OntoBPR: Ontology-based workflow and concept for building permit reviews

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Abstract. Commonly, building permits are executed and checked manually and not digitized, requiring a high level of effort. In Germany, building codes in practice are currently not yet designed to be automatically checked during the building permit process. To avoid a digital disruption in planning buildings and structures, this paper presents a workflow in which building codes are represented as machine-readable knowledge graphs and ontologies. The building permit process is analyzed, and possible applications of ontology-based knowledge representations are explored. An ontology-based building permit review (OntoBPR) is proposed, reusing two existing ontologies for modeling the permit review workflow for representing the building codes. The paper aligns the two ontologies, validated through a case study conducted using Shapes Constraint Language (SHACL) rules generated from the building code knowledge graphs. The result of the paper is an evaluated, viable concept and workflow, prototypically implemented for the OntoBPR.

1. Introduction

Building permits, representing essential elements in the life cycle of buildings, are crucial to the legality of buildings. The building permit process is complex because various actions, actors, and disciplines need to be considered, such as construction project management, law, and public administration (Ullah et al., 2022). While the building permit process defines all process steps dedicated to building permits (including planning and design), a building permit review describes the process of checking building applications by building officials in building permit authorities and includes managing and reviewing administrative as well as building-related requirements (Plazza et al., 2019). Building permits are primarily reviewed manually and only digitized to a small extent (Noardo et al., 2022). Therefore, building permit reviews require a high level of effort and are error-prone. In addition, not all requirements are thoroughly checked due to the high effort required for checking. In the international context, not always complete checks regarding all requirements of relevant building codes are carried out but only random samples and plausibility checks (Fauth, 2021). Furthermore, various regulatory documents need to be considered throughout building permit reviews. The information required for building permit reviews is usually available in regulatory documents but not as formalized knowledge. Moreover, regulatory documents are not yet represented in machine-readable formats, which impedes automated checking during the building permit review. Although several approaches to the automation of substeps within building permit reviews exist, there is a lack of interconnection between the substeps. Therefore, integrating the building permit review workflow with building data (representing data relevant to buildings) and automated code compliance checking is required. Nawari (2018) describes ontology standardization as a vital factor in resolving the manual code compliance-auditing process.

To overcome the aforementioned drawbacks in building permit reviews, this paper presents a workflow in which building codes are represented as machine-readable knowledge graphs, using two ontologies developed in previous studies – the *Ontology for Building Permit Authorities (OBPA)* presented by Fauth et al. (2023) and the *Interconnected Data Dictionary Ontology (IDDO)* introduced by Zentgraf et al. (2022). The ontologies are reused for an Ontology-based Building Permit Review concept, referred to as "OntoBPR". The proposed OntoBPR concept includes regulation checks and administrative rules. For instance, administrative rules assign building applications (applications submitted by building owners to building permit authorities to have buildings approved) to respective building officials (proceeding building permit reviews in building permit authorities), and involve agencies of public interest for providing statements in a project-based manner. Furthermore, formalized regulatory knowledge is used for code compliance checking of digital building models using the Shapes and Constraint Language (SHACL). Semantic Web technologies and domain-specific ontologies support the OntoBPR concept.

In the remainder of this paper, a brief description of linked building data and building code knowledge graphs is given in Section 2. The details of OntoBPR, including descriptions of OBPA and IDDO, are explained in Section 3. The case study is presented in Section 4, followed by a brief discussion and conclusions as well as an outlook on future research.

