Change toolkit for digital building permit

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Contents

1. Executive Summary

This deliverable addresses the critical need for interoperable and scalable solutions to support the digitalization of building permit processes in Europe. The fragmented landscape of standards in the construction and geospatial domains poses a major obstacle for municipalities seeking to automate compliance checks.

The objective of Deliverable D7.6. (Standards and Best Practices) is to formulate CHEK's contributions to standardization by:

- Developing, writing and testing best practices for digital building permits (DBPs).
- Contributing to the development and extension of existing standards to better support DBPs use case (but not limited to).
- Proposing new standardization items to OGC and buildingSMART to better support DBPs use case (but not limited to).
- Supporting cross-project and cross-SDO harmonization (CHEK, ACCORD, DigiChecks).

This deliverable consists of two parts:

1. **Enhanced Standards**: CHEK provided direct contributions to international standardization bodies, buildingSMART, OGC, ISO, and CEN, by improving IFC, IDS, CityJSON, and LOIN specifications, submitting actionable feedback, and initiating and extending new **approaches supporting standards**, such as the OGC Data Exchange Toolkit for geospatial standard data models profiling or OGC Building Blocks approach.
2. **Proven Best Practices**: The project formalized a series of best practices in three categories:
   a. *BP (Best Practices Based on Existing Standards)*: Application of IFC, IDS, CityJSON, and LOIN in DBP workflows and recommendations to standardization organizations (BsI; OGC) or Working Groups such as ISO/CD 23143-1 for Information exchange between BIM and GIS.Information exchange between BIM and GIS.

   b. *JBP (Joint Best Practices, for BIM-GIS interoperability)*: Orchestration of GeoBIM workflows, APIs, and validators for seamless data exchange.

   c. *Use Case Management based on the Ascoli Piceno Case: standardizing the results of the project regarding the integration of the GEOBIM standards included in the Process Map, and EIRs including the tables in appendixes related to all EIRs included in the project (e.g CHEK IFC, CHEK CITYGML). The UCM document is submitted and under review by BSI.*

Deliverable D7.6 is therefore a reference document that ensures the reusability, standardization potential, and policy alignment of the CHEK project's outcomes. It serves as a bridge between technical experimentation and international standardization, reinforcing the long-term impact of the CHEK framework and supporting EU-wide adoption of digital building permits.

2. Introduction

This deliverable outlines the CHEK project's contribution to international and European standardization efforts in the domain of digital building permits. It is produced as part of CHEK Work Package 7, which focuses on communication, dissemination, and outreach, including the formal integration of project outputs with relevant standardization frameworks.

The content of this document is based on:

- **Technical developments and pilot implementations were** conducted across several EU municipalities.
- **Expert contributions** from partners specializing in Building Information Modeling (BIM), Geographic Information Systems (GIS), and legal-regulatory frameworks.
- **Structured engagement with Standard Development Organizations** (SDOs) such as buildingSMART, the Open Geospatial Consortium (OGC), ISO, and CEN.
- **Inputs and feedback** gathered through the EUnet4DBP community and joint activities with sister projects (ACCORD and DigiChecks).

This deliverable is particularly relevant to:

- **Standardization experts** who are seeking practical use of cases and feedback on existing and proposed specifications.
- **Municipalities, policy makers and public agencies** aiming to adopt digital permitting workflows based on open standards.
- **Researchers and industry developers** who are interested in using open data standards effectively.

This deliverable builds directly on the initial plan defined in Deliverable D7.2 (Dissemination & Exploitation), reporting on the implementation of standards and following up on the plan outlined in D7.2 for submissions and recommendations to standardization organizations. It provides input to these organizations going beyond the specific use case of the digital building permit and is complementary to both D3.4 that focuses on GEOBIM best practices and D6.5, which reports best practices for the specific use case of digital building permit implementation and uptake overall. The importance of this document lies in its role as a bridge between experimental implementation and policy-level standardization, with a focus on long-term interoperability, scalability, and regulatory readiness.

2.1. Challenges: Key Interoperability and Regulatory Gaps Blocking DBPs

The CHEK pilots showed that digital building permits are not just a technical challenge – they touch legal frameworks, municipal processes, and everyday work for designers and civil servants. Below we summarize the main barriers that are still holding back large-scale adoption.

2.1.1. Data Interoperability Gaps

Although affirmed open data models exist in both the GIS and BIM domains, in both fields the use of such data models is not per se sufficient to produce a 100% interoperable model. This is due to the different ways the model itself can be interpreted and used by the data modelers and implemented in the software. This can result in inconsistent models. Moreover, the use and storage of geometries is not always easy or straightforward. For example, even certified BIM software can produce IFC files with hundreds of small but critical errors, which makes automated checks unreliable. On the GIS side, CityGML/CityJSON is powerful but suffers from potential multiple interpretations or use of the comprehensive data model, being prone to inconsistent interpretations. National examples exist to capture legal attributes such as maximum heights or setback lines, but no international options are agreed. Without consistent and validated data, municipalities cannot rely on automated processes. Moreover, BIM and GIS worlds still “speak different languages.” Among the main gaps, IFC models often come without proper georeferencing, so when they are placed in a city model they do not align with cadastral parcels or zoning layers.

2.1.2. Standardization Gaps

The standards we rely on are evolving. buildingSMART Information Delivery Specification (IDS) has proven useful for making requirements machine-readable, but it still cannot merge or interlink multiple IDS files, such as those needed for separate IFC exports covering different specifications.

In practice, CHEK often needed multiple IDS files, for BIM-to-Geo workflows, for site (plot), terrain, building data and the surroundings buildings. This limitation, discussed with the CHEK partners bSI and RDF, was identified as a key improvement point and is expected to be addressed in future IDS versions. IDS also has limited ability to express certain geometrical requirements.

Moreover, its potential to express certain rules, such as geometrical requirements is low. CityGML and CityJSON allow extensions, but zoning-related concepts still need to be formalized. The Level of Information Need (LOIN) framework is promising, but was still immature, currently missing templates that reflect regulatory purposes. And while Open APIs enable data exchange, municipalities and vendors are still missing tested orchestration patterns to make them work seamlessly in daily processes.

2.1.3 Regulatory & Legal Gaps

Perhaps the hardest challenge is not technical but legal. Many municipal rules are written in free text, full of subjective terms such as “harmonious with the surroundings” or “sufficient daylight.” These cannot yet be turned into clear machine-readable checks. Even when rules are digitized, there is no common European template for structuring them in a transparent, reusable way. This makes it difficult to guarantee legal traceability from “rule in the book” to “rule checked in the model.”

2.2. CHEK Standardization and Interoperability Strategy

To overcome these challenges, CHEK's standardization and interoperability strategy is built on five complementary activities, as initially defined in Deliverable D7.2. In D7.6, these activities are updated to reflect the latest project results, including further development of standards applied within CHEK and recommendations for submission to Standardization Development Organizations (SDOs).

1. **Activity 1- Providing feedback to SDOs to improve existing standards (Section 3) Feedback** has been submitted to buildingSMART (IDS v1.1), OGC (CityGML/CityJSON), and ISO/CEN (Level of Information Need) throughout the project, based on pilot experiences and validation testing (see Figure 2).
2. **Activity 2 - Developing best practices on how to apply current standards (Section)** CHEK produced structured guidance for IFC use in permitting, GeoBIM integration workflows (D3.4), and IDS/CityJSON profiles, ensuring municipalities and designers can adopt them consistently.
3. **Activity 3 - Ensuring integration across standards through workflows and APIs (Section 4) CHEK** promoted the use of OpenAPI and OpenCDE specifications, to ensure interoperability between online software tools, and permitting platforms, as well as OGC API Process standard, for an even higher interoperability level. This allows multiple tools (e.g., rule engines, validation services) to operate within the same DBP ecosystem.
4. **Activity 4 - Publishing a Use Case Management to guide DBP stakeholders (Section 5)** CHEK formalized its DBP Use Case Management (UCM) template, aligned with buildingSMART's UCM service.

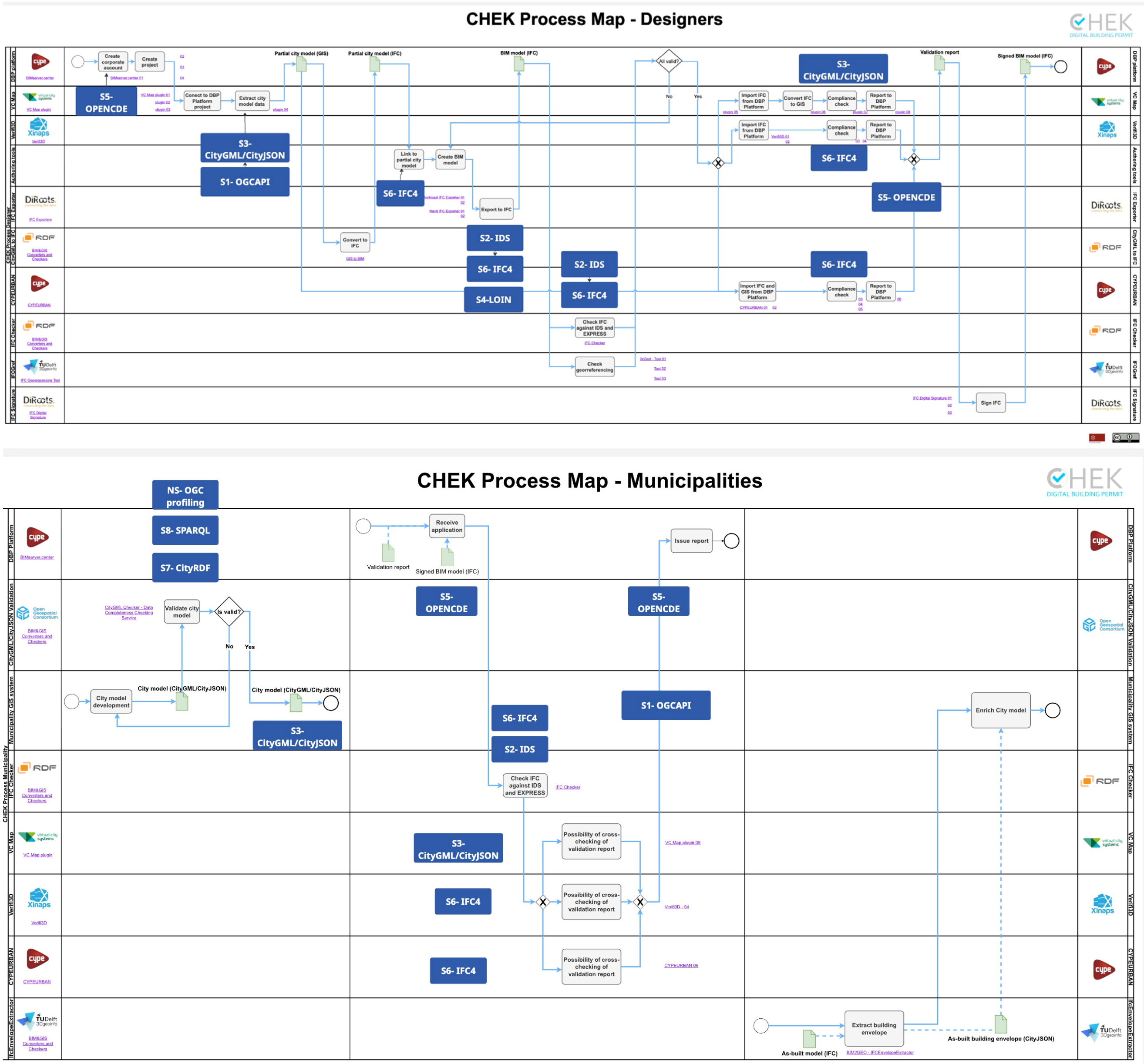

Figure 1: Used CHEK standards and exchange requirements during the designer and municipality process map workflows.

