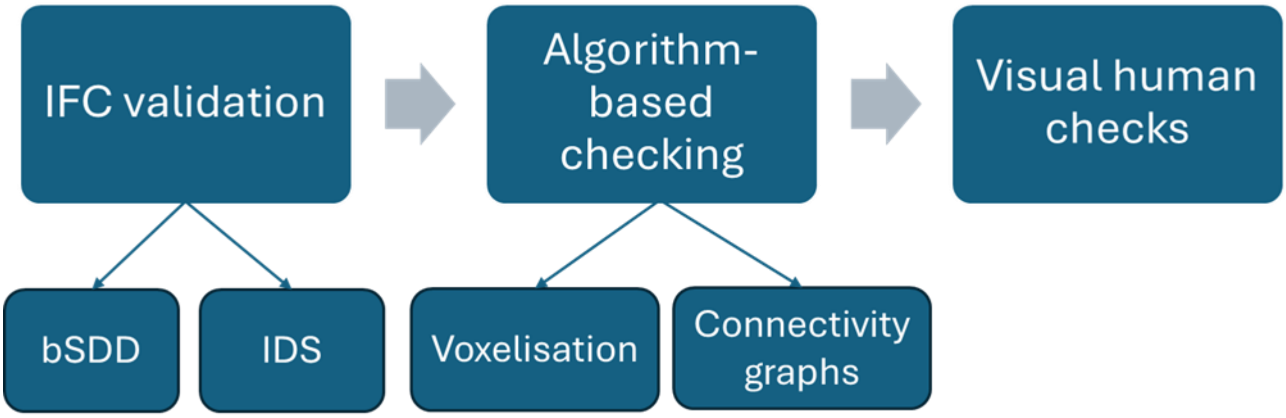
D3.2 – Information Reliability Measures Paper

August 28, 2024



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101056973.

Funded by the European Union

UK Participants in the Horizon Europe Project [ACCORD] are supported by UKRI grant numbers [10040207] (Cardiff University), [10038999] (Birmingham City University and [10049977] (Building Smart International).

Innovate UK

Funded by the European Union. The views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HaDEA). Neither the European Union nor the granting authority can be held responsible for them.

Project Title	ACCORD - Automated Compliance Checks for Construction, Renovation or Demolition Works, grant agreement No: 101056973.
Deliverable:	D3.2 – Information Reliability Measures Paper
Type:	R — Document, report
Dissemination level:	Public
Work package:	3
Lead Beneficiary:	BSI
Deliverable leader:	BSI
Contributing partners:	FUNITEC, FUI, FHG, VTT, TEGEL, SOL
Due date:	31.8.2024
Date:	28.8.2024
Status – version, date:	V0.8, 28.8.2024
Authors:	Léon van Berlo (BSI)
	Gonçal Costa (FUNITEC)
	Rick Klooster (FUI)
	Katja Breitenfelder (FHG)
	Rita Lavikka (VTT)
	Konstantin Schneider (TEGEL)
	Pasi Paasiala (SOL)