2. Linked building data and building code knowledge graphs

Semantic Web, linked data, and knowledge graphs are increasingly used in the planning, construction, and operation phases of assets in the built environment (Pauwels et al., 2022). Linked data and knowledge graphs modeled in the Resource Description Framework (RDF) are utilized to describe many aspects of buildings, structures, and systems and thus can also be referred to as linked building data (LBD) (Rasmussen et al., 2019). LBD can describe, e.g., the topology of buildings using the internationally discussed and established Building Topology Ontology (BOT) or managing changing properties of any feature of a built asset using the Ontology for Property Management (OPM) (Rasmussen et al., 2019). Besides BOT and OPM, several domain-specific ontologies are provided in public repositories, e.g., the DiCon ontology suite (Zheng et al., 2021). To generate LBD from building models in the Industry Foundation Classes (IFC), the IFCtoLBD converter has been developed by Bonduel et al. (2018), which converts IFC hierarchy, elements, and property sets into RDF data using the BOT ontology and attaches the properties of the elements with generated predicates based on their definition in the originating IFC file. Using this converter, access to LBD is facilitated. Using LBD offers various advantages, such as querying specific data with the SPARQL Protocol and RDF Query Language (SPARQL) to retrieve or generate specific information in an LBD Knowledge Graph. Besides querying, validation and checking of LBD is a focused research topic. Oraskari et al. (2021) have provided the parallels of checking building data with the Semantic Web technology Shapes Constraint Language (SHACL) and the IFC-based checking with model view definitions. A study on the applicability of SHACL for LBD and corresponding building data has been provided by Hagedorn and König (2021) showing examples and best practices for validating cross-domain LBD data. Representations of building codes in knowledge graphs using Semantic Web technologies are examined by Jiang et al. (2022) and Zentgraf et al. (2022). The following section describes how two ontologies from the domain of building code knowledge graphs can be aligned to check linked building data.

3. Ontology-based Building Permit Review (OntoBPR)

This section introduces the concept of OntoBPR. Furthermore, OBPA and IDDO are explained and the performed alignment is presented. Building permit reviews, which take place within authorities, consist of several substeps. The five main steps are: (1) formal review (including, for example, completeness checks of documents), (2) assignment (which building official processes which building application), (3) participation (involvement of other agencies and authorities for statements), (4) content review (checking substantive building information, e.g., minimum door width, or building height), and (5) issuance of notification letter (processing the final decision on a building application) (Fauth, 2021). All substeps are of organizational nature, except content review, which has substantive character (Figure 1). This paper aims to map the procedural approach of the building permit review as depicted in Figure 1 to the ontological data schemes developed within two ontologies. The workflow and the administrative structure underlying the OntoBPR are provided using the OBPA. Building codes to be checked during the building permit are formalized regarding an ISO 23386 (2020) conforming schema in IDDO. IDDO defines a property schema for building data, which encodes boundary values (e.g., an upper and lower bound of length measures), units (of physical quantities), enumerated values (such as lists of possible values of properties), and other constraints. Properties, according to IDDO, are stored in a knowledge graph and can be assigned to any feature of interest inside a construction project during the planning phase. A relation between IDDO and OBPA is provided within the paper to connect both ontologies and embed the ontologies into the OntoBPR concept.

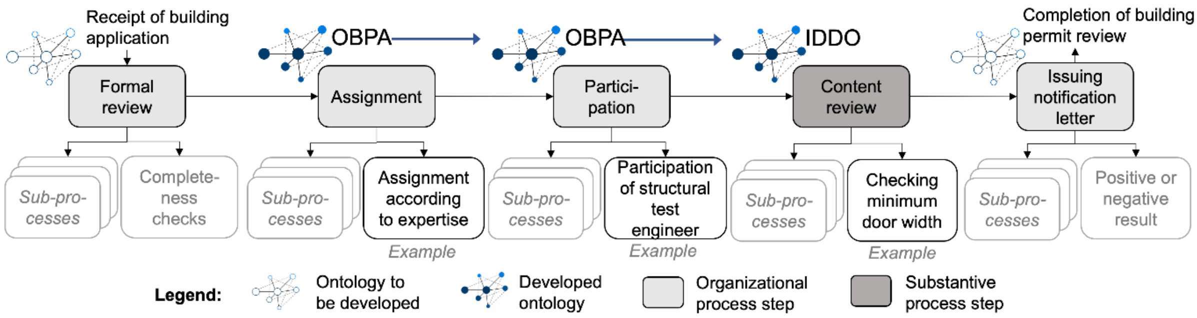

Figure 1 Building permit process and mapping to ontological data schemas

Figure 1 shows an abstract mapping of the OBPA and IDDO ontologies to the process as the main part of the OntoBPR concept. The main goal of the mapping is to reuse the ontologies to the highest possible degree because domain ontologies are hardly reused even within the same domain, which is primarily due to missing maintenance, licenses, or online resources of ontologies (Fernández-López et al., 2019). Ontology reuse has also been a topic in the AEC industry (Terkaj et al., 2017) and has been undertaken to reuse the topology defined by the BOT ontology in other domain ontologies (Schneider, 2017). One approach is to collaboratively develop reusable ontologies (Fernández-López et al., 2019) and to use formalized methodologies for the development, reuse, and maintenance of ontologies. One methodology well established for ontology development and includes ontology reuse as a key step is the Linked Open Terms (LOT) methodology developed by Poveda-Villalón et al. (2022). LOT describes four major steps to elicit requirements and to implement, publish, and maintain an ontology. The ontology development step is subdivided into conceptualization, reuse, encoding, and evaluation. Conceptualization and reuse can be an iterative process influencing each other to approximate a concept from new terminologies and reused vocabulary. For the ontology development in this paper, the OBPA and IDDO are fully reused and just a small amount of additional vocabulary is iteratively defined to connect the concepts of both ontologies for achieving the proposed automated building permit process.