This deliverable brings together CHEK's work on standards and best practices for Digital Building Permits (DBPs), showing how the project's outcomes can guide both municipalities and standardization bodies. It covers CHEK's feedback and extensions to existing standards such as IFC, IDS, CityJSON, LOIN, and OpenAPI, and explains where each is applied within the DBP workflow (see Figure 2). It also formalizes a set of best practices: how to apply, extend, and profile IFC, IDS, CityJSON, and LOIN in permitting; how to connect BIM and GIS through GeoBIM conversions, validators, APIs, and orchestration; and how to use domain practices like the buildingSMART UCM template to structure DBP processes. Together, these elements form a bridge from pilot implementations to concrete recommendations for international standardization, supporting the path from experimental solutions towards scalable, EU-wide adoption of DBPs.

2.3. Background: Standards

OGC APIs

OGC APIs are designed to facilitate the use and provision of geospatial data on the web, integrating it with other types of information. These standards are the evolution of the previous OGC web services but define resource-centric APIs that take advantage of modern web development practices.

Specifically, the OGC API - Features allows for efficient access and manipulation of vector geospatial data, using modern web technologies such as REST and JSON. This facilitates the integration of geospatial data in web applications and promotes interoperability between different systems and platforms. OGC API - Process allows providing tools in an easily connectable and interoperable format, facilitating reuse and modularity of architectures. This approach supports scalable integration, simplifies orchestration of distributed processes, and promotes alignment with modern web and cloud-native practices.

In the CHEK project, validation and rule-checking functionality was exposed as OGC API endpoints, wrapping tools (e.g., IFC/CityJSON validation) into standardized web services. This enables modular, interoperable access to rule services across municipalities and vendor tools, following best practices of modular API design and vendor-neutral integration.

OpenAPI

An Open Common Data Environment (OpenCDE) must rely on recognized standards to ensure interoperability and long-term reliability. CHEK platform (BIMserver.center) was made fully accessible through a standardized REST API, specified according to the OpenAPI format. This enabled integration of six different vendor tools, automation of uploads, validations, and results retrieval, without proprietary connectors. During the CHEK project, and to implement the DBP platform CYPE:

- Implemented DBP workflows via OpenAPI REST APIs.
- Enabled automation and interoperability across heterogeneous systems.
- Produced APIs openly documented via Swagger with version control.
- Ensured Security via vendor authentication, user session validation, and access approvals.

GeoSPARQL

GeoSPARQL is an OGC standard that defines a vocabulary for representing geospatial data in RDF and a set of query functions for spatial relationships (e.g., topological, directional, metric). Originally published in 2012, it enables integration of geospatial information with the semantic web. The upcoming GeoSPARQL 1.3 expands support for 3D geometries and profiles, making it relevant for GeoBIM and DBP validation where both building models and land parcels need to be queried. Within CHEK, GeoSPARQL was applied alongside SHACL/SPARQL validation to formalize rule checking across BIM and GIS data, and contributions from CHEK partners have been incorporated into the evolving GeoSPARQL 1.3 specification.

CityGML/CityJSON standards

CityGML is a data model for the representation of 3D topographical data, including most of the common features and objects found in cities and landscapes, such as buildings, roads, rivers, bridges, vegetation and city furniture. It is an official standard of the Open Geospatial Consortium (OGC)[1]. GML is the default encoding standard[2]. CityJSON is a simpler JSON-based encoding of a CityGML profile including a wide part of the CityGML data model. CityJSON was chosen for the CHEK project in order to leverage more effectively the open sources tools available for it, particularly the geometric validation tools developed by TU Delft (Val3dity). CityJSON version 2.0 implements a profile of the CityGML version 3.

A CityJSON file describes both the geometry, and the semantics of the city features of a given area, as well as the relationships between them. It also defines different standard levels of detail (LoDs) for the 3D objects, which allow us to represent different resolutions of objects for different applications and purposes. The CityGML v.3 standard proposes four specific LoDs (Figure 3). CityJSON supports these LoDs but also allows additional LoDs, including the finer-grained framework by Biljecki et al. (2016), in which each LoD is refined into four different sub-levels.

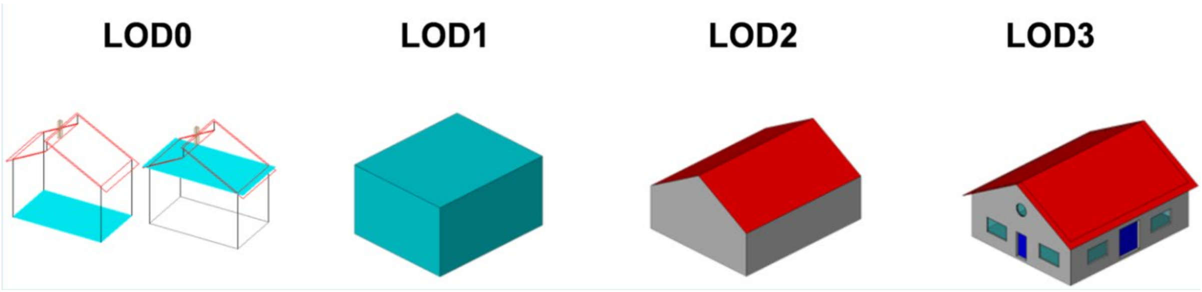

Figure 2: The four levels of detail available in the CityGML v.3 standard: LoD0 (footprint), LoD1 (block model), LoD2 (generalized roof), LoD3 (detailed exterior).

[1] https://www.ogc.org/standards/citygml/
[2] https://www.cityjson.org/
[3] https://docs.ogc.org/cs/20-072r5/20-072r5.html

Figure 3:The extended LoD framework from Biljecki et al. (2016).

The types of objects stored in CityJSON/CityGML are grouped into different modules, each of which contains different relevant city objects (i.e. classes). These are: **Appearance** (textures and materials for other types); **Bridge** (bridge-related structures, possibly split into parts); **Building** (the exterior and possibly the interior of buildings with individual surfaces that represent doors, windows, etc); **CityFurniture** (benches, traffic lights, signs, etc); **CityObjectGroup** (groups of objects of other types); **Generics** (other types that are not explicitly covered); **LandUse** (areas that reflect different land uses, such as urban, agricultural, etc.); **Relief** (the shape of the terrain), **Transportation** (roads, railways and squares), **Tunnel** (tunnels, possibly split into parts); **Vegetation** (areas with vegetation or individual trees); and **WaterBody** (lakes, rivers, canals, etc).

The geometries in a CityJSON/CityGML file are based on those available in the GML standard[4], which are themselves based on those in the ISO19107 standard. However, only linear/planar geometries are supported. Specifically, the supported types are MultiPoint, MultiLineString, MultiSurface, CompositeSurface, Solid, MultiSolid, CompositeSolid and GeometryInstance. For CityJSON, vertices are indexed and stored separately, and the geometries in a file can be validated using val3dity[5] or the online validator.[6]

[4] https://www.ogc.org/standards/gml/
[5] https://github.com/tudelft3d/val3dity
[6] http://geovalidation.bk.tudelft.nl/val3dity/

The specifications of CityJSON are defined using JSON Schema[7] and are available in the schema section of the CityJSON website. A CityJSON file can be validated against the schema using the cjval software[8] or the online validator.

Level of Information Need (LOIN):

The adoption of international standards to define the Level of Information Need (LOIN) is an effective solution for digitizing and automating the verification of design compliance with legal documents of Municipality during the building permit process. That's why municipal experts must verify that the design complies with constraints contents in the legal document. Each type of check requires that precise entities and properties are present within the Geo and the BIM models. It is therefore necessary to define the Level of Information Need (LOIN) for each entity. The LOIN framework provides a structured approach to defining the prerequisites and both the geometrical information, alphanumerical information and documentation required for a given purpose.

The mapping from the prerequisites to the LOIN ensures that the information required directly corresponds to the regulatory purpose, avoiding unnecessary complexity and maintaining consistency across municipalities. The international standards ISO 7817-1 for LOINs, ISO 19650-4 for actors involved in data exchange, and ISO 23386 for property structuring coherently GeoBIM information requirements. ISO 19650-4 supports the definition of stakeholders and roles in the digital process, while ISO 7817-1 enables uniform structuring of BIM and GIS information, promoting interoperability between domains for a specific purpose. This alignment is essential for linking BIM-based building representations with geospatial constraints typically managed in GIS environments, such as zoning levels, infrastructure networks, or cadastral data.

In order to map the necessary entities and properties, it is essential to define the data dictionaries to be used for each domain involved. For BIM data, Industry Foundation Classes (IFC) version 4.3 ADD2 was used, while for GIS, CityGML/CityJSON of Open Geospatial Consortium (OGC) and INSPIRE were used. The Level Of Information Need standard was developed and published in parallel with the CHEK development. Examples from CHEK were used within the standard itself, especially regarding the inclusion of information from both the BIM and GIS domains.

EIR (Exchange Information Requirements) does appear as an acronym to be revised within the current systematic review of the EN ISO 19650 Standard series, centered upon the notion of Information Production. However, Such Information Requirements (to be tailored according to the DBP procedure, quite different from a contractual relationship occurring between a client and a contractor) inform the LOIN for each entity. **IDS** could support partially **LOIN** in enabling the provision of machine-readable requirements dealing with the alphanumerical dimension.

ISO 7817-1

ISO 7817-1 was used to define the prerequisites and LOIN. The prerequisites allow you to define the purpose, the information delivery milestone, the actors, and the reference object. The purposes should be specified in order to clarify why the information is needed. In fact, the level of information need should be used for the purposes for which it was requested. For the use case described in this work, it was necessary to establish digital building permits as a high-level purpose and checks on the selected urban regulations (i.e. maximum building height and minimum distance between buildings and objects in the context) as purposes. Deadlines for submitting information should be specified in order to clarify when the information is required. The information delivery milestone is the design for the inclusion of information

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[7] https://json-schema.org
[8] https://github.com/cityjson/cjval

requirements in the models and the subsequent delivery of the design for the building permit process. The actors involved in this phase are defined in accordance with ISO 19650-4, as included in the following subparagraph. The specification of prerequisites is essential for specifying the level of information need for each object. In fact, the definition of LOIN is closely related to prerequisites and cannot be generalized. The level of requirements consists of three key concepts: geometric information; alphanumeric information; documentation. More specifically, geometric information should specify precise aspects such as:

- **Detail:** textual description of the object's geometry. Depending on the purposes defined in the prerequisites, it may have a simple geometry (e.g., a parallelepiped for a door) or require more finishing touches (e.g., the insertion of the fixed and movable frame and the handle in the door).
- **Dimensionality:** number of spatial dimensions that characterize the object (e.g., 0D, 1D, 2D).
- **Location:** description of the absolute location, whether relative to a reference point or relative to another object, and its orientation. If known, include the reference system.
- **Appearance:** description of the visual representation of the object, such as the colour, transparency, and reflectance of an object.
- **Parametric behaviour:** describes whether the shape, position, and orientation of the object are designed to remain dependent on other information associated with the object, or on the context in which the object is placed, allowing for complete or partial reconfiguration.

