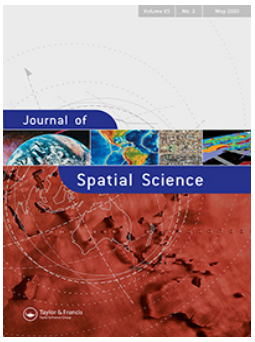
Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges



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Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges

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ABSTRACT
The integration of geoinformation with BIM (GeoBIM) is critical to underpin solutions to many city-related challenges. However, to achieve an effective integration it is necessary to consider not only data and technical options but also current practice and users' needs. This paper describes work carried out within the EuroSDR-GeoBIM project to address this challenge. After investigating potential uses for GeoBIM and existing challenges, we address a planning permits for buildings use case, to help bridging the gap between theory and practice. The resultshighlights a high-level harmonised workflow envisaging the use of GeoBIM information for automating the planning permits process.

KEYWORDS
GeoBIM; National Mapping and Cadastral Agencies; building permits; GIS; BIM

1. Introduction

In recent years, a number of studies have been carried out to examine the potential of integrating geoinformation (especially 3D city models) with building information models (BIM) ('GeoBIM') (Fosu *et al*. 2015, Liu *et al*. 2017, Song *et al*. 2017, Ohori *et al*. 2018). It is recognised by authorities, companies and academia that this integration would provide substantial advantages (urban planning, large infrastructure projects, specific issues relating to health and safety).[1] GeoBIM information could enable a high level-of-detail cadastre (El-Mekawy *et al*. 2015, Atazadeh *et al*. 2017), a more efficient building permit process (Van Berlo *et al*. 2013, Olsson *et al*. 2018), improved level-of-detail and maintenance of 3D models (Isikdag and Zlatanova 2009, Deng *et al*. 2016), as well as improved analyses in use cases such as asset management (Boyes *et al*. 2017), escape routes determination (Tashakkori *et al*. 2015), health and safety, shadow analysis, effective information exchange with other professionals, and more.

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However, while theoretically beneficial, GeoBIM is only recently becoming an emerging reality (Fosu *et al*. 2015), and the challenges that remain before such technology is mainstream are both technical and organisational.

This paper outlines the research carried out to address some of these challenges with a particular focus on identifying the overall potential of GeoBIM in a specific context (planning/permits).

Developing a coherent approach to GeoBIM integration requires consensus between multiple stakeholders from both the geoinformation and the BIM sides, working at an international level. To reflect this, the research described here has been carried out by the GeoBIM project (https://3d.bk.tudelft.nl/projects/eurosdr-geobim/) co-funded by EuroSDR, the research association of European National Mapping and Cadastral Agencies (NMCAs) and the involved partners: NMCAs from 12 European countries, five academic institutions and partner municipalities in Sweden and The Netherlands (full list of participants in the Acknowledgements section).

The first phase of the project concerned the investigation of current state of implementation of GeoBIM in the participating countries. It was fulfilled through a questionnaire (Section 3) and is being updated with the progress of related ongoing (national) activities by all the partners during recurring project workshops. They took place on 26 September 2018 in Amsterdam (NL) and on 13th-14 February 2019 in Copenhagen (DK). The summary of ongoing national activities in this paper (Section 4.2) is a result of those workshops. The second phase focuses on the development of specific solutions utilising GeoBIM information by means of two use cases (identified during the first phase as key opportunities): issuing building permits (considered in this paper) and assets and facilities management (still in a preliminary phase).

In the case of the building permit process, there are several advantages given by a GeoBIM approach compared to the current situation, which, in most countries today, is based on 2D cross-section drawings (of the building) and a 2–2.5D situation plan (showing where the building is situated on a municipal map). For example, several building regulations could benefit from a GeoBIM approach for enabling automation. In a Swedish case study (Olsson *et al*. 2018), it was shown that it was possible to check e.g. the building heights (which in Swedish regulation includes roof forms, main viewing direction, etc.) using a GeoBIM approach. Also, visual building regulations such that a new building should maintain the character of a built-up area would benefit of a GeoBIM approach.

Furthermore, the objectivity in the interpretation of regulations, by both the designer and the Municipality offices in charge of issuing building permits, would increase, with clear advantages for both parties.[2] Moreover, the GeoBIM approach allows the effective use and reuse of the data. In the current situation:

(1) building designers design the building in BIM;
(2) they export the needed 2D data for building permission (with obvious loss of data from such a rich and powerful tool as BIM);
(3) locate some of the 2D drawings in the city map to show the context, without a defined methodology and with consequent possible errors and blunders in the location;

(4) the Municipality office checks the regulations compliance through a partial view of the project: the 2D representations aided by a report submitted by the applicant about dimensions, technical details, and so on;
(5) after the building is approved and built, the existing BIM is not used again (and potentially lost) and the city model needs to be updated through new surveying, modelling and checking phases.

Instead, by using GeoBIM, the rich information produced by design (1) and correctly georeferenced into the 3D city model through a tested methodology (3) can be effectively and objectively used in its completeness by the Municipality (4) and the same, checked, data can converge into the 3D city model to update it (5). One only building model would therefore be used in a complete workflow, together with the 3D city model, instead of many disconnected (or little connected) different data, which would be lost after the end of the process with the additional benefit of fewer inconsistencies.

2. Previous work on BIM and geospatial integration

Applications that can benefit from GeoBIM range from planning and planning permits (de Laat and Van Berlo 2011), asset management (Boyes *et al*. 2017), materials location on large projects (Rizal *et al*. 2013) and building demolition, routing and navigation (Jayakody *et al*. 2013), flood damage prediction (Amirebrahimi *et al*. 2016), noise analysis (Deng *et al*. 2016b, Ellul *et al*. 2017) and more (e.g. Song *et al*. 2017).

Moreover, a number of studies (reviews in Liu *et al*. 2017, Zhu *et al*. 2018) have addressed the task of integrating BIM and geoinformation through integrating their data models (e.g. Hwang *et al*. 2012, Kang 2018, Floros *et al*. 2018, Knoth *et al*. 2018, Pouliot *et al*. 2018). However, technical challenges still remain due to:

- differences between how BIM (architecture domain) and geoinformation (geography) model the world;
- geometry representations: boundary-representation for geoinformation and solids for BIM, and further topological problems such as self-intersecting data and non-manifold geometry in BIM models (Ohori *et al*. 2017);
- scale of representation: BIM focuses on details within a single construction project, whilst 3D geoinformation represents wide areas of land and cities with many levels of detail (and varying accuracies);
- intended use of the data: BIM is designed primarily for construction, geoinformation can be used to support administration tasks and environmental analysis;
- coordinate systems: BIM generally uses local Cartesian systems (Uggla and Horemuz 2018) whilst geoinformation is encoded in national (or international) geodetic reference systems.

In addition, different open standards for structuring building and geo-information exist, which is the most commonly addressed challenge in the cited studies. Among these, the most widespread ones are CityGML by the Open Geospatial Consortium (OGC) for geoinformation (www.citygmlwiki.org) and Industry Foundation Classes (IFC), by buildingSMART, for BIM (https://www.buildingsmart.org/, Vanlande *et al*. 2008, Casey and Vankadara 2009, Laakso and Kiviniemi 2012). Another comprehensive data model useful to represent geoinformation is the INSPIRE Data Model (https://inspire.ec.europa.eu/data-model/approved/r4618-ir/html/), developed within the European Directive 2007/2/EC to enable a common infrastructure for spatial information in the European Community (INSPIRE) in order to harmonise the cross-boundary maps for supporting common environmental analysis and policies. However, CityGML was considered in this research because it is more internationally known, and the foreseen domain of its representation is the city, instead of the county-level and international scale forming the focus of INSPIRE.

