TUM Department of Civil, Geo and Environmental Engineering
Chair of Computational Modeling and Simulation
Prof. Dr.-Ing. André Borrmann

Analysis of Exchange Requirements for BIM-based Fire Code Compliance Checking

Sina Pfuhl

Bachelorthesis
for the Bachelor of Science Course Civil Engineering

Author: Sina Pfuhl
Student ID:
Supervisor: Prof. Dr.-Ing. André Borrmann
M.Sc. Jimmy Abualdenien
Date of Issue: May 9, 2018
Date of Submission: October 8, 2018

Abstract

Digital building models have become increasingly common in recent years. These models use intelligent objects that contain geometrical information as well as semantic information such as materials and fire protection properties. This kind of building models can be used to automate the checking of complex building requirements. The purpose of this work is to develop a Model View Definition (MVD) which checks compliance with basic fire protection requirements and thus supports creators of a building model. To achieve this, exchange formats published by buildingSMART are analyzed: the open standard Industry Foundation Class (IFC), the MVD and the data dictionary. Concurrently, the fire protection requirements of the Bavarian Building Regulations (BayBO) are translated into English and organized into a tabular representation. Thereafter, to develop the MVD, IFC attributes are combined with the requirements of the building regulations by *PropertySets* from the IFC schema. Prospective, this MVD can reduce inconsistencies during the exchange of building model data and improve the fire safety of buildings. Although a check can not yet be made when requirements need a cross-object query. In addition, problems and potentials for improvement are collected and described, regarding the interaction of software from different software producers.

Zusammenfassung

Die Nutzung von digitalen Gebäudemodellen nimmt in den letzten Jahren stark zu. Dafür werden intelligente Objekte genutzt, die neben geometrischen Informationen auch semantische Inhalte wie zum Beispiel Material- oder Brandschutzeigenschaften enthalten können. Die Informationen dieser Objekte können zur automatischen Kontrolle von komplexen baulichen Anforderungen genutzt werden. Das Ziel dieser Arbeit ist die Entwicklung einer Model View Definition (MVD), die es dem Ersteller eines Gebäudemodells ermöglicht, die Einhaltung von grundlegenden Brandschutzanforderungen zu überprüfen. Dafür werden zunächst der offene Standard Industry Foundation Class (IFC), die MVD sowie das Datenwörterbuch von buildingSMART analysiert. Gleichzeitig werden die Brandschutzanforderungen der Bayerischen Bauordnung (BayBO) als geltendes Baurecht in Bayern sinngemäß ins Englische übersetzt und in eine tabellarische Darstellung überführt. Anschließend erfolgt eine Zusammenführung von IFC Attributen mit den Anforderungen der BayBO durch sogenannte PropertySets aus dem IFC Schema und schließlich die Entwicklung der MVD. Objektübergreifendes Abfragen von Bedingungen steht jedoch noch nicht zur Verfügung, sodass umfassende Prüfungen nicht möglich sind. Trotzdem können mit dieser MVD langfristig Inkonsistenzen bei Austauschvorgängen von Gebäudemodelldaten reduziert und die brandschutztechnische Sicherheit von Gebäuden verbessert werden. Zusätzlich werden Probleme und Verbesserungsmöglichkeiten bezüglich der Interaktion von Software unterschiedlicher Hersteller gesammelt und beschrieben.

Contents

List of Figures

List of Abbreviations

AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
ASR	Technische Regeln für Arbeitsstätten - Technical Guideline for Workplaces
BayBO	Bayerische Bauordnung - Bavarian Building Regulation
BIM	Building Information Modeling
bSDD	buildingSMART Data Dictionary
CAD	Computer-Aided Design
CORENET	Construction and Real Estate Network
IFC	Industry Foundation Class
IFD	International Framework for Dictionaries
IDM	Information Delivery Manual
ISO	International Organization for Standardization
LOD	Level of Development
MBO	Musterbauordnung - Model Building Regulation
MVD	Model View Definition
SMC	Solibri Model Checker
STEP	Standard for the Exchange of Product model data
XML	eXtensible Markup Language
XSD	XML Schema Definition

Chapter 1

Introduction

Failures in fire protection cause enormous material damage in the event of a fire, and often endanger human lives. Recent examples are the the Grenfell Tower fire in London in 2017 or the continuing delays in fire protection at Berlin Airport. If structural or technical fire protection measures are incorrectly implemented, they can also lead to additional damage such as fire-fighting water damage or the contamination of ventilation systems with smoke gases. Consequently, it is essential to consider the basic fire prevention requirements as early as the planning phase.

In Germany, building permits, including fire prevention certificates are mandatory for construction projects. Fire prevention engineers manually create these certificates, comprising escape routes, to analyze possible dangers. The requirements given in building codes differ from country to country, rendering automation in code checking and simulation complex and challenging. Code checking requires a tremendous expertise about the applicable law and a differentiated analysis for each special case; it is time consuming and error-prone.

Fire prevention engineers need a set of information given by architects in construction plans. They analyze the the set comprehensively and suggest certain fire prevention measures in accordance with the building code. Once finished, they return a certificate back to the architect and the owner, demanding changes to the plan if necessary. This process can be repeated many times, depending on the dimension of the project and the integrity of the exchange data. It is time-consuming because it is simultaneously carried out by other stakeholders involved in the construction project, such as technicians or static planners. This is particularly vexatiously when unwanted iteration cycles become necessary due to modifications demanded by the respective authorities or errors in the construction process. An additional challenge is caused by different stakeholders requiring different data. Therefore, many data losses and inconsistencies are the consequences of the manual data exchange. A methodology to automate simulation preparation and execution could make this process much more effective.

In the past years, digital building models have become increasingly common in the Architecture, Engineering and Construction (AEC) industry. Buildings are designed with intelligent objects containing geometrical and semantically information. This methodology, called Building Information Modeling (BIM), is used to describe the life-cycle process of construction projects.

With the increasing prevalence of BIM, various tools and methods have entered the market to improve data exchange and reduce inconsistencies. They also have enabled stakeholders to transfer and check information directly and digitally. The independent, open and standardized data model format Industry Foundation Class (IFC) is the most important one, because it exchanges BIM data between numerous software programs and ensures interoperability. However, it leads to new inconsistencies and problems with the data transfer, but it also offers the basis to automate building code checking as well as escape route simulation, and may improve the distribution of information.

As leading, non-government organization, buildingSMART e. V. encourages the development of open standards and data transfer by developing various tools and establishing standards like the IFC and Model View Definition (MVD) format. Whereas IFC is used to exchange and share BIM data between different applications without the software having to support numerous native formats; MVD translates processes into technical requirements to specify a subset of the IFC schema. In this way, MVD allows the determination and verification of exchange requirements according to local building codes. The interaction between these tools is studied in this thesis to make escape route simulations and checks come true.

Different programs have already enabled the automation of various tasks. Since the construction models and their information can also be shared via open standards, other tasks still need to be developed. One of these tasks is to ensure that a building has at least two safe escape routes and complies with building codes in general. This tasks are referred to as escape route simulation and will be tried to develop in this thesis. For this purpose, the requirements of the Bayerische Bauordnung - Bavarian Building Regulation (BayBO), the applicable law in Bavaria, is analyzed.

Summarizing, the thesis will explain how the combination of BIM, IFC and MVD help to define information needed for fire prevention checks in Germany. It develops an mvdXML file to check basic compliance with the BayBO.

Chapter 2

Background and Tools

2.1 Building Information Modeling

2.1.1 Definition

Building Information Modeling (BIM) describes a comprehensive digital model of a building with much more information than only the geometric data. Apart from the 3D and 2D data for visualization, BIM contains also the building component relationships. In addition, these components have further information about their material, purpose, physical quantities and even costs and manufacturer specifications. Therefore, BIM is used to describe the life-cycle process of a comprehensive building.

The National Building Information Model Standard Project Committee defines BIM as:

> "Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition." (NIBS, 2018)

The most important characteristic of BIM is the derivation of consistent 2D construction plans like floor plans and sectional drawing from the three-dimensional model. In contrast to the pure 3D modelling programs, BIM offers a construction related design tool with building components, for instance walls, pillars, windows and doors. Apart from the geometric information, the objects include more detailed attributes and important relationships to other objects. These attributes and relationships are extremely important because it gives the user the possibility to comply with all relevant regulations already during the planning. Moreover, the 3D object-oriented planning ensures the direct use of different analysis- and simulation tools. (Borrmann *et al.*, 2015)

2.1.2 Benefits and Challenges

The idea of the BIM has been arisen by German and international construction informatic research since the 1990s. The current status of practical use differs widely internationally. In the USA the introduction of BIM in the AEC industry has been consistently pursued since the mid-2000s. The Scandinavian countries are leading in Europe: In Finland, several BIM pilot-projects in the construction industry have been successfully implemented since 2001. In Norway the use of BIM has even been compulsory since 2010. (Borrmann *et al.*, 2015)

Germany is lagging behind but addresses the advance of BIM in the "Digital Planning and Construction" plan, targeting the compulsory usage until 2020. (Federal Ministry of Transport and Digital Infrastructure, 2015)

Nevertheless, a study by the Fraunhofer IAO institute found out, that BIM is only used by 29% of the German AEC industry players and only 10 % are planning it for the future. One in five respondents do not know the BIM method at all. (Braun *et al.*, 2015)

Therefore, one of the greatest challenges in Germany is the digitization of the AEC industry and consequently the implementation of BIM. Particularly important in order to take this step are junior staff with comprehensive BIM knowledge to bring it into the everyday life of planning and engineering offices. This has already been recognized by some universities, so that BIM is being taught more and more. In Addition it needs the establishment of qualified training and further education offers from public institutions, such as building administrations and other institutions. (Brokbals & Čadež, 2017)

BIM does not only mean the use of three-dimensional intelligent models, but also significant changes in workflow and project management. To achieve sustainable change in the German construction industry, it must be ensured that all players are familiar with the advantages of BIM. In his article "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry" Azhar (2011) deals intensively with the advantages and areas of application of BIM which are mentioned here in extracts:

- "Visualization: 3D renderings can be easily generated with little additional effort.
- Code reviews: Fire departments and other officials may use these models for their review of building projects.
- Cost estimating: BIM software has built-in cost estimating features. Material quantities are automatically extracted and updated when any changes are made in the model.
- Construction sequencing: A building information model can be effectively used to coordinate material ordering, fabrication, and delivery schedules for all building components.

- Conflict, interference, and collision detection: Because building information models are created to scale in 3D space, all major systems can be instantly and automatically checked for interference's. For example, this process can verify that piping does not intersect with steel beams, ducts, or walls.
- Forensic analysis: A building information model can be easily adapted to graphically illustrate potential failures, leaks, evacuation plans, and so forth.
- Facilities management: Facilities management departments can use it for renovations, space planning, and maintenance operations."

According to Azhar (2011), the collaboration within project teams should improve, which leads to enhanced profitability, reduced costs, better time management and improved customer relationships with increasing use of BIM .

A recent study by the Association of Bavarian Industry together with various professors of the Technical University of Munich dealt with the obstacles and the need for action in connection with BIM on the Bavarian and German markets. Here too, the lack of knowledge and training options are mentioned in particular. In addition, users also criticize the high investment costs for these training courses and BIM-software. The study also presents the legal difficulties associated with the exchange of data between stakeholders.(Borrmann *et al.*, 2018)

In summary, the digitization of the construction industry offers enormous opportunities, which have so far been used only hesitantly. The available software products are already largely technically matured and are constantly being improved and expanded.

2.2 Exchange Standards

Communication between numerous participants is essential for project collaboration in AEC industries with BIM. Recently BIM is becoming increasingly common all over the world, with the result that more and more applications are being developed by different software vendors. Owing to this, it is necessary to ensure a data standard to take the advantage of all opportunities offered by BIM. Therefore a digital language which will allow advanced information technology to openly and freely exchange structured information throughout a building's lifecycle is indispensable for the future of BIM. According to buildingSMART e.V. (2018c), Figure 2.1 illustrates five leading basic methodology standards.

As the leading international, non-governmental, non-profit organization, buildingSMART is dedicated to an open forum for discussion and the standardized definition of exchange formats. It is a community of industry participants and operators from all over the world.

buildingSMART promotes the active dissemination, the usage and further development of software-independent exchange formats in BIM projects. In addition, buildingSMART provides tools and examples for users.

Name	Standard	Task
Industry Foundation Class **(IFC)**	ISO 16739:2013	transports data / information
Model View Definitions **(MVD)**	buildingSMART MVD	translates processes into technical requirements
Information Delivery Manual **(IDM)**	ISO 29481-1 and ISO 29481-2	describes processes
BIM Collaboration Format **(BFC)**	buildingSMART BFC	changes coordination
International Framework for Dictionaries **(IFD)**	ISO 12006-3 and buildingSMART data dictionary	maps terms

Figure 2.1: Basic Bethodology Standards (buildingSMART e.V., 2018c)

This thesis focuses on the IFC, MVD and IFD standards, which will be explained more detailed in the following subsections.

2.2.1 Industry Foundation Classes

The Industry Foundation Class (IFC) is an independent, open and standardized data model managed by buildingSMART. It is the main buildingSMART data model standard and also the established International Organization for Standardization (ISO)-Standard - ISO 16739:2013 since the release of IFC 4 in March 2013. IFC is used in the AEC industry to exchange and share BIM data between different applications without the software having to support numerous native formats to ensure interoperability and intelligent use. (Laakso *et al.*, 2012);(buildingSMART e.V., 2018a)

The particular character of IFC is the open format and the declarative, object-oriented EXPRESS language, which is originally the data modeling language of Standard for the Exchange of Product model data (STEP) (Schenck & Wilson, 1994). However, STEP is standardized as ISO 10303-11. Whereas antecedent developments were elaborated primarily for the exchange of pure geometric data between Computer-Aided Design (CAD) systems, IFC is intended to handle a much wider range of product-related data and enabled the use and rise of BIM. Furthermore, due to the openly accessible data format and the neutrality IFC ensures a software's broad application range and flexibility in all countries of the world. (Borrmann *et al.*, 2015)

For sake of clarity, maintenance and slighter extension, the complex IFC model is divided into four layers: Domain, Interoperability, Core, and Resource layer. Each layer contains categories which define sets of entities. The main principle is, that entities on layers can only be related to or reference an entity at the same or lower layer, but not one at a higher layer. The Domain Layer is the highest layer and contains eight different domains representing different disciplines like *BuildingControl* or *StructuralElements*.

Below, the Interoperability Layer is located. Here, classes derived from the Core Layer are defined and used for numerous applications. Construction element classes like *IfcWall* or *IfcWindow* are defined in five different so-called *SharedElements*.

The Core Layer contains the basic structures, basic relationships and general concepts. In this layer lies the kernel, which represents abstract basic classes like *IfcRoot*, *IfcProduct*, *IfcProject* and *IfcObject*. Besides the kernel, the Core Layer also contains the *ControlExtension*, the *ProductExtension* and the *ProcessExtension*. Most important for this thesis is the *ProductExtension*, which contains subclasses of the *IfcProduct* like *IfcBuilding*, *IfcBuildingStorey* or *IfcSpace*.

The lowest layer is the Resource Layer, which provides basic data structures that can be found throughout the IFC data model. The classes in the Resource Layer such as *MaterialSource*, *PropertyResource* or *MeasureResource* are not derived from *IfcRoot* in the Core Layer. This means that they cannot exist as separate objects in an IFC model, but need to be referenced by other objects. (Borrmann *et al.*, 2015)

The architecture thus provides a type of indexing system into the IFC model, which is also defined in EXPRESS. The IFC model is quite large, still growing and customizable. (Eastman *et al.*, 2008)

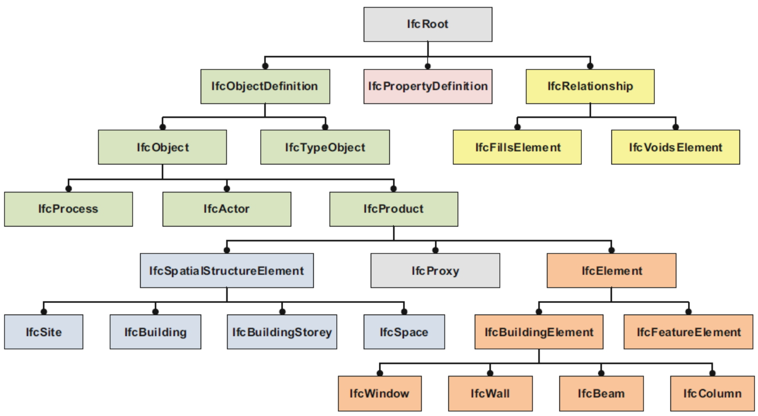


Figure 2.2: Inheritance Hierarchy in the upper IFC Model Level (Borrmann *et al.*, 2015)

Given the IFC hierarchical object sub-typing structure, the objects used in exchanges are nested deeply. Figure 2.2 summarize the most important entities of the uppermost level of the inheritance hierarchy. There are three fundamental entity types in the IFC model:

IfcObjectDefinition, *IfcPropertyDefinition* and *IfRelationship*. Each entity defined outside of the Resource Layer of the architecture schema inherits directly or indirectly from the *IfcRoot* entity. For example, a window entity has a trace down the tree:

$$\text{IfcRoot}\rightarrow\text{IfcObjectDefinition}\rightarrow\text{IfcProduct}\rightarrow\text{IfcElement}\rightarrow\text{IfcBuildingElement}\rightarrow\text{IfcWindow}$$

Relationships are a main part and poses an unique position of the IFC Model. In contrast to the previous data exchange models, the IFC Model bring the interaction between different objects to the fore. (Borrmann *et al.*, 2015)

Fundamental characteristics of the objects like the window in the example are stored directly in the schema of the IFC model using attributes in an entity definition. For a standardized window common attributes might be *OverallWidht* and *OverallHeight*.