To verify the OntoBPR concept and to showcase the combination of the ontologies, a use case representing the organizational aspects of the building permit review and the technical checking of building data regarding building codes is devised. As a case study, a public building design modeled using IFC is checked for accessibility according to the building code of the state of North Rhine-Westphalia, Germany. For the SHACL checking procedure, the IFC model is first transformed into RDF data using the IFCtoLBD converter. The assignment of properties selected from the building code knowledge graph to the RDF building data is implemented with property mapping. For the properties, SHACL rules are automatically generated from the building code knowledge graph and can be applied for semantic checking of the RDF data.In the next subsections, OBPA and IDDO are described followed by the description of the alignment.

3.1 Ontology for Building Permit Authorities (OBPA)

OBPA handles the knowledge and information of building authority, including building officials and the building application. The ontology is designed as a domain ontology and can therefore be specified to the application by any building authority. Furthermore, the ontology is related to upper-level ontologies like the Friend of a Friend Ontology (FOAF) or vCard to ensure clarity of terminology, understanding, and reusability of the ontology. As can be seen from Figure 2, OBPA is based on three main entities *obpa:BuildingAuthority*, *obpa:Person*, and *obpa:BuildingApplication*.

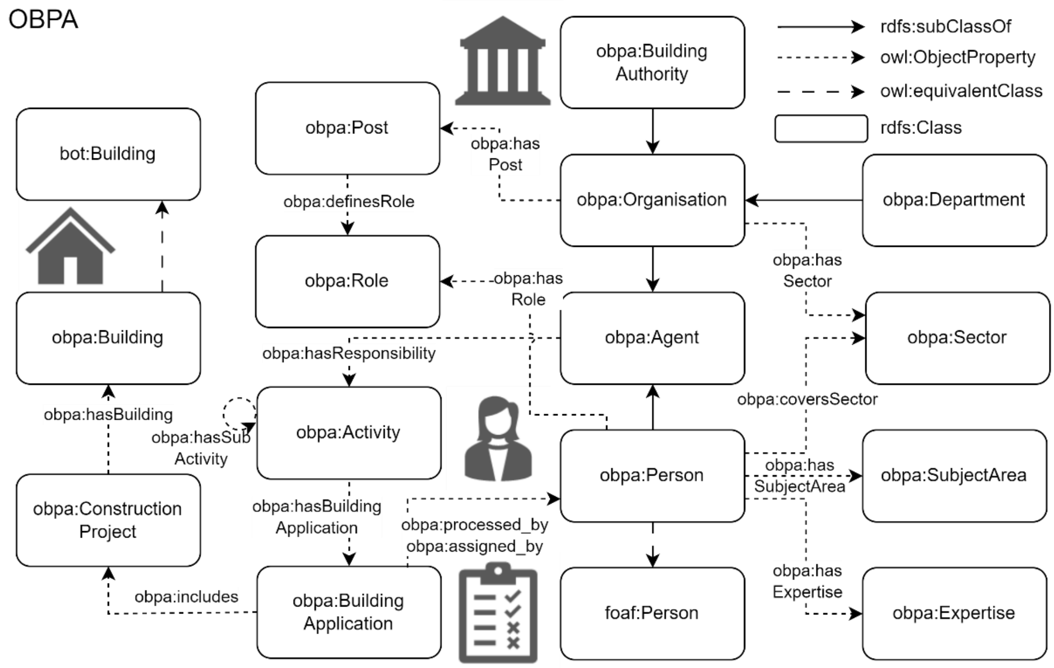

Figure 2 OBPA overview

As described in Figure 2, the class *obpa:Person* links to an *obpa:BuildingApplication* and the *obpa:BuildingApplication* to an *obpa: Construction* project. The assignment of a building official as obpa:Person to an *obpa: BuildingApplication* is described by the relation *obpa:processedby*. The *obpa:Building Application* is generally assigned by a supervisory building official to a technical or administrative building official. The assignment process is based on the worker roles, skills, and responsibilities represented as obpa:Person and hired by the *obpa:BuildingAuthority*. The *obpa:BuildingAuthority* is a subclass of *obpa:Organization*.