The alphanumeric information should specify:

- **Identification:** used to position an object within a decomposition structure. The name of the object, its classification, any coding, and reference structure are defined.
- **Information content:** list of all requested properties.

The last concept to be defined in order to complete the LOIN is documents. In fact, the required documents should be specified, i.e., the documentation for an object or set of objects supporting processes, decisions, approvals, and verification of the information content produced. The definition of LOIN allows for the detailed definition of the information that the object must contain according to its purpose and use. Therefore, the use of ISO 7817-1 provides a conceptual framework for establishing what information is needed, when it is needed.

ISO 19650-4

In the case of digital building permits, this structure is particularly useful for formalizing interactions between the parties involved. In this context, the information provider is the designer (or design team), who is responsible for producing the information model and technical documentation necessary for verifying building compliance. On the other hand, the information receiver is the municipality, i.e., the body responsible for regulatory check and design evaluation. The standardization of actors with ISO 19650-4 clarifies the responsibilities of each part involved in the exchange of information by structuring a transparent and traceable process for the transmission and control of information, supporting the digitalisation of the authorization process.

ISO 23386

ISO 23386 has been used to standardize the alphanumeric information contained in LOIN that is necessary for automatic verification of building compliance, such as the identification of the main facade or the “IsExternal” property for perimeter walls. As already specified in the previous paragraphs, the data dictionaries used to uniquely define objects and properties related to buildings are IFC v.4 ADD2 TC1 and CityGML/CityJSON and INSPIRE for objects and properties related to context. In addition, as required by the standard, for each property it has been indicated whether it is mandatory and whether it is calculated directly by the modelling software (such as the GUID), whether the property is required to manage the rule, the data type, and, if applicable, the list of values. The use of the standard avoids terminological ambiguities between designers, software, and public administrations, ensuring that each property is interpreted in the same way by all parties involved. Structuring according to ISO 23386 is therefore a key step towards interoperability between BIM and GIS systems and for the traceability and validation of information requirements in the context of the digitalisation of authorization procedures.

Figure 4 shows the structure of the data using the standards described above relating to the wall object for the building permit, specifically for two types of control: building height and distances between the building and surrounding objects.

Prerequisites						Level of information need									
Why		When	Who		What	How									
High level purpose	Purposes	Information Delivery Milestone	Actor(s) ISO 19650-4		Object	Level of Information Need									
			Information provider	Information receiver											
Digital Building Permit	Maximum building height - Distances	Design - Delivery plan	Designers	Municipal experts	WALL	Geometrical information	Detail	The wall must be modelled with a simplified geometry, with a single shape. Its geometric representation is influenced by adjacent objects, so a basic fitting operation is required (must include connection). No need for operating zones. It is not necessary to go into detail about the stratigraphy of the element. There is no need to further articulate the features of the wall with decorative elements.							
							Dimensionality	3D							
							Location	Absolute - CRS - EPSG:3004							
							Appearance	Not requested							
							Parametric behaviour	Not requested							
						Alphanumerical information	Identification	buildingSMART Data Dictionary WALL - IfcWall [https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/link/ifcwall.htm]							
							Information content	Code	Name	Description	Example	Interconnected data dictionaries management rule	Request from management rule	Type	List of values
								PA01	Globally unique identifier	Globally unique identifier	538b13b8-7bfe-4105-ab87-	Mandatory Calculated	Not relevant	String Single-value	-
								PA02	IsExternal	Given that it defines the function of the wall. It distinguishes the perimeter wall from the interior wall.	Yes	Mandatory	Mandatory	List Single-value	Yes No
						Documentation	Set of documents		Not requested						

ISO 23386

Figure 4: Structuring of data relating to the wall object in accordance with ISO standards

During CHEK project, LOIN ensured DBP models contain exactly the level of information needed for automated checks. CHEK applied ISO 7817-1, ISO 19650-4, and ISO 23386.

Industry Foundation Classes (IFC)

buildingSMART and ISO standard (ISO 16739) that describes an open data model for the management of information on buildings and construction projects. Growing needs from construction and asset management use cases has generated the need to anchor these models in a geospatial context (coordinates, reference systems). From version 4 of IFC, a set of classes, among which, primarily, IfcMapConversion (IFC4) offer a formal framework for specifying the geographical location of an IFC model. However, in practice, there was a lack of clear guidelines for their systematic use, especially due to how BIM authoring software uses such classes in the IFC exporting phase.

The upcoming buildingSMART IFC 5 standard represents the next major evolution of the Industry Foundation Classes, building on over three decades of openBIM development. IFC 5 introduces a modernized and more consistent data model, addressing long-standing challenges in interoperability, performance, and scalability. It is designed to better support infrastructure as well as buildings, ensuring alignment across the entire built environment. With a stronger focus on linked data, semantic clarity, and streamlined exchange mechanisms, IFC 5 will enable more precise information requirements and more reliable digital workflows. Developed in collaboration across the wider buildingSMART community, IFC 5 is set to become the foundation for the next generation of openBIM solutions, ensuring that data remains usable, future-proof, and open.

CHEK pilots revealed several limitations in current IFC use for permitting, especially around GeoBIM integration, georeferencing, and IDS. These gaps were discussed with bSI partners and are proposed as upgrade inputs for IFC 5 or future versions.

Geo ↔ BIM integration: Current workflows struggle with parcels (plot modeling), surrounding buildings, and urban context. IFC's IfcSite can represent plots, but Revit does not support multi-sites, and cadastral parcels are not natively handled. Surrounding buildings are often modelled as proxies, and constraints such as building lines or gross floor areas depend on external converters or rule-checking tools. CHEK proposes extending IFC to better handle multi-plot scenarios, codify surrounding building categories, and improve gross area and floor number outputs. These improvements would reduce reliance on ad-hoc tools and make DBP checks more robust.

Georeferencing: BIM authoring software still exports IFC with inconsistent coordinate reference systems. CHEK recommends enhancing IFC 5 with explicit projected CRS support (e.g. IfcCoupleCRS) to improve accuracy and ensure BIM–GIS alignment, a key requirement for urban permitting.

IDS and CHEK IFC: Current IDS files cannot reference each other, which creates inconsistencies, and geometry requirements are only partially supported. CHEK proposes standardized IDS authoring guidelines, the ability to interlink IDS packs. This would make requirement validation more modular and scalable across municipalities. This would make requirement validation more modular and scalable across municipalities.

3. Standards Used, Extended, or Evaluated in CHEK

The Open Geospatial Consortium (OGC) and buildingSMART International (bSI) organizations provided a relevant part of the standards involved in CHEK.

The general approach to the development of currently existing and maintained standards followed the phases:

- **Throughout the project** Continuous report and exchange about the use of each standard with the Standard Development Organization (SDO) staff (whether partners in the project, such as buildingSMART and OGC), first, and with the community of members supporting and developing the standard itself. This happened within the Member meetings and using standard development groups mailing lists or contacts to share or discuss specific issues or proposals. It allowed us to keep the interested people up to date and possibly influence the development direction of the working groups.
- **End of the project** Submission of specific feedback from the tests and/or development proposal to improve the standards after the achievement of related CHEK results, including with this deliverable.
- **End of the project and beyond]** Following according to the specific standardization procedure for each case.

During the course of the project, the work was developed closely with buildingSMART International (bSI), the Open Geospatial Consortium (OGC), ISO and CEN, providing feedback on the evolution of existing standards. The remainder of this section documents each of these standards, how they were further developed or evaluated in CHEK, evaluation of the relevance and including limitations and **recommendations to SDOs** and **practical guidance**.

S1 – IDS specification standard

Lead partner	RDF	**Related task**	T2.4, T2.2
Standards Development Organisation (SDO)	buildingSMART International	**SDO WG/Task Force**	TBD
CHEK contribution to the standard development	At the CHEK proposal writing stage, mvdXML was the dominant open standard for requirement capture. During CHEK mvdXML was deprecated by buildingSMART. We made a reassessment with 5 different options, and IDS was selected as a more practical and up-to-date alternative, despite the absence of an official release at that time. CHEK contributed by: Developing a standalone open-source IDS validator (RDF) made available on GitHub. Updated to support IDS 1.0 once available. Collaborating with vendors (e.g., Solibri) to improve IDS support and resolve interpretation issues. Developing IDS-based IFC exporters for Revit and ArchiCAD (by DiRoots) that allow CAD users to align IFC exports with IDS requirements.		

Best practices	- Transition from outdated mvdXML to IDS for clearer requirement specification. - Open-source IDS tools and validation pipelines to ensure transparency. - Vendor collaboration (Solibri, DiRoots) to strengthen market support for IDS adoption. - IDS Specifications good practice based on CHEK project, is to separate files into 4 IDS for each pilot, and Entities mapped automatically via IFC Exporter to these 4 IFC formats: • IFC of the building • IFC of the undeveloped plot • IFC of the topography • IFC of the neighboring buildings
Limitations	- IDS currently lacks the ability to reference other IDS files. - IDS is limited for explicit geometrical requirements. - Challenge to interlink separated IDS files and standardize requirements to avoid inconsistencies. - Inconsistency in the definition of the standard, partly IFC independent, partly IFC dependent
Recommendations to SDOs	- Based on CHEK outcomes, extend IDS 1.x to support modular referencing between different IDS files. - Promote integration of IDS into mainstream CAD workflows, ensuring broader vendor uptake. - This limitation, discussed with the CHEK partners bSI and RDF, was identified as a key improvement point and is expected to be addressed in future IDS versions. IDS also has limited ability to express certain geometrical requirements. - Enhance the IDS concept and functionalities to include geometrical constraints and the representations of requirements which are currently provided as human-readable modelling guidelines (D2.2), since no standard for machine-readable alternatives is available.

S2 - CityGML Standard

Lead partner	OGC	**Related task**	T2.4
Standards Development Organisation (SDO)	OGC	**SDO WG/Task Force**	CityGML SWG / CityJSON community / CityRDF initiators group/ OGC CityGML SWG
CHEK contribution to the standard development	CHEK adopted CityJSON as the encoding for CityGML to align with developer workflows and simplify implementation in DBP tools. CityJSON's extension mechanism enabled the addition of DBP-specific attributes (e.g., legal height, façade/windows) while leveraging existing CityGML data model classes and attributes. This provided a practical and developer-friendly basis for regulatory data exchange. In order to enable semantic validation via the OGC Data Exchange Toolkit, the needed data model profile and involved datasets have been converted to linked data technologies formats (RDF-		

	SHACL). From these attempts and synergizing with the ACCORD sister project, the development of an RDF encoding for the CityGML data model was initiated (CityRDF[9]).
Limitations	Need for profiling, following the best practice described. No official RDF implementation existing Profiling mechanism not standardized as an official best practice yet.
Recommendations to SDOs	Acknowledge the profiling practice and building blocks approach officially. Ensure standard dignity to different CityGML encodings, including CityJSON and CityRDF in the future. Follow up with the CityRDF implementation Document profiles and alignments between the different encodings. Dissemination through OGC-led webinars for broader community uptake. OGC: formalize CityRDF and CityRDF uplift workflows as Best Practices for validation. Promote integration of CityRDF methods in wider OGC Urban Digital Twin and validation activities.
An outcomes standardization strategy	The results obtained from using CityGML and experimenting with the related practices are relevant reference for making the standard used, connected to other key technologies and organized according to an agile and flexible approach. The next step is to bring these materials to the Standards Working Groups for being used in the standardization process itself. Furthermore, additional developments were achieved in the ACCORD project, sister project of CHEK, with which we need to synergise to obtain higher quality results. The diagram in Figure 5 represents a proposal about the follow up from the two projects to the CityGML Working Group, as well as to additional entities, which might result in the chartering of additional Working groups. For example, a discussion with bSI on the need of connecting OGC vocabularies with the buildingSMART Data Dictionary (bSDD) is already ongoing to initiate some joint developments and common profiling approaches. The time frame expected for systematize such inputs is approximately two years, during which they can be further developed and tested within further use cases. According to the success of some tested approaches (e.g. building blocks approach for standard developments) a proposal is under development for OGC to change some of the high-level policies to integrate such good practices (see the examples in the best practice section below).