Other important and desirable attributes such as fire safety, security or thermal insulation can be extended. As these extensions always causing a modification of the schema and further would make the implementation tedious, two varying features were defined: The static defined attributes, enshrined in the schema and the dynamic creatable properties. The IFC model addresses the limited scope of a general product model using this properties, organized in property set definitions. The specification of property set definitions can be made outside of the main IFC model by specialists within their domain.

This property sets, called *psets* are important for the approach of this thesis and will be used for the analysis of the exchange requirements for the BIM-based escape route simulation in chapter 4.

2.2.2 Model View Definition

Model View Definition (MVD) translates processes into technical requirements. For the successful exchange of BIM data between different stakeholders working on the same construction project, it is necessary to know what data should be delivered of whom, when and how.

Therefore, buildingSMART developed the Information Delivery Manual (IDM) and MVD methodology. While IDM, standardized in ISO 29481, defines only the discipline-specific exchange information, the MVD specifies a subset of the IFC schema, which is needed to satisfy the exchange requirements. MVD forms the basis for a software development process for the buildup of IFC import and export functions. Together with instructions and validation rules, this results in an MVD concept. This concept can be created with the method mvdXML. (Weise *et al.*, 2016)

Ideally, the rules, set out in such an mvdXML file, are then prepared for automatic model checking. A differentiation is made between static and dynamic files. While dynamic mvdXML files can be used more than once across projects, static files have specific rules and application areas. Dynamic files are of great importance when it comes to automating processes such as fire protection checking. Which rules are needed always depends on the wishes and programs of the users. Therefore, MVD is also a tool for more interoperability. (buildingSMART International Ltd., 2018b)

Since the release of mvdXML 1.1 in 2016, the tool can also be used for model checking, IFC subset schema generation, and data filtration. In contrast to the existing validation formats like XML Schema Definition (XSD), EXPRESS (ISO 10303-11), Schematron, and validation frameworks within programming languages and tools, the goal of mvdXML is to automate the approaches in a way that information requirements may be defined at a higher level. In this level, downstream validation formats are available for automatic generation. To give an example, IDM may require that a window provide a fire rating and pre-determined dimensions to be used as fire exit. MVD specifies for this case the related technical IFC parameter, such as *OverallWidht*, *OverallHeight* and *FireProtectionClass*. (buildingSMART International Ltd., 2018a). However, these functions have recently attracted more attention, the focus is still on pure MVD documentation. Each of these applications have specific requirements, but the definition of an MVD is generally similar.

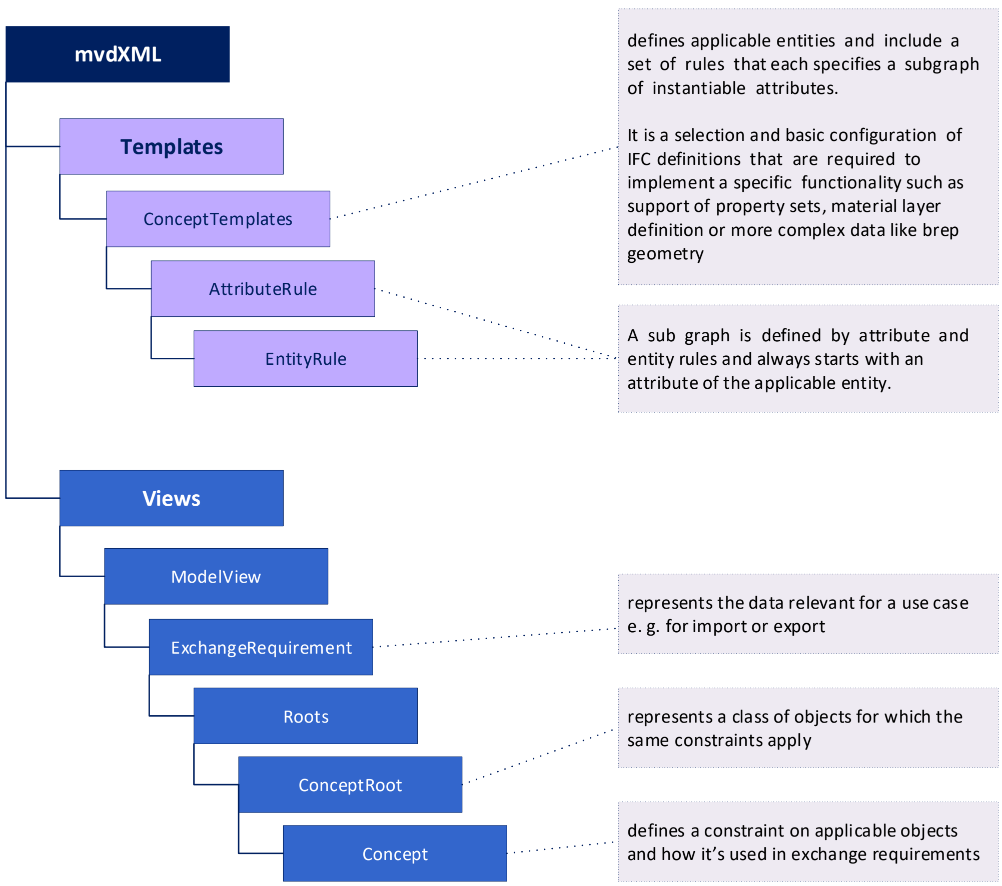


Figure 2.3: Schema of an mvdXML file (adapted from Weise *et al.* (2016))

The main elements of an MVD can be roughly divided into 2 parts: The *Templates* and the *Views*. The *Templates* contain the *ConceptTemplates* which uses *AttributeRule* and *EntityRule*, whereas the *Views* contain one or more *ModelView*s which are the main container for *ExchangeRequirement*s, *ConceptRoot*s and *Root*s. Figure 2.3 explains the structure and the individual definitions of an mvdXML file.

It is possible using various types of text- or eXtensible Markup Language (XML) editors to create mvdXML files. For simplifying the process of editing and documenting this files, buildingSMART International provides an application called ifcDoc. To run the ifcDoc application, a base file must first be imported. This basic file contains the complete IFC schema specification and a pre-selected set of a dynamic MVD concept definition, so that the operator does not have to program it elaborately himself. It allows to expand the generic MVD concepts easily and simplifies the whole process of development. (buildingSMART International Ltd., 2018a)

Using an example, which loads the information for the width and height of a window into a *ConceptTemplate*, Figure 2.4 exemplifies the representation in ifcDoc and Listing 2.1 represents the corresponding mvdXML code. The advantage of ifcDoc is the graphical representation as well as the creation of the codes by mouse click. Above all, this support the less programming oriented creator.

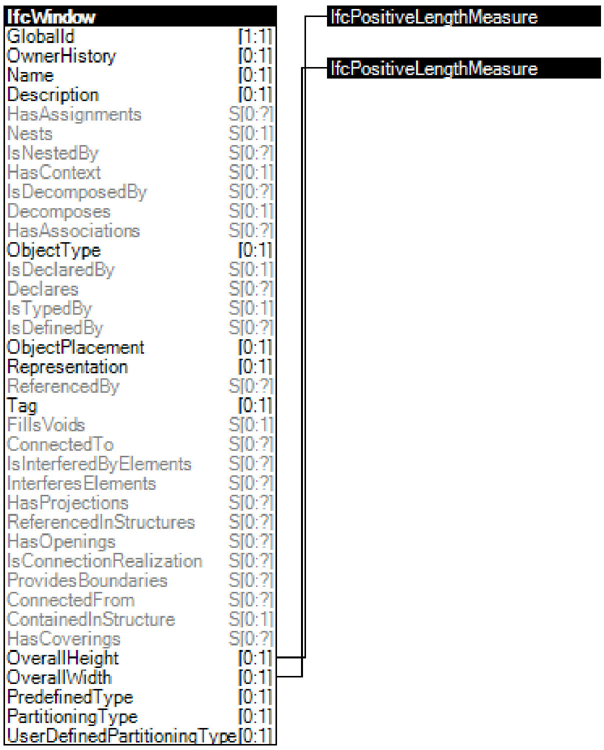


Figure 2.4: Visual Representation of the Exemplary *ConceptTemplate* in ifcDoc

```
<Templates>
<ConceptTemplate uuid="00000000-0000-0000-0000-000000000000" name="Example" code="6bcd8a47-fd48-4377-b90a-f3726aea2b94" status="sample" applicableSchema="IFC4">
 <SubTemplates>
 <ConceptTemplate uuid="d45a8319-85b8-42de-b1d3-bab27b43d4fc" status="sample" applicableSchema="IFC4" applicableEntity="IfcWindow">
  <Rules>
  <AttributeRule AttributeName="OverallHeight">
   <EntityRules>
   <EntityRule EntityName="IfcPositiveLengthMeasure" />
   </EntityRules>
  </AttributeRule>
  <AttributeRule AttributeName="OverallWidth">
   <EntityRules>
   <EntityRule EntityName="IfcPositiveLengthMeasure" />
   </EntityRules>
  </AttributeRule>
  </Rules>
 </ConceptTemplate>
 </SubTemplates>
</ConceptTemplate>
</Templates>
```

Listing 2.1: mvdXML code of the exemplary *ConceptTemplate*

To visualize how the BIM-based exchange requirements can be used for automated model checking, web-based solutions such as BIM-Q and the mvdXML extension of the Xbim toolkit have been developed. These allows the user not only to display the pure 3D model but also the graphical and list-based demonstration of the results of a MVD run.

With this standardized methodology, buildingSMART offers a strong technical implementation for the definition of exchange requirements and validation rules for the AEC industry, which is still in its early stages.

2.2.3 BuildingSMART Data Dictionary

The buildingSMART Data Dictionary (bSDD), formerly International Framework for Dictionaries (IFD), is a library of objects and attributes used as collection of IFC data and enables the user to browse bSDD data like a web-search engine. It contains approx. 775 000 names and 735 000 relations in 36 languages. Users all over the world can easily share definitions. A great benefit of bSDD is an unique ID for every subject or attribute which leads to an xml file containing all information like links to other terms provided in the dictionary. It is developed by buildingSMART to make the building process more efficient because with this tool "handrail" means the same in Norway as in Germany or France (buildingSMART e.V., 2018b). Figure 2.5 shows the interface of bSDD with the example search "handrail".

Especially new and useful is the implementation of Omniclass and IFC4 Propertysets. The bSDD interface provides a user-login module which were made authoring of bSDD data. However, this option was deactivated due to abuse during the completion of this thesis.

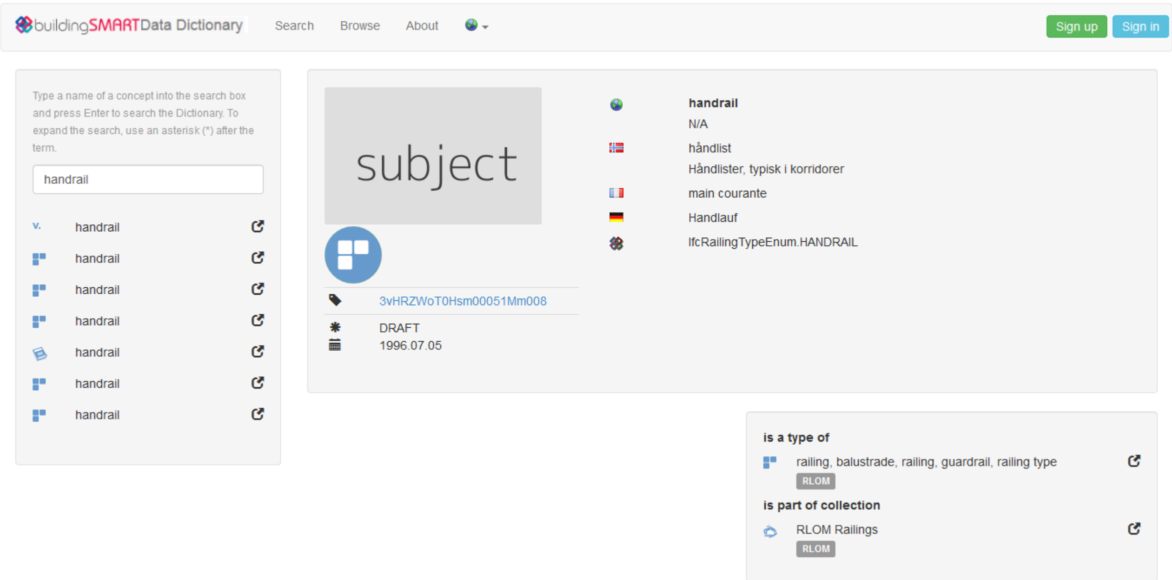


Figure 2.5: Interface of bSDD for the Example "handrail"

2.3 Level of Development

2.3.1 Definition

The Level of Development (LOD) defines the information content of the digital building models in different stages of the design and construction process, regarding the geometric and semantic information. In some cases it depends on the respective discipline as well as the performance phase. A consistent use does not yet exist, but would be highly desirable, as LOD is becoming increasingly important to avoid false conclusions and technical evaluations. (Abualdenien & Borrmann, 2018)

The international directives have different definitions. The fuzziness starts with the name; "LOD", which may be interpreted as the level of development, the level of definition or the level of detail. Further technical terms such as "LOG" (Level of Geometry) and "LOI" (Level of Information) are used in the literature. So far, there is rarely method to explicitly define an LOD's requirements nor any specification of its uncertainty. (Abualdenien & Borrmann, 2018)

Several guidelines trying to define LOD have been evolved. The most popular one by the American Institute of Architects (AIA), which divides the LOD Shema into five stages, was improved by the BIMForum named LOD Specification. The BIMForum is an organized collection of interpretations of the AIA's LOD definitions. It describes input and information requirements, providing graphical examples of the different levels of development to reduce the scope for interpretation. (BIMForum, 2018)

In contrast to the LOD Shema, the LOD Specification is divided into six stages. It introduces a new level, LOD 350, but neglects LOD 500, because LOD 500 refers to field verification and not to the transition to a higher level. However, it is not omitted but also not further defined by the BIMForum. Table 2.1 shows the definitions of BIMForum's LOD Specification published annually.

Table 2.1: The Level of Development Specification (BIMForum, 2018)

LOD	**BIMForum's Interpretation**
100	Provides a generic concept which does not contain geometric representations.
200	Consists of generic elements as placeholders, which are geometrically and semantically recognizable.
300	Includes model elements with precise geometry, quantity, shape and location. Non graphic information may be attached to the element.
350	Introduces a way to coordinate a wall element with other systems in the structure like supports and connections.
400	Incorporates detailed additional information like on fabrication and assembly.
500	Provides model elements as built, regarding size, shape, location, quantity and orientation.

2.3.2 Benefits and Challenges

Although the definitions of the individual LODs are fuzzy, there is no method to define requirements for each LOD so far. The BIMForum (2018) even points out that the definition of the requirements of the respective LOD is up to the corresponding project team. Nevertheless, the availability of precise definitions can significantly reduce the risk of misunderstandings and miscommunications, as expectations and goals may be defined more precisely.

Due to this uncertainty, Abualdenien & Borrmann (2018) introduced a multi-LOD data model which represents the composition of the level of geometry and semantic information out of the Level of Information. This multi-LOD data model enables to check ”the consistency of geometry as well as the topologic and semantic coherence across the different LODs.”

In order to become stronger in the BIM area, further research and an exact definition are essential. Then LOD will be able to significantly improve the work and especially the communication in the digital construction industry.

2.4 Escape Route Simulations

2.4.1 Introduction

Automated and semi-automated code checking, the analysis, and compliance of standards have been an active field of research since the 1960s (Han *et al.*, 1997). Various requirements of different building codes place complex demands. Especially for internationally operating owners it is hard to find and apply the valid building codes for their projects. In practice, escape routes are manually checked and evaluated as part of fire prevention by a fire prevention engineer. To verify this, an inspector has to go through the same process and may interpret the requirements differently from the operator. In addition, one inspector may interpret a given section of the code different than another inspector. This traditional building plan checking and verification process is inefficient and time-consuming. Automated checking offer various benefits: Flaws can be allocated within seconds instead of hours and inconsistencies can be avoided. This could speed up the building process and reduce costs. Automating this process therefore has the potential to create a consistent framework for applying codes to stakeholders and avoid delays.