To describe the task of a person assigned to a building permit, activities are linked to both the person and the building permit using the *obpa:Activity* class, which has a defined start and end date, as well as a duration. The activities can be further specified by subclasses, such as testing, acceptance, or filing activities, to categorize and specify the activities. By developing constraints, the approval process can be ensured to follow a specific sequence of steps, enabling compliance with established test sequences and avoiding procedural errors.

OBPA is divided into three functional modules, an organizational module, an agent module, and a building application module, which allows an improved organization, readability, and extensibility of the ontology (Zhai et al., 2018). The ontology can be adapted to specific building authorities, enabling a flexible and expandable system to represent the heterogeneous process of obtaining building permits, as well as the assignment processes and structures within building authorities. Furthermore, it is possible to add additional components or to remove components that are not needed. The ontology used to align OBPA is IDDO, which is explained in the following section.

3.2 Interconnected Data Dictionary Ontology (IDDO)

IDDO has been developed to digitize knowledge from building codes as well as construction-related guidelines and to transfer this knowledge into a hierarchically structured tree of property groups and properties derived from natural language texts (Zentgraf et al., 2022). Each property group and property is annotated with metadata and managerial information according to the ISO 23386 (2020) standard. Moreover, properties contain information and constraints regarding the values for which the properties can be materialized. The constraints can be sets of boundary values with lower and upper values and an accompanying unit, possible values from enumerations and arrays or interconnection to other properties, and the dynamic calculation of properties.

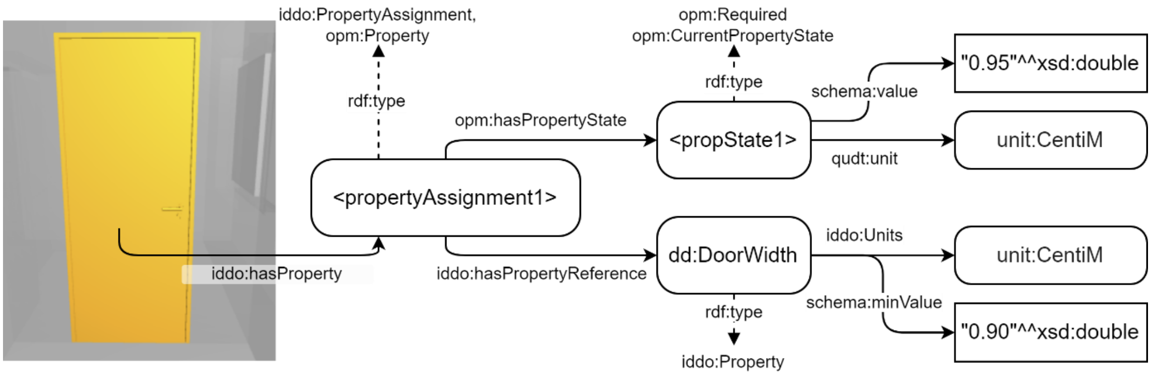

Figure 3 Property assignment example using IDDO vocabulary

As provided by Zentgraf et al. (2022), properties can be assigned to any feature of interest (FOI), e.g., a construction site entity, a *bot:Building*, or a *dice:Equipment* (Figure 3). This property assignment is designed using the OPM property state pattern specified by Rasmussen et al. (2019), defining a blank node that branches the predicate paths between the instantiation of the property value for a specific property state and the property reference from the data catalog provided by the IDDO ontology. The description and encoding of the ontology are publicly available from the ontology documentation (Zentgraf and Hagedorn, 2021).

To maximize the compatibility with existing standard ontologies in the Semantic Web, the given structure of IDDO based on the ISO 23386 is extended with vocabulary from the Data Catalog Vocabulary (DCAT), which is a recommendation by the World Wide Web Consortium (W3C) (Albertoni et al., 2020). Each dictionary that is modeled using IDDO vocabulary contains one instance of *iddo:Dictionary* that is a subclass of *dcat:Catalog*. The instances of the dictionary class can be subdivided into parts using one or more instances of the *iddo:DictionarySubset* class as a subclass of *dcat:Dataset*. Subsets refer to the actual "Reference document" instance of *iddo:GroupOfProperties* via the *iddo:DictionaryReference Document* instance that is a subclass of *dcat:Distribution*. Further *iddo:GroupOfProperties* instances can be used to structure the full amount of *iddo:Property* instances in the dictionary.