DOCUMENT HISTORY

Version	Date	% Complete	Comments	Main Authors (organisation)
0.1	15.12.2023	10	Outline of the paper	Laura Tan, Léon van Berlo (BSI)
0.2	26.1.2024	20	Main idea, contribution, title	Léon van Berlo (BSI), Gonçal Costa (FUNITEC), Rick Klooster (FUI), Katja Breitenfelder (FHG), Rita Lavikka (VTT), Konstantin Schneider (TEGEL), Pasi Paasiala (SOL)
0.3	19.2.2024	45	Review of the paper	Léon van Berlo (BSI), Gonçal Costa (FUNITEC), Rick Klooster (FUI), Katja Breitenfelder (FHG), Rita Lavikka (VTT), Konstantin Schneider (TEGEL), Pasi Paasiala (SOL)
0.4	4.4.2024	60	Change in structure	Léon van Berlo (BSI), Gonçal Costa (FUNITEC), Rick Klooster (FUI), Katja Breitenfelder (FHG), Rita Lavikka (VTT), Konstantin Schneider (TEGEL), Pasi Paasiala (SOL)
0.5	17.5.2024	75	Finetuning	Léon van Berlo (BSI), Gonçal Costa (FUNITEC), Rick Klooster (FUI), Katja Breitenfelder (FHG), Rita Lavikka (VTT), Konstantin Schneider (TEGEL), Pasi Paasiala (SOL)
0.6	30.5.2024	90	Submission to the CIB W78 conference	Laura Tan, Léon van Berlo (BSI)
0.7	25.6.2024	92	Changes based on review comments	Léon van Berlo (BSI), Gonçal Costa (FUNITEC), Rick Klooster (FUI), Katja Breitenfelder (FHG), Rita Lavikka (VTT), Konstantin Schneider (TEGEL), Pasi Paasiala (SOL)
0.8 FINAL	28.8.2024	100	Quality control and submission	Rita Lavikka (VTT)

Statement of originality:

Executive summary

This deliverable presents the results of Task 3.2, “Information Reliability Measures”, of the ACCORD project, which aims to digitalise building permitting and compliance procedures to improve the quality and productivity of design and construction processes and support the development of a sustainable built environment. This is achieved by adopting a semantic approach where different individual software components are combined to create flexible solutions that eliminate the need for expensive centralised systems that are difficult to establish and manage.

Compliance checks must yield reliable outcomes. False positives from rule checks are unacceptable as they could lead to legal complications. The rules created in WP2 and WP4 assume valid data input. For instance, a rule checking the height of a step in a stair assumes all stairs are identifiable. The rule interpreter might not recognise data representing a staircase without semantic annotation. Reliable information and correct semantic data labelling are essential for accurate permit checking. Task 3.2 explores measures to improve the information reliability of BIM models for automated building permit checking processes.

Building a good base for Building Information Modelling (BIM), which supports automated building permit processes, is a driving force for automated building permit checking. The industry has a consensus that using open data standards is crucial to this process. The Industry Foundation Classes (IFC) open data standard provides checking worldwide. It has a large semantic definition of classes (objects/entities) that is supported by almost all software tools in the architecture, engineering, and construction (AEC) domain. IFC has technically proven useful and efficient for digital building permit checking. BIM modelling, according to data requirements in IFC, is a crucial factor in achieving trusted results. However, many examples exist where the delivered IFC datasets are inconsistent or lack information, leading to unreliable results from automated code compliance checks. For example, providing values for properties inconsistent with the geometry representation can lead to a false positive result in a digital building permit check. The lack of sufficient information can result in checks not being executed or being executed incorrectly during the digital permit checking procedures.

This deliverable provides industry examples and risks of inconsistent IFC requirements. Evaluation results of known solutions to check IFC datasets without assuming semantic reliability are presented. The deliverable concludes with recommendations for government organisations, architects, engineers, and technology providers. The combination of strict information requirements, precise modelling, advanced technology, and trained human oversight is essential for a reliable automated permit-checking workflow. The results were originally published in a peer-reviewed conference paper, “BIM Information reliability consequences for digital permit checking”, which is to be presented at CIB W78 2024[1] in Marrakesh, Morocco, in October 2024.

[1] https://cibw78-conference.org/

Table of Contents

List of Figures

1 Introduction

1.1 The ACCORD Project

The ACCORD project aims to provide a framework for the digitalisation of building permitting and compliance processes, using Building Information Modelling (BIM), Geographic information system (GIS), and other data sources to improve the productivity and quality of design and construction processes. ACCORD is based on the principle that these digitised processes must be human-centred, transparent, and cost-effective for the permit applicants and authorities and, above all, relevant to the industry within which they are to be employed.