2.4.2 Types of Escape Route Simulation

The analysis of escape route simulation is addressed in the literature as evacuation models and building code checking. Escape routes are part of the fire protection measures for buildings. In this thesis, checking compliance with fire prevention requirements is referred to as escape route simulation. Therefore, evacuation models are introduced shortly to give another point of view, but the focus is on checking building fire codes.

Evacuation Models

Professionals can choose from a wide variety of evacuation models. Evacuation models try to describe human behaviour in the event of a evacuation, for example because of a fire or other disasters. Different models consider a different focus: generally, models are able to simulate human behaviour for example stress and evacuation time, or human movement, like evacuation ways and shortages.

In contrast to the compliance check, evacuation models visualize the movement of pedestrians in a plan as an animation. The animation can help architects and engineers to detect flaws in the design of their building. Mainly, the models assist engineers to improve the fire safety of a building, to plan emergency situation, to manage crowd movements and to avoid fire exit flaws. Therefore, evacuation models are used more commonly in the development of emergency and evacuation plans than in the early planning stage of construction projects. (Kannala, 2005)

For engineers it is difficult to choose the optimal model for their projects because the evacuation models vary widely. Each model contains different features, making the decision confusing. In addition, it is not always possible to import CAD or BIM models; often models have to be modified manually before import. (Kuligowski & Milke, 2004)

Building Fire Code Checking

Building regulations ensure the quality and safety of building projects and differ from country to country. They represent minimum requirements that a building must comply with in a number of areas. Model Checking denotes the automated, rule-based verification of the model for building code requirements. Typically, the building codes include fire prevention, structural safety, accessibility, technical requirements and other aspects. For this work, fire safety is the most important part of the building codes, which is why this area is referred to as fire code in the following.

Automation in checking processes with building code compliance becomes increasingly important. The more complex and objective the work, the more effective its impact can be. For example, Finland and Singapore developed BIM-based automated regulation checking processes.

The Solibri Model Checker (SMC) by the Finnish company Solibri Co. is the most popular international software for code checking. The SMC is a validation and optimization tool for digital building models in IFC data format. It provides a library of rules and guidelines from which the user can select and build an individual review process according to his own requirements. In addition to the quality of the imported IFC model, the SMC mainly checks geometrically-oriented rules. These include space management, accessibility and collision checks. The rule sets are implemented within the SMC and can only be modified or individualized in cooperation with Solibri Co. (Eastman *et al.*, 2009)

In 1995, the Construction and Real Estate Network (CORENET) project in Singapore has been launched. Since then, the aim of optimizing cooperation between all project participants has been well implemented. In 2002, the separate module "CORENET e-Plan Check" was introduced to check code compliance. CORENET is now mandatory for all building permits to be issued in Singapore. This makes the program one of the most comprehensive approaches in the area of automated code compliance checking, as it covers a large part of Singaporean guidelines and is used in over 2500 companies in the AEC industry. The provided checking features are based on the nationally valid regulations in the areas of building control systems, accessibility and fire protection, but the predefined checking functions cannot be changed by the user. (Lin & Fatt, 2006)

2.4.3 Limitations

The first challenge of compliance checking programs is the translation of rules into a language that can be interpreted by the computer. The idea of digitizing the language has existed since the beginnings of computer science and is still one of the most important challenges in a wide range of applications. The aim is to translate content as precisely as possible into binary codes. (Schiffer, 1997)

When it comes to requirements from building codes, the translation poses a major challenge as building codes could not be more different and abstract. Often, compliance with building regulations can only be checked by semi-automation, meaning data exchange from BIM models and human input. Human knowledge still has to be converted into digital resources and many exceptions given in building codes enormously hampering the automation process.

The introduced methods SMC and CORENET are so-called black box systems. This implies that both cannot be changed or customized without the cooperation of the suppliers (no open-source software) (Borrmann *et al.*, 2015). This contradicts the idea of IFC's open standard. Therefore a possibility of the compliance check with an MVD is developed in this thesis. MVD is a so called white-box system, which can be configured individually by each user. Obviously, such a system is not suitable for a building permit verification because manipulations would be far too easy. However, it is suitable to initiate the development of such a process and to make it available for further elaboration. After all, due to the increased use of BIM, it is necessary to develop an automated checking process for BIM data in Germany.

Chapter 3

Escape Route Requirements in German law

3.1 Introduction

Escape route requirements are a primary part of building codes which are used everywhere to control quality of building and engineering provision, to avert dangers to life and limb, and to avoid damage to third-party property. The codes differ from country to country, but the aim remains the same; the building information needed for code compliance is consistent.

This thesis focuses on the applicable law in Bavaria, Germany. The German history of fire protection originates in the late Middle Ages as an orally passed down award with neighborhood protecting demands in the "Sachsenspiegel". With this regulation, fire protection entered the German history of town ordinances and privileges, and finally became an integral part of the urban regulatory and security policy as a statutory law. In the 20th century, fire protection was "mandated". It has become part of a governmental regulatory policy that pays, next to fire fighting, particularly great attention to architectural fire protection. (Heilmann & Weller, 2015)

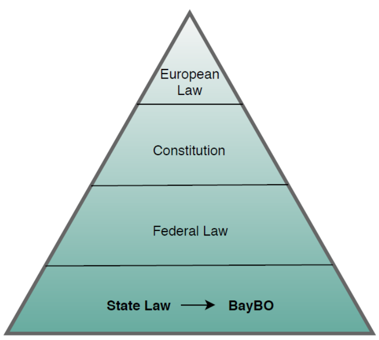


Figure 3.1: Hierachy of German Law

3.2 Bayerische Bauordnung - Bavarian Building Regulations

The current German Federal Fire Guideline, the Musterbauordnung - Model Building Regulation (MBO), is an orientation framework for the Building Regulations Ordinance of the different states and is not used as law. It contains the minimum requirements the states have to implement. In Bavaria, the applicable law is the BayBO. As shown in Figure 3.1, the BayBO is state law, meaning that it is the responsibility of each individual federal state to enforce the building requirements in Germany.

The BayBO governs the requirements that must be complied with during construction projects. It is divided into eight sections; the five most important sections are shown in the circle-like shapes in Figure 3.2. The oval shapes present examples from the respective sections. Section six to eight contain misdemeanor, implementation provisions and concluding provisions.

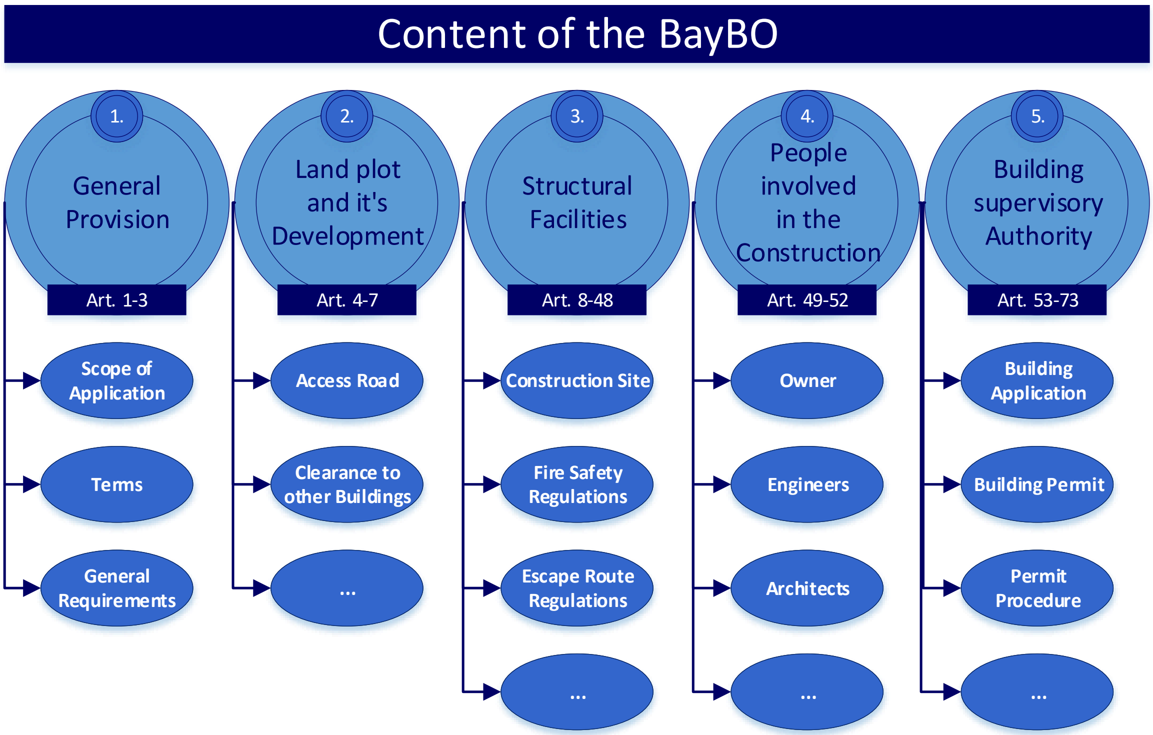


Figure 3.2: Content of the BayBO

As Article 25-35 BayBO describe the specific requirements for fire safety and escape routes, this thesis focuses on the third section: Structural Facilities. To analyze the exchange requirements for BIM-based escape route simulations, additional technical guidelines like the Technische Regeln für Arbeitsstätten - Technical Guideline for Workplaces (ASR) A.2.3. are necessary for some special usecases because the BayBO is not always precisely defined.

3.2.1 Explanation of the Most Used Terms

To get an overview about the terms used in this thesis and their specific meanings, Table 3.1 shows the explanation of the most important ones.

Table 3.1: Explanation of Terms used in the Thesis

Term	**Explanation**
Escape Route	Escape routes are traffic routes which are subject to special requirements and serve to guide individuals away from a possible hazard area. Escape routes lead outdoors or into a secure area. In contrast to the Bavarian Building Regulation, the requirements for escape and rescue routes according to the ASR A2.3 are the same.
Fire Compartment	A fire compartment is a structurally demarcated area which intended to burn out and prevent the fire from spreading to other areas. Fire Compartments are designed using fire-resistant components.
Fire Wall	Firewalls prevent the spread of fire to other buildings or fire compartments for a sufficient period of time. They must be built as room-closing components and have special requirements. (BayBO, 2007)
Building Class*	Buildings are divided into Building Classes in accordance with the building regulations of the individual federal states. The classification of a building into a Building Class depends on the height and area of the building. Further information's are given in Chapter 3.2.3, Classification in Building Classes on page 24.
Special Constructions*	Special constructions are facilities and rooms of a special kind or use which fulfill one of the requirements of Art. 2 Abs. 4 Bayerische Bauordnung - Bavarian Building Regulation (BayBO). (BayBO, 2007) Figure 3.3 in Chapter 3.2.2, Scope and Protection Target shows it more detailed.
Storey	Floors are above-ground storeys when their upper edges project on average more than 1.40 m above the ground surface; otherwise they are basement storeys. Cavities between the top ceiling and the roof, in which abode rooms are not possible, are not storeys. (BayBO, 2007)

Term	**Definition**
Abode Rooms*	Abode rooms are rooms that are intended or suitable for not only temporary use by people. Abode rooms must have a clear room height of at least 2.40 m. In the attic, over half of their useful area must be 2.20 m high; room parts with a clear height of less than 1.50 m are not considered. This does not apply to abode rooms in residential buildings of Building Classes 1 and 2. In addition, they must be sufficiently ventilated and exposed to daylight and must have windows with a window opening shell dimension of at least 1/8 of the net area of the room.(BayBO, 2007)
Utilization Unit*	The utilization unit is the combination of individual rooms with comparable or related-use rooms. In an apartment building, for example, each apartment is a utilization unit; in a school there can be several utilization units, e.g. all classrooms. Exceptions regarding multi-storey usage units exist in residential buildings, in agriculture and in other small buildings. Utilization units are decisively for the determination of the escape routes.
Fire Exit	A fire exit is an exit along an escape route that leads directly into the open or into a secure area. These can be doors, hatches, windows or other escape openings in the building. The number and location of the emergency exits depend on the hazards due to the building's use and on the number of people present. In the event of danger, it must always be ensured that all persons can leave the rooms quickly and safely. Fire exit doors must open in the direction of escape.

Term	**Definition**
Smoke-proof Openings*	Smoke-proof openings are doors or windows intended to prevent the spread of smoke in the building by a seal on all four sides. Their requirements are defined in DIN 18095-1 "Doors; Smoke Protection Doors; Terms and requirements". According to this standard, they are self-closing doors which, when closed, prevent the passage of smoke. This is done in such a way that the room behind them can be used to rescue people without respiratory protection for about 10 minutes in the event of fire.
Tight-closing Openings*	In contrast to smoke-proof openings, the requirements for tight-closing openings are not standardized. Tight-closing openings referred windows or doors with a door leaf that is butt-folded or rebated and which have a seal on at least three sides. In this case the floor gap is not sealed. Glazing in tight-closing doors is permitted.
Fire Resistant*	Fire resistance duration of 90 minutes, meaning that the component continues to perform its function for at least 90 minutes in the event of fire (= Fire resistance class F90 to DIN 4102) (DIN 4102–2, 1977)
Highly Fire Retardant*	Fire resistance duration of 60 minutes, meaning that the component continues to perform its function for at least 60 minutes in the event of fire (= Fire resistance class F60 to DIN 4102) (DIN 4102–2, 1977)
Fire Retardant*	Fire resistance duration of 30 minutes, meaning that the component continues to perform its function for at least 30 minutes in the event of fire (= Fire resistance class F30 to DIN 4102) (DIN 4102–2, 1977)
Flammability	EN 13501-1 assesses the fire behaviour of building materials on the basis of their flammability and other criteria, such as smoke development and burning dripping. The national standard DIN 4102-1 divided combustible building materials into building material classes as light, normal or flame retardant. (DIN 13501-1:2010-01, 2010)

Term	**Definition**
Fire Hazard	Fire hazard is generally described as the possible extent of personal injury or property damage caused by fire. The Bavarian Building Regulation demands special requirements for rooms with an explosion- or increased fire hazard. However, the classification is not always clear. Rooms with an increased fire hazard are e.g. storage rooms, work rooms, magazines and laboratories.
Fire Protection Certificate*	The fire Protection Certificate is a confirmation from a fire prevention engineer that the requirements of the Bavarian Building Regulations, including the relevant special regulations, are complied with. The certificate is mandatory for every construction project and contains important requirements regarding fire protection and escape routes.
Fire Protection Plan*	The fire protection plan consists of planning documents and an explanatory report with a text section and, if necessary, the definition of requirements in table form. It is created by a specialist or a fire protection engineer. It is not mandatory but useful for example for insurance matters.

The translations marked with an asterisk are the author's own, since no "common" terms exist in English-speaking countries.

3.2.2 Scope and Protection Target

The BayBO applies to all buildings and construction products. It also applies to plot of land as well as other facilities subject to requirements under this law. However, it does not apply to:

a public transport facilities and their ancillary facilities and works except buildings at airports,

b facilities and installations which are subject to mountain supervision,

c pipe systems and wiring of all kinds except in buildings,

d cranes and crane facilities,

e scaffoldings,

f fireplaces not meant for space heating or domestic water heating except gas household cooking appliances,

g exhibition stands and exhibition buildings.

The BayBO requires that facilities be arranged, constructed, modified, and maintained according to building culture and the generally accepted rules of architecture. This means that public safety and order, life and limb, and natural resources should not be endangered. Buildings must be regularly maintained, comply the general requirements for their intended purpose, and be usable without maladministration their whole life-cycle. (BayBO, 2007)

Furthermore, facilities must be arranged, constructed, modified, and maintained in a way that prevents the generation of fire and the spread of fire and smoke. In the event of a fire, it must be possible to extinguish effectively and rescue lives. (BayBO, 2007)

For the owner and operator of a building, a building permit is fundamentally important. By granting this permit, the building authority establishes that the building regulations have been complied with and that the protection target will be achieved. Without this building permit, which sets out further requirements in addition to fire protection issues, construction may not take place in Germany. The process-less measures mentioned in Art. 57 of the BayBO represent the only exception. They include, for example, modifications to non-load-bearing components. For all other construction projects, the compliance with fire protection regulations in a fire protection certificate is mandatory. The fire protection certificate must be submitted for buildings of Building Class 5, for special buildings, medium and large garages for verification. The owner can chose between the lower building supervisory authority or a verification expert for fire prevention.

In addition to the fire protection certificate, which is required for the building permit, there is also the fire protection concept to ensure the protection goals. It is always used if the construction project deviates from the legal fire prevention regulations and an individual fire protection concept should be developed. Apart from building law procedures, fire protection concepts are also used to analyze the building status or private law issues, for instance insurances.

3.2.3 Classification in Building Classes

Among other terms, the first section, Article 2 BayBO describes the classification in so-called Gebäudeklassen - Building Classes. It is one of the most important Articles of the BayBO; the classification is an essential part of the building process and it is used in every component of building law in Germany.