3.3 Integrating OBPA and IDDO into the building permit review

This section describes the alignment of the OBPA and IDDO, conducted in this study for underpinning the building permit process with an integrated data schema. Two new object properties and the corresponding inverse properties are introduced to align the two ontologies on a terminological level (Figure 4, green rectangles).

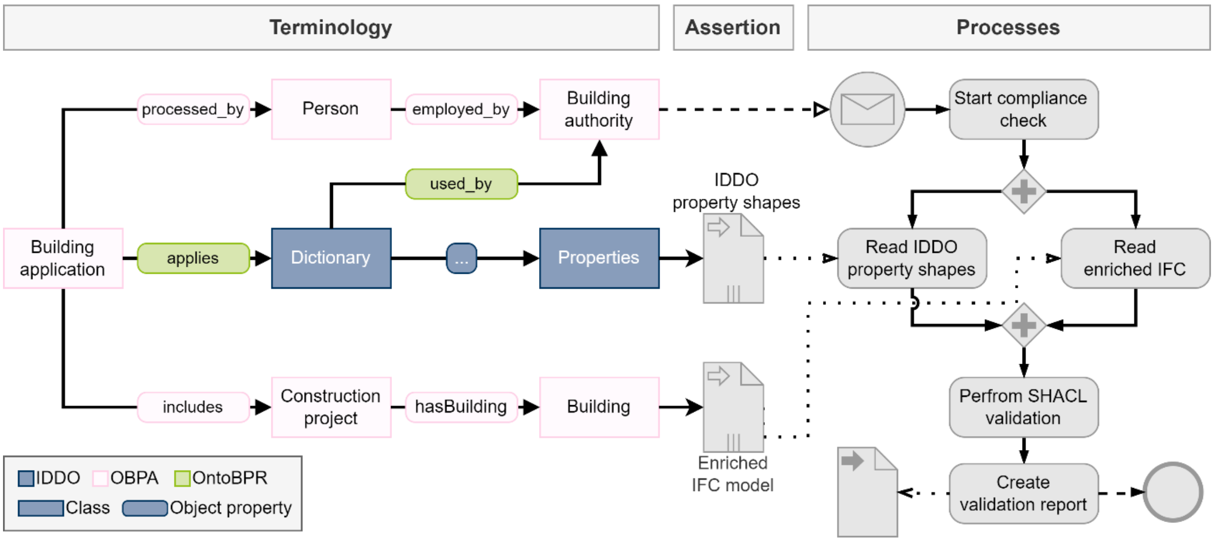

Figure 4 Alignment of OBPA and IDDO ontologies and integration into the OntoBPR review

The object property *obpr:applies* connects the *opba:BuildingApplication* and the *iddo:Dictionary* class. This allocation indicates that a building application can involve one or more specific dictionaries. The second object property *obpr:used_by* links the class *iddo:Dictionary* with the class *obpa:BuildingAuthority*. It describes that rules, regulations, and requirements from a dictionary are used by a building authority to perform a compliance check during a building permit process.

Two data sets are instantiated when asserting statements from the defined ontological data schema. Using IDDO, a set of property constraints is derived from the rules and requirements emerging from the corresponding dictionary. The property constraints can be used in the process to check the conformity of the enriched IFC model, which is an instance of the *obpa:Building* class. The IFC model consists of the geometric representation of the building model in an LBD representation and the properties specified by the applied data dictionaries.

Upon initiating the compliance checking process by an *obpa:BuildingAuthority*, both asserted instance datasets are read as input data for the SHACL processor. SHACL validation checks whether the information provided in the enriched IFC model satisfies the constraints and requirements defined in the IDDO property constraints. In the last step of the process, a validation report is created, which contains the results and possible errors of the performed validation. The validation report can be connected to the building application for documentation purposes.

4. Case study building application: Accessibility of a public building

The OntoBPR workflow developed in this study is illustrated as a proof of concept using a public building. In Germany, and particularly in the state of North-Rhine Westphalia, the respective building code BauO NRW 2018 (2022) requires certain demands to be met according to the accessibility of public buildings according to § 9a (Fn 9) of BauPrüfVO 1995 (2022). The requirements concern, for example, barrier-free access to the building with a ramp with a slight slope or certain minimum dimensions of passages and rooms in order to be able to use move with a wheelchair without restrictions. This study examines, as an illustrative example, a minimum door width that must be at least 90 cm in public buildings.