To address this challenge, ACCORD has developed a semantic framework for European digital building permitting processes, regulations, data, and tools. This framework will drive the formalisation of regulations into a set of rules and the integration of existing tools to check compliance with building codes and regulations as microservices in a dynamic ecosystem. Software solutions will be developed, providing consistency, interoperability and reliability with municipal, regional, national, and international regulatory frameworks, processes, and standards.

1.2 Objectives

This deliverable reports the results of task 3.2, "Information Reliability Measures", of the ACCORD project. Task 3.2 explores measures to improve the information reliability of BIM models for automated building permit checking processes. Compliance checks must yield reliable outcomes. False positives from rule checks are unacceptable as they could lead to legal complications. The rules created in WP2 and WP4 assume valid data input. For instance, a rule checking the height of a step in a stair assumes all stairs are identifiable. The rule interpreter might not recognise data representing a staircase without semantic annotation. Reliable information and correct semantic data labelling are essential for accurate permit checking.

This deliverable provides industry examples and risks of inconsistent IFC requirements. Evaluation results of known solutions to check IFC datasets without assuming semantic reliability are presented. The deliverable concludes with recommendations for government organisations, architects, engineers, and technology providers. The results were originally published in a peer-reviewed conference paper, "BIM Information reliability consequences for digital permit checking", which is to be presented at CIB W78 2024[2] in Marrakesh, Morocco, in October 2024.

1.3 Methodology

Task 3.2 takes an exploratory approach to formulate a hypothesis on improving the information reliability of BIM models for automated building permit checking. The exploratory research suits the investigation of a situation when there are no earlier studies to refer to, and the goal is to gain familiarity for the preliminary stage of investigation (Patton, 2002). The task follows three research steps: 1) identify known solutions to check IFC datasets without assuming semantic reliability, 2) ideate how to use them for better IFC check reliability, 3) formulate a hypothesis for future research.

[2] https://cibw78-conference.org/

2 BIM Information reliability

Automated building permit checking represents an opportunity for significant advancement in the management and verification of permits. This enhances operational efficiency and significantly improves compliance with regulatory standards. The use of digital permit checking is particularly beneficial in the construction industry, where safety and legal compliance are paramount. Buildings are one of the projects. The effort that can be invested into the design and checking it against the building regulations is small compared to those of mass-produced products. Any automation in this process has a great upside, but only when the required input for automation does not bring more work.

The state of the art in automated building permit checking is based on the use of the Industry Foundation Classes (IFC) data standard. IFC only defines the specification of objects, properties and structure of data but needs an additional definition of information requirements per use case. Experiments with adding surroundings and 3D planning information have been explored by Berlo et al. (2013) but are out of scope for this task.

Current industry practice is to define more requirements for every use case. A typical simple project already accounts for multiple pages of Excel rows with information requirements on properties and objects. Most of these are often not standardised and need to be manually added to a BIM dataset. The movement towards adding more and more information requirements is inefficient and error-prone. This creates a false sense of completeness that is unrealistic and may lead to an unjustified feeling of security. Thus, this task explores alternative solutions to defining more information requirements. It identifies industry examples where fewer requirements have led to more reliable results in digital permit checking and sets realistic expectations for digital permit checking.

A typical process of digital permit checking with BIM goes as follows:

1. In most cases, a BIM model in IFC format is required, and it must comply with a list of information requirements, usually defined in a guide provided by the administrative body (a municipality or other checking authority).

2. A permit applicant needs to adapt the modelling of the design so that the result meets the data requirements requested by the authority. In practice, this means manual work to define classes in a certain way and to add properties and values just to create an IFC that can be used for automated checking. The permit applicant generates a new IFC file specific to the permit check.

3. The permit applicant uploads the IFC file to the digital/automated permit checking system.

4. The digital/automated permit checking system relies on the semantics inside the IFC dataset to run rules to perform the check.