Figure 3.3 graphically depicts the Building Classes and their allocations. The classification affects the requirements with regard to fire protection (and escape routes), abode rooms usage, and the qualification of the concept creator and inspector.

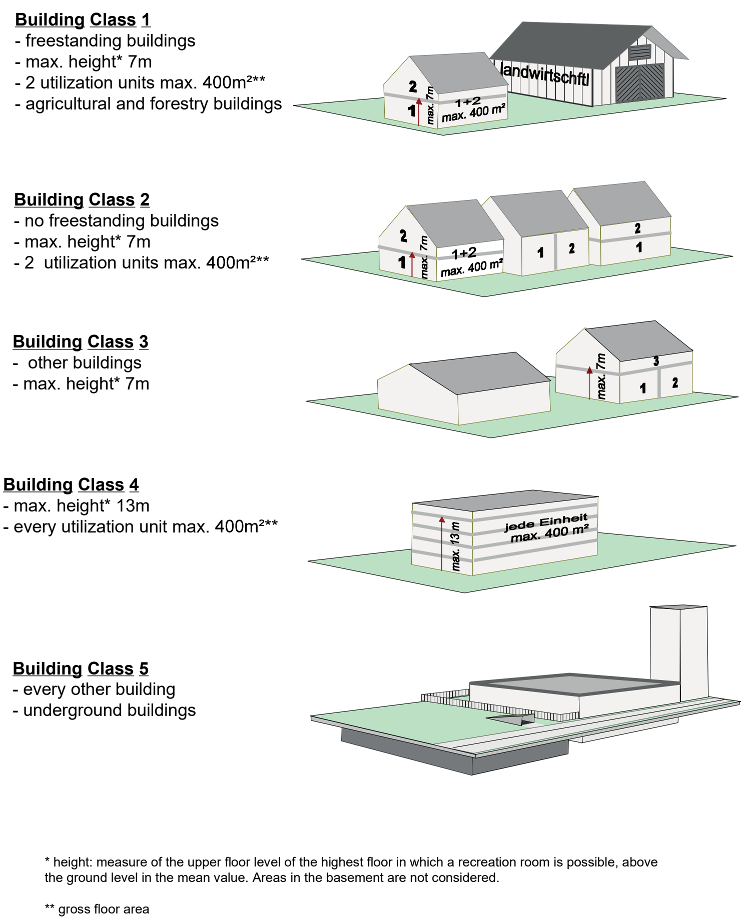


Figure 3.3: Building Classes in the BayBO

Additionally, German buildings can be grouped into "Regelbau" (standard buildings), "nicht-geregelter Sonderbau" (non-regulated special constructions), and "Sonderbau" (special constructions). Special constructions are facilities and rooms of a particular nature or use, like high-rise buildings, shops, hotels, and hospitals, that fulfill one of the conditions shown in Figure 3.4. Green boxes denote structures that are subject to the BayBO alone.

For special constructions, further laws, like the "Versammlungsstättenverordnung" (Regulations for Places of Assembly) or the "Beherbergungsstättenverordnung" (Regulations for Accommodation Establishments) are necessary. They ensure to comply the protection target even under special hazards, for example if people are not able to save their-selves (hospitals) or escape routes need to be used by many people (high-rise buildings). For non-regulated special constructions, certain requirements may be imposed or permission may be granted by the building authority if the general protection target will be achieved as a result. The Building authority in Germany often uses requirements from the different laws of the special constructions as guidelines for the non-regulated special constructions too.

For this thesis, the BayBO provide sufficient information because further laws mainly contain stricter requirements for different properties, but generally the content is related.

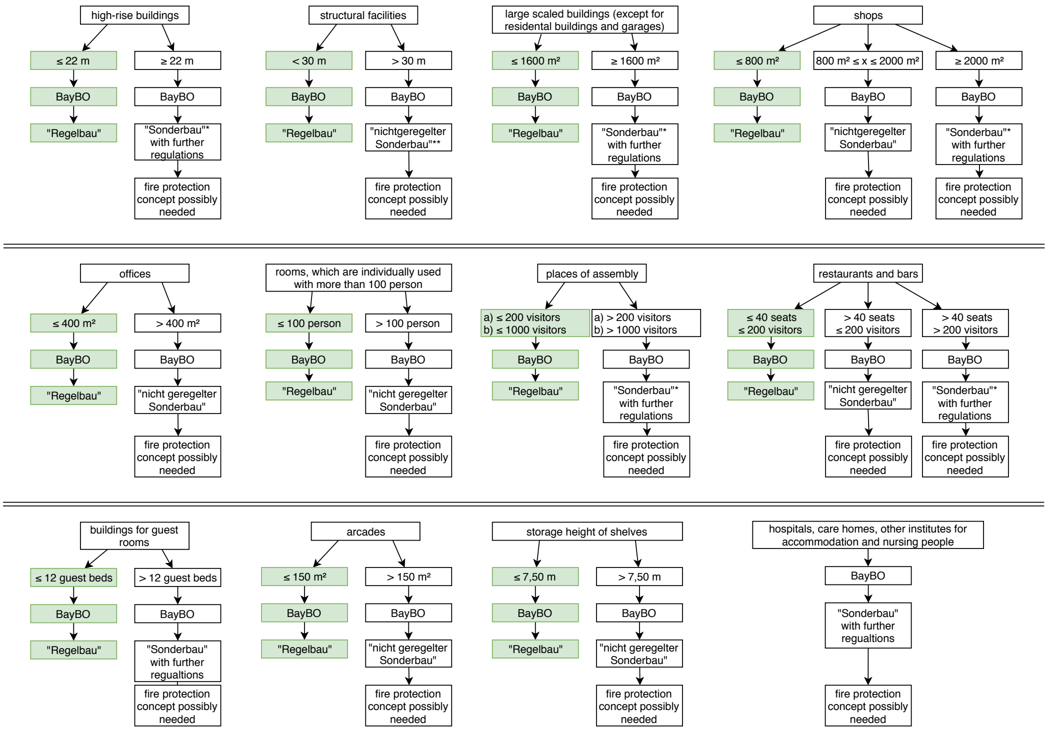


Figure 3.4: Special Constructions According to Article 2 BayBO

3.2.4 Types of Proceeding/Verification

The BayBO distinguishes different types of proceeding, covering the way of permission for a construction project. These are shown in Figure 3.5. The allocation to a type affects the scope of verification by the building supervisory authority. This means the fire prevention and escape route planning will be verified under certain circumstances.

These circumstances will not be part of this thesis, but might be interesting to clarify the scope of it. To reduce extensive, protracted, and inaccurate human work, automated checking systems could help in these procedures. Moreover, automated checking systems could increase future security development and improve fire prevention.

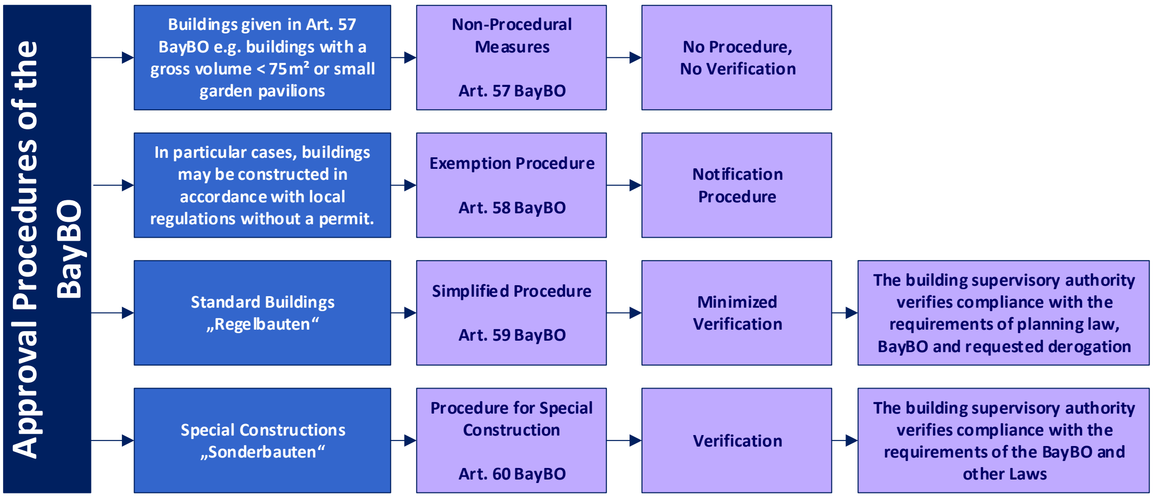


Figure 3.5: Procedures of the BayBO

Depending on the type of construction, proceeding and verification, fire safety engineers provide comprehensive knowledge to comply with the German law requirements and protection targets. They work as experts and create or verify fire protection certificates and concepts. These documents ensure the compliance of the building requirements given in German law, including the escape route requirements.

Chapter 4

Methods

4.1 BIM-based Exchange Requirements

For the scope of this thesis, the Bavarian Building Regulation is initially analyzed in detail. The analytic work is focused on the Articles 25 to 35 as explained in Chapter 3.2.

Specifying requirements for computer-based systems is a complex and sensitive process. It should be complete, consistent and, above all, understandable to the user; in practice, these goals are not achievable. For technical, human and environmental reasons, the quality of information will always be inadequate. However, even if the aims seem impossible to achieve, there are factors that can influence the quality. Developers of application requirements need to better organize and present information to assist with verification (Sommerville & Sawyer, 1997).

The Articles of the BayBO are delineated in their full scope, in a structured and clear way, using a tabular representation. This table is attached in the Appendix A.1. The columns correspond to the elementary Building Classes whereas the rows refer to the individual articles of the BayBO, translated from German into English. If the fields are left empty, there are no requirements for the respective components in the given Building Class. Numerous exceptions and special cases hampered the conversion considerably because they are frequently vaguely formulated and their realization is at the discretion of a fire prevention engineer.

By way of example, Article 27, which is about partition walls, is quoted below.

> "Partition walls must be built as space-enclosing components and must remain stable against fire spread for rooms or utilization units within a floor for a sufficient period of time." BayBO (2007)

Even if more detailed information is given in the following sentences of the article, this statement is not directly tangible or quantifiable for the computer. It takes several years of experience in the field of fire prevention to know how to achieve the protection target of the Bavarian Building Regulations.

A similar case is seen in Article 31, which is about the first and second escape routes. In general, the first escape route must be a necessary stairway or the direct access to the outside. The second escape route may be a second stairway or a window with the help of fire brigade's rescue devices. In the case of Special Constructions, however, the solution with the rescue devices of the fire brigade is only permitted if there are no concerns about the rescue of persons.

Experienced fire prevention engineers should be able to identify and analyze all the circumstances together to decide whether the rescue devices of the fire brigade may be used or not. In practice, they create a comprehensive impression of the building with all hazards and present them in a fire protection certificate. Information such as a sprinkler system or the storage of hazardous materials can also be included in the certificate. Although the BayBO does not require a sprinkler system, such a system can be used to compensate hazards. The experienced engineer might then tolerate non-compliance with another regulation, like a minimum exceeding of escape route lengths.

The components for which requirements are defined are the same within the Bavarian Building Regulations. Mainly the level of requirements changes depending on the Building Class.

4.2 IFC Property Set Mapping

Several IFC entities have properties that relate directly to fire engineering as needed for the approach of this thesis. To find the relevant container, the IFC schema has been searched using the compendium by Liebich *et al.* (2018) and the bSDD tool from buildingSMART.

The IFC model includes entities referring to the entire building, individual rooms, or objects. For example, integrated in the interoperability layer, there are the *ifcsharedbldgelements*, which provide property sets for objects such as beams, windows, and doors. These elements are the main components of the raw building structure, which is of essential importance for the exchange of project data. Besides a geometric usage definition, other properties are also provided. These are stored in the property sets. Most of them have similar attributes, so a tabular representation of the properties and their definitions in Table 4.1 is chosen. The check-mark in the corresponding row means that the property is present in the respective property set. The data types are also mentioned.

Property name and data type	Definition	Property set definition and associated IFC entity in ifcsharedbldgelements																
		Pset_WallCommon	Pset_CurtailWallCommon	Pset_PlateCommon	Pset_CoveringCeiling	Pset_RoofCommon	Pset_BeamCommon	Pset_ColumnCommon	Pset_SlabCommon	Pset_CoveringCommon	Pset_WindowCommon	Pset_DoorCommon	Pset_StairCommon	Pset_StairFlightCommon	Pset_RailingCommon	Pset_RampCommon	Pset_RampFlightCommon	Pset_TransportElementCommon
FireRating *(IfcLabel)*	Fire rating given according to the national fire safety classification.	x	x	x		x	x	x	x	x	x	x	x			x		
FlammabilityRating *(IfcLabel)*	Flammability Rating for this object. It is given according to the national building code that governs the rating of flammability for materials.									x								
FragilityRating *(IfcLabel)*	Indication on the fragility of the covering (e.g., under fire conditions). It is given according to the national building code that might provide a classification for fragility.									x								
Combustible *(IfcBoolean)*	Indication whether the object is made from combustible material (TRUE) or not (FALSE)	x	x						x	x								
SurfaceSpreadOfFlame *(IfcLabel)*	Indication on how the flames spread around the surface, It is given according to the national building code that governs the fire behaviour for materials.	x	x						x	x								
IsExternal *(IfcBoolean)*	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the outside of the building.	x	x	x		x	x	x	x	x	x	x	x		x	x		
ExtendToStructure *(IfcBoolean)*	Indicates whether the object extend to the structure above (TRUE) or not (FALSE)	x																
LoadBearing *(IfcBoolean)*	Indicates whether the object is intended to carry loads (TRUE) or not (FALSE)	x		x			x	x	x									
Compartmentation *(IfcBoolean)*	Indication whether the object is designed to serve as a fire compartmentation (TRUE) or not (FALSE)	x							x									
SmokeStop *(IfcBoolean)*	Indication whether the object is designed to provide a smoke stop (TRUE) or not (FALSE)										x	x						
FireExit *(IfcBoolean)*	Indication whether this object is designed to serve as an exit in the case of fire (TRUE) or not (FALSE). Here it defines an exit window in accordance to the national building code.										x	x	x			x		x
HasDrive *(IfcBoolean)*	Indication whether this object has an automatic drive to operate it (TRUE) or no drive (FALSE)										x	x						
SelfClosing *(IfcBoolean)*	Indication whether this object is designed to close automatically after use (TRUE) or not (FALSE)											x						
NumberOfRiser *(IfcCountMeasure)*	Total number of the risers included in the stair.												x					
NumberOfTreads *(IfcCountMeasure)*	Total number of treads included in the stair.												x					
HandicapAccessible *(IfcBoolean)*	Indication that this object is designed to be accessible by the handicapped. Set to (TRUE) if this stair is rated as handicap accessible according the local building codes, otherwise (FALSE). Accessibility maybe provided by additional means.												x					

Figure 4.1: Property Set Definition and Associated IFC 4 Entity in *ifcsharedbldgelements* (adapted from Spearpoint (2006))

In contrast to the *ifcsharedbldgelements* which concentrate on the common building elements, the *ifcproductextention* provides product information for individual product occurrences. This includes basic concepts like the spatial project structure, which defines the property, the building, the storeys, and rooms.