[9] https://github.com/ogcincubator/cityrdf

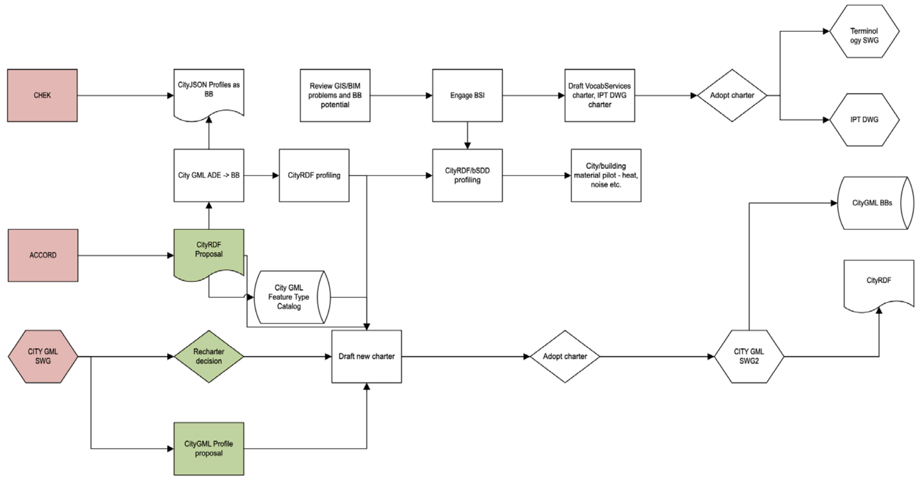

Figure 5: Standardization strategy to bring the results of CHEK into the current standardization activity.

S3 – Level of Information Need (LOIN)

Lead partner	UBS	**Related task**	T2.1, Results LOIN APC
Standards Development Organisation (SDO)	**ISO/CEN** Link	**SDO WG/Task Force**	SO19650 / CEN TC442 WG3
CHEK contribution to the standard development	CHEK defined LOIN templates tailored to digital building permitting (DBP) use cases such as maximum building height and minimum distances to boundary using International Standard (ISO 7817-1; ISO 23386; ISO 19650-4). Data dictionaries such ad IFC (version: IFC4.3) and CityGML/INSPIRE were chosen to uniquely define the properties and, after specifying the prerequisites, the data was structured according to ISO 7817-1, specifying the geometrical information, alphanumerical information and supporting documents required for regulatory checks.		
Limitations	Current LOIN standards do not fully cover regulatory or GeoBIM-specific needs. Limited adoption of DBP-oriented LOIN templates in municipalities; broader dissemination is needed.		
Best practices	Formalizing LOIN templates for regulatory requirements. Using IFC (v. 4.3) + CityJSON/INSPIRE data dictionary to capture both geometry and semantics. Embedding DBP-specific rules into structured templates for consistency.		
Recommendations to SDOs	ISO/CEN: expand LOIN guidance to explicitly cover regulatory purposes. Include different levels (e.g., high level purpose) in the scope of the prerequisites for the application of LOINs in order to fully define the context in which one operates. Integrate DBP use cases into ISO 7817-2 and extend LOIN templates with geometrical and semantic context requirements from GIS moving towards a GeoBIM vision. Alphanumeric data is standardized through the application of IDS, whereas standards or microservices would need to be developed for geometric information.		

S4 – IFC

Lead partner	RDF	**Related task**	T2.2 CHEK IFC
Standards Development Organisation (SDO)	buildingSMART International	**SDO WG/Task Force**	buildingSMART regulatory and technical domains.
CHEK contribution to the standard development	CHEK used IFC4 ADD2 TC1, the most up-to-date and sufficiently supported ISO version at project start. Adoption of IFC4.3 ADD2 is ongoing but not yet supported by many CAD tools used in CHEK. Future alignment with IFC4.3 is essential, as it strengthens georeferencing and improves validation reliability.		
Best practices	IFC with georeferencing as a foundation for BIM–GIS integration. Use of open-source validators (IDS) to detect schema/syntax issues. Systematic validation of IFC exports as part of workflow.		
Limitations	Many CAD systems lack proper georeferencing support in IFC. Thousands of export errors were identified in files from certified CAD tools. Ambiguous or undefined representation specification for some elements. For example, it is important for digital building permit use case, to represent certain elements, which need to be references for the checks (e.g. building main entrance) or, on the contrary, should be excluded from calculations and analysis in some case (e.g. balconies, chimneys, decorations). The representation of context elements, especially other buildings, is not foreseen in IFC and it generates issues in the import of different files representing the context and the new building together. Used IFC4 Add 2 standard, is limited in IFC entities and parameters that serve the Regulatory affairs. The lack of IFC entities with geometry ready to represent elements like parcel, parcel boundary, building footprint, facade decor, parking lot/lots, setbacks/recessions etc. is hindering the DBP processes. Also, there is a need for adding parameters to the schema too, like Building Height, Total Height, SetbackFront/Side/Rear, Parking Type etc. Generally, there should be a dedicated property set for regulatory affairs, like Pset_Regulatory Check. The limitation on software vendor side is that it is very complex to export multiple buildings as separate IfcBuilding on one IfcSite and in one IfcProject. The buildingSMART International's Validation Service is reporting errors every time on submitted IFC files. This creates confusion for practitioners since it seems that the problem is in the BIM authoring tools.		
Recommendations to SDOs	- buildingSMART: strengthen certification/validation services for IFC4.3 to ensure reliable exports. - IFC roadmap: consolidate georeferencing improvements to support BIM–GIS use cases. - Based on CHEK results buildingSMART recommendations are to use IFCCoupleSRS to associate accurate reference systems in the next IFC version (IFC5) and will integrate IDS and BCF for the upcoming upgrades of the version to include explicit geometry requirements as it was a limitation faced during CHEK project and reported to buildingSMART international. - Integrate the classes specification to represent in a standard way the entities involved in building permit checks (balconies, main entrances, facades, main facades, chimneys) and the elements of the context that should be considered in		

	the regulations checks or contribute to the design of buildings as reference (e.g. other buildings in the neighborhood)

S5 - Modeling Guidelines alongside IDS

Lead partner	RDF	**Related task**	T2.5/T2.2
Standards Development Organisation (SDO)	buildingSMART International	**SDO WG/Task Force**	TBD
Description	While IDS now provides a machine-readable way to express most model requirements (including geometry), it does not yet replace the need for clear **human-readable modeling guidelines**. For Digital Building Permits, guidelines ensure that designer's model consistently (e.g., setting *IsExternal* flags, roof intersections, or storey areas), making IDS validation effective and supporting automation.		
Best practices	- Always complement IDS files with concise, human-readable modeling guidelines. - Specify geometry, attributes, and documentation in a form understandable by both software and designers. - Ensure consistency across municipalities and projects by reusing shared guideline templates.		
Limitations	No official bSI standard yet exists for standardized modeling guidelines. Municipalities currently rely on project-based templates.		
Recommendations to SDOs	**buildingSMART:** Develop a formal specification for modeling guidelines to accompany IDS, ensuring global consistency. CHEK recommends establishing this as a standard in future IDS versions.		

S6 – RDF/SHACL/GEOSPARQL

Lead partner	OGC	**Related task**	T2.4
Standards Development Organisation (SDO)	OGC	**SDO WG/Task Force**	GeoSPARQL WG
CHEK contribution to the standard development	CHEK actively contributed to the GeoSPARQL WG by submitting 3D geometry use cases (BIM and GEO checking) and providing pull requests for semantic and editorial improvements. CHEK partners also co-authored requirements for GeoSPARQL 1.3 and participated in GeoNovum activities, including a whitepaper on future semantic integration. GeoSPARQL was showcased in webinars as a key enabler for linking 2D land parcel data wth 3D building models.		
Best practices	- Use of SHACL and SPARQL for automated validation of CityGML/CityJSON datasets. - Contribution of BIM/GIS-inspired 3D use cases to international standardization. - Active knowledge dissemination through OGC/W3C webinars and whitepapers.		

	- Reuse existing standards and ontologies whenever possible.
Limitations	GeoSPARQL 1.3 still under development; limited implementation in tools. High complexity of SHACL/SPARQL rules limits accessibility for municipalities without specialized expertise. No official RDF ontology for CityGML/CityJSON (“CityRDF”) exists, hindering interoperability with regards to semantic representations of city datasets.
Recommendations to SDOs	OGC: accelerate finalization of GeoSPARQL 1.3 with stronger 3D/GeoBIM support, and of CityRDF. W3C LBD CG: promote reusable SHACL shapes for building and land-use validation.

4. Best Practices in CHEK

Based on the results of the project, best practices are proposed, starting from the project's deliverables. These best practices will be submitted to the relevant Standard Development Organization working groups and sent to the relevant community for further testing, feedback collection, review, and final approval. The procedure will continue after the end of the project, according to the timing and procedure foreseen by the involved standardization organization.

Best practices are organized in three categories:

1. **Best practices (BP) for Existing Standards** (how to use IFC, IDS, CityJSON/CityGML and LoIN correctly in DBP), see Section 4.1.
2. **Best practices on Joint Connection, Integration & Interoperability (Joint best practices –JBP)** (how to connect BIM–Geo and orchestrate services), see Section 4.2.

Each entry below indicates the purpose, a short "how to apply" sequence, and the SDO pathway (where relevant). Milestones match the project schedule and the D7.6 workflow. Some of the Best practices are already detailed in other project deliverables or in appendix, including the best practice on GEO and BIM integration (JBP1) (D3.4), and the use case management practice.

4.1. Best Practices for Existing Standards (BP)

Throughout the CHEK project, interim guidance was shared with relevant SDO working groups (buildingSMART, OGC, ISO, CEN), and iterative feedback was collected. With consolidated results, CHEK has prepared best-practice documents that demonstrate how open standards can be profiled and applied in the **Digital Building Permit (DBP)** domain. These practices will be submitted to SDO WGs and broader communities for review, testing, and formal approval. Updates may continue beyond the project in line with SDO procedures.

Below, we present the guidelines, reports for good practice developed during the project, which include the key approaches, methodologies and recommendations to guarantee interoperability, standardization and effective adoption of the proposed solutions. These guidelines have been developed in collaboration with industry experts and standards bodies, with the aim of facilitating their implementation in different regulatory and technical contexts.

BP1 – Leverage CityGML different encodings

Lead partner	OGC/TUD/TUD	**Related task**	T2.3 T2.4	Link	**Link**
Description	Use the encoding of CityGML which is mostly useful for the intended application and tools to be used. CityJSON is advised for streamlined encoding and developer adoption. The under-development CityRDF is advised for semantic validation purposes (via the OGC Data Exchange Toolkit) and linked data processing. Tools are available to support such conversions, such as citygml-tools[10] and the OGC Data Exchange Toolkit itself.				