2.1. Research gaps and remaining challenges

Much of the research to date has focussed on technical challenges, especially relating to data conversion. Within this context, even though a number of issues have been addressed from a theoretical standpoint and many solutions have been successfully tested in an 'idealised' context (e.g. using 'perfect' BIMs modelled by academia), additional challenges still exist when dealing with real-world 3D models (geometrical inaccuracies, semantic errors and topological issues) (Boyes *et al*. 2017, Ohori *et al*. 2018). Additionally, much of the integration happens in one direction (from BIM to geoinformation), and the needs of users and organisational challenges are not discussed.

Another critical issue to be solved is not technical, and covers the conscious involvement of the stakeholders at different levels and in the two domains.

At institutional level, the laws and regulations guiding the use cases applications (included the building permission issuing) should change for considering the enhanced opportunities given by GeoBIM and consequently adapt the new needs (e.g. required data), the procedures (e.g. automated workflows, different tasks for human operators) and the data management practices (to use different data). For example, in the Netherlands (following initial investigations within the Municipalities of Rotterdam, Den Haag and Amsterdam) PDF documents are required for the building permission application in order to be able to store version-determined, electronically signed documents not relying on a specific software (and software version). However, these characteristics can also be found in IFC files, which, for example, have a human-readable text format and contain 'creation time' information. It is however understandable that it is necessary to increase the confidence in such kinds of data in order to avoid misunderstandings. The same is true for the level of trust given to the automatic tools on which the checks should rely. It is not an easy shift, but some initiatives (including the EuroSDR GeoBIM project) demonstrate the willingness of institutions to develop towards such a direction.

At a practitioners' level, there is also the need to overcome difficulties and misunderstandings that are connected to the little knowledge of the field (geoinformation or BIM) where one is less involved in. For example, it is essential to know the IFC or CityGML standards (e.g. characteristics and management possibilities) to avoid preconceptions about their use. This same knowledge would foster the development of the two kinds of models according to criteria already taking into account the need for integration. Some initiatives are being developed to fill this gap: e.g. the introduction of the GeoBIM topic in MSc courses in Geomatics (Hijazi *et al*. 2018, Noardo *et al*. 2019); projects involving NMCAs (like the EuroSDR GeoBIM project); the discussion about this topic in practice-oriented conferences, for example, the 'GEOdesign+BIM' conference by Geospatial Media and Communications (https://geo-bim.org/europe/) and more. Cooperation is also being established between software vendors in the BIM-domain and the geodata domain to increase the interoperability between their systems. This would facilitate an easier solution to many discrepancies which are at present preventing a fluent integration.

3. The EuroSDR GeoBIM project – phase 1: the state of play of GeoBIM in Europe

To address the lack of understanding of user needs and challenges, the first phase of the EuroSDR GeoBIM project used a questionnaire distributed amongst the network of participating project partners using a snowballing approach (https://en.wikipedia.org/wiki/Snowball_sampling). Questions sought to identify the current level of GeoBIM adoption in each country, perceived opportunities and challenges (technical and organisational) to fully achieve GeoBIM integration. Further details can be found in Ellul *et al.* (2018), with a summary of the key results presented here.

Results show that, notwithstanding the varying levels of GeoBIM maturity across the participating countries, participants were clearly able to identify opportunities for such integration (Figure 1).

The survey also asked respondents to identify technical and non-technical challenges, both at organisational and national level (Table 1). As could be expected, technical issues do indeed relate to the issues of integrating data (Section 2) with IFC and CityGML also being identified as the most commonly used standards. However, a second perhaps more fundamentally important key challenge mentioned, was the general lack of

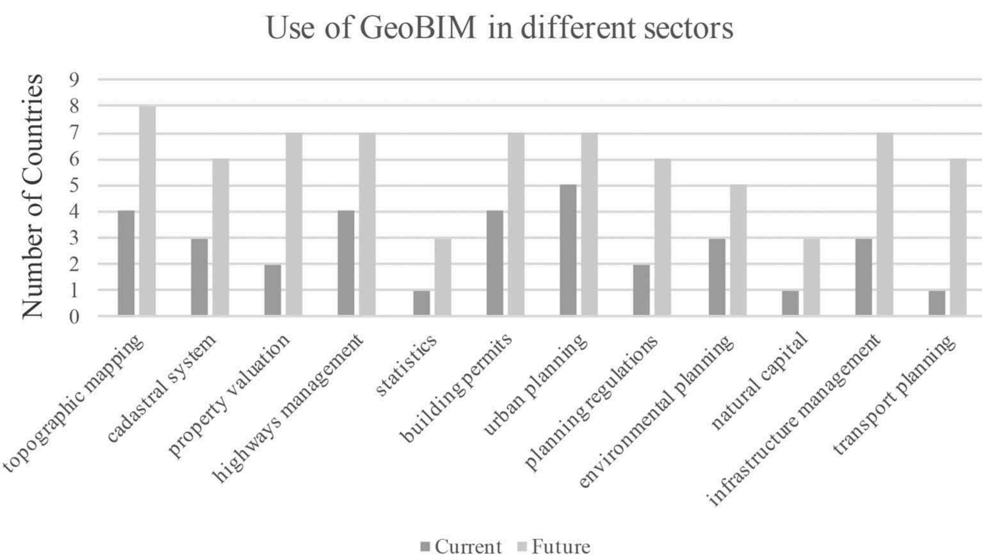

Figure 1. Frequency of interest in using GeoBIM information in the future, and of existing applications at the moment of the questionnaire answer, in the considered countries by the investigation in the first phase of EuroSDR GeoBIM project.

Table 1. Summary of GeoBIM challenges identified by respondents.

	Organisational-level	National-level
Non-technical	- lack of knowledge, expertise and focus on GeoBIM; - lack of clarity of the role of an NMCA in the context of BIM; - lack of clarity of the role of BIM in existing tasks such as urban planning - slow adoption of new technologies; - lack of available BIM data;	- lack of awareness, knowledge, and expertise regarding what GeoBIM is, especially among top-level decision makers; - lack of a national strategy; - lack of investment; - parallel initiatives (sometimes carried out by competing entities) due to the lack of coordination between GIS and BIM entities.
Technical	- lack of interoperability (e.g. with systems such as transport modelling); - disciplinary divide between architects, engineers and geographers; - lack of suitable software; - not harmonised geo- and BIM data	- lack of standards; - different data models; - software incompatibility - absence of software which can support both BIM and Geo data, along with having GeoBIM capability.

awareness, at regional/country level, of the importance of GeoBIM integration and its potential, and how it relates to current NMCAs and BIM activities.

The second key challenge, in terms of technical integration, is the need of a fundamental solution supporting the life-cycle of objects, rather than ad-hoc conversion processes within individual projects and researches.

To address these challenges, two specific use cases were identified as the most interesting and useful for further investigation and developing initial tangible solutions: issuing of building permits and life-cycle asset and facility management.