5. A result report is generated.

6. A human often does the final check, and other procedures might occur before the permit is granted.

This setup relies on three aspects: 1) a clearly defined set of information requirements, 2) a valid IFC file and 3) a software tool/system that executes the rules for the checks. These three aspects depend on each other. It is necessary to have the BIM model in IFC so that the software can execute the check. In addition, the information needed to perform the check also has to be provided in the

IFC model. To achieve automation of checking, the system should include all the necessary rules according to each regulation. More rules require more information in the IFC file, and therefore, the information requirements document has been extended. This results in more manual work that designers/permit applicants need to perform to enable automated checking. At some point, the manual work of adding information to an IFC file can outweigh the gains of the automated permit check. Asking for more information in the IFC to feed the checking system also increases the dependency on reliable information in the IFC file.

When the information needs to be manually added to the IFC, the reliability shifts from an automated checking rule to a user manually inputting data. For example, when an automated system checks the slope of a ramp based on a custom property value, the check relies on the manual input of a user to provide that property value. When the IFC is not structured correctly, the ramp might not even be provided in the IFC file as a proper IfcRamp, but as a different class. These situations lead to a false sense of reliability in the automated checking system. Observing a trend where more specifications are being made that ask for more data in the IFC file, the sense of security is falsely increasing, while the efficiency is decreasing due to manual labour and the risks for 'false positive' results are growing.

False positives, where the system incorrectly identifies a building permit as valid when it is not, and false negatives, where the system incorrectly identifies a building permit as invalid, must be prevented in automated building permit checking. The risks associated with false positives and negatives in digital permit checking are multifaceted and significant.

3 Potential Solutions for improving the reliability of checks

BIM-based solutions for building checking can provide better opportunities for the reliability of checks compared to traditional methods, such as those based on 2D CAD files or drawings. However, if these solutions are not implemented correctly, they can have the opposite effect. Within this BIM-based solutions context, one strategy that can help achieve greater reliability is using microservices, resulting in more flexible, smarter, and tailored checking solutions. Each microservice can be specialised to handle specific aspects of BIM models, such as geometry processing, data validation, etc. This enables a more focused and high-quality development of each microservice, including scalability and performance issues.

However, a quality check process for BIM models is required to obtain reliable results. When opting for the IFC standard, requirements can involve validations at different levels. For example, IFC models must be consistent with the IFC data schema, including the version for which they are intended to be created. In addition, they must comply with the data requirements for each type of checking. Figure 1 shows an example of different independent quality-checking services combined using a service orchestrator to create one automated check process. Nowadays, many services can be integrated through APIs.