[10] https://www.cityjson.org/tutorials/conversion/

BP2 – Profile CityGML for the intended use case (e.g., DBP) for data retrieval / modelling and validation

Lead partner	OGC/TUD	**Related task**	T2.3 T2.4	Link	**Link**
Description	Use standard data model profiling mechanism, via OGC Data Exchange Toolkit, to specify the required subset of the data model and possibly extend the existing classes and properties with DBP-specific attributes (e.g. legal height, façade/window requirements). Implement modular profiles at a sufficiently granular level such that they can be easily reused for other cases and register them as OGC building blocks. Possibly, a set of profiles might be indicated in the future as a template for DBP city data requirements, likely coming from analyzing a sufficient number of implementation cases in practice. CHEK defined CityGML/CityJSON profiles[11] tailored to DBP workflows for the regulations chosen. Profiling ensures that 3D city models can encode city and building-level information, LoDs and regulatory attributes. Profiles are specified by identifying the necessary objects and information represented in the dataset, which are useful for checking the regulations, starting from the regulatory text interpretation itself. Detailed requirements need to be explained. These are later mapped to the relevant standard data model (CityGML in this case) and attributes or metadata attributes filled as comprehensively as possible. Data requirement profiles are defined using the RDF Profiles Vocabulary to describe their metadata, and a collection of SHACL shapes containing the actual checks to be performed. Other vocabularies are used for metadata properties, such as the Dublin Core Metadata Initiative (DCMI) Metadata Terms10 for commonly used properties, or the Software Description Ontology11 and the Hydra Core Vocabulary12 for the profile input parameters. A sample profile definition, in RDF Turtle format, and with the core metadata items supported by the application, a SHACL shapes artifact (i.e., document containing the actual shapes), and a single optional input parameter ("myParameter") **The OGC Data Exchange Toolkit** The OGC Data Exchange Toolkit, developed as a methodology and initial prototype, supports standard-based data requirements definition and semantic validation, against a standard data model profile, in connected machine-readable and human-readable formats. It is based on semantic technologies (OWL, RDF, SHACL) leveraging the OGC Registry for Accessible Identifiers of Names and Basic Ontologies for the Web (RAINBOW) and was mostly tested with CityJSON so far. A methodology has been defined for representing GIS (in CityGML or CityJSON format) and INSPIRE (in XML, GML or JSON format) data as linked data (RDF) by using the semantic data pipelines functionality provided by the OGC Data Exchange Toolkit, on top of which complex validation rules (data completeness, building regulations) can then be applied. Sample pipelines have been developed for validating the completeness of CityJSON and INSPIRE GML datasets.				

[11] https://github.com/ogcincubator/chek-profiles

Due to the unavailability of normative RDF ontologies for this goal, ad hoc target RDF models are currently being used; however, the pipelines can be adapted in the near future should this situation change.

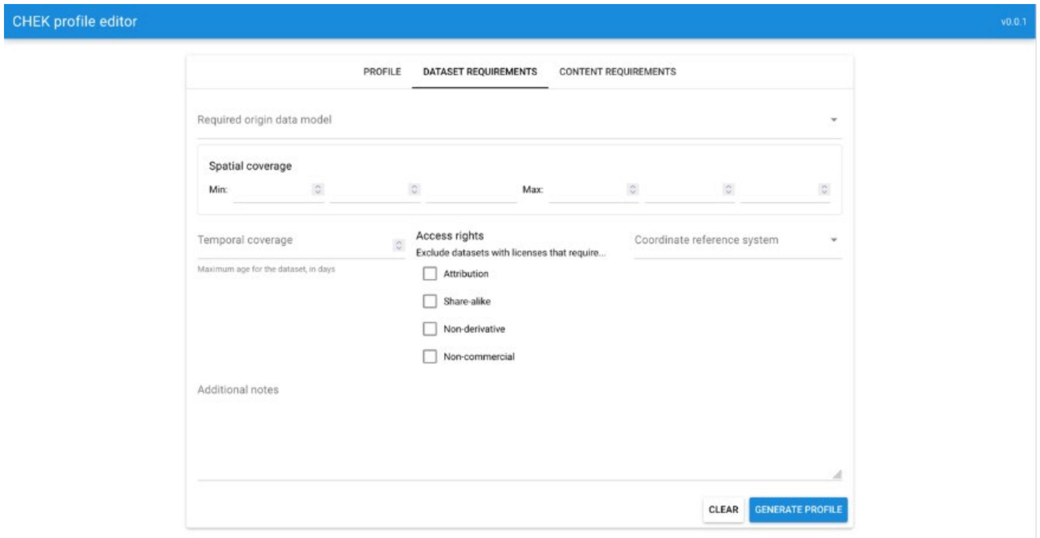

Figure 6: OGC Data Exchange toolkit user-friendly interface

In order to implement the OGC Data Exchange Toolkit described above (Figure 6), allowing the expression of data requirements in machine readable format, some preliminary steps were necessary, including the encoding of the reference data models in linked data formats and the semantic uplift of datasets to perform the initial testing phase. Relevant part of the developments towards the implementation of a CHEK CityGML validator has been achieved in n the T2.4 (see Annex 2 – Validation workflow for detailed achievement).

To be able to perform complex data validation rules checking that may span datasets across different formats, input data is first converted into RDF as a common metamodel. RDF allows accurately describing the data and describing links for entities across datasets. Additionally, the Shapes Constraint Language (SHACL), a language for defining validation constraints that can be applied to RDF data graphs, and for which several mature implementations exist, can be employed to codify the checks and requirements necessary for CHEK.

OGC Building Blocks

The OGC Building Blocks[12] are part of the OGC RAINBOW[13] ecosystem, whose goal is to facilitate the creation and reuse of semantically enabled resources for developers and implementers, fostering both reusability (by “packaging” common practices and solutions to frequent problems as documentation, JSON Schemas, JSON-LD contexts, etc., to help implementers not to “reinvent the wheel”) and interoperability (by providing a centralized and common understanding that different implementations can refer to).

[12] https://blocks.ogc.org
[13] https://defs.opengis.net/prez/

	The OGC Building Blocks borrow the Object-Oriented Programming concepts of inheritance and composition to compartmentalize and modularize concerns. Thus, the author of a given building block can also reuse other building blocks either to specialize in their behavior or to leverage them as components. They enable the implementation of modular and flexible architectures facilitating scalability of standardized solutions. Additionally, the Building Blocks come with tooling support and can be deployed on GitHub infrastructure, featuring ready-to-use CI/CD/CT pipelines for automated deployment and validation. In the context of CHEK, the OGC Building Blocks have been used to define each of the profiles supported by the data requirements validator (OGC Data Exchange Toolkit), as well as their relationships (e.g., profile inheritance / specialization). New building blocks for validation profiles (and even new collections of building blocks) can also be defined in the future. The diagram in Figure 7 depicts the practice workflow to be used for contributing to building blocks developments.

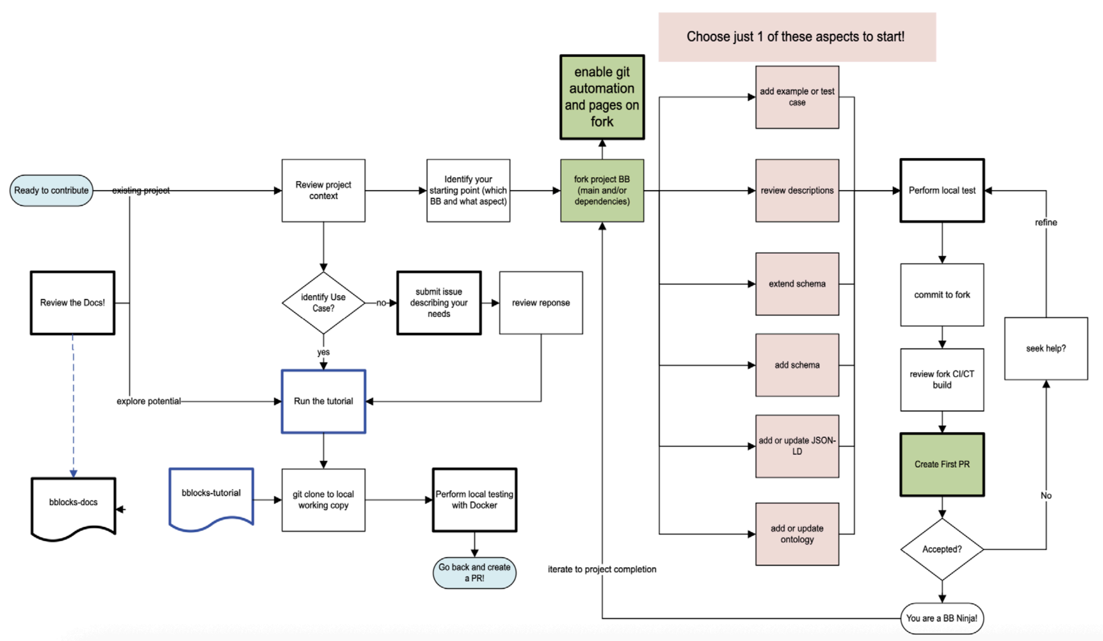

Figure 7: OGC Building blocks approach

BP3 – Validate CityGML data against the defined data requirements (standard profiles) data against the defined data requirements (standard profiles) (standard profiles)

Lead partner	OGC/TUD	**Related task**	T2.3 T2.4	Link	**Link**
Description	Use the OGC Data Exchange Toolkit, integrated with Val3dity (by TUDelft) to validate semantically and geometrically the CityGML data (in CityJSON encoding). This step makes the data reliable and trustworthy. The standard profiles defined in the previous step should be leveraged to validate the data against them.				

	The following diagram shows an overview of the whole process for providing SHACL-based data requirements and how these are used to validate datasets against them, once such datasets are converted from INSPIRE and CityGML into RDF in the OGC Data Exchange Toolkit.

BP4- How to use IFC for permit requirements and validation

Lead partner	RDF	**Related task**	T2.2 T2.4	Link	Link
Description	IFC was profiled into **CHEK IFC** using **IDS1.0** and extended with custom Property Sets (e.g., *Height*, *NumberOfLevels*, *IsCornerBuilding*). An IFC validator ensures that BIM models meet DBP requirements before automated rule checks. Exporters and post-processing tools improve model validity.				

BP5- How to use IDS (Information Delivery Specification) for DBP Requirements

Lead partner	RDF/BSI	**Related task**	T2.2 T2.4	Link	IDS Checker – RDFApps GitHub
Description	CHEK specified **DBP-specific IDS profiles** based on Exchange Information Requirements (EIRs) and Level of Information Need (LOIN). IDS made requirements machine-readable and testable in IFC files. You can refer to the deliverable's link above to learn how IDS have been defined in CHEK.				

