, K.A. & Stoter, J. (2020). Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges. *Journal of Spatial Science*, 65(2), pp. 209-233.

Pauwels, P., & McGlinn, K. (Eds.). (2022). Buildings and Semantics: Data Models and Web Technologies for the Built Environment (1st ed.). *CRC Press.* https://doi.org/10.1201/9781003204381.

Poblet, M., Aryani, A., Manghi, P., Unsworth, K., Wang, J., Hausstein, B., Dallmeier-Tiessen, S., Klas, C.-P., Casanovas, P. & Rodriguez-Doncel, V. (2018). Assigning Creative Commons Licenses to Research Metadata: Issues and Cases. In: Pagallo, U., Palmirani, M., Casanovas, P., Sartor, G., Villata, S. (eds) *AI*

Approaches to the Complexity of Legal Systems. Lecture Notes in Computer Science, vol 10791. Springer, Cham. DOI: 10.1007/978-3-030-00178-0_16.

Sowa, John F. (2000). Knowledge Representation: Logical, Philosophical, and Computational Foundations. *Brooks Cole Publishing Co.*, Pacific Grove, CA. ISBN 0-534-94965-7.

Zentgraf, S., Fauth, J., Hagedorn, P., Seiß, S., Smarsly, K., König, M., & Melzner, J. (2023). OntoBPR: Ontology-based workflow and concept for building permit reviews. *EG-ICE 2023 Conference Papers*. EG-ICE International Conference on Intelligent Computing in Engineering, London.

Zentgraf, S., Hagedorn, P. & König, M. (2022). Multi-requirements ontology engineering for automated processing of document-based building codes to linked building data properties. *IOP Conference Series Earth and Environmental Science*, 1101(9), Article-ID: 092007. DOI: 10.1088/1755-1315/1101/9/092007.

Zhai, Z., Martínez Ortega, J.-F., Lucas Martínez, N. & Castillejo, P. (2018). A Rule-Based Reasoner for Underwater Robots Using OWL and SWRL. *Sensors*, 18(10). DOI: 10.3390/s18103481.

Zheng, Z., Zhou, Y.C., Lu, X.Z. and Lin, J.R. (2022). Knowledge-informed semantic alignment and rule interpretation for automated compliance checking. *Automation in Construction*, 142, p.104524. DOI: 10.1016/j.autcon.2022.104524.

Zhou, P. and El-Gohary, N. (2021). Semantic information alignment of BIMs to computer-interpretable regulations using ontologies and deep learning. *Advanced Engineering Informatics*, 48, p.101239. DOI: 10.1016/j.aei.2020.101239.