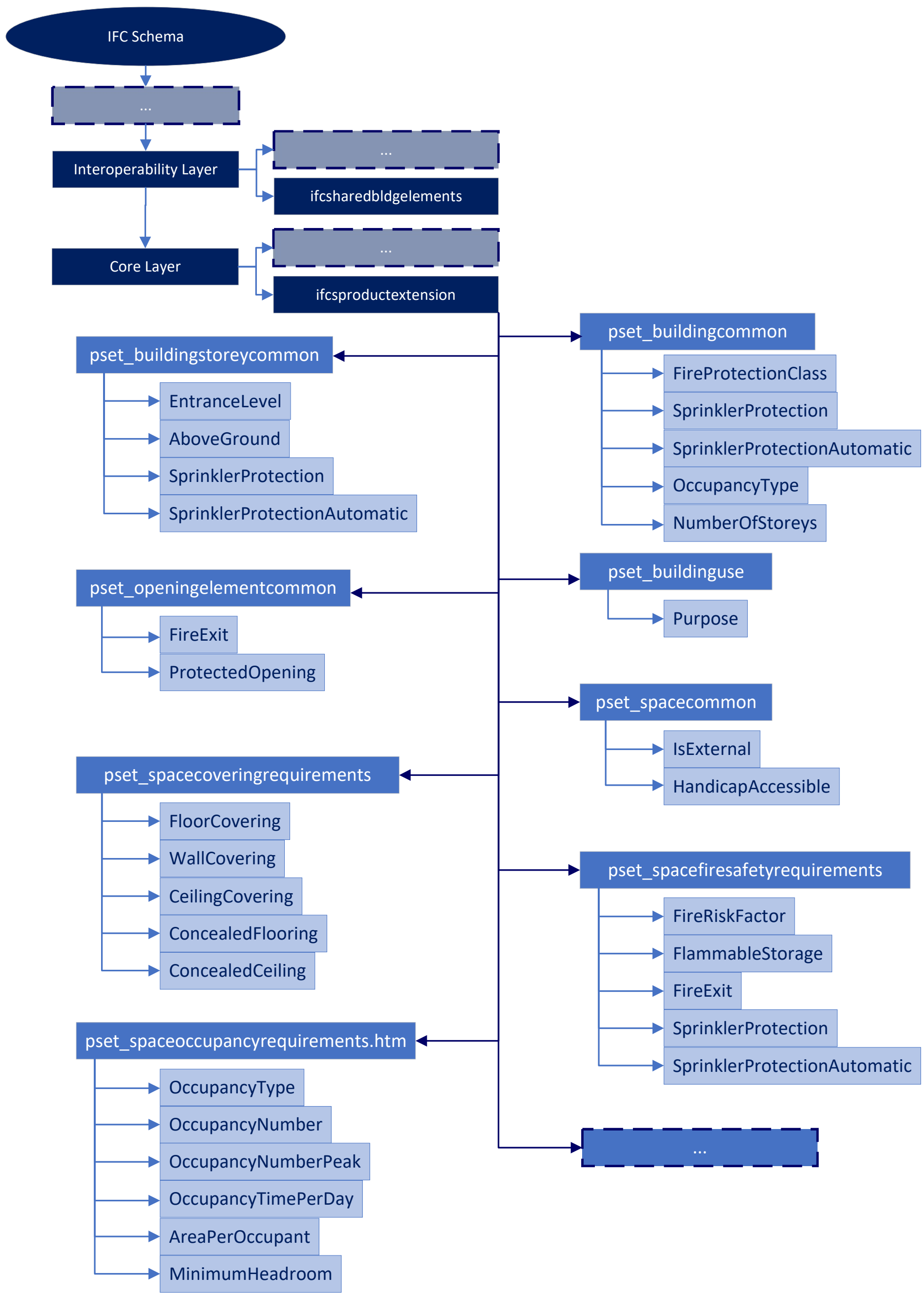


Figure 4.2: Tree of used Property Set Definition in IFC

In addition, relationships between the spatial structure and the elements are defined; so walls can be used as spatial boundaries (Liebich *et al.*, 2018). Here too, rooms and spaces have specific fire protection properties defined in the property sets. They consider building measures due to fire protection depending on the room's usage by various attributes such as *FireRiskFactor* and *FlammableStorage* in the *pset_spacefiresafetyrequirements* or the *FireProtectionClass* and the *OccupancyType* in the *pset_buildingcommon*. Figure 4.2 shows a selection of the *psets* in *ifcproductextention* and the position in the schema of IFC of *ifc-sharedbldgelements* and *ifcproductextention*.

Because it is still not possible to connect the Table A.1 given in the Appendix directly with the entities in IFC, it is split into individual parts. This is done with the help of flowcharts in which requirements are linked to a corresponding container in IFC, as exemplary illustrated in Figure 4.3.

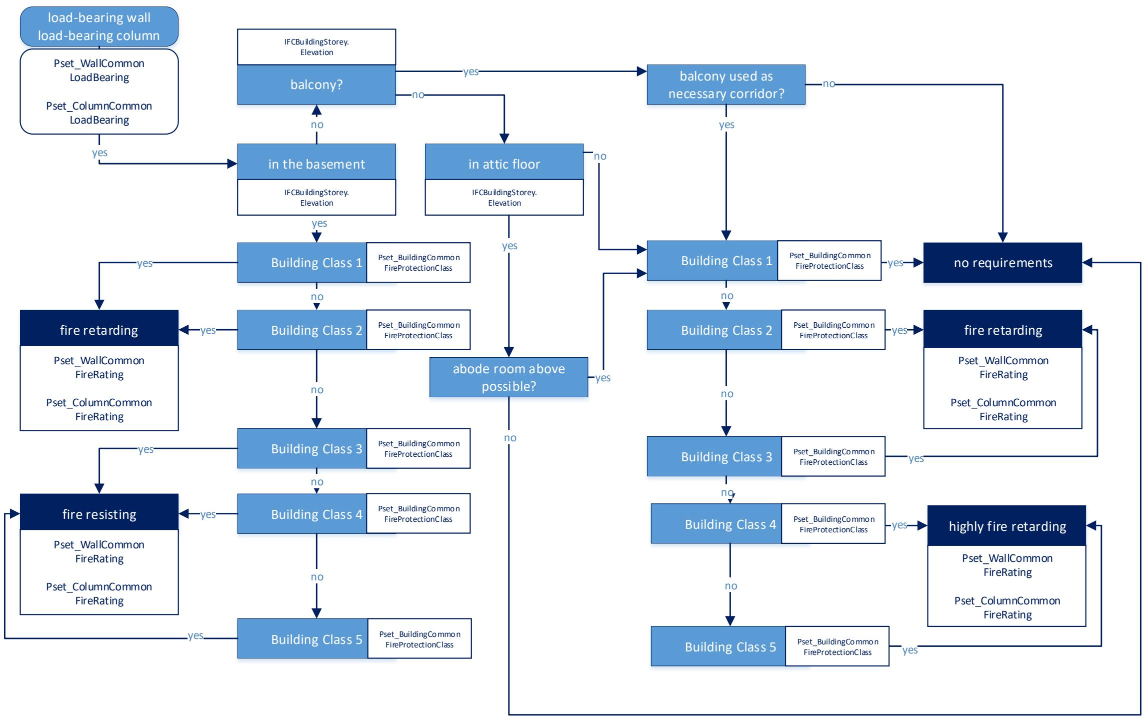


Figure 4.3: Flowshart Mapping Requirements from the BayBO to Corresponding Container in IFC

This technique is used as mind-mapping to combine the two information carriers (BayBO and IFC schema). The possibilities provided by the mvdXML method have not yet been considered. It becomes clear again that much information might be implemented in IFC but are not yet part of the standard because they are too specific for a general use. Examples are explained in more detail in the Chapter 5.

4.3 Simplification

The first step of every fire protection verification is the definition of the Building Class and the possibly classification into the Special Construction. As already mentioned in Chapter 3.2.3, the Special Construction regulations are omitted from this work. The Building Class is determined as illustrated in Figure 4.4. While the goal at the beginning of this thesis was to accomplish an as automatic as possible examination of the requirements of the BayBO, it is evident here that alone the automatic determination of the Building Class represents a considerable effort.

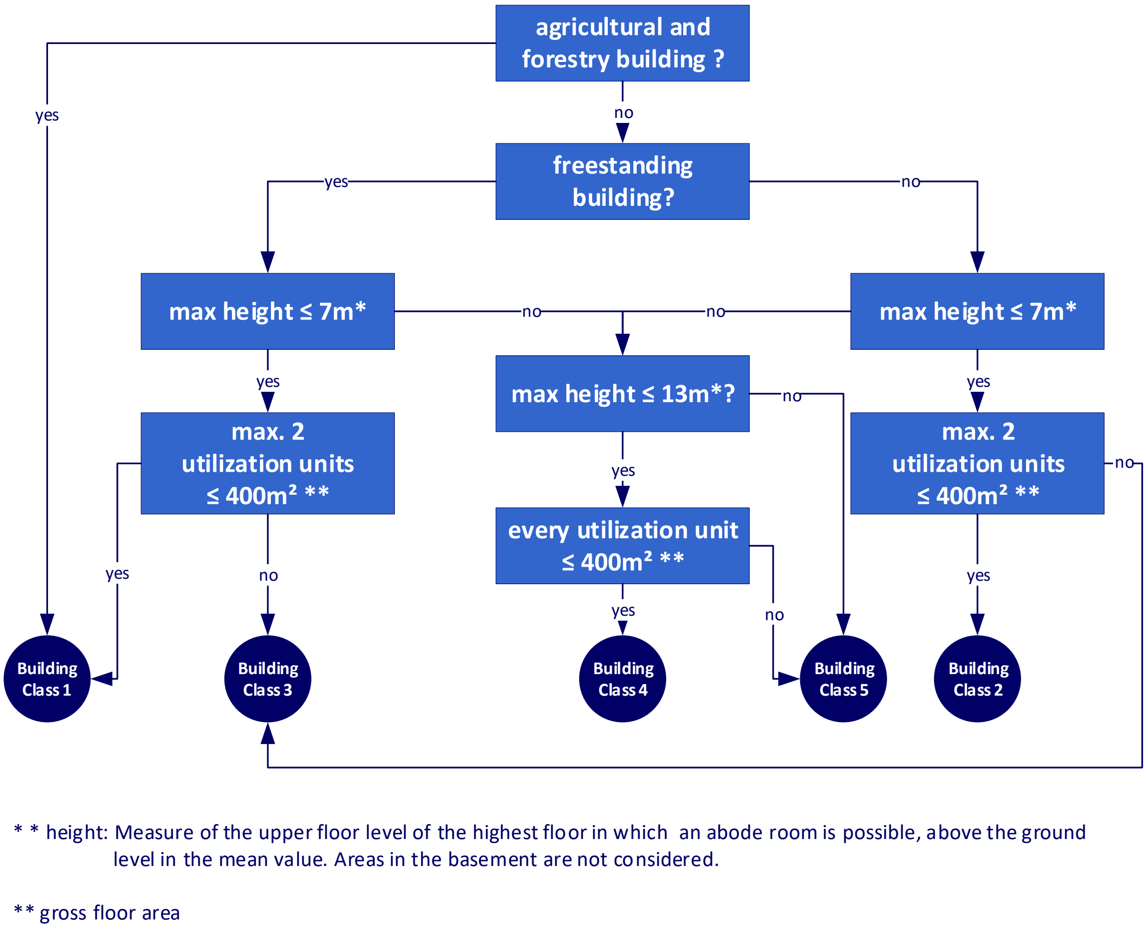


Figure 4.4: Determination of the Building Classes

Even if the building height in *IfcBuilding* and the use in *ifcproductextension* would be relatively easy to check, the definition of utilization units is a task an engineer performs in practice with a sense of proportion. The engineer has a comprehensive view of which requirements could be circumvented with a skillful definition of the utilization unit. As well, the costs for certain measures are also taken into account. A prime example of this are the partition walls between utilization units. These have special requirements and therefore higher costs. Smartly placed, partition walls not only save material costs but also reduce further requirements. Article 34 of BayBO exempts utilization units in apartments that are smaller than 200m^2 from the compulsory requirement to form necessary corridors. This saves material costs for partition walls as well as a large number of follow-up costs such as doors with special requirements in necessary corridors. Another skill of a fire prevention engineer is to group rooms in a way that avoid further requirements.

To simplify the analysis of the exchange requirements, the following creation of the mvdXML file focuses on Building Class 1. In order to the challenges given in the previous paragraph and the fact of the similarity of the requirements within the Building Classes, Building Class 1 should provide sufficient information for the analysis. Therefore, Table A.2 is extracted from Table A.1 with the requirements for a building of Building Class 1. In order to connect the requirements with the attributes tangible for the computer, two new columns are introduced. Requirements are linked to engineer and computer. For better clarity, parts of the building and objects, which do not have requirements are removed.

4.4 Development of mvdXML Rules

The creation of an MVD with the focus on model check is done with the same elements as described in Chapter 2.2.2. However, the underlying methodologies for the mvdXML check are the *ConceptRoot* and the *Concepts*. As already shown in Figure 2.3, these concepts are located in the lower part of the MVD, in the *Views*. The *ConceptTemplates* should not be part of this thesis and were taken from a given template which include the required basic configurations like Chipman *et al.* (2016) recommends in his mvdXML documentation.

To check exchange requirements, constraints and applicabilities have to be defined. A short example: If all windows should be checked whether they are used as fire exit then all instances of *IfcWindow* have to be selected in the *ConceptRoot* and the property *Pset_WindowCommon.FireExit* has to be selected in the *Concept*, more specifically, in the *TemplateRule*. Additional constraints, such as only windows with a fire rating should be checked, can be defined in the *Applicability*-section of the *ConceptRoot*. This methodology is shown in the following examples.

For the creation of the mvdXML file, the requirements from the BayBO are translated row by row into the XML language and the corresponding *Templates*. The developed MVD can be found in the appendix. In the following, the development of some *ConceptRoots* are presented as examples. For this purpose, the respective articles from the BayBO in Table A.2 are introduced, the corresponding code of the *ConceptRoots* is shown and problems are described.

Due to the vague description, it is not possible to translate the first sentence of the requirements for load-bearing walls and pillars (shown in Figure 4.5) and check it automatically. Also the second sentence is only partially verifiable. It is possible to check that all load-bearing walls and pillars have a *FireRating*, but the specification that walls and pillars only in the basement need to be checked, cannot be made. As shown in the flowchart in Figure 4.3, the storey, especially the basement, is stored in *IFCBuildingStorey.Elevation*, but the problem rather is the structure of the MVD, in which such a reference cannot be considered.

Requirement to	Requirement in Building Class 1	Possible Exception	to be checked by an engineer	to be checked by an mvdXML file
Tragende Wände, Stützen (Art. 25 BayBO) *(Load-Bearing Walls and Pillars)*	must remain stable sufficiently long in the event of fire	-	✓	**x**
- load-bearing walls and pillars in the basement	fire retarding	-	✓	(✓)

Figure 4.5: Requirements to Load-bearing Walls and Pillars According to the BayBO

Listing 4.1 shows the requirement from Figure 4.5 translated to mvdXML. The information whether the wall or pillars are located in the basement is not saved in the *IfcWall* object or its property sets. From my knowledge and the current mvdXML methodology documentation by Chipman *et al.* (2016) it is not intended to use property sets from different entities.

```
<ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d63" name="BuildingClass1wall" applicableRootEntity="IfcRoot">
<!--This ConceptRoot should check if all loadbearing walls in the basement have a fire rating. -->
    <Applicability>
        <Template ref="00000000-0000-0000-0001-000000000001"/>
        <TemplateRules operator="and">
        <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='LoadBearing'␣AND␣Value[Value]='TRUE'"/>
        </TemplateRules>
    </Applicability>
    <Concepts>
            <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d604" name="FireRatingWall">
                <Template ref="00000000-0000-0000-0001-000000000001"/>
                <Requirements>
                    <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
                </Requirements>
                <TemplateRules operator="and">
                    <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Exists]='TRUE'"/>
                </TemplateRules>
            </Concept>
    </Concepts>
 </ConceptRoot>
```

Listing 4.1: Requirements to load-bearing walls as mvdXML code

Apparently, the mvdXML code does not exactly reproduce what Figure 4.5 requires. Special restrictions are:

- The relationship between *IfcWall* and *IfcBuildingStorey* can not be formed.

- In Building Class 1 the requirement for walls and pillars in the basement is "fire retarding", in *Pset_WallCommon.FireRating* and *Pset_ColumnCommon.FireRating* this value can be entered individually according to the national fire safety classification. However, it is not possible to check the spelling which is used by the architect or engineer, so an exact check is not doable. The query is therefore only advisable if a check is made as to whether a FireRating is available at all: <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon' AND PropertyName[Value]='FireRating' AND Value[Exists]='TRUE'"/>

- The code in Listing 4.1 must be must be repeated for load-bearing columns; the check for load-bearing walls and pillars cannot be summarized in one *TemplateRule*.

The next part about fire walls is very comprehensive. Table 4.6 shows only a part to illustrate that the classification of a wall to a firewall must be done by an architect or engineer. In practice, fire walls play an important role in escape route verification, as they represent important sections and are elementary for the fire brigade. For example, the fire wall must be placed after 40m, as the fire brigade hoses are not longer than 40m. However, if the fire brigade is able to reach the burning object from another side just as well, a fire protection engineer may also be liable for omitting such a wall. This is difficult to consider when implementing in the mvdXML code.