4. The EuroSDR GeoBIM project – phase 2: use case 'planning and permits'

The remainder of the paper describes preliminary work addressing interoperability and awareness issues in the context of the first use case, building permits, which was chosen because of the current extensive use of NMCA data in the permit application process; to address commonalities of the permit application process across the partner countries, meaning that a multi-country perspective can be obtained; and to show the opportunities offered for this use case by the increasing use of BIM in architectural design (driven by governments BIM mandates).

4.1. Methodology

Opportunities for GeoBIM in planning can be identified both at the design phase (where the context of any proposal can be examined by importing geoinformation into BIM) (Van Berlo *et al*. 2013) and at the proposal evaluation stage, where compliance of all the characteristics of the proposed plan can be checked against existing related regulations (Olsson *et al*. 2018). Such regulations generally relate to dimensions, relationship with existing neighbouring buildings and context, safety rules, aesthetics, consideration of historical or artistic values, physical and construction requirements (e.g. energy features).[3]

Given the above opportunities, three core questions were identified in relation to the development of the permits/planning use case:

(1) *What workflow should be followed for effectively using GeoBIM information for a Building Permission use case?* A more complex workflow than the one currently followed is needed, including conversions through different data formats (at least CityGML and IFC should be considered) and automatic tools.
(2) *What are the regulations that can be (semi)automatically checked by a GeoBIM approach?* A set of constraints that are common across the participating countries, and can be used to highlight the potential of GeoBIM in planning, will be identified.
(3) *What are the related requirements for, and availability of, data for this automation?* This question will address the technical integration aspects: what data are needed to exploit the potential of GeoBIM in a real-world case study? This will identify also the gaps between existing and required data (both BIM and geo).

To investigate these questions and identify suitable and concrete solutions relevant to multiple stakeholders, each participating partner in the EuroSDR GeoBIM project first carried out a review of the current practice of building permit processing in their country, along with ongoing local research and initiatives related to the use of GeoBIM for building permits, both from an academic and practitioner perspective (Section 4.2). This review was presented to the other partners during the last project workshops in September 2018 and February 2019 (see Introduction). Based on the permit workflows in each country, an initial high-level harmonised workflow for the use of GeoBIM in planning/permits (Section 4.4) was drafted and discussed, which in turn forms the basis of in-depth investigation of each stage, and will provide context for interviews with planners and municipality officers in a later stage.

4.2. GeoBIM-connected national ongoing initiatives

Perhaps because of the complexities of the current paper-based planning processes, in many countries, the awareness of the potential of GeoBIM in planning is increasing. In many cases, it is driven by national BIM strategies, in which governments define rules and use cases where BIM has to be used for documentation and management tasks in relation to construction: e.g. in the UK (GCS 2011), in the Netherlands (Rgd 2012) and in most other European countries, as consequence of the adoption of the Directive 2014/24/EU of the European Parliament and of the Council on public procurement, strongly encouraging the use of BIM for public projects. Therefore, in many countries from 2018, a process began towards the mandatory adoption of BIM at least for public buildings, to be fully implemented by 2022: this includes Slovenia, Spain, Italy, France, Germany, among others. Moreover, in some additional countries, there are no rules defined by the government, but decisions to enforce the use of BIM in construction projects are made by authorities, as done by e.g. the Swedish transport administration.

In addition to this, a number of ongoing projects are being developed in the participating countries to build a standardised **national 3D city model**, which are essential data to build integrated GeoBIM: e.g. Denmark; France; in the Netherlands, Kadaster already produced a 3D city model in CityGML, LoD1, of the whole country (Stoter *et al*. 2017).

Other projects are addressing the development of an integrated system fostering automation: for example, in the Netherlands, Kadaster (Greefhorst *et al*. 2018) and several municipalities (e.g. Rotterdam, Den Haag, Amsterdam, Almere) are working on automating the building permission checks through **GeoBIM** information. For example, in Rotterdam, a workshop was organised, as far back as 2011, in order to test a procedure to automatically issue a building permit (including application review and decision) in one day (Deloitte 2011). Furthermore, a BIM information delivery standard is also under development by 'BIM Loket', the national institute dealing with BIM employment in the Netherlands (www.bimloket.nl).

In Ireland, academic research has been carried out in relation to automatically checking regulations (e.g. fire regulations) supporting building permission using BIM and geoinformation.

In France, ongoing projects relate to automatic checks for errors in the BIM. Moreover, the Institut Géographique Nationale (IGN), the national mapping agency, is developing a project to validate urban constraints automatically for building permits. In particular, geometric rules are being considered (maximum height, distance from the street, shadows) with data sourced from CityGML buildings, cadastral parcels from INSPIRE specification and a zoning map for the planned land use, employing a national standard close to INSPIRE. The resulting SimPLU tool generates an error report if rules are violated (Chapron et al., n/d).

In Sweden, the 'Smart Built Environment' program (https://www.smartbuilt.se/in-english/) is looking at exploiting GeoBIM information for many use cases in the built environment. A specific project 'Detailed delivery specifications for Geodata-BIM' commenced in 2019. Within this, one of the work packages focuses specifically on specifications for digital deliveries for GeoBIM in the building permits. This project has close links with a national project aimed at improving the whole building permit process (*Får jag lov?*; https://farjaglovprojektet.wordpress.com/) coordinated by the Swedish National Board of Housing, Building and Planning.

In Slovenia, some activities are also being performed with similar aims: the development of a 3D topographic database and the achievement of a 3D cadastre and 3D city models are underway: the e-PROSTOR (meaning 'e-SPACE') project aims at the digitalisation of the full process from plan submission (e-PLAN) to issuing the permit (e-CONSTRUCTION). This includes: a common infrastructure for spatial information; a spatial information system supporting spatial planning and development; an improved real estate information system (Tekavec *et al*. 2018); together with the improvement of the quality of spatial data (http://www.projekt.e-prostor.gov.si/).

In Denmark the completed 'Indoor geography', integrates IFC BIM, the Danish addresses databases, and the geoinformation of Denmark ('GeoDenmark'); domain-specific data will be added to use such information in specific use cases.

In the UK, the role of BIM in Urban Planning is on the radar of the Centre for Digital Built Britain (CDBB), although not specifically articulating this in a geospatial context. Current CDBB recommendations push towards an aware and nationally driven adoption of BIM, particularly supporting planning (Allmendinger and Sielker 2018). The wider potential of using such data in planning has also been noted by the UK Future Cities Catapult report (setup to building better cities, linking industry and other stakeholders) (FCC 2018).

An additional project of great relevance here, both because of its international value and its focus (partly) on IFC/CityGML integration in the context of urban planning, is the OGC's Future City Pilot (FCP 2018). This looked at three case studies relating to planning, sensor integration and flooding, with the planning-related scenario focusing on the validation of BIM models against urban planning regulations and the use of open standards in this task. The authors noted challenges of converting BIM data to CityGML arising from mistagged features in the BIM, and trialled two approaches to develop a demonstrator of this process. A second phase of the study (http://docs.opengeospatial.org/per/16-099.html) provided Web Processing services to: validate building height, determine the ratio of built area to land area and validate that the proposed building is within the land boundary.