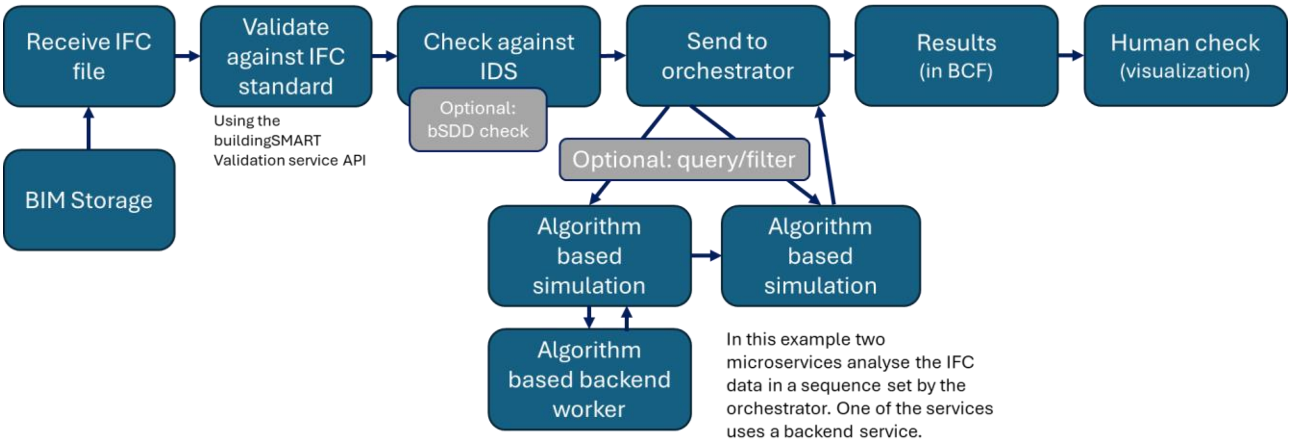


Figure 1. An example of different independent quality checking services combined using a service orchestrator to create one automated check process.

By using smart online microservices that perform specific analyses, complex calculations can be performed without entering additional (manual) information. Information can be derived instead of depending on manual, labour-intensive and error-prone inputs. Voxelization and connectivity graphs are examples of techniques that can be implemented in microservices for automated checking purposes. These are described below.

3.1 Voxelisation of geometry/agents

A voxel represents a single sample, or data point, on a regularly spaced, three-dimensional grid (See Figure 2). Using voxels as geometry instead of the default triangulated geometry opens the opportunity for different kinds of analysis. Transforming the IFC data to voxels that are independent of the semantic meaning of objects or connected properties creates a Minecraft-style visualisation. Certain human behaviour can be simulated by sending an agent (algorithm) through the voxels. This method has been applied to a minimally viable product in Estonia. The technology was used for fall detection checks and the detection of free head space. This way, non-semantic objects and wrongly classified objects are also taken into consideration. The method is quite processor-intensive. The server load would be high, and therefore, the technology is not expected to be cheap or available for free. This experiment's Technology Readiness Level (TRL) could be considered around 5 or 6. It requires quite some technical expertise to use this functionality in any environment.

Figure 2. An example where the use of voxelisation showed that people can fall from the stair flight due to a lack of protection (railing, etc.). Source: ACCORD demo country Estonia.

3.2 Connectivity Graph

Another way to derive information from the IFC data without relying on semantic definitions is using a so-called connectivity graph. Certain types of objects with certain properties are connected. Instead of manually modelling these connections, they can be derived from the geometry. For example, all public spaces are connected through doors. Calculating the fastest or shortest exit route can then be derived through analysis. An ACCORD microservice from Future Insight and BIM.works is tested to define the fire safety route. The analysis showed more reliable results than manually defined routes in the IFC data. Figure 3 shows an example. This example is a mix of using the semantic meaning of IFC objects (IfcDoor and IfcSpace) and calculating other parts. This mix is chosen since IfcDoor and IfcSpace are things that are typically already available in an IFC dataset, but escape routes are not. This way, modellers do not have to manually add information that then can be 'automatically checked'. This lowers the threshold for the applicant and lowers the reliance on manually input data. There is a broader perspective of derived values. Many attributes and properties in IFC could be derived. Examples like thickness, height, length, etc., can all be automatically and independently measured by a receiving software tool. By deriving these characteristics instead of manually entering values, many human errors, or errors in the export of the IFC, can be eliminated.

This technology is considered TRL level 7 but also requires quite some (expensive) computing power. buildingSMART International is currently experimenting with information consistency checks in the buildingSMART IFC Validation service. The information consistency checks will derive height, volume, area, and other characteristics from the geometry and compare the calculated values to the values in the attributes, properties and quantity sets. When the values are consistent (within a small margin of error), the IFC is marked as valid by the buildingSMART IFC Validation service. Otherwise, an error or warning is reported. The buildingSMART IFC Validation service is being integrated into the ACCORD framework through a newly developed API in work package 4. The TRL of this information consistency check in the validation service is currently at 4.

Figure 3. Visualisation of the calculated (derived) fire escape route.