BP6- How to apply Level of Information Need (LOIN) to DBP

Lead partner	UBS	**Related task**	D2.2, D2.3	Link	
Description	LOIN was applied to map **permit-specific requirements** (e.g., LOIN needed for building height vs. floor area). CHEK highlighted gaps in current LOIN standards, Recommendations included extending LOIN with **DBP-specific attributes and for GEO context requirements**. Based on CHEK results in regulations interpretations, LOIN is recommended as a crucial practice to define minimum requirements (geometrical and alphanumerical) from both BIM and GEO context before starting DBP project, to facilitate encoding into IDS and other machine-readable format. See in the Figure 8 below the results of the LOIN created for the project pilot (municipality of Ascoli Piceno)				

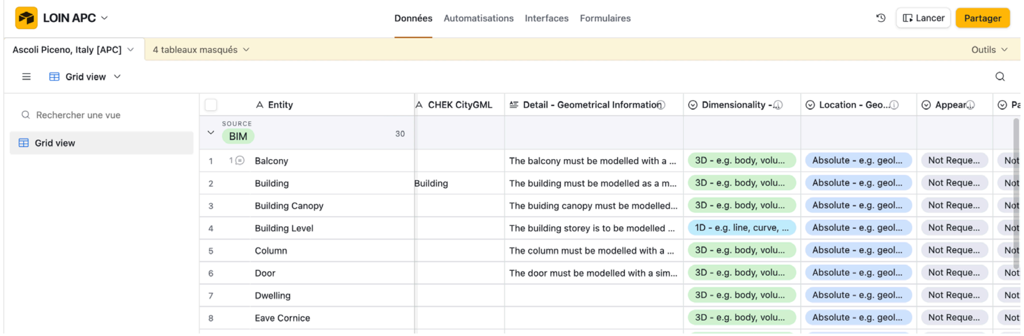

Figure 8: LOIN table for Ascoli Piceno

4.2. Best Practices on Connection, Integration & Interoperability (JBP)

CHEK addressed interoperability challenges by developing joint best practices (JBPs) that bridge standards (IFC, CityGML/CityJSON, IDS, APIs) and ensure that DBP workflows can run seamlessly across BIM and GIS workflows and software. These practices will be submitted to relevant working groups (like the BIM-GIS group) for endorsement as formal best-practice documents at (joint) OGC, buildingSMART, ISO, and CEN.

Table 1: Joint Best practices for DBP integration and interoperability.

Cross-SDO collaboration on interoperability and integration workflows

Best Practice Title	Standards Involved	SDOs	Related Tasks	Lead Partner	SDO WG / Task Force	Reporting Period (SDO WGs)	Final Proposal Submission	SDO Policy / Expected Output
JBP1 – GeoBIM Interoperability for DBPs (BIM2GEO conversion and federation)	IFC4.3, CityGML/CityJSON, OGC APIs	OGC, bSI (GeoBIM WG), ISO/TC211, CEN/TC442	T3.1–T3.3	TUD	OGC GeoBIM DWG, bSI Regulatory Room	M18–M30	M36 (Sept 2025)	Best Practice package consolidating BIM↔Geo workflows, submitted to OGC/bSI.
JBP2 – City Validation Workflows for DBPs	CityGML/CityJSON, SHACL, val3dity, OGC API Processes	OGC	T2.4, T4.4	TUD	OGC CityGML SWG, Urban Digital Twin DWG	M20–M32	M36 (Sept 2025)	Proposed OGC Best Practice on validation-first DBP workflows.
JBP3 – OpenAPI and OpenCDE Orchestration for DBPs	OpenAPI 3.0, OpenCDE APIs, IFC Digital Signature	bSI, OGC	T4.4, T4.5	CYPE + BSI	bSI API Room, OGC API DWG	M22–M34	M36 (Sept 2025)	Contribution to bSI OpenCDE and OGC API standards, ensuring DBP interoperability.

Joint Best Practices	Collaborating SDOs	Timeline
3	4	2023-2025 Development and submission

JBP1 -Best Practice on Geo and BIM integration – check D3.4 for detailed practices

Lead partner	TUD	**Related task**	T3.3, T3.4	Link	D3.4 **SDO:** ISO/TC 59/SC 13/JWG 14.

<table>
<tr><td>Description</td><td>D3.4 summarizes final specifications and best practices for GeoBIM, focusing on GIS–BIM conversion, IFC georeferencing, and BIM–GIS envelope extraction (i.e., BIM to GIS conversion). Provides semantics/geometry mappings, LoD use, validation and recommendations for OGC and buildingSMART standards.

Practical guidelines and workflows openly available in GitHub repositories: IFC Georeferencing Tool · Envelope Extractor,</td></tr>
</table>

JBP2 - How to validate CityJSON/CityGML 3D City datasets for DBP

<table>
<tr><td>Lead partner</td><td>OGC/TUD</td><td>Related task</td><td>T2.4</td><td>Link</td><td>Link</td></tr>
<tr><td>Description</td><td colspan="5">

CHEK developed three complementary validation workflow patterns for CHEK-CityGML compliant city models, enabling municipalities to ensure data completeness and geometric validity before DBP checks.

The validation of 3D city datasets: via these tested workflow steps:

- Upload CityJSON/CityGML to CHEK Validator (API or GUI).
- Apply SHACL-based semantic profiles for DBP (zoning, GFA).
- Validate geometry/topology via val3dity.
- Generate JSON-LD report with structured compliance status.
- Visualize errors either in server-hosted viewer (Flask) or client-side app (Three.js).

You can find guidelines on how to create SHACL rules in this CHEK webinar: Webinar

And for further detailed workflow you can see other use case practices used during CHEK project and recommended in: D2.4 and Annex 2: Validation workflow best practices. In the last one you can find three implementations that illustrate a solid set of best-practice workflows, from API-only service, self-hosted web portal, or static client-app solutions. Project teams can assess which pattern best aligns with their organizational constraints, development resources, and end-user requirements to choose the right deployment pattern for their scale, security, and user-experience.

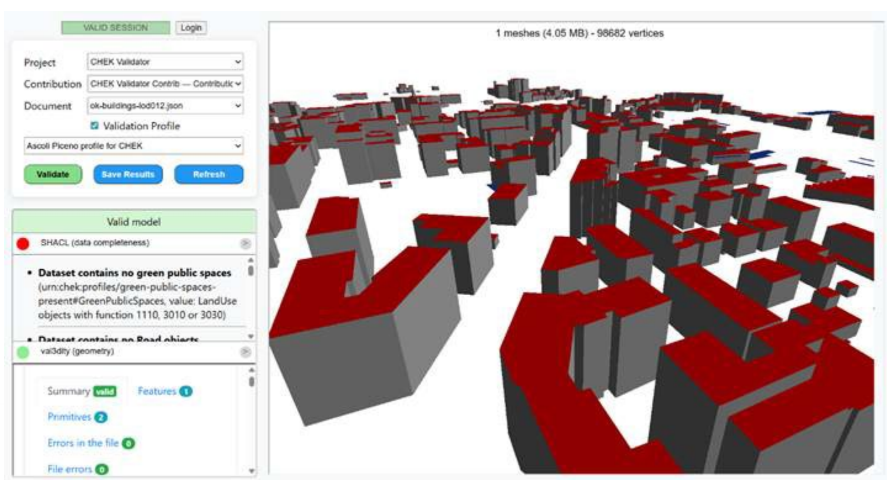

Figure 9: User interface of the web-only workflow

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5. UCM: Digital Building Permit Process based GEOBIM solutions

buildingSMART Use Case Management

Digital Building Permit Process based GEOBIM solutions

The **Use Case Management (UCM)** framework provides a structured way to describe the **Digital Building Permit (DBP) process** based on GeoBIM solutions. Within CHEK, a DBP-specific UCM template has been created and submitted to buildingSMART, formalizing how information exchanges and regulatory checks are represented in a transparent, reusable format.

The UCM is built around two main components:

1. **Process Map with Exchange Requirements (ERs) (Figure 10):**
   Each workflow step (from extracting city model, **plots,** to BIM exports, validations, rule-checks, and signing) is linked to explicit exchange requirements. These are defined in tables specifying the workflow step, description, format, and required files (e.g., IFC with IDS, CityJSON profiles, validation reports, signed IFCs).
2. **Level of Information Need (LOIN) – Modeling Guidelines:**
   For each Exchange Requirement, CHEK defines the minimum geometry, attributes, and documentation needed to support automated compliance checks. For example, parcel extraction (ER-1) requires CityJSON parcels and DEM terrain with zoning attributes; BIM export (ER-3) requires outer shell geometry, façade details, and properties such as *IsExternal* and *Height* flagged in IFC.

This structure ensures **traceability between regulation and model**, covering the entire DBP lifecycle:

- **Pre-check phase** (data extraction, conversion, IFC export, schema/IDS validation).
- **Regulatory checks** (rule validation, 4 categories checks, consolidated reports).
- **Approval and record-keeping** (IFC signing, as-built model updates into city datasets).

By aligning exchange requirements (ERs) with LOIN guidelines, the UCM ensures consistency between BIM, GIS, and permitting systems. It provides municipalities with a standardized, machine-readable template to configure their DBP workflows, while also delivering input to **buildingSMART (UCM portal), OGC (CityJSON/validation), and ISO/CEN (LOIN standards)**.

5.1. Process Map based Exchange requirements

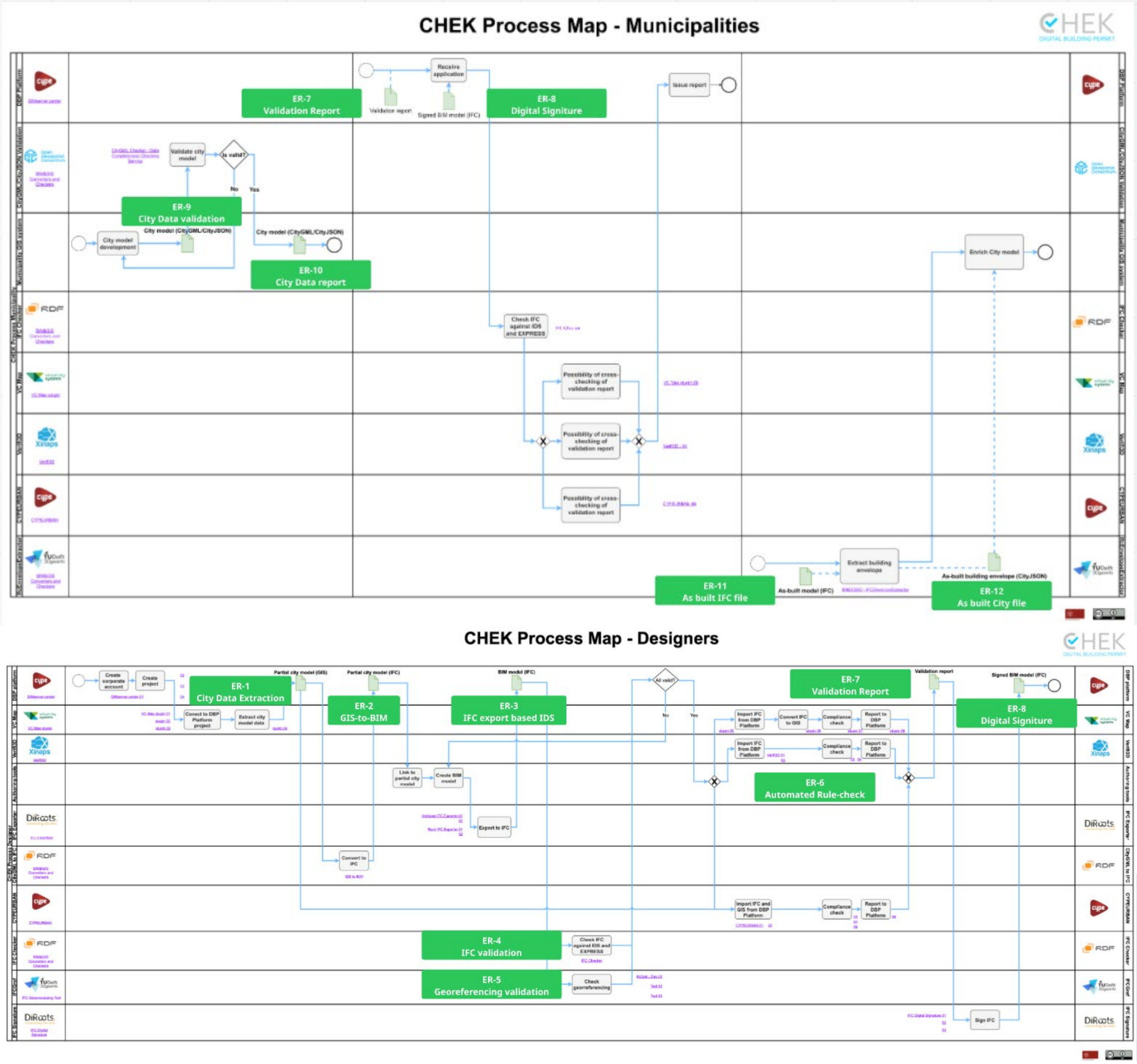

Figure 10: Process map updated with Exchange Requirements

5.2. Exchange requirements table (APC)

ER ID	Workflow Step / Name	Description	Format / Link
ER-1	City Data Extraction	Extract parcels, terrain, adjacent buildings.	CityGML / CityJSON / GML /
ER-2	GIS-to-BIM Conversion	Convert CityGML/CityJSON to IFC.	IFC4 ADD2 TC1 + Log (XLS/CSV): table of attribute conversion
ER-3	BIM Export to IFC based IDS	Export BIM with zoning + context props.	IFC4 ADD2 TC1 + IDS (.xml)