Brandwände (Art. 28 BayBO) (Fire Walls)	Fire walls must prevent the spread of fire to other buildings or fire compartments for a sufficiently long time as space enclosing components to enclose buildings (building termination wall) or to subdivide buildings into fire compartments (inner fire wall).	-	✓	(✓)
inner fire wall for sectioning buildings in parts < 40 m	highly fire retarding	-	✓	(✓)
inner fire wall for sectioning buildings used for agricultural and forestry purpose in parts < 10.000m³ volume capacity	highly fire retarding	-	✓	(✓)
inner fire wall for sectioning the residental part and the agricultural and forestry used part of a building	highly fire retarding	-	✓	(✓)
exterior fire wall for exterior walls with a clearance for property line < 2,50m	highly fire retarding	-	✓	**X**
exterior fire wall for sectioning residental buildings and assembled agricultural and forestry buildings	even under mechanical stress fire resisting and made out of non-combustable materials	if the volume capacity of the agricultural and forestry building part < 2000 m³, fire resisting walls are possible	✓	**X**

Figure 4.6: Requirements to Fire Walls According to the BayBO

Listing 4.2 shows the requirements from Figure 4.6 translated to mvdXML. The information why a compartment is created is not storable. Neither it is the information whether the wall is able so remain sufficiently long in the event of fire or not. So basically, the MVD can check whether a fire wall that serves as a *Compartmentation* also fulfills the other given requirements like space enclosing (=*Pset_WallCommon.ExtendToStructure*) or the fire rating.

```xml
<ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d36" name="BuildingClass1wall" applicableRootEntity="IfcWall">
<!--This ConceptRoot should check if all compartment walls are extended to structure and have a fire rating. -->
    <Applicability>
        <Template ref="00000000-0000-0000-0001-000000000001"/>
        <TemplateRules operator="and">
            <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='Compartmentation'␣AND␣Value[Exists]='TRUE'"/>
        </TemplateRules>
    </Applicability>
    <Concepts>
        <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d111" name="CompartmentationWall">
             <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
                <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
                <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='ExtendToStructure'␣AND␣Value[Value]='TRUE'"/>
                <TemplateRule Parameters="PsetName[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Exists]='TRUE'"/>
            </TemplateRules>
        </Concept>
    </Concepts>
</ConceptRoot>
```

Listing 4.2: Requirements to Fire Walls as mvdXML Code

However, this mvdXML code does not exactly reproduce what Figure 4.6 requires. Special restrictions are:

- The relationship between *IfcWall*, *Pset_Compartmentation* and *IfcBuildingSpace* can not be formed. So it is not possible to check if a wall needs to be a wall for compartment. An Engineer or Architect needs to give this information to the BIM model.
- In Building Class 1 the requirement for these walls is "highly fire retarding". In *Pset_WallCommon.FireRating* this value can be entered individually according to the national fire safety classification. Again, it is not possible to check the spelling which is used by the architect or engineer, so an exact check is not doable.

- The code in Listing 4.2 would be need to be repeated for exterior fire walls which divides the residential building from the assembled agricultural and forestry building. In this case the wall have special requirements but it is not possible to do the selection why a compartment wall is needed within the *Applicability*.

- Non-combustible fillings in cavities of walls are not provided for in IFC 4 and can not be implemented.

The developed MVD contains the following seven *Concepts*: FireRatingWall, FireRatingColumn, CompartmentationWall, FireRatingSlab, FireRatingStair, FireExitEscalator and FireExitWindow. All of them are able to check various attributes which need to be implemented in the BIM model. Unfortunately it is not possible to represent the requirements given in the BayBO, but it shows the concept, how an mvdXML file works.

4.5 Use-Case: Fictitious Building Model

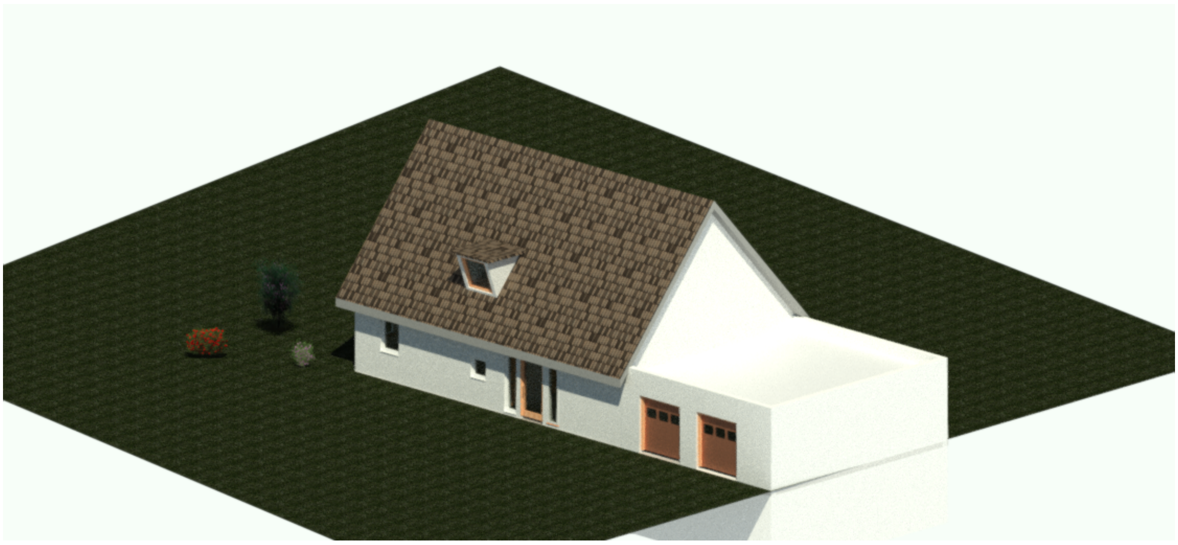


Figure 4.7: Testcase Model (Building Class 1)

To test the created MVD, a Revit Architecture model of a building is created (see Figure 4.7). It is a freestanding building with two utilization units: a residential part and an agricultural part, each part smaller than $400m^2$, hence Building Class 1.

Although most properties can be defined and queried in IFC, a problem arises if these properties need to be defined exemplary in Revit Architecture 2018. Revit possesses only a few default properties as parameters. Nevertheless, there are two ways to add parameter properties to object families: The parameter type *family parameters*, which is used to create specific parameters for the family an the parameter type *shared parameters*, which adds parameters that can be used across multiple families and projects. The *shared parameters* can be created directly in Revit or provided and imported using an external text file called a shared parameter file. This procedure allows to share the file with other users and set mandatory parameters for an MVD file.

For this model, *shared parameters* for property sets in IFC 4 were added. This file is published within the Revit IFC Handbook by Bews & Schurig (2019). It enables the import of all IFC 4 property sets into Revit. However, these property sets must still be associated with the corresponding objects and families. This is done in Revit Architecture 2018 via the 'Project parameters' icon. Here, the *shared parameters* are selected and assigned to the objects. Most important is the definition of the parameter as type or exemplar. A parameter created as a type is generally valid for all objects from the family type. In contrast, exemplar parameters refer to a single selected copy only. Parameters can be arranged in groups. For this model, the imported property sets are grouped in IFC-Parameters.

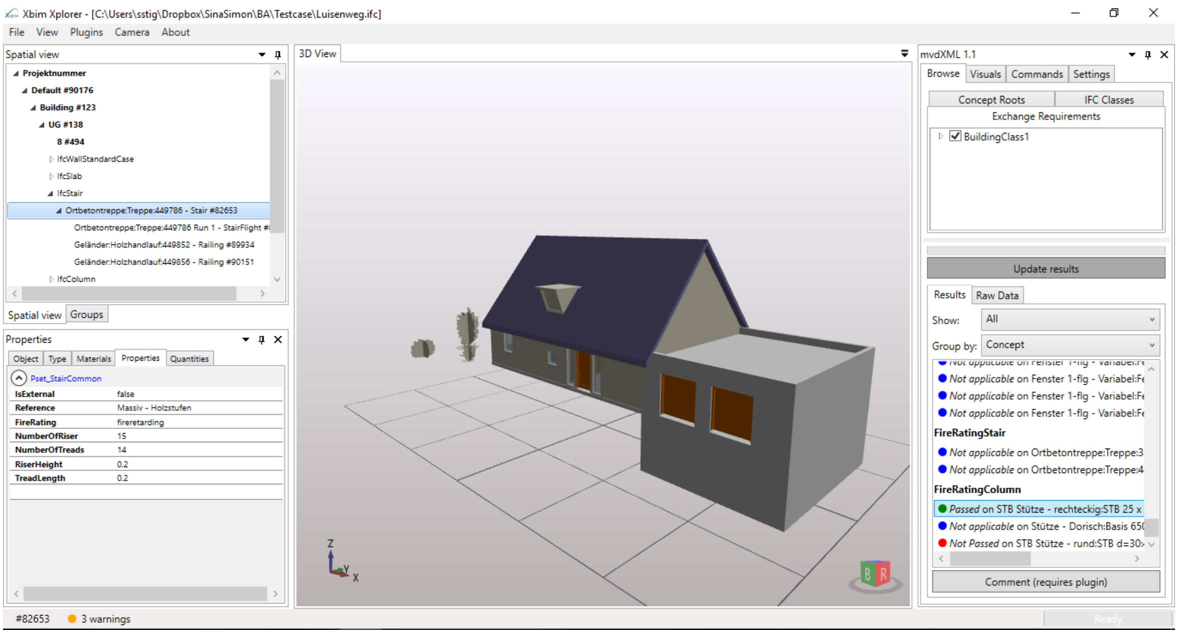


Figure 4.8: Testing Exchange Requirements in Created mvdxml-file with Xbim Xplorer

The created model partly fulfills the requirements of the BayBO. Properties such as *Compartmentation* or *FireRating* for various objects were defined. After the model was completed, it was exported to *IFC 4 Design Trafer View* and then loaded into the Xbim Xplorer.

The Xbim Xplorer is a free, open-source IFC viewer, capable of loading IFC2x3 and IFC4 models. It is extendable with the BuildingSmart mvdXML validation Plugin for checking compliance with mvdXML files.

The Xbim Xplorer has a divided interface. On the left side, the IFC schema of the respective model is displayed. In the centerthe model is visualized. With a mouse-click it is possible to browse along the IFC list-structure to show the individual objects and their information given in IFC. This also works by direct a click in the model. On the right side, the created MVD file can be loaded. The results are displayed after a click on 'Update Results' grouped by elements, concepts or requirements. In addition, the result can be displayed in coloured form in the model using the ' Visuals' tab. The results of the MVD can be 'not applicable' (blue), 'passed' (green) or 'failed' (red). Figure 4.8 shows the result of the developed MVD.

This test case demonstrates successfully that the defined exchange requirements and the developed MVD work.

Chapter 5

Conclusion

5.1 Limitations

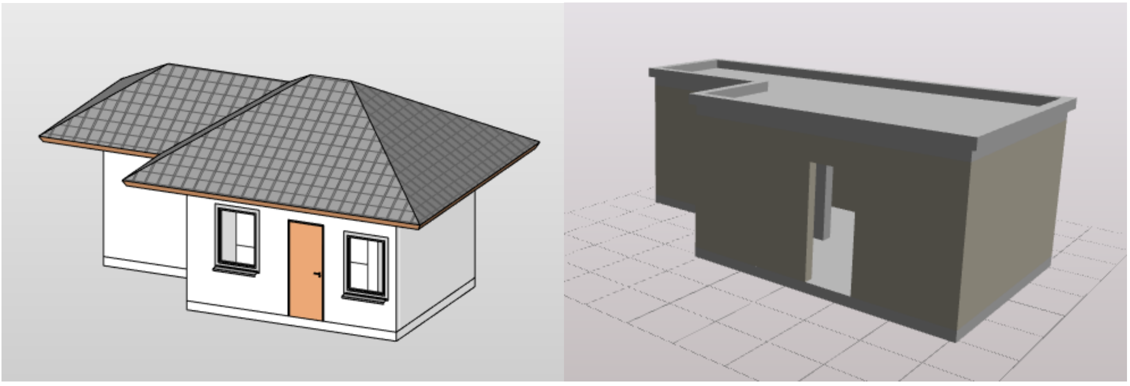
During the work with this thesis several problems and limitations have been identified. These made the progress considerably more difficult and further research was necessary. The limitations and problems are described below, sorted by their subject.

1. The buildingSMART Data Dictionary simplifies the work with MVD and IFC. It is an excellent tool for translation and orientation within the extensive data jungle. Unfortunately, at the beginning of this five-month work, many errors occurred when searching for keywords. However, after contacting support, it worked to completion. In addition, the translations often have redundant entries, which makes the results confusing. For example, the entry 'handrail' is available once as a subject in English and Norwegian, three times as a subject in Dutch and once summarized in English, German, French and Norwegian, which is also linked to IFC. This is the result of the open source concept with which buildingSMART wanted to reinforce the cooperation of all community members to generate this dictionary. The redundant entries still have to be removed, which indicates a lack of quality assurance.

2. Initially, the IfcDoc by buildingSMART was intended to be used for the development of the MVD. Although there is a graphical user interface (instead of programming manually with knowledge of the language mvdxml), the development of an MVD was not possible even after weeks of familiarization. The program requires extensive knowledge of the IFC schema and the published documentation is insufficient. Without a complete and detailed documentation this tool is not practicable for the ordinary user. The greatest challenge turned out to be that it is not possible to create *TemplateRules* within the user interface. When creating requirements IfcDoc always places them in the

ConceptTemplates. Therefore, there is still a need for improvement and the development of adequate documentation.

3. Autodesk publishes a new version of the Revit tool every year. The latest release is Revit 2019.1, published in August 2018. This was first used for the construction of the use case. However, when exporting to IFC 4 and opening to SMC and XBIM, many bugs occured. The model cannot be represented correctly, as shown in Figure 5.1. Therefore, Revit 2018.1 had to be used; the export works perfectly using IFC 4.



(a) Testcase Model in Revit Architecture 2019 **(b)** Testcase Model created in Revit Architecture 2019, exported in IFC 4 and represented in Xbim Xplorer

Figure 5.1: Failed Revit Architecture 2019 and IFC 4 Testcase Model

4. All BIM products offer many advantages and have their reasons for existence. However, it becomes clear that there is a lack of sufficient documentation and instructions for the programs. Without experience it is difficult to become familiar with the individual programs. Therefore, in addition to the documentation, the educational possibilities should also be expanded. In today's world there are often video tutorials, which are quickly outdated due to the multitude of publications. Therefore, in my opinion it is particularly important to train civil engineers and architects already at the university, in order to become familiar with different programs, IFC and the possibilities of BIM.

5. Numerous program crashes especially in ifcDoc and Xbim Xplorer complicated the work even more and need to be fixed.

6. As already pointed out in chapter 4.1, the BayBO is too vague and comprehensive for an precise representation in MVD. Translating the requirements into a computer interpretive language requires more time and profound knowledge. Further research and development is definitely necessary.

7. Propetysets in IFC were analyzed extensively. In the past IFC releases, more and more propertysets have been implemented to provide fire protection, but there are not yet

enough for the Bavarian Building Regulations. Although it is possible to define and create missing properties individually, this makes the work unmanageable and difficult to reproduce. This is not yet ideal for the automation of compliance checks. It is particularly difficult because BIM, IFC and its property sets are supposed to be valid internationally and each building code requires different properties.

8. As already outlined in chapter 4.4, it is not possible to create cross-object queries in MVD. For example, should a load-bearing wall in the basement be checked, IFC 4 provides the corresponding information in various data containers, but a *ConceptTemplate* can only refer to one container. In other words, the storey or the wall. The problem could be solved by creating own propertysets or adding a new property to *Pset_WallCommon* like *Storey*. However, this would result in a lack of precision of the IFC file and would enlarge it significantly. It must therefore be the goal to provide a possibility to create such relationships in MVD.

5.2 Summary and Outlook

For the coordination of different technical disciplines in the construction industry and the increasing digitization, an extension of automated code checking is absolutely necessary.

As a result of this thesis, it is possible to define and check exchange requirements with MVD. Even if the queries do not yet comply exactly with the BayBO requirements, it has been shown that the fundamental concept works. However, it requires still many more efforts to develop and implement a comprehensive checking concept.

In the future, more attention should be paid to interface-software in order to avoid user's input errors. Continuous checks in early design stages must be introduced in order to detect and eliminate flaws as early as possible. For this purpose, the definition of LOD can be used to ensure that fire prevention requirements are taken into account from early planning stages, even in the case of frequent changes. Further research can be useful, such as the investigation of the LOD to evaluate in which LOD certain requirements can already be checked.

It should be pointed out again, that the possibilities presented do not provide completeness and can only serve as assistance for conventional fire prevention planning. It is currently not possible to automate the checking of the BayBO completely. The work of fire prevention engineers is still indispensable.