From the process perspective, the public building also influences the substeps "assignment" and "participation", represented by OBPA. With the complexity of a public building, the expertise of a building official for such building types can be crucial to the assignment (i.e., if a building in a building application is a public building, then a building official with expertise in public buildings is assigned for the review). In addition, in a public building review, structural test engineers must be called in to check the structural analysis (i.e., if a building project is a public building, then a structural test engineer needs to be involved in the review).

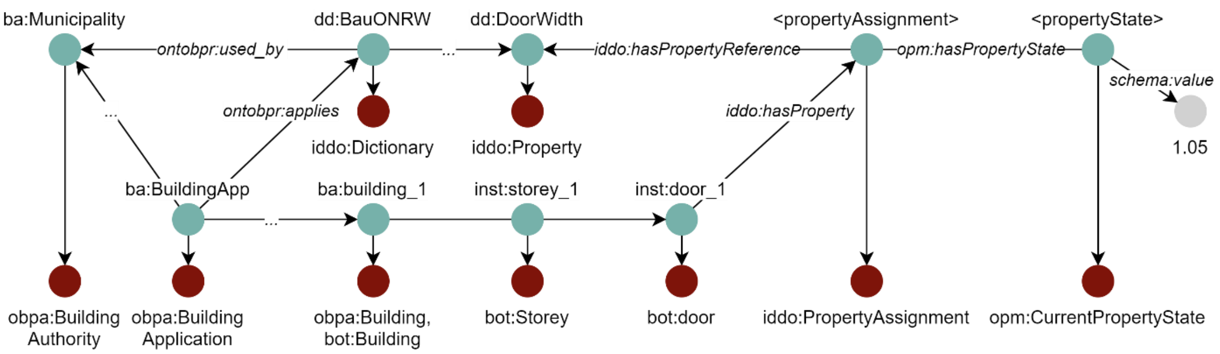

Figure 5 Excerpt from the RDF graph for the compliance check for minimum door widths

Some preliminary steps are necessary to check the minimum door width in the building model. First, the data dictionary containing the building code for accessibility of public buildings is created as *dd:BauONRW* (Figure 5). Next, a property set is created that contains a group of properties for a specific feature of interest represented by the instance *dd:DoorProperties* of the type *iddo:GroupOfProperties* containing the instance *dd:DoorWidth* of the type *iddo:Property* to be checked for all doors in the building model of the building application. In its inherent boundary conditions, the property prescribes that doors must have a minimum width of 90 cm and that the measurements must be in centimeters. In parallel with the creation of the property set, the model in IFC format is converted into LBD using the IFCtoLBD converter (Bonduel et al., 2018), and henceforth, the *dd:DoorWidth* is assigned to all door instances of the model.

The assignment is performed according to the OPM property state pattern process (Rasmussen et al., 2019). An example of this assignment for a specific door instance in the context of a building permit process can be seen from Figure 5. Subsequently, IDDO property constraints are created from the property set using an IDDO constraint generator developed for this use case. The constraint generator contains four SPARQL queries that generate a SHACL shape for the constraints prescribed in the *iddo:Property dd:DoorWidth*. Two queries (generators) construct the outer structure of the SHACL shape, the conditions to be checked, and define the error message if the conditions are violated. The other queries (annotators) add a name and a definition to the SHACL shape as metadata to improve the traceability of the shape itself. The traceability improvement is particularly helpful when simultaneously testing various shapes in one data graph.

In the next step, the SHACL validation is performed with the IDDO property constraints constructed herein as a shapes graph and with the enriched IFC model instances as a data graph (Figure 4, processes box). Figure 6 displays an excerpt of the before-described SHACL shape (Figure 6, top) for the compliance check of all door widths. The SHACL validation results show that the width of two doors is outside the specified boundaries (Figure 6, bottom and right).