ER-4	Schema Validation	Validate IFC schema against EXPRESS. Validate IFC props against IDS	IFC validation report PDF (add APC validation report)
ER-5	Georeferencing Validation	Validate IFC CRS, origin, EPSG.	Table at ifcgeoref tool and 3D view on map
ER-6	Automated Rule-check	Run zoning/buildability compliance check.	JSON/(VCMap), PDF (CYPEURBAN), CSV/XLS (Verifi3D) ADD the APC JSON rulset file
ER-7	Validation report	Export results of municipal validation.	PDF report
ER-8	IFC Signing	Apply digital signature before submission.	Signed IFC (XAdES / XML)
ER-9	City Validation	City data validation profiling	Input city profiles Add the APC city Profile JSON
ER-10	Consolidated Validation Report	City data validation report based on City validator report (geomoerty and semantics validation	Output validated cityjson file report
ER-11	As-built IFC File	Upload as-built model after construction.	IFC4 ADD2 TC1 (as-built)
ER-12	As-built City File	Update city model with validated construction data.	CityGML/CityJSON file

5.3. Level of information Need – Modeling guidelines (APC)

ER (ID + Name)	LOIN (Geometry / Attributes / Docs)	Modeling Guidelines (Entities, Properties, Rules)
ER-1 City Data Extraction	**Geometry:** Parcels (LoD0), terrain DEM, LoD1 blocks. Surrounding building LOD? **Attributes:** Parcel ID, zoning ref. **Docs:** Metadata of source.	-Use CityJSON/CityGML standards for 3Dcitymodeling/profiles. -Include surrounding buildings with IDs. -Terrain DEM must reference EPSG CRS. -Neighbouring buildings as LoD2.2 solids.
ER-2 GIS-to-BIM Conversion	**Geometry:** LoD1 extrusions for context. **Attributes:** table of mapping attributes (check appendix). **Docs**: Conversion entities and attributes table.	-Map CityJSON → IFC using consistent attribute mapping. -Keep zoning code as IfcPropertySingleValue. -Preserve parcel IDs.Store mapping table (XLS/CSV).
ER-3 BIM Export to IFC based IDS	**Geometry:** Building outer shell, roof intersection line, façade LoD2–3. **Attributes:** Pset_WallCommon.IsExternal, CHEK_common.Height, storey areas. **Docs:** Legal ref.	- Prepare 3. IDS: terrain, building, surrounding - Export IFC with IDS template. -Model walls with IsExternal flag. -Roof lines must match zoning height. -Storey areas must be assigned to IfcSpace/IfcBuildingStorey. -Check against CHEK IDS (xml).
ER-4 Schema & IDS Validation	Geometry: Solids must be valid IFC shapes... Attributes: Required Psets	-Run IFC schema check (EXPRESS). -Validate against IDS. -Ensure GFA, heights, distances requirements exist in Psets.

	Docs: Validation log	- Output validation report (PDF).
ER-5 Georeferencing Validation	Geometry: Origin, rotation, scale validated. Attributes: EPSG codes, vertical datum. Docs: Survey coordinates reference.	-Use IfcSite + IfcMapConversion.Align with official CRS (EPSG). -Check units (m) and orientation (north). -Report via IfcGref tool.
ER-6 Automated Rule-check	**Geometry:** Height roof→terrain, parcel distances, façade planes with windows. **Attributes:** +hasWindows, zoning functions. **Docs:** Thresholds per regulation.	- Encode ruleset json in rule engine (VCMap, Verifi3D, CYPEURBAN). - Check distances from parcel boundary. Flag façades with windows.
ER-7 – Validation Report	**Geometry:** Validated geometries (envelopes). **Attributes:** Pass/fail per entity. **Docs:** Consolidated results.	Collect results of rule checks + schema validation. Produce structured JSON/XML + human-readable PDF. Link each result to IFC element GUID.
ER-8 – IFC Signing	**Docs:** Signed IFC + metadata. **Attributes:** Signature ID, timestamp.	-Apply XAdES/eIDAS signature. -Embed digital signature in IFC or separate XML. -Ensure proof of origin + integrity.
ER-9 – City Data Validation	**Geometry:** LoD2+ buildings, parcels, zoning. **Attributes:** Land use, legal height. **Docs:** City profile specs.	-Validate CityGML/CityJSON with SHACL. -Check zoning codes exist. -Ensure semantic completeness (building function, height).

6. Conclusion

The CHEK project, through Deliverable D7.6, aims to consolidate and present best practices in standardisation to ensure that digital building permit (DBP) solutions can move from pilot demonstrations to scalable, interoperable adoption across Europe. While D6.5 validated technical feasibility and organisational readiness, D7.6 highlights the standardisation pathways required to embed these results into sustainable frameworks at municipal, national, and European levels beyond CHEK project.

6.1 Key Findings

- **Standards-first foundation:** Open standards (IFC, CityGML, IDS, OpenAPI) are the backbone of scalability, enabling interoperability and reducing vendor lock-in.
- **Best practices for DBP:** Process mapping, interoperability-first data handling, modular architecture, and user co-design emerged as critical enablers.
- **Recommendations:** Formal integration of CHEK outputs into **standards bodies (buildingSMART, OGC, ISO, CEN)** and European networks (EUnet4DBP) is key to harmonised uptake.

6.2 Limitations

Despite clear progress, CHEK's current outputs reveal limitations that must be addressed through further standardisation and refinement of best practices. The **scope of encoded regulations remains narrow**, with only a limited set of rules translated into structured, machine-readable formats. This restricts the ability to demonstrate legal traceability and undermines confidence in automated checks. In parallel, **fragmented toolchains and workflows** prevent municipalities from adopting a consolidated, standards-aligned DBP environment, making replication more complex. Another key limitation is the **lack of localisation and multilingual alignment**, which are essential to ensure that best practices can be applied within diverse national legal systems. Finally, CHEK's IFC and CityGML profiles, rule encoding methods, and OpenAPI specifications require formal submission and endorsement within bodies such as buildingSMART, OGC, ISO, and CEN to ensure consistency and long-term evolution.

Until these limitations are resolved through coordinated **standardisation actions** and embedding of best practices into formal guidelines, large-scale adoption of DBP workflows across Europe will remain uneven and dependent on local initiatives rather than harmonised frameworks.

6.3 Forward Outlook

The next phase of CHEK must prioritise **anchoring best practices within formal standardisation processes** to guarantee long-term scalability. Encoded rule libraries should be aligned with **buildingSMART IDS/IFC specifications** and **OGC/CityGML profiles**, ensuring legal traceability and multilingual interoperability. Consolidation of workflows should be framed as a **reference implementation for national DBP programmes**, with OpenAPI interfaces documented and tested through CEN/TC 442 and ISO task groups.

Equally, CHEK's process mapping, interoperability-first data handling, and modular architecture should be advanced into **normative guidelines,** moving from project-based pilots to internationally recognised specifications. This requires continuous engagement with **standards development organisations (SDOs)**, creation of **conformance checklists** for municipalities, and integration of training and governance practices into standards frameworks.

6.4 Standarization actions to SDO in Coordination with Sister projects

Sister projects of CHEK are ACCORD and DigiChecks.

Automated Compliance Checks for Construction, Renovation or Demolition Works (ACCORD) developed a semantic framework for European digital building permitting processes, regulations, data and tools. This framework will drive rule formalization and integration of existing compliance tools as microservices. Solutions and tools are to be developed, providing consistency, interoperability and reliability with national regulatory frameworks, processes and standards. The solutions are implemented and demonstrated across construction projects in various EU regulatory contexts: UK, Finland, Estonia, Germany and Spain. 17

DigiChecks developed a solution to provide flexibility, ease-of-use and efficiency to the permit validation and approval system in the construction project environments, allowing – regardless of the country, region or municipality - an easy interoperability with the tools commonly used in construction. The use of the DigiChecks framework does not imply a change in the processes, but rather effectively implements a new form of exchanging information between the different actors involved in a permit procedure. 18

There are two levels of coordination among the projects. The two standardisation organisations buildingSMART and the Open Geospatial Consortium are both involved in both CHEK and ACCORD. It means that the connection among those two projects, especially from the point of view of standardisation, will be naturally stricter. Several standardisation activities of the two projects will overlap and additional efforts will be dedicated to find further agreements and harmonisation of the respective solutions, as far as possible, or document both as alternatives within the developed best practices and documents.

Second level is the coordination among all the three projects. In this case the coordination was initiated under the umbrella of the EUnet4DBP, within which several partners in the three projects are participating: Francesca Noardo (OGC - ACCORD and CHEK), Silvia Mastrolembo Ventura and Angelo Ciribini (University of Brescia – CHEK), Jaan Saar (Ministry of Economic Affairs and Communications for Estonia - ACCORD), Christopher Raitviir (Tallinn Urban planning development – ACCORD), Miguel Azenha and José Granja (University of Minho – CHEK), Jantien Stoter (Delft University of Technology – CHEK), Rita Lavikka (VTT – ACCORD), Ruben Verstraeten (Ghent University - DigiChecks), Gregorio Saura (SIA.architect – CHEK), Trajche Stojanov (Zwei Ltd – CHEK), Goncal Costa (Institut de Tecnología de la Construcción de Catalunya - ACCORD), Rick Klooster (Future Insight – ACCORD), Léon van Berlo (buildingSMART – ACCORD and CHEK), plus others in the advisory boards.

The three projects were present in public events through the last three years, which gave the opportunity to present their plans and results and exchange based also on the questions from the audience. Such opportunities will be organised by the institutions in the related domain as part of their networking activities at least once per year. Among the mentioned organisations: European Commission and the High Level Construction Forum network; the European Network for Digital Building Permit; the Building Digital Twin association; buildingSMART Regulatory Room; Open Geospatial Consortium.