4.3. The building permit process – current practice, challenges and opportunities for GeoBIM

As emerging from initial investigations and from preliminary approaches to the building permit issuing practices in all participating countries, at present, checking the application against all the regulations requires manual work by specific planning experts in the municipalities; it usually takes long time and is resource-intensive. Moreover, both the regulations and the documents describing the building design are often open to interpretation, so that different judgements and decisions could be made for similar situations.

Furthermore, the rules and regulations themselves can also be manifold and set at different levels of the governmental hierarchy. Examining the situation in the UK provides an example of this complexity: planning regulation setting and approvals are multi-level, including neighbourhood plans: local communities are able to choose where they want new homes, shops and offices, what these should look like and what infrastructure should be provided, and grant planning permission for new buildings they want to see go ahead (MHCLG 2018). Higher up the hierarchy, each local authority (around 400 https://www.buyaplan.co.uk/blog/posts/64-planning-authorities-of-england-scotland-and-wales) produces its own planning guidance documents (e.g. Exeter 2008, Brent, n/d). Guidelines are produced by Regional planning, covering multiple authorities and aimed at strategic projects, e.g. the London Plan (London Plan 2017).

Despite this complexity, it can be envisioned that GeoBIM does at least have the potential to automate constraint checking at some levels. Although a system should be envisaged where each specific authority can customise the rules at a very local level, if required, many local and municipal planning rules need support for quite common tasks. Some examples are summarised in Table 2, and they will be further investigated during the next phase of the project, through specific interviews with municipalities officers in case studies.

To automate planning/permit processes with GeoBIM, the detailed development plans need to be in a computer-readable standard. In many countries, this is still in a development phase (e.g. Brasebin *et al*. 2016). Additionally, a number of municipalities have already commenced working on automating and simplifying constraints checking (Section 4.2).

However, within all participating EuroSDR partner countries, current planning/permit practice relies on PDF (or even paper) documents (2D drawings, blueprints, elevations and cross-sections), which are delivered by the building designers as part of the request for a permit.[4] Thus, even where a development has been designed in BIM, the required outputs need to be PDF format.

Table 2. Common checks in planning that will benefit from an integrated GeoBIM approach.

Needed check	3D Spatial aspects	Semantics aspects	GeoBIM-related advantages
Zoning and dimensions:	Maximum height and distances from the other buildings, considering also overhanging objects (like balconies); volume; densification level (total building footprint area divided by real estate area)	Not all the building elements follow the same rules in their dimensioning requirements (e.g. heights of the ventilation pipes in restaurants in Amsterdam should rise 2 m higher than the surrounding buildings).	Heights limits in some cases are related to the surrounding buildings (e.g. again, the case of restaurants' chimneys in Amsterdam, but also cases in which the maximum height in buildings follow geometric rules also considering the view angle from the surrounding areas). A 3D GeoBIM approach would be able to consider overhanging objects (like balconies or other elements) which may not be visible in a 2D section of the building taken where no overhanging objects are visible; The automatic calculation of surface area and volume of the building would be more accurate than a manual one.
Parking availability and plans connected to the new buildings	parking spaces underground and in covered areas (which may be on different/multiple floors) should be considered	Different functions have different parking needs; different kinds of parking spaces are required in some cases (e.g. cars, bikes …).	In an integrated GeoBIM environment it is possible to consider the parking spaces in covered areas and specific buildings or building spaces both existing or designed, as well as those in the neighbourhood. This makes the calculation of the required number of new parking spaces according to the accurate automatic measurements of the new building (volume, surface area and so on) and the identification of these in the building and its surroundings
Impact of the building **on its environment and of the environment on the building in higher detail**: *shadows* analysis, and connected possibility to exploit (new or existing) *solar* energy systems; *noise* analysis; *air quality*.	*The influence of the building in terms of shadows cast (determined from the 3D model)*; for noise analysis the distribution of building spaces and elements is important (e.g. noise barriers and 3D distance from noise sources); for air quality the position of ventilation devices and open areas, and possible pollution barriers, are important.	The functions of specific spaces is important as a potential source of pollution (noise, air pollution) or area where such pollution should be minimised. Moreover, the kind of materials and surfaces (e.g. glass) can be relevant.	The integration of the designed building (including 3D shape, materials, specific functions and so on) with the 3D city context enables enhanced (with a richer information and a higher level of detail) analysis of the resulting city and the impact the proposed building will have. Shadows cast by the building on surrounding buildings (hence impacting their lighting and heating needs) and vice versa (permitting the prediction of the lighting and heating needs of the new building) can be determined at an early stage of design.

PDFs are usually manually checked by the dedicated offices and services in the municipalities and a decision is taken on this basis. In many cases (Denmark, the Netherlands, Finland, among others), a web service, sometimes national (Finland) and often regarding the single municipality, is available for submitting such documents, but the following work is still manual. Even if, in some cases, it is possible to upload a BIM of the project (it is possible in Finland, especially for big projects, and in some Dutch cities), it is usually not used for automatic analysis and checks (again in some cases legal directives prevent this, e.g. in the Netherlands).

An additional level of complexity is added by the fact that city regulations are also usually encoded as text, associated with 2D zoning maps, and will have to be translated in a machine-readable and possibly spatialised (3D) format in order to be effectively used for automatic validation.

4.4. Developing a GeoBIM workflow

As a first outcome of the shared experiences, activities and investigations into current practices, the steps involved in the building permit issuing process in different countries were detailed to harmonise the workflows, in order to ensure that no key steps are omitted (which would prevent the resulting methodology from being widely applicable).

The procedural workflows followed for building permission are usually very complex and many steps are involved by different municipalities' officers. However, for the purpose of harmonisation, the main steps are considered and reported in this paper. The macro-scale needs of these steps (involved stakeholders, processes and data) will be sufficient to match the similar ones through countries and to associate the respective phases of the proposed GeoBIM technical workflow. The next phase of the research will consist of defining exactly what data (with what characteristics) and what stakeholders should be involved.

4.4.1. UK

In the UK, although many local variations exist, the planning permit process follows five core steps (DCLG 2015):

- submit an application;
- consultation with neighbours;
- application reviewed (does it comply with local or national planning guidelines);
- planning decision (by the planning officials within the municipality or by a planning committee);
- opportunity to appeal the decision;
- start of construction.

4.4.2. The Netherlands

In the Netherlands the main steps are (Deloitte 2011):

- submit application;
- phasing and publishing;
- stake out requests for advice and additional eventual complementary advice process. The specific features of the proposed building are analysed by experts in

mainly five domains, according to the specific domain regulations, namely: 10 structural safety, 2) fire prevention, 3) architectural features including, for example, dimensions, 4) building physics, related, for example, to energy and installation performances, and 5) welfare issues, including, for example, aesthetic characters and city monuments;
- planning decision is finally made and communicated;
- start of construction.

4.4.3. Sweden

In Sweden the steps are also similar:

- Submit application;
- Check of the plans against the Planning and Building Act and related regulations;
- Building permit granted;
- Eventually, a technical consultation with the committee to describe plan and organisation of the work, inspection plan and other documents (https://www.boverket.se/en/start/building-in-sweden/swedish-market/laws-and-regulations/building-process/guide-building-process/);
- Starting clearance;
- Start of construction.

In Sweden, as in some of the other countries, an important part of the process is represented by inspections, which have to be specifically planned both during and after the construction works.