Appendix A

Appendix

A.1 BayBO Table

	GK 1	GK 2	GK 3	GK 4	GK 5	Possible Exception
Tragende Wände, Stützen (Art. 25 BayBO) *(load-bearing walls and pillars)*	must remain stable sufficiently long in the event of fire					-
- applies for attic floors only, if above an abode room is possible - doesn't applie for balconies, eccept for open aisles which are used as necessary corridor	-	fire retarding	fire retarding	highly fire retarding	fire resisting	-
basement	fire retarding	fire retarding	fire resisting	fire resisting	fire resisting	-
Außenwände (Art. 26 BayBO) *(exterior wall)*	The fire spread in these building components must remain stable sufficiently long in the event of fire					-
non-load-bearing walls	-	-	-	non-combustible building materials	non-combustible building materials	combustible materials are allowed, if space-enclosing components are fire resisting
surfaces, cladding and insulations	-	-	-	flame retardant and must not falling (dripping) in a burning state	flame retardant and must not falling (dripping) in a burning state	-
substructures	-	-	-	flame retardant and must not falling (dripping) in a burning state	flame retardant and must not falling (dripping) in a burning state	normal-flammability construction materials are allowed, if the fire spread in these building components must remain stable sufficiently long in the event of fire
Balcony cladding, which is higher than the neccessary guard	-	-	-	flame retardant	flame retardant	-
solar panels at exterior walls, which are higher than two storeys	-	-	-	flame retardant	flame retardant	-
rear-ventiled exterior wall claddings	-	-	-	special precautions	special precautions	-
exterior wall constructions with hollow or air spaces going over serverals storeys e.g. double facades	-	-	special precautions	special precautions	special precautions	-
Trennwände (Art. 27 BayBO) *(partition walls)*	space-enclosing components of rooms or utilization units within a floor must remain stable sufficiently long against fire spread					
Between different utilization units and between utilization units and different used rooms (except for the necessary corridors) partition walls must be rise to the roof skin or ceiling skin.	-	-	like Art. 25 BayBO	like Art. 25 BayBO	like Art. 25 BayBO	If partition walls only reach to the row ceiling, the ceiling must be built as a space enclosing component, including the bear-loading and stiffened components being fire retarding
between abode rooms and different used rooms in the basement partition walls must be rise to the roof skin or ceiling skin.	-	-	like Art. 25 BayBO	like Art. 25 BayBO	like Art. 25 BayBO	
for termination of rooms with danger of explosion or fire artition walls must be rise to the roof skin or ceiling skin.	-	-	fire resisting	fire resisting	fire resisting	
openings	-	only allowed, if they are limited for the required number required size and have fire resisting connections to other building components				
Brandwände (fire walls)						
inner fire wall for sectioning buildings in parts < 40 m	highly fire retarding	highly fire retarding	highly fire retarding	even under mechanical stress highly fire retarding	even under mechanical stress fire resisting and made out of non-combustable materials	
inner fire wall for sectioning buildings used for agricultural and forestry purpose in parts < 10.000m³ volume capacity	highly fire retarding	highly fire retarding	highly fire retarding	even under mechanical stress highly fire retarding	even under mechanical stress fire resisting and made out of non-combustable materials	
inner fire wall for sectioning the residental part and the agricultural and forestry used part of a building	highly fire retarding	highly fire retarding	highly fire retarding	even under mechanical stress highly fire retarding	even under mechanical stress fire resisting and made out of non-combustable materials	
exterior fire wall for exterior walls with a clearance for property line < 2,50m	highly fire retarding	highly fire retarding	highly fire retarding	even under mechanical stress highly fire retarding	even under mechanical stress fire resisting and made out of non-combustable materials	
exterior fire wall for sectioning residental buildings and assembled agricultural and forestry buildings	even under mechanical stress fire resisting and made out of non-combustable materials					if the volume capacity of the agricultural and forestry building part < 2000 m³, fire resisting walls are possible
arrangement of the fire walls	must be built directly one above another in all storeys					only storeywise moved, if - walls are fire resisting even under mechanical stress and made out of non-combustable materials - connected ceilings haven't got openings, are fire resisting and are made of non-combustible materials - building parts which support the wall or ceilings are fire resisting and made of non-combustible materials - the outer walls are fire resistant in the width of the offset in the storey above or below the offset - openings are arranged in the outer walls in the region of the offset or other precautions are taken so that a fire spread to other fire sections is not to be feared
upper closure	Fire walls must be rised at least under the roof skin. Remaining voids must be completely filled with non-combustible building materials.			Fire walls must be rised 0.30 m above the roof or must be closed with a fire-resistant plate of non-combustible building materials projecting on either side 0.50 m at the height of the roof, flammable parts of the roof must not be led over the roof.		

	GK 1	GK 2	GK 3	GK 4	GK 5	Possible Exception
Fire walls of buildings or building parts colliding over corner	the distance of this wall from the inner corner must be at least 5 m					this is not necessary if the angle of the inner corner is more than 120 degrees or at least one outer wall of 5 m length is designed as a fire-resistant wall made of non-combustible building materials without openings, or in buildings of building classes 1 to 4 as a highly-fire-retardarding wall without openings
Decken (Art. 29 BayBO) *(ceiling)*	Ceilings must be build as space enclosing components between different floors, They must must remain stable and resistant sufficiently long in the event of fire					
- only applies for attic floors if above an abode room is possible **- not for balconies**	-	fire retarding	fire retarding	highly fire retarding	fire resisting	
basement	fire retarding	fire retarding	fire resisting	fire resisting	fire resisting	
ceilings below and above rooms with danger of explosion or fire	no requirements in housings	no requirements in housings	fire resisting	fire resisting	fire resisting	
ceilings between agricultural and forestry used rooms and the residential part of the building	fire resisting					
connection to the exterior walls	The fire spread in these building components must remain stable sufficiently long in the event of fire					
openings into ceilings for ceilings which has explicitly requirements for resistance to fire	allowed	allowed	only allowed within a utilization unit smaller than 400m² and <= 2 storeys or if they are limited for the required number required size and have the connections with the same fire resisting class as the ceiling	only allowed within a utilization unit smaller than 400m² and <= 2 storeys or if they are limited for the required number required size and have the connections with the same fire resisting class as the ceiling	only allowed within a utilization unit smaller than 400m² and <= 2 storeys or if they are limited for the required number required size and have the connections with the same fire resisting class as the ceiling	
Dächer *(Roofs)*	Roofs must be sufficiently resistant to fire exposure from outside due to flying sparks and radiant heat (hard roofs)					
	hard roof (relief on certain conditions)			hard roof		
Erster und zweiter Rettungsweg (Art. 31 BayBO) *(first and second escape route)* ***ER***	All utilization units with abode rooms on each level must be accessible to the outside via at least two escape routes that are independent from one another. Both escape routes are allowed to go through the same necessary aisle within a storey					
first ER (not at ground level)	necessary stairs					
second ER (not at ground level)	another necessary stairway or rescue devices from the fire brigade (from a spandrel height of 8m only if the fire brigade has the reqired devices)					a second ER is not reqired, if the building has safety stairwell (it's a stairwell in which fire an smoke can't enter)
Treppen (Art. 32 BayBO) *(stairway)*	Every storey which is not at ground level and every usable attic room of a building must be accesible via at least one stairway or a flat ramp (necessary stairway)					
escalator as necessary stairway	not allowed					
retractable stairs and ladders	only permitted as acces to an attic space without a abode room	only permitted as acces to an attic space without a abode room	not allowed	not allowed	not allowed	
connected storeys	-	-	-	Necessary stairways has to be led in a train to all connected storeys; they must be directly connected to the stairs to the attic rooms	Necessary stairways has to be led in a train to all connected storeys; they must be directly connected to the stairs to the attic rooms	Art. 33 Abs. 1 Satz 3 Nr. 2
load-bearing parts of a necessary stairway	-	-	non-combustible building materials or fire retarding	non-combustible building materials	non-combustible building materials and fire retarding	
load-bearing parts of a necessary external stairway	-	-	non-combustible building materials	non-combustible building materials	non-combustible building materials	
width of the necessary stairway	The usable width of the flight of stairs and landings of necessary stairways must be sufficient for the largest expected traffic.					
handrail	Stairways must have a strong and secure handrail.They should be provided on both sides and, in the case of large usable width, also intermediate handrails. 1. in buildings with more than two non-accessible apartments, 2. in other cases, as far as traffic safety requires.					
notwendige Treppenräume, Ausgänge (Art. 33 BayBO) *(necessary stairwell and exits)*	no necessary stairwell required	no necessary stairwell required	necessary stairwell required	necessary stairwell required	necessary stairwell required	stairs without ther own stairwells are permissible for the connection of max. two floors within the same utilization unit < 200 m², e. g.as in maisonette apartments, if in every storage another rescue and escape route can be achieved or external stairwells, if it's usage is possible over a sufficiently long period and not dangerous in the case of fire
exits	exits into the outside or a necessary stairwell must be lead in maximun 35 meters from any position of a abode room or basement room					not for buildings used for agricultural and forestry purpose
basements that are placed one on top of the other	at least two exits into the outside or a necessary stairwell					
allocation of different necessary stairwells	ideally in the opposite direction and escape routes as short as possible					

	GK 1	GK 2	GK 3	GK 4	GK 5	Possible Exception
walls of necessary stairwells	-	-	fire retarding	even under additional mechanical load highly fire retarding and space enclosing components	walls must be built as space enclosing components in the quality of fire walls	if exterial walls of stairwells made of non-combustible building materials and other components connected to the wall are not in danger in case of fire
upper connection of the stairwell as space-enclosing component	-	fire retarding	fire retarding	highly fire retarding	fire resisting	
exit out of the necessary stairwell	lead directly into the open or in a interstice with special requirements					
width of the interstice of the necessary stairwell	min. as wide as the stair flights					
interstice connection to the necessary corridor	smokeproof and self-closing					
interstice openings in the necessary stairwell	not allowed (eccept for necessary corridors)					
interstice walls	-	-	fire retarding	even under additional mechanical load highly fire retarding and space enclosing components	walls must be built as space enclosing components in the quality of fire walls	if exterial walls of stairwells made of non-combustible building materials and other components connected to the wall are not in danger in case of fire
surfaces, cladding and insulations of the necessary stairwell	need to be built from non-combustible materials					
walls and ceilings from combustible materials in necessary stairwells	need cladding from non-combustible materials in a sufficiently width					
floor covering	minimum built from highly flame retarting materials					
- to basements, undeveloped attic, workshops, stores, storage and utility units > 200m² (except from residential buildings)	fire retarding, smokeproof and self-closing closings					
- to necessary aisles	smokeproof and self-closing closings					
- to other roms and utility units	imperforate, tightly and self-closing closing					
illumination of necessary stairwells	necessary stairwells need an illumination, stairwells higher than 13m and without windows need a security illumination					
ventilation and smoke extraction	necessary stairwells need to have a windows with a free cross-section of at least 0.50 m², which can be opened, in each above-ground storey, or an opening for smoke extraction at the very top of the stairwell					if the height of the building > 13m, it needs an opening for smoke extraction at the very top of the stairwell with a free cross-section of at least 1 m² and be able to open from the ground level and the highest storey
Notwendige Flure, offene Gänge (Art. 34 BayBO) *(necessary corridor, open aisle)*	Corridors through which escape routes from abode rooms or units with abode rooms lead to exits into necessary stairwells or into the open air (necessary corridors) must be arranged and designed in such a way that they can be used for a sufficiently long time in case of fire					necessary corridors aren't needed in, 1. in residential buildings in building classes 1 and 2, 2. in other buildings in building classes 1 and 2 eccept for basement levels 3. within a utilization unit smaller than 200m² and inside dwellings 4. within a utilization unit which is used as office or administrative rooms smaller than 400m²
minimum width of inner necessary corridors	sufficient wide for the largest expected traffic					
minimum steps of stairs within inner necessary corridors	3					
maximum path lenght of inner necessary corridors	30m					
subdividing of inner necessary corridors (if longer than 30m)	Necessary corridors are to be subdivided into smoke sections with non-lockable, smoke-proof and self-closing closures.					
closure connection of the smoke section to the ceiling	closure connections must achieve to the row ceiling					closure connections can achieve to the suspended ceiling of the corridor, if these suspended ceiling is fire retarding
maximum corridor lenght with only one direction to safety stairwells	15m					
walls of necesary corridors	to be built fire retarding and as a space enclosing component					
walls of necesary corridors in the basement	in basements where the load-bearing and reinforcing components must be fire-resisting, walls must also be fire-resisting					
closure connection of the walls of necessary corridors to the ceiling	walls must achieve to the row ceiling					walls can achieve to the suspended ceiling of the corridor, if this suspended ceiling is fire retarding and a closure
doors in walls of necssary corridors	must close tightly (against smoke)					
doors in walls of necessary corridors to storage rooms in the basement level	fire retarding, tight and self-closing closures					
necessary corridors as open aisles in front of the external walls	parapets and walls must be built fire retarding as a space enclosing component					
necessary corridors as open aisles in front of the external walls in the basement	in basement floors where the load-bearing and reinforcing components need to be fire resisting, walls must also be fire resisting					
windows in walls which are next to open aisles used as necessary corridors	windows in these walls are permitted from a spandrel height of 0,90 m					
panels, plaster, suspended ceiling and insulation in necessary corridors	must be buit from non-combubstable materials					
walls and ceiling fom combustable materials in necessary corridors	need cladding from non-combustible materials in a sufficiently width					
Fenster, Türen, sonstige Öffnungen (Art. 35 BayBO) *(windows, doors, other openings)*	-					
Clear passage width of entrance doors of apartments, which must be accessible via elevators	90cm					
basement level without windows	a basement level without windows need to have at least one opening into the outside for smoke extraction					
minimum dimensions of windows which are used as rescue route	width: 0,60 m, height: 1,00 m, to open from inside, max. 1,20 m above floor level					

A.2 Table Building Class 1

Requirement to	Requirement in Building Class 1	Possible Exception	to be checked by an engineer	to be checked by an mvdXML file
Tragende Wände, Stützen (Art. 25 BayBO) *(Load-Bearing Walls and Pillars)*	must remain stable sufficiently long in the event of fire	-	✓	x
- load-bearing walls and pillars in the basement	fire retarding	-	✓	(✓)
Außenwände (Art. 26 BayBO) *(Exterior Wall)*	The fire spread in these building components must remain stable sufficiently long in the event of fire	-	✓	x
Brandwände (Art. 28 BayBO) (Fire Walls)	Fire walls must prevent the spread of fire to other buildings or fire compartments for a sufficiently long time as space enclosing components to enclose buildings (building termination wall) or to subdivide buildings into fire compartments (inner fire wall).	-	✓	(✓)
inner fire wall for sectioning buildings in parts < 40 m	highly fire retarding	-	✓	(✓)
inner fire wall for sectioning buildings used for agricultural and forestry purpose in parts < 10.000m³ volume capacity	highly fire retarding	-	✓	(✓)
inner fire wall for sectioning the residental part and the agricultural and forestry used part of a building	highly fire retarding	-	✓	(✓)
exterior fire wall for exterior walls with a clearance for property line < 2,50m	highly fire retarding	-	✓	x
exterior fire wall for sectioning residental buildings and assembled agricultural and forestry buildings	even under mechanical stress fire resisting and made out of non-combustable materials	if the volume capacity of the agricultural and forestry building part < 2000 m³, fire resisting walls are possible	✓	x
arrangement of the fire walls	must be built directly one above another in all storeys	only storeywise moved, if - walls are fire resisting even under mechanical stress and made out of non-combustable materials - connected ceilings haven't got openings, are fire resisting and are made of non-combustible materials - building parts which support the wall or ceilings are fire resisting and made of non-combustible materials - the outer walls are fire resistant in the width of the offset in the storey above or below the offset - openings are arranged in the outer walls in the region of the offset or other precautions are taken so that a fire spread to other fire sections is not to be feared	✓	x
upper closure	Fire walls must be rised at least under the roof skin. Remaining voids must be completely filled with non-combustible building materials.	-	✓	(✓)
Fire walls of buildings or building parts colliding over corner	the distance of this wall from the inner corner must be at least 5 m	this is not necessary if the angle of the inner corner is more than 120 degrees or at least one outer wall of 5 m length is designed as a fire-resistant wall made of non-combustible building materials without openings, or in buildings of building classes 1 to 4 as a highly-fire-retardarding wall without openings	✓	x
Decken (Art. 29 BayBO) *(Ceiling)*	Ceilings must be build as space enclosing components between different floors, They must must remain stable and resistant sufficiently long in the event of fire	-	✓	(✓)
ceilings in the basement	fire retarding	-	✓	(✓)
ceilings below and above rooms with danger of explosion or fire	fire resisting but no requirements in residental buildings	-	✓	x
ceilings between agricultural and forestry used rooms and the residential part of the building	fire resisting	-	✓	x