3.3 Visual (Human) checks

Although the technologies, as mentioned earlier, will bring additional reliability to automated checks, there will always be caveats or exceptions. Therefore, for the time being, it is wise to have people continue to perform visual checks. Even the technologies mentioned depend on data input. Objects may still be incorrectly modelled, which will cause unexpected results. A typical example is an IfcDoor that is mistakenly exported as IfcWindow, breaking the fire exit route calculation. In this situation, however, it is most likely that the check will result in a negative output. In other words, no permit will be given, and the author will be stimulated to model better. In classic rule-based checking, an incorrect dataset (IFC file) can result in a false positive result (a permit is granted that should not have), which still makes the algorithmic approach the better option for the case of permit checking.

By displaying various objects with common errors in a visually distinctive manner and the correct combination, errors and inconsistencies can quickly become visible to the (trained) human eye. By setting up a number of these types of displays for different visual checks, a final quality control step can be built into the workflow.

4 Recommendations to improve information reliability of BIM models

As others have already proven by Krijnen and Tamke (2015), the algorithmic approach to IFC analysis has potential. Based on the listed potential solutions, this research suggests the following pathway for improving the reliability of BIM models and compliance checks (see Figure 4). First, IFC validation should be performed. Here, e.g. the buildingSMART Data Dictionary (bSDD) can be used. bSDD is an online service, which offers a collection of interconnected data dictionaries (buildingSMART International, 2024d). These dictionaries define terms related to the built environment. The main objective of bSDD is to maintain uniform and standardised terminology across different software applications and among various participants in the construction sector. Another solution is Information Delivery Specification (IDS) which is a format for a computer-readable document that outlines the requirements for exchanging information in a model-based format (buildingSMART International, 2024c). After IFC validation, an algorithm-based checking should be performed, including, e.g. voxelisation and connectivity graphs. Finally, visual checks should be conducted by humans to ensure accuracy and completeness.

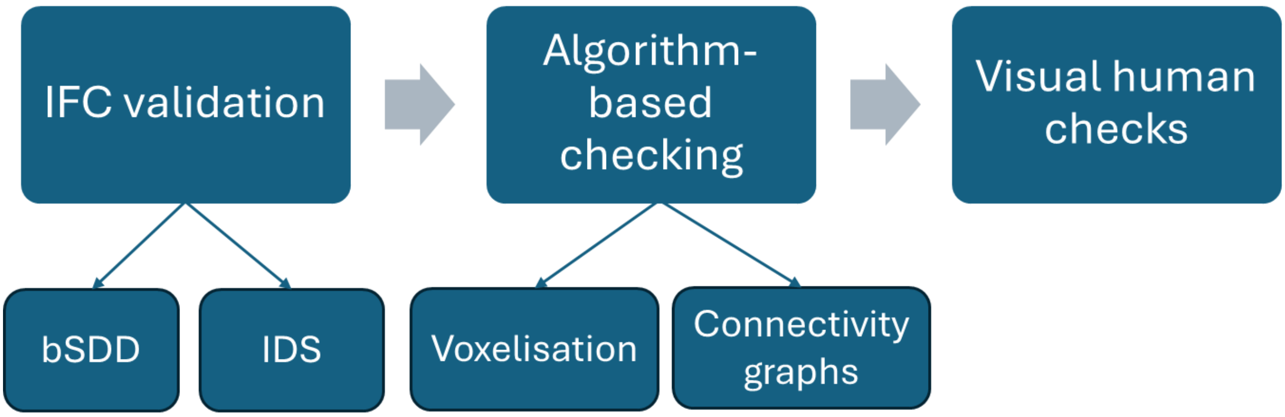


Figure 4. Steps (with suggested services and technologies) to improve the reliability of IFC files and compliance.

The three steps presented come with the following recommendations, which should be tested and verified in real-life BIM-based building projects:

- Keep the information requirements as simple and clear as possible to make it feasible. The more complex these requirements are, the more possibilities arise to interpret them. ACCORD follows the recommendation from Tomczak et al. (2022) to use the buildingSMART International (2024c) Information Delivery Specification (IDS).