4.4.4. Slovenia

In Slovenia, the main steps are:

- Submission of application;
- Checks on formal requirements;
- Checks on contents requirements from regulations;
- Building permission issued;
- Start of construction.

4.4.5. Other countries and the high-level harmonszed workflow

The workflows in the other countries participating in the project (France, Ireland, Catalunya, Switzerland, Denmark, Norway, Finland, Poland) were not analysed in detail. However, as resulted from the workshops, no additional significant steps were identified.

A more comprehensive overview of the current building permission workflow in many European countries was given by Meijer and Visscher (2017), Meijer and Visscher (2016), Pedro *et al*. (2011) and Meijer *et al*. (2002). From these sources, it is possible to divide the building permit workflow into the following core steps, also considering the parts of the workflow that take place after the start of construction, even if not explicitly reported by the participant countries:

- Pre-consultation;
- Application submission;

- Consultation with neighbours or other citizens;
- Application review and regulation checks;
- Planning decision made;
- Start of construction
- Site inspections during the works
- Completion and notification to building authorities;
- Final inspection
- Completion certificate/use permit issuing.

These references one were used as main reference for harmonising the other workflows in a common one (Figure 2).

While most of the steps are clear, some of the involved phases, not common everywhere need more explanation: i.e. the pre-consultation, consultation with neighbours, and phasing. These steps are described in the following text. Moreover, Table 3 summarises the data useful in each step of the workflow using GeoBIM.[5]

The 'pre-consultation' step provides a preliminary meeting with the planning authority to discuss the planned work and building design and request information about specific issues and requirements. It is voluntary in most of the European countries, and even not 'official' in some of them.

The 'consultation with neighbours' is mentioned in the UK process, where neighbours have the opportunity to give opinions about the proposed building. In other countries, this is again not explicitly mentioned, but the design can be published in order to allow eventual (strongly motivated) objections.

The 'phasing' step provides the possibility to divide the application into several phases. Especially for complex projects, this can be useful to avoid developing a full project when something in the preliminary ('outline') design may not be approved. When the phasing is permitted, the design is usually divided in the following stages (Pedro *et al.* 2011):

(1) intended use of the lot, zoning planning in detail and preliminary design of the building layout and volumes;
(2) technical design;
(3) detailed drawing supporting construction.

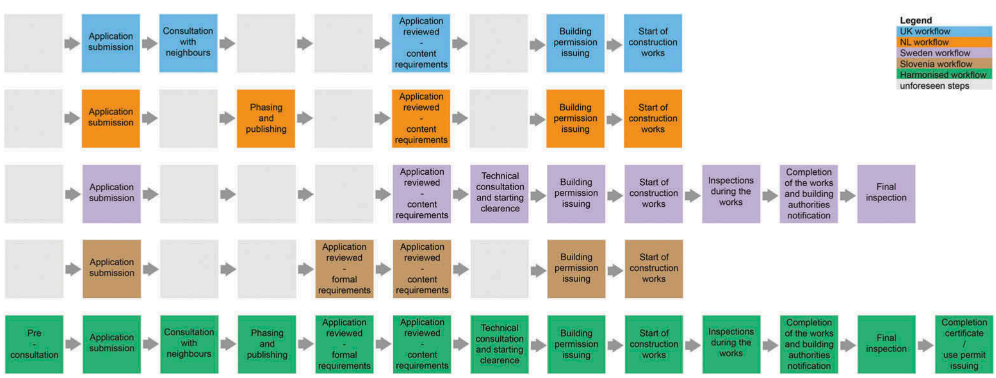

Figure 2. Parallel representation of core procedural steps in the considered planning permission workflows, and the finally harmonised one (in green).

Table 3. GeoBIM Data supporting the building permit workflow steps.

Workflow step	Required GeoBIM data
Pre-consultation	• Existing (up-to-date) 3D city model (CityGML); • Digital regulations
BIM design	• 3D city model (CityGML) eventually converted to IFC to be read in the BIM environment.
Application submission	• BIM (IFC)
Consultation with neighbours	• Submitted BIM (IFC) provisionally inserted in the 3D city model. This could be with or without conversion to CityGML if a 3D viewer could support both data types (CityGML and IFC) at the same time.
Phasing and publishing	• Definition of different levels of development for the different phases (e.g. LOD 200 phase 1; LOD 300 phase 2; LOD 350/400 phase 3).
Review of the application (formal)	• Submitted BIM (IFC) compliant with guidelines
Review of the application (contents)	• Submitted BIM (IFC); • Submitted BIM converted to CityGML and integrated in the existing 3D city model • Existing 3D city model (CityGML) • Digital regulations
Technical consultation	• Submitted BIM (IFC) • Submitted BIM converted to CityGML and integrated into the existing 3D city model
Inspections during the works	• Submitted (and eventually updated) BIM (IFC)
Completion of the works	• Delivery of the up-to-date BIM (IFC)
Final inspection	• Final ('as-built', LOD 500) BIM (IFC) • New version of the 3D city model (CityGML) including the new building from the delivered IFC.

4.4.6. The resulting GeoBIM workflow

Following on from the above analysis of current practice and workflows and ongoing projects in the participating countries, we propose a draft for a more technical workflow to be followed in the use of GeoBIM integrated information for building permits (Figure 3 shows a very synthesis of the workflow, which is represented in more detail in Figure 4; Figures 5–8 underline the parts of the workflow relevant to each specific phase). The following steps outline the proposed workflow:

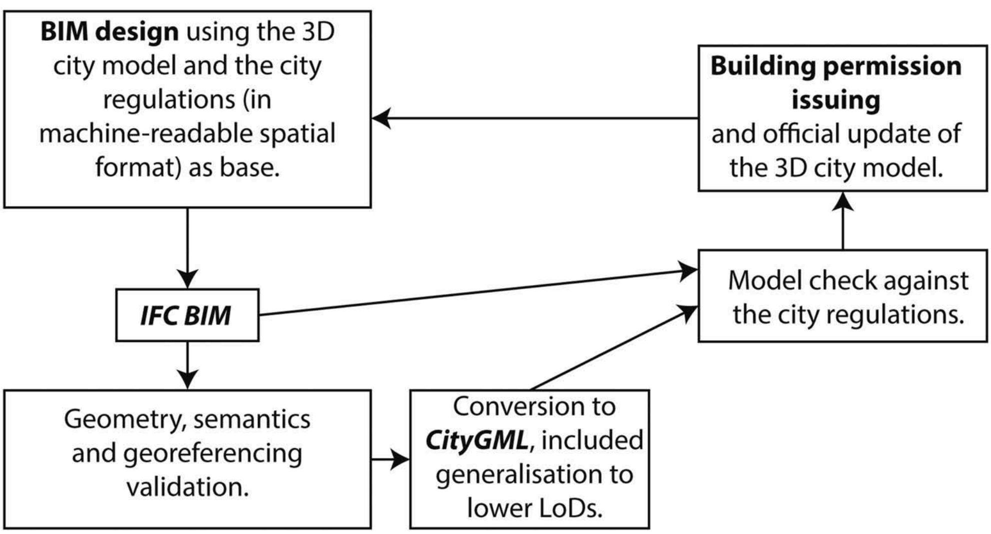

Figure 3. Synthetic representation of the technical workflow using GeoBIM information for planning permissions.