In addition, the three projects planned regular internal meetings approximately every 3 months, starting with the first one held on 15th November 2022. The goal of such meetings is to find potential contact points of the three projects in which we could extend the results already obtained and delivered by the single projects by further investigating the options to align, whether relevant.

Possible activities to be considered in the future include the **publication of joint documents** (best practices, white papers), **joint scientific papers** on common topics (with sister projects), and the **organisation of common dissemination events** such as digital panels on standardisation (building on the Kaunas declaration on GeoBIM applicability and the CHEK Final Event panel results).

7. References

Filip Biljecki, Hugo Ledoux, and Jantien Stoter. **An improved LOD specification for 3D building models**. *Computers, Environment and Urban Systems*, 59: 25–37, 2016.

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List of used abbreviations

API – Application Programming Interface

bSI – buildingSMART International

CDE – Common Data Environment

CityGML – City Geography Markup Language

DBP – Digital Building Permit

IDS – Information Delivery Specification

IFC – Industry Foundation Classes

LOIN – Level of Information Need

OGC – Open Geospatial Consortium

UCM – Use Case Management

Annex 1: Validation workflow best practices

To better understand the possible workflows to follow for which purpose, we present three distinct implementations of the CHEK city model validation workflow, each demonstrating alternative trade-offs between processing location, deployment overhead, and user interaction. These variants build upon the same core engine which is an OGC API-compliant service that ingests CityJSON and CityGML models, applies SHACL-based data-completeness rules and val3dity geometric checks, and produces structured JSON reports. They differ however in how they integrate visualization and model conversion. The three complementary architectures demonstrate possible paths of automated integration of data-completeness and geometric-consistency checks into 3D city-model workflows, each offering a different balance of server-side processing, client-side interactivity, and ease of deployment.

Core Validator as a Standalone Service

At the heart of the ecosystem sits the CHEK Data Completeness Validator: a web-based engine that ingests CityJSON or CityGML files, applies SHACL-based semantic rule profiles, and invokes val3dity for geometry and topology-level checks. It exposes the validation engine solely via HTTP endpoints. It is intended for seamless integration into external pipelines, scripts, or third-party platforms, enabling automated gating of data quality without any accompanying front-end. Nevertheless, a simple user interface is provided to allow simple and direct interaction with it (see Fig. 11).

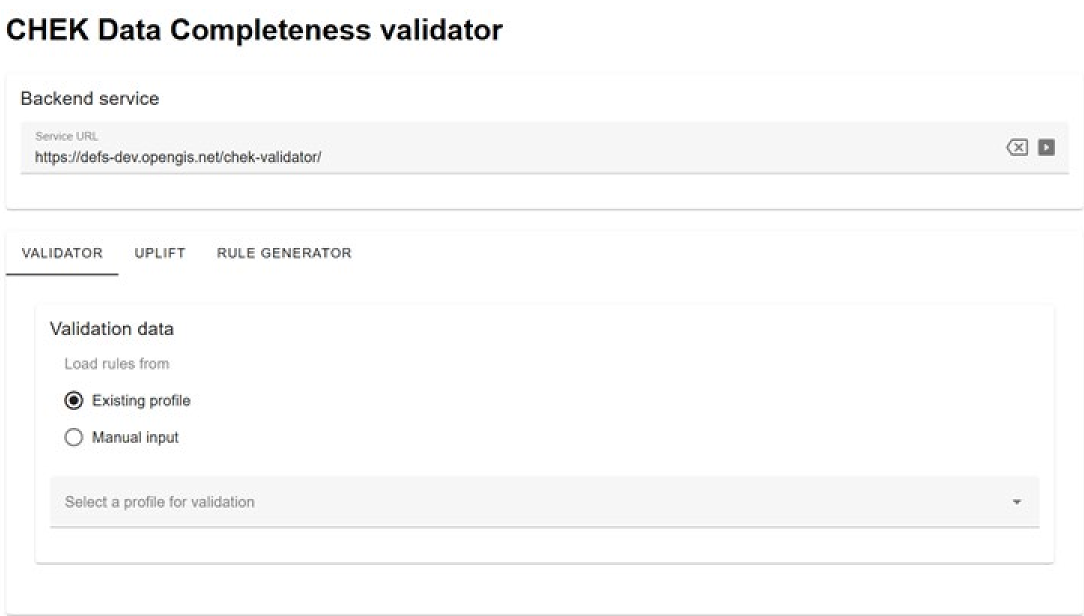

Figure 11: Web interface of CHEK's core city model validator.

Users simply drop in their model files alongside a chosen validation profile (expressed in RDF/SHACL), and the service returns a structured JSON report containing four main sections: overall val3dity status, SHACL status, the full SHACL report (as embedded JSON-LD), and per-file validation details (including individual val3dity outcomes).

Complex profiles, ranging from attribute presence to multi-dataset cross-checks, are defined in GitHub-hosted templates, and an OGC API – Processes interface (with OpenAPI/Swagger documentation) makes the engine programmatically accessible. This configuration exemplifies a pure "validation-only" service: lightweight, highly reusable, and easily containerized or deployed on any web server.

Flask-Backed Viewer with Server-Side Conversion

Building atop the core validator's HTTP endpoints, the first visualization layer is a minimal Python/Flask application that bundles upload, validation, and 3D rendering into a single server-hosted package. When a CityJSON file is uploaded, Flask handles two tasks in sequence: (1) it proxies the file to the CHEK Validator for SHACL checks, and (2) it invokes cjio to convert the model into glTF Binary (GLB). The resulting GLB is then served to a Three.js frontend, which overlays geometric-invalidity highlights and inline attribute-completeness warnings based on the validator's JSON report (see Fig 9). This approach keeps all processing under centralized control, simplifies client requirements (no local dependencies beyond a browser), and secures profile management, but it does require maintaining a Python server and associated libraries.

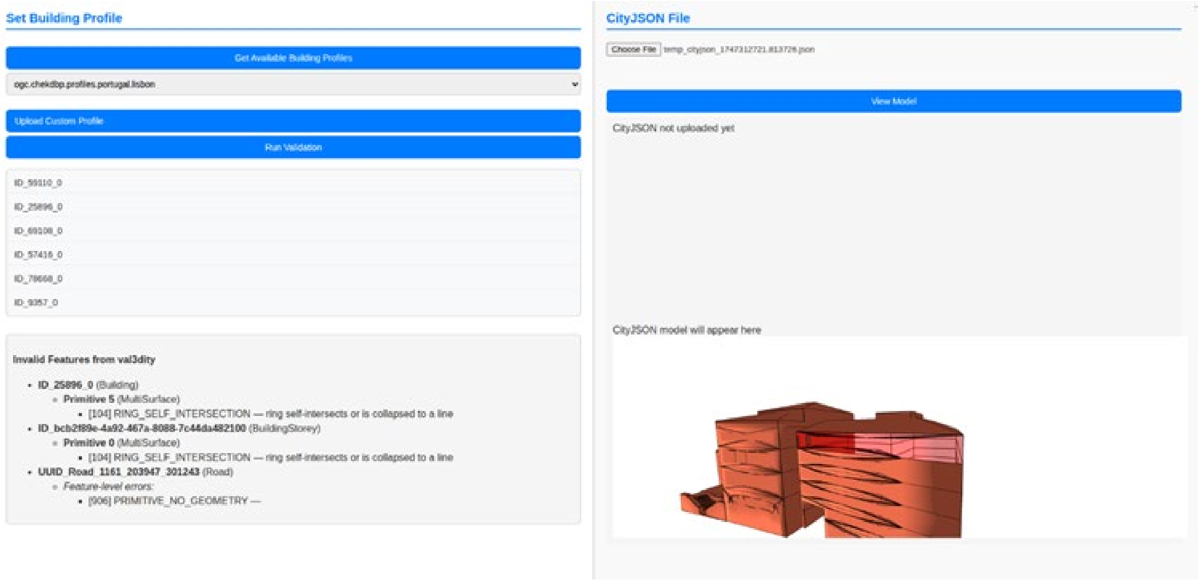

Figure 12: User interface of the client-server workflow

Pure Client-Side App with Cloud Service Integration

The second visualization layer pushes interactivity entirely into the browser by marrying a static web app with two cloud services: BIMServer.center (as a CityGML/CityJSON repository) and the CHEK Validator API.

After Auth-based authentication against BIMServer.center, users browse their projects and fetch models directly in memory. Validation requests are dispatched via HTTP calls to the CHEK service, with polling for job completion and JSON-LD/val3dity response retrieval. In the browser, a CityJSON Three.js viewer renders the checked model and offers an interactive report viewer visualising both val3dity (for geometry and topology errors) and SHACL (for completeness) violations (see Fig. 10). Results can even be pushed back as new contributions to the user's BIMServer workspace. This fully client-side pattern eliminates the need for any custom backend (beyond optional secure token proxying), leverages HTML5 and JavaScript to its fullest, and showcases a frictionless way to deliver validation and visualization entirely from static hosting.

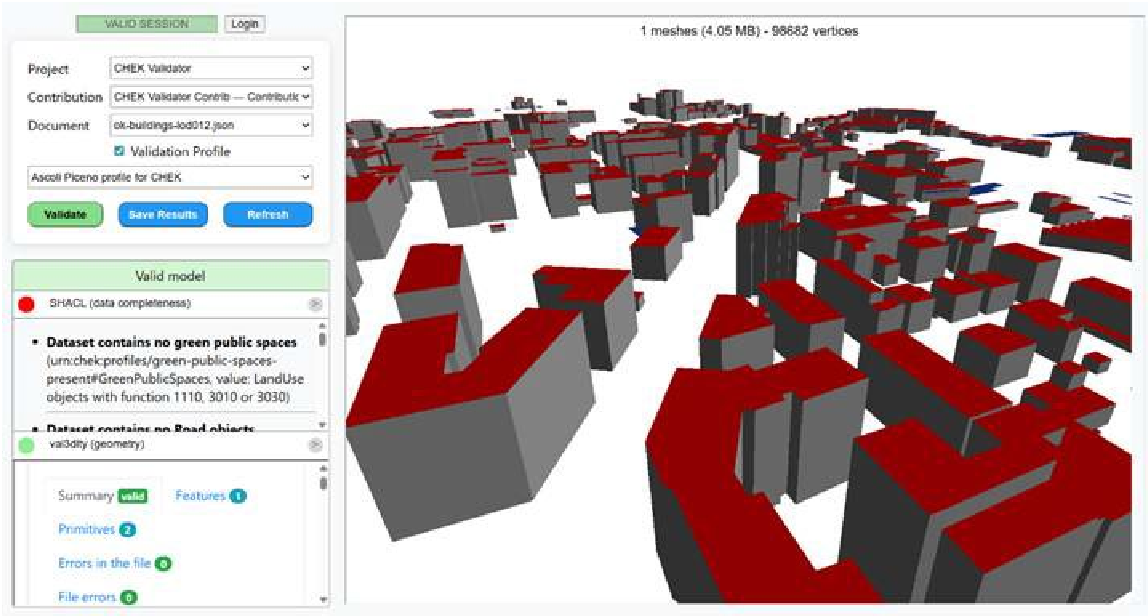

Figure 13: User interface of the web-only workflow.

Together, these three implementations illustrate a solid set of best-practice workflows, from API-only service, self-hosted web portal, or static client-app solutions. Project teams can assess which pattern best aligns with their organizational constraints, development resources, and end-user requirements to choose the right deployment pattern for their scale, security, and user-experience.