- When configuring the checks and the accompanying information requirements, make sure to do this with a small multidisciplinary team of at least a permit issuer, a legal expert and a technical expert. Only this way will a proper translation of a regulation to an automated check and minimal and realistic requirements occur.

- Make sure the requirements are automatically processable. As long as requirements are only available in an Excel or PDF file, it is impossible to automatically check the quality of an available IFC file. By ensuring that the defined requirements are available in IDS, they can be checked automatically.

- Avoid dependency on manually entered values. People make mistakes, especially when entering complex values. Use libraries with the correct and certified values and, when possible, have them automatically linked to objects. This can be done using the buildingSMART International (2024d) solution for Data Dictionaries (bSDD).

- Make the quality check as easy as possible available to the people creating the IFC dataset. This allows BIM authors to check their own work. The lower the threshold and the better access to the actual testing tool, the higher the chance of a good-quality model. Communication about potential model improvements can be done using buildingSMART International (2024a) BIM Collaboration Format (BCF).

- Use the official buildingSMART International (2024b) IFC Validation service to check the quality of the IFC data.

5 Conclusion

Digital tools can create a sense of false security. This task has raised the issue of possible risks with rule-based digital permit checking with IFC. Rule-based checks can give unreliable results when the input data from the BIM is not properly modelled. As a result, this task suggests an approach where IFC validation is first performed utilising microservices. Then, algorithm-based checking, e.g., Voxelization or Connectivity Graphs, is performed. And finally, visual checks are conducted by humans to ensure accuracy and completeness.

The task explored solutions to improve the information reliability of BIM models for the use case of digital and automated permit checking. While the solutions discussed show promise, they are still in the early stages of maturity and require significant computing power. The solutions will never cover full reliability on their own either; thus, human checks and sensibility remain necessary to ensure the accuracy and completeness of compliance checks.

The task provides recommendations for government organisations and technology providers to mitigate the risks associated with poor information reliability of BIM models. The combination of strict information requirements, precise modelling, advanced technology, and trained human oversight is essential for a reliable automated permit-checking workflow. Focusing on just one of these aspects could lead to unreliable results.

6 References

Berlo, L. v., Dijkmans, T., & Stoter, J. (2013). Experiment for integrating dutch 3d spatial planning and bim for checking building permits. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-2/W1, 279–284. https://doi.org/10.5194/isprsannals-II-2-W1-279-2013

buildingSMART International. (2024a). Bim collaboration format (bcf). https://www.buildingsmart.org/standards/bsi-standards/bim-collaboration-format/ (accessed: 14.08.2024).

buildingSMART International. (2024b). Ifc validation service. https://www.buildingsmart.org/users/services/ifc-validation-service/ (accessed: 14.08.2024).

buildingSMART International. (2024c). Information delivery specification (ids). https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/ (accessed: 14.08.2024).

buildingSMART International. (2024d). Solution for data dictionaries (bsdd). https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/ (accessed: 14.08.2024).

Krijnen, T., & Tamke, M. (2015). Assessing implicit knowledge in bim models with machine learning [Design Modelling Symposium Copenhagen 2015 (DMSC 2015), September 30-October 2, 2015, Copenhagen, Denmark, DMSC 2015; Conference date: 30-09-2015 Through 02-10-2015]. In M. Ramsgaard Thomsen, M. Tamke, C. Gengnagel, B. Faircloth, & F. Schreuder (Eds.), Modelling behaviour. design modelling symposium (pp. 397–406). Springer. https://doi.org/10.1007/978-3-319-24208-8_33

Patton, M. Q. (2002). Qualitative research and evaluation methods. SAGE Publications.

Tomczak, A., Berlo, L. v., Krijnen, T., Borrmann, A., & Bolpagni, M. (2022). A review of methods to specify information requirements in digital construction projects. IOP Conference Series: Earth and Environmental Science, 1101(9).