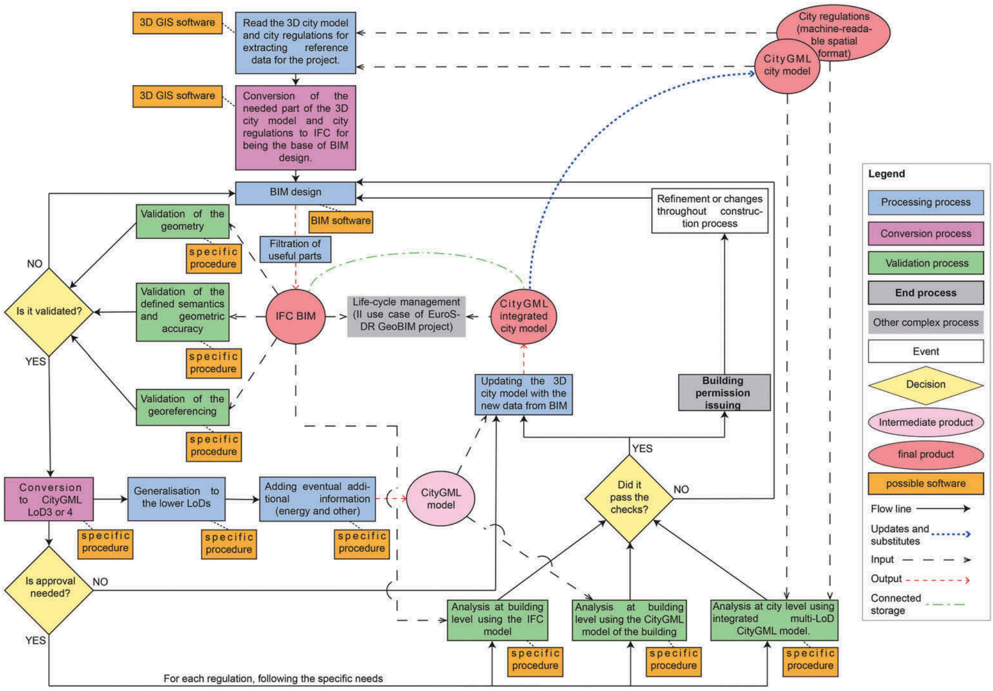

Figure 4. Expanded representation of the technical workflow using GeoBIM information for planning permissions.

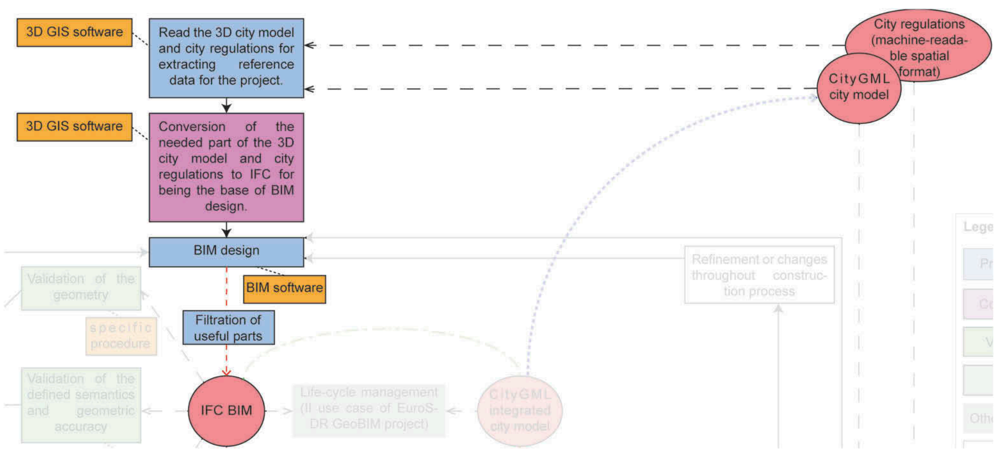

Figure 5. Workflow portion showing the first step: design of the new building aided by reading and use of the 3D city model and digital regulations and export of the useful parts of the model for submission to IFC.

(1) read and use of 3D city model and the machine-readable regulations (e.g. cadastral parcels, existing built environment, context, vegetation, 3D high-level-of-detail existing building models as base for restoration or new intervention) to support and guide the design, analysing the existing

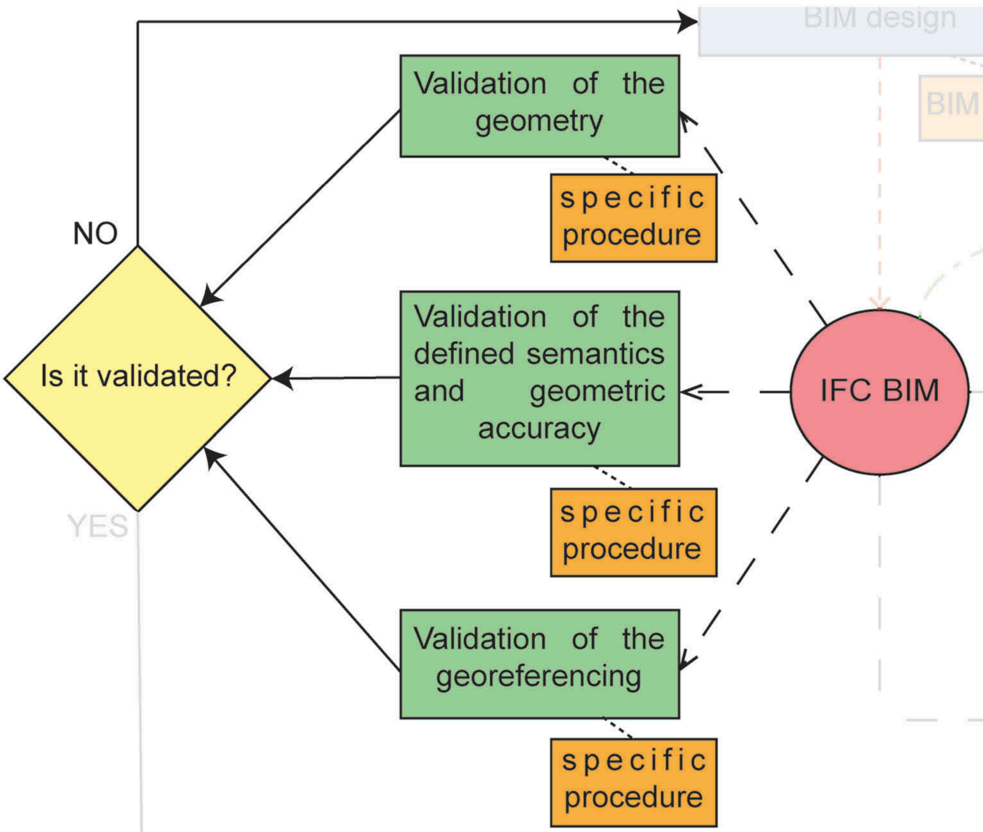

Figure 6. Workflow portion showing the validation of the submitted IFC model.

environment, importing the data directly in the design software for having immediate reference and preliminarily testing different design solutions in the building's context (Figure 5);

(2) check of the validity of the designed BIM geometry, semantics and georeferencing (exported in IFC) (Figure 6);
(3) conversion of the BIM to an open standard (CityGML) (likely in LoD4 or 3), generalisation to the lower levels of detail (LoD2 and LoD1) and integration of the information with further necessary attributes (Figure 7);
(4) analysis of the integrated information for checking the selected city regulations (in the detailed development plan) (Figure 8);
(5) building permit issuing. The BIM will be finally stored in a connected repository linked to the new entity in the 3D city model, available for subsequent use;
(6) if the new building project does not comply with regulations, or the design is changed, the BIM should be modified and the whole process needs to be repeated.