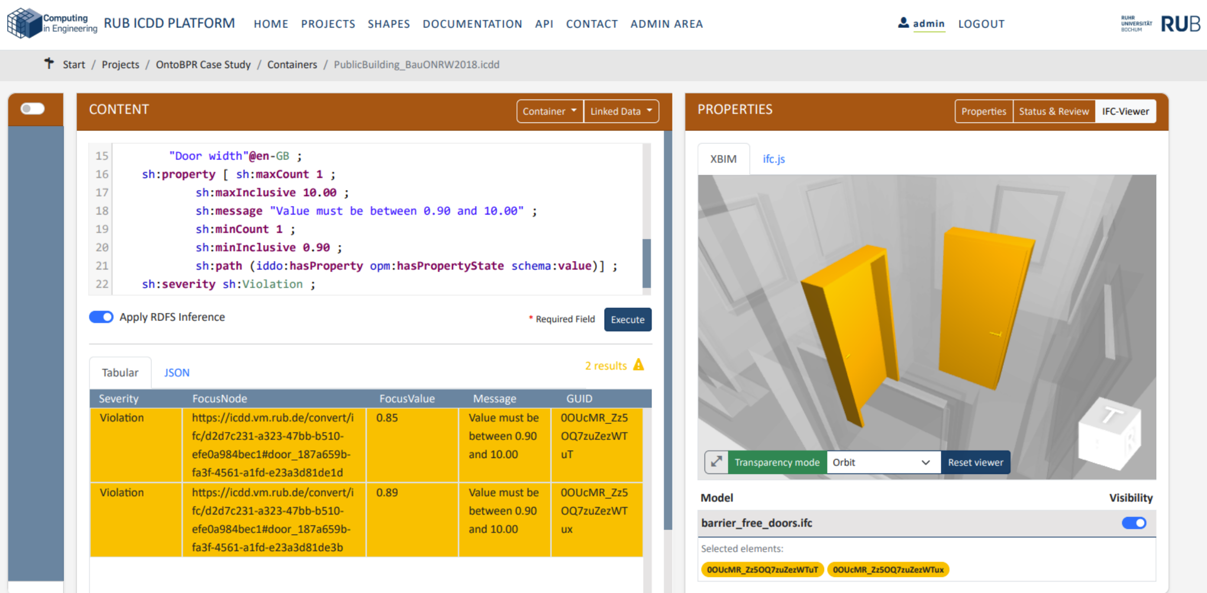

Figure 6 Result of the compliance check for minimum door widths, visualized in a web application

5. Discussion and Conclusions

The aim of this paper was to present a workflow in which building codes can be represented as a machine-readable knowledge graph and semi-automatically checked to provide a concept for an OntoBPR. Instead of solely digitalizing the actual building permit process, the workflow itself is modified by checking the entirety of requirements from building codes that apply to a building, which is not only possible at the permit stage but also during the submission of the building permit, delivering direct feedback to the applicant. The OntoBPR workflow ensures legal certainty for all parties involved, prevents defects, and minimizes the susceptibility to errors. Compatibilities and extensions for the specific countries will have to be created for implementation in practice so that, e.g., the XBau exchange format for communication in the building application process in Germany can be incorporated into OntoBPR. The technical advantages of using ontologies, particularly for the presented approach, are modularity and flexibility for tackling the challenges of the rather heterogeneous construction industry. Due to the possible decentralization brought by the usage of the Semantic Web, it is possible to process data in a distributed way, e.g., the building code data dictionaries and generated SHACL rules. Decentralization facilitates the process of parallel checking different building codes by different stakeholders and combining the results afterward for the review report. However, to fully grasp the potential of the OntoBPR, further ontologies need to be developed, as depicted in Figure 1, for the process steps of the formal review and the issuance of notification letters, and eventually aligned with the existing ontologies. So far, only boundary values of numerical data can be tested with IDDO, which is why an expansion is necessary. However, the proof of concept is available and can be used for other constraints.

The paper has presented a workflow and a concept for OntoBPR. The concept supports objectivity, transparency, and robust decision-making in the building permit review processes. With the alignment of IDDO and OBPA, the code-checking results are semi-automatically provided to building permit authorities and building officials. From the approach presented in this paper, further application possibilities arise, which may be considered in follow-up studies. Thus, IDDO can already be applied in the design phase of buildings. OBPA, on the other hand, could be used for other administrative processes to be more transparent and efficient. Strategies for implementing the OntoBPR on the administrative level considering aspects of law, personal competencies, availability of digital building codes, and technical implementations that go beyond the prototype implementation presented in this paper. Hence, the prototype requires real-world data verification to impact actual building permit processes, which may be considered in future research efforts.

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