Requirement to	Requirement in Building Class 1	Possible Exception	to be checked by an engineer	to be checked by an mvdXML file
ceiling's connection to the exterior walls	The fire spread in these building components must remain stable sufficiently long in the event of fire	-	✓	x
openings into ceilings for ceilings which has explicitly requirements for resistance to fire	allowed	-	✓	(✓)
Dächer (Art. 30 BayBO) *(Roof)*	Roofs must be sufficiently resistant to fire exposure from outside due to flying sparks and radiant heat (hard roofs)	-	✓	x
Roof	hard roof (relief on certain conditions)	-	✓	x
Erster und zweiter Rettungsweg (Art. 31 BayBO) *(First and Second Escape Route (ER))*	All utilization units with abode rooms on each level must be accessible to the outside via at least two escape routes that are independent from one another. Both escape routes are allowed to go through the same necessary aisle within a storey	-	✓	x
first ER (not at ground level)	necessary stairway	-	✓	x
second ER (not at ground level)	another necessary stairway or rescue devices from the fire brigade (from a spandrel height of 8m only if the fire brigade has the reqired devices)	a second ER is not reqired, if the building has safety stairwell (it's a stairwell in which fire an smoke can't enter)	✓	x
Treppen (Art. 32 BayBO) *(Stairway)*	Every storey which is not at ground level and every usable attic room of a building must be accesible via at least one stairway or a flat ramp (necessary stairway)	-	✓	x
escalator used as necessary stairway	not allowed	-	✓	✓
retractable stairs and ladders	only permitted as acces to an attic space without an abode room	-	✓	x
width of the necessary stairway	The usable width of the flight of stairs and landings of necessary stairways must be sufficient for the largest expected traffic.	-	✓	x
handrail	Stairways must have a strong and secure handrail.They should be provided on both sides and, in the case of large usable width, also intermediate handrails. 1. in buildings with more than two non-accessible apartments, 2. in other cases, as far as traffic safety requires.	-	✓	x
Notwendige Flure, offene Gänge (Art. 34 BayBO) *(Necessary Corridor, Open Aisle)*	Corridors or escape routes from abode rooms or units with abode rooms lead to exits into necessary stairwells or into the open air are necessary corridors. They must be arranged and designed in such a way that they can be used for a sufficiently long time in case of fire	necessary corridors aren't needed in, 1. in residential buildings in building classes 1 and 2, 2. in other buildings in building classes 1 and 2 eccept for basement levels 3. within a utilization unit smaller than 200m² and inside dwellings 4. within a utilization unit which is used as office or administrative rooms smaller than 400m²	✓	x
minimum width of inner necessary corridors	sufficient wide for the largest expected traffic	-	✓	x
minimum steps of stairs within inner necessary corridors	3	-	✓	✓
maximum path lenght of inner necessary corridors	30m	-	✓	x
subdividing of inner necessary corridors (if longer than 30m)	Necessary corridors are to be subdivided into smoke sections with non-lockable, smoke-proof and self-closing closures.	-	✓	x
closure connection of the smoke section to the ceiling	closure connections must achieve to the row ceiling	closure connections can achieve to the suspended ceiling of the corridor, if these suspended ceiling is fire retarding	✓	x
maximum corridor lenght with only one direction to safety stairwells	15m	-	✓	x

Requirement to	Requirement in Building Class 1	Possible Exception	to be checked by an engineer	to be checked by an mvdXML file
walls of necesary corridors	to be built fire retarding and as a space enclosing component	-	✓	x
walls of necesary corridors in the basement	in basements where the load-bearing and reinforcing components must be fire-resisting, walls must also be fire-resisting	-	✓	x
closure connection of the walls of necessary corridors to the ceiling	walls must achieve to the row ceiling	walls can achieve to the suspended ceiling of the corridor, if this suspended ceiling is fire retarding and a closure connection is ensured	✓	x
doors in walls of necssary corridors	must close tightly (against smoke)	-	✓	x
doors in walls of necessary corridors to storage rooms in the basement level	fire retarding, tight and self-closing closures	-	✓	x
necessary corridors as open aisles in front of the exterial walls	parapets and walls must be built fire retarding as a space enclosing component	-	✓	x
necessary corridors as open aisles in front of the exterial walls in the basement	in basement floors where the load-bearing and reinforcing components need to be fire resisting, walls must also be fire resisting	-	✓	x
windows in walls which are next to open aisles used as necessary corridors	windows in these walls are permitted from a spandrel height of 0,90 m	-	✓	x
panels, plaster, suspended ceiling and insulation in necessary corridors	must be buit from non-combubstable materials	-	✓	x
walls and ceiling fom combustable materials in necessary corridors	need cladding from non-combustible materials in a sufficiently width	-	✓	x
Fenster, Türen, sonstige Öffnungen (Art. 35 BayBO) *(Windows, Doors, other Openings)*	-	-	-	-
Clear passage width of entrance doors of apartments, which must be accessible via elevators	90cm	-	✓	x
basement level without windows	a basement level without windows need to have at least one opening into the outside for smoke extraction	-	✓	x
minimum dimensions of windows which are used as rescue route	width: 0,60 m, height: 1,00 m, to open from inside, max. 1,20 m above floor level	-	✓	✓

A.3 Model View Definition Code

```
<Views>
    <ModelView uuid="761daf9e-6bfb-4601-bbaf-658d606e3b18" name="BuildingClass1" applicableSchema="IFC4" code="BC1">
        <Definitions/>
        <ExchangeRequirements>
            <ExchangeRequirement uuid="8781746d-68d1-4447-bf36-dbfe0fec4c8d" name="BayB0check" code="BayB0" applicability="export">
                <definitions/>
            </ExchangeRequirement>
        </ExchangeRequirements>
        <Roots>
            <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d63" name="BuildingClass1wall" applicableRootEntity="IfcWall">
             <!--This ConceptRoot should check if all loadbearing walls in the basement have a fire rating. -->
              <Applicability>
          <Template ref="00000000-0000-0000-0001-000000000001"/>
          <TemplateRules operator="and">
            <TemplateRule Parameters="Set[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='LoadBearing'␣AND␣Value[Value]='true'"/>
          </TemplateRules>
        </Applicability>
        <Concepts>
          <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d603" name="FireRatingWall">
            <Definitions/>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
              <TemplateRule Parameters="Set[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Exists]=TRUE"/>
            </TemplateRules>
          </Concept>
        </Concepts>
            </ConceptRoot>
            <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d64" name="BuildingClass1Column" applicableRootEntity="IfcColumn">
            <!--This ConceptRoot should check if all loadbearing pillars in the basement have a fire rating. -->
              <Applicability>
          <Template ref="00000000-0000-0000-0001-000000000001"/>
          <TemplateRules operator="and">
            <TemplateRule Parameters="Set[Value]='Pset_ColumnCommon'␣AND␣PropertyName[Value]='LoadBearing'␣AND␣Value[Value]=TRUE"/>
          </TemplateRules>
```

```
        </Applicability>
                <Concepts>
            <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d604" name="FireRatingColumn">
            <Definitions/>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
              <TemplateRule Parameters="Set[Value]='Pset_ColumnCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Value]='fireretarding'"/>
            </TemplateRules>
          </Concept>
                </Concepts>
            </ConceptRoot>
            <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d65" name="BuildingClass1wall" applicableRootEntity="IfcWall">
              <!--This ConceptRoot should check if all compartment walls are extended to structure and have a fire rating. -->
              <Template ref="00000000-0000-0000-0001-000000000001"/>
          <Applicability>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <TemplateRules operator="and">
            <TemplateRule Parameters="Set[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='Compartmentation'␣AND␣Value[Value]='true'"/>
            </TemplateRules>
          </Applicability>
                  <Concepts>
          <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d105" name="CompartmentationWall">
            <Definitions/>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
              <TemplateRule Parameters="Set[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='ExtendToStructure'␣AND␣Value[Value]='TRUE'"/>
              <TemplateRule Parameters="Set[Value]='Pset_WallCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Exists]=TRUE"/>
            </TemplateRules>
```

```
          </Concept>
              </Concepts>
            </ConceptRoot>
            <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d66" name="BuildingClass1slab" applicableRootEntity="IfcSlab">
            <!--This ConceptRoot should check if all ceilings in the basement have a fire rating. -->
            <Template ref="00000000-0000-0000-0001-000000000001"/>
                <Concepts>
          <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d606" name="FireRatingSlab">
            <Definitions/>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
              <TemplateRule Parameters="Set[Value]='Pset_SlabCommon'␣AND␣PropertyName[Value]='FireRating'␣AND␣Value[Exists]='TRUE'"/>
              <TemplateRule Parameters="Set[Value]='Pset_SlabCommon'␣AND␣PropertyName[Value]='ExtendToStructure'␣AND␣Value[Value]=TRUE"/>
            </TemplateRules>
          </Concept>
                </Concepts>
            </ConceptRoot>
            <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d67" name="BuildingClass1stair" applicableRootEntity="IfcStair">
            <!--This ConceptRoot should check if stairs used in a necessary corridor as fire exit have minimum 3 steps -->
        <Applicability>
          <Template ref="00000000-0000-0000-0001-000000000001"/>
          <TemplateRules operator="and">
            <TemplateRule Parameters="Set[Value]='Pset_StairCommon'␣AND␣PropertyName[Value]='FireExit'␣AND␣Value[Value]='TRUE'"/>
          </TemplateRules>
        </Applicability>
                <Concepts>
          <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d707" name="FireRatingStair">
            <Definitions/>
            <Template ref="00000000-0000-0000-0001-000000000001"/>
            <Requirements>
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
```

```
        <TemplateRules operator="and">
          <TemplateRule Parameters="Set[Value]='Pset_StairCommon'␣AND␣PropertyName[Value]='NumberOfTreads'␣AND␣Value[Value]='&gt;␣3'"/>
        </TemplateRules>
      </Concept>
          </Concepts>
        </ConceptRoot>
        <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d68" name="BuildingClass1escalator" applicableRootEntity="IfcTransportElement">
        <!--This ConceptRoot should check that elevators are not allowed to be used as fire exit -->
    <Concepts>
      <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d708" name="FireExitEscalator">
        <Definitions/>
        <Template ref="00000000-0000-0000-0001-000000000001"/>
        <Requirements>
          <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
        </Requirements>
        <TemplateRules operator="and">
          <TemplateRule Parameters="Set[Value]='Pset_TransportElementCommon'␣AND␣PropertyName[Value]='FireExit'␣AND␣Value[Exists]=FALSE"/>
        </TemplateRules>
      </Concept>
          </Concepts>
        </ConceptRoot>
  <ConceptRoot uuid="ea3ea778-8fa6-488d-82c3-8ad1e1c61d69" name="BuildingClass1slab" applicableRootEntity="IfcWindow">
        <!--This ConceptRoot should check if windows used as fire exit have a defined width and height.-->
    <Applicability>
      <Template ref="00000000-0000-0000-0001-000000000001"/>
      <TemplateRules operator="and">
        <TemplateRule Parameters="Set[Value]='Pset_WindowCommon'␣AND␣PropertyName[Value]='FireExit'␣AND␣Value[Value]='TRUE'"/>
      </TemplateRules>
    </Applicability>
          <Concepts>
      <Concept uuid="4dbc1987-5727-4b33-8746-9c2af9f8d709" name="FireExitWindow">
        <Definitions/>
        <Template ref="00000000-0000-0000-0001-000000000001"/>
        <Requirements>
```

```
              <Requirement applicability="export" exchangeRequirement="8781746d-68d1-4447-bf36-dbfe0fec4c8d" requirement="mandatory"/>
            </Requirements>
            <TemplateRules operator="and">
              <TemplateRule Parameters="Set[Value]='IfcWindow' AND ParameterName[Value]='OverallWidth' AND Value[Value]&gt;'0.6'"/>
              <TemplateRule Parameters="Set[Value]='IfcWindow' AND ParameterName[Value]='OverallHeight' AND Value[Value]&gt;'1'"/>
            </TemplateRules>
          </Concept>
                </Concepts>
            </ConceptRoot>
        </Roots>
    </ModelView>
</Views>
```

Bibliography

Abualdenien, J. & Borrmann, A. (2018). Multi-LOD model for describing uncertainty and checking requirements in different design stages. In: *eWork and eBusiness in Architecture, Engineering and Construction: Proceedings of the 11th European Conference on Product and Process Modelling (ECPPM 2018)*, Copenhagen, Denmark.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering* 11(3), S. 241–252.

BayBO (2007). Bayerische Bauordnung, BayRS 2132-1-B, last modified July 10, 2018. http://www.gesetze-bayern.de/Content/Document/BayBO. visited: 2018-09-08.

Bews, A. & Schurig, B. (2019). Autodesk BIM Blog: IFC Shared Parameters. http://a360.co/2CLyfTm. visited: 2018-09-20.

BIMForum (2018). Level of Development Specification Part I & Commentary, Public Comment Draft. https://www.scribd.com/document/389401769/BIMForum-LOD-2018-Spec-Part-1-and-Guide-2018-09. visited: 2018-09-30.

Borrmann, A., König, M., Koch, C. & Beetz, J. (2015). *Building Information Modeling: Technologische Grundlagen und industrielle Praxis*. Springer-Verlag.

Borrmann, A., Lang, W. & Petzold, F. (2018). Digitales Planen und Bauen Schwerpunkt BIM. Forschungsbericht, vbw - Vereinigung der Bayerischen Wirtschaft e. V.

Braun, S., Rieck, A. & Köhler-Hammer, C. (2015). Ergebnisse der BIM-Studie für Planer und Ausführende. *Digitale Planungs-und Fertigungsmethoden, Fraunhofer-Institut für Arbeitswirtschaft und Organisation, Stuttgart*.

Brokbals, S. & Čadež, I. (2017). BIM in der Hochschullehre: Entwicklung–Status quo–Handlungsbedarf. *Bautechnik* 94(12), S. 851–856.

buildingSMART e.V. (2018a). BIM know-how standards. https://www.buildingsmart.de/bim-knowhow/standards. visited: 2018-05-08.

buildingSMART e.V. (2018b). buildingSMART Data Dictionary. http://bsdd.buildingsmart.org/#. visited: 2018-08-29.

buildingSMART e.V. (2018c). Open Standards - the basics. https://www.buildingsmart.org/standards/technical-vision/open-standards/. visited: 2018-05-08.

buildingSMART International Ltd. (2018a). MVD Overview summary. http://www.buildingsmart-tech.org/specifications/mvd-overview. visited: 2018-08-31.

buildingSMART International Ltd. (2018b). Overview on mvdXML 1.1 release. http://www.buildingsmart-tech.org/specifications/mvd-overview/mvdxml-releases/mvdxml-1.1. visited: 2018-08-31.

Chipman, T., Liebich, T. & Weise, M. (2016). Specification of a standardized format to define and exchange Model View Definitions with Exchange Requirements and Validation Rules (Version 1.1). http://www.buildingsmart-tech.org/downloads/mvdxml/mvdxml-1.1/final/mvdxml-1-1-documentation. visited: 2018-09-20.

DIN 13501-1:2010-01 (2010). Klassifizierung von Bauprodukten und Bauarten zu ihrem Brandverhalten–Teil 1: Klassifizierung mit den Ergebnissen aus den Prüfungen zum Brandverhalten von Bauprodukten.

DIN 4102–2 (1977). Brandverhalten von Baustoffen und Bauteilen; Bauteile, Begriffe, Anforderungen und Prüfunge.

Eastman, C., Lee, J.-m., Jeong, Y.-s. & Lee, J.-k. (2009). Automatic rule-based checking of building designs. *Automation in construction* 18(8), S. 1011–1033.

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2008). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* John Wiley & Sons.

Federal Ministry of Transport and Digital Infrastructure (2015). Road Map for Digital Design and Construction. https://www.bmvi.de/SharedDocs/EN/publications/road-map-for-digital-design-and-construction.pdf?__blob=publicationFile. visited: 2018-09-01.

Han, C. S., Kunz, J. & Law, K. H. (1997). Making automated building code checking a reality. *Facility Management Journal*, S. 22–28.

Heilmann, S. & Weller, I. B. (2015). *Entwicklung des Brandschutzes in Deutschland vom späten Mittelalter bis zur Moderne (13. bis 20. Jahrhundert).* Verlag für Brandschutzpraxis.

Kannala, M. (2005). Escape route analysis based on building information models: design and implementation. In: *Department of Computer Science and Engineering.* Helsinki University of Technology Helsinki.

Kuligowski, E. D. & Milke, J. A. (2004). A Performance-Based Design of a Hotel Building Using Two Egress Models: A Comparison of the Results. In: *Human Behaviour in Fire Symposium*, S. 399–410.

Laakso, M., Kiviniemi, A. *et al.* (2012). The IFC standard-a review of history, development, and standardization. *Journal of Information Technology in Construction*.

Liebich, T., Adachi, Y., Forester, J., Hyvarinen, J., Richter, S., Chipman, T., Weise, M. & Wix, J. (2018). Industry Foundation Classes Release 4 (IFC4). http://www.buildingsmart-tech.org/ifc/IFC4/final/html/. visited: 2018-09-08.

Lin, T. A. & Fatt, C. T. (2006). Building Smart-A strategy for implementing BIM Solution in Singapore. *Synthesis Journal. Singapore*, S. 117–124.

NIBS (2018). National Institute of Building Sciences, National BIM Standard United-States. http://www.nationalbimstandard.org/faqs#faq1. visited: 2018-04-28.

Schenck, D. A. & Wilson, P. R. (1994). *Information modeling the EXPRESS way.* Oxford University Press.

Schiffer, S. (1997). *Visuelle Programmierung: Grundlagen, Potentiale und Grenzen.* Addison-Wesley.

Sommerville, I. & Sawyer, P. (1997). Viewpoints: principles, problems and a practical approach to requirements engineering. *Annals of software engineering* 3(1), S. 101–130.

Spearpoint, M. (2006). Fire engineering properties in the IFC building product model and mapping to BRANZFIRE.

Weise, M., Liebich, T., Nisbet, N. & Benghi, C. (2016). IFC model checking based on mvdXML 1.1. *eWork and eBusiness in Architecture, Engineering and Construction*, S. 19.

Declaration of Originality

With this statement I declare, that I have independently completed this Bachelor's thesis. The thoughts taken directly or indirectly from external sources are properly marked as such. This thesis was not previously submitted to another academic institution and has also not yet been published.

Munich, October 8, 2018

Sina Pfuhl

Sina Pfuhl
Baubergerstr. 21
D-80992 Munich
e-Mail: sina.pfuhl@gmx.de