It is important to note that within this broad workflow, further refinements can be added to account for the need to check a vast range of requirements both in terms of planning constraints but also those defined by other fields of expertise involved (e.g. building physics experts, fire safety experts).

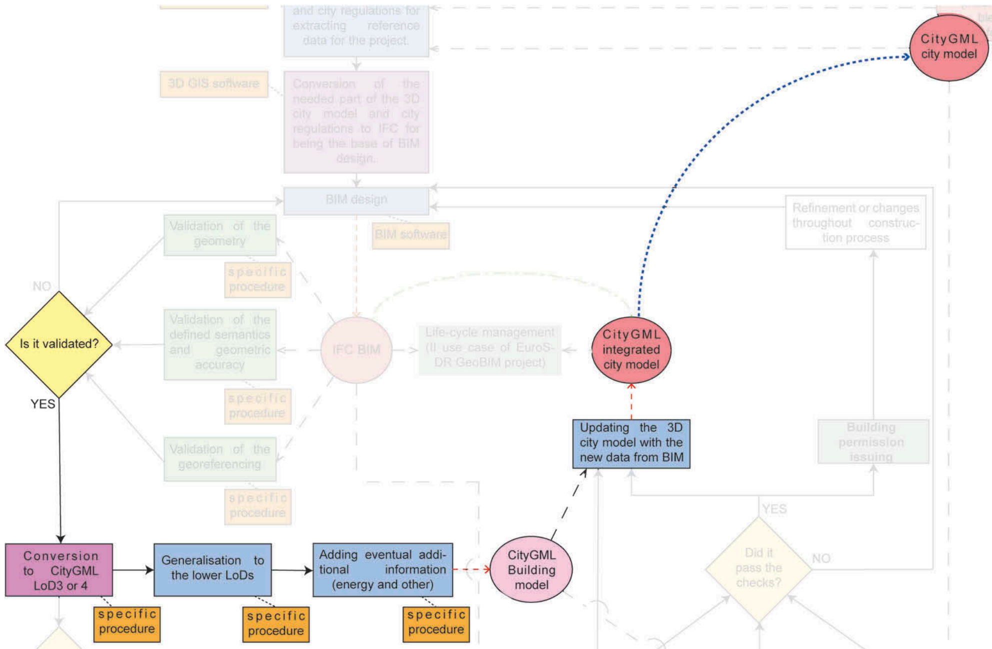

Figure 7. Workflow portion showing the conversion of the submitted and validated IFC model to CityGML.

The diagram also allows the identification of critical data interchange points, which in turn permits the identification of the specific conversion requirements that will enable the above workflow. The conversions should result in consistent models through the whole cycle as the model undergoes several transformations (shown in a high-level overview in Figure 9):

(1) modelling in the used BIM software format;
(2) export to IFC;
(3) conversion to CityGML;
(4) import into the GIS (or other) software (and likely converted from CityGML to the specific format) for analyses;
(5) re-export to CityGML;
(6) conversion to IFC;
(7) import into the BIM software for any modifications.

Moreover, the data should also be available to be modified/analysed through different, perhaps discipline-specific tools e.g. for noise measurement or air quality modelling.

Finally, each step of the current workflows (harmonised as in Figure 2), intended as procedural steps, is finally associated to the specific steps and related data of this more technical proposed workflow employing GeoBIM information (Figure 10).

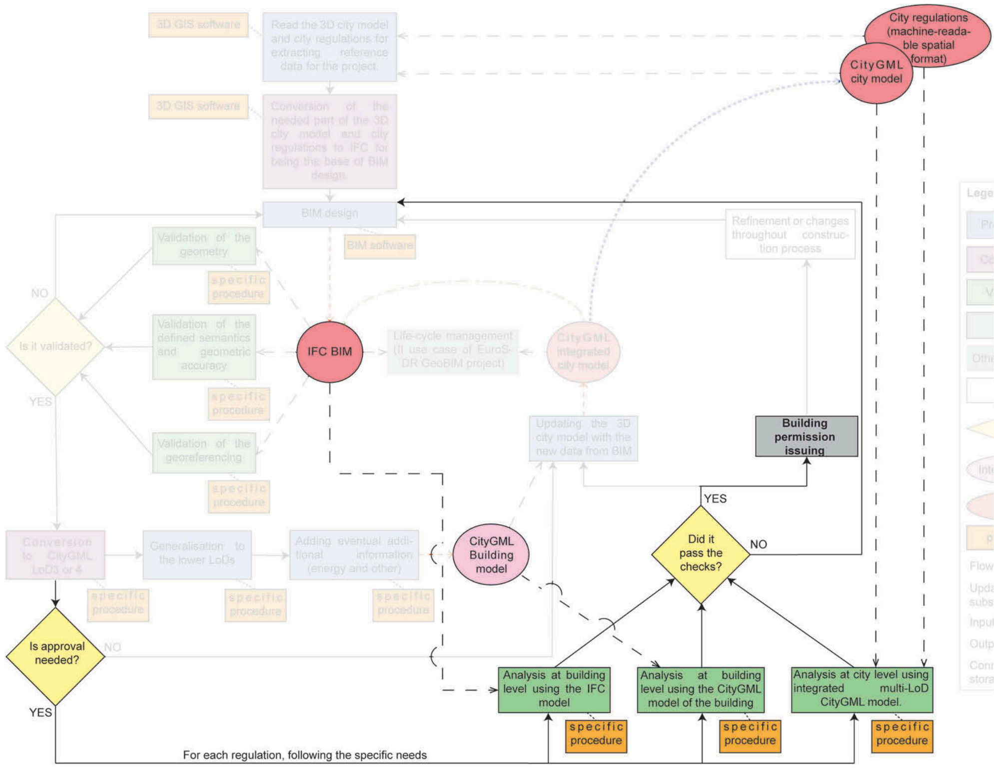

Figure 8. Last portion of the technical workflow, concerning the check of the new plan against the regulations constraints using all the involved and integrated data: IFC model, CityGML version of the designed building, 3D city model and digital city regulations.

5. Discussion and conclusion

Applications benefiting from GeoBIM can be identified by considering any application that combines geometric and semantic data about the built environment (sourced from GIS) with data about indoor structures or detailed engineering structures sourced from BIM.

This paper presented the results of research into the use of GeoBIM across Europe. As well as highlighting the wide range of opportunities identified for GeoBIM uptake, we also noted key challenges that are currently preventing it: technical (software and data), but, equally important, a lack of understanding of the potential of GeoBIM integration.

To start address these challenges, a planning/permit use case was investigated.

Despite the complexity of the planning processes, it was possible to identify commonalities across multiple nations and demonstrate that GeoBIM does have the potential to automate constraint checking at some levels.

However, the research also highlighted vast gaps in the data required to achieve this digital integration. In the majority of cases, permit applications are submitted as PDF documents, planning regulations are encoded as 2D/text documents and the process is additionally complicated by a multi-level regulatory and decision-making hierarchy.

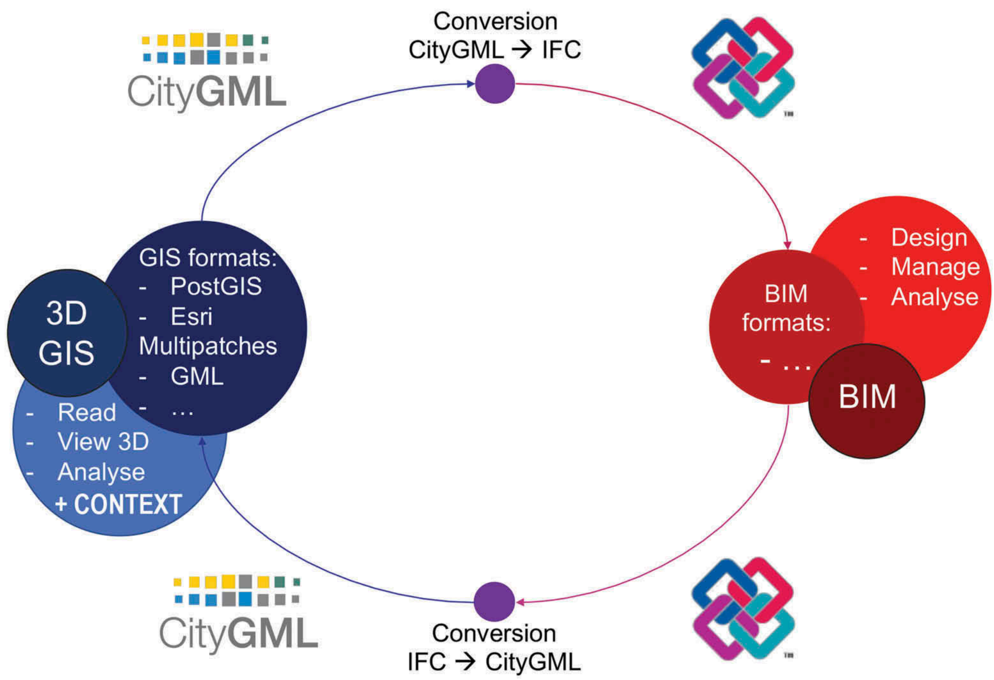

Figure 9. High-level schema summarising the kinds of data conversion needed in the management of GeoBIM information.

A high-level harmonised workflow was defined, which highlights GeoBIM information interchange at multiple phases of the planning process. The defined workflow clearly demonstrates multiple key integration points and highlights specific translation and other analytical tasks (to validate the design at various phases of the process) and the context, BIM or GIS, in which these should take place. This provides a preliminary foundation for the identification of specific tools to be used at each stage of the process, and for the development of detailed data requirements for each phase.

Data required for the process include the 3D city models, the BIMs, and the regulations to be checked. Moreover, the simple availability of such data for a specific project is not a sufficient condition to fully enable the workflow. The characteristics of the data should be known and they will need to comply with as-yet-to-be-defined requirements in terms of geometry, semantics, georeferencing, currency, level of detail, and so on. No doubt, a uniform method for describing the data's metadata will help save time and effort and would avoid the risk of misinterpreting them (e.g. for 3D city models, Labetski *et al*. 2018).

5.1. Future work

Work on the EuroSDR project is ongoing, and following the development of the workflow, we will focus on drilling down into the detail of each phase, to identify detailed

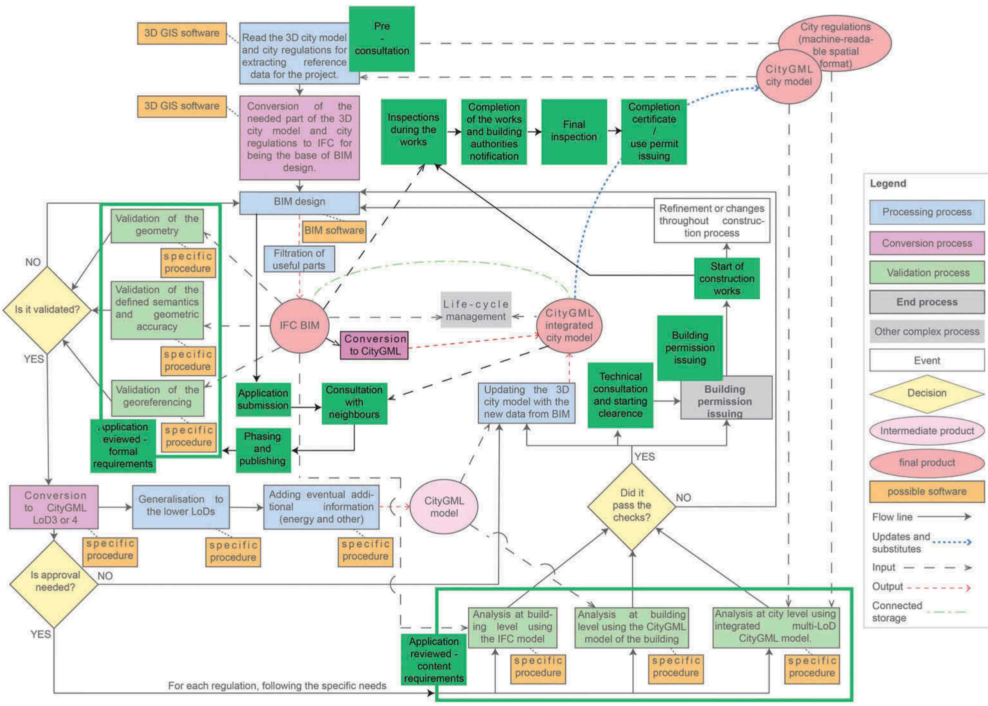

Figure 10. Comprehensive schema associating the procedural steps of the high-level harmonised workflow (Figure 2) and the technical steps useful to manage the planning permission through GeoBIM information (Figure 4).

data requirements for exchange, design an appropriate way to encode the constraints and also identify software suitable for conversion processes and constraints checking, resulting in a toolbox listing the tools and data specifications required to underpin GeoBIM in planning.

An additional, related, challenge concerns the software or procedures (orange boxes in Figure 5) that are required for the different processing phases of the workflow. The main challenge for the tools and methods performing the processing in all the phases, is the import, export and conversion of the same models many times in different formats. The investigation of the available technical alternatives and their performances is, indeed, the objective of a related ongoing initiative, funded by ISPRS (www.isprs.org) and EuroSDR, the 'GeoBIM benchmark' (https://3d.bk.tudelft.nl/projects/geobim-benchmark/).

Additionally, further work is required in order to standardise the encoding of these rules, even including the possibility to accommodate local variations in a flexible manner.

Finally, of key importance for our subsequent work is working with stakeholders (architects, planners, local municipalities) to validate whether the generic approach can be customised on a case-by-case basis to specific local needs, to identify planning rules/constraints that can be automated and to identify any institutional challenges that will need to be overcome (with the help of the outcomes of this work) for widespread implementation.

5.2 Conclusion

The harmonisation of the multi-country experiences and challenges for GeoBIM into a framework considering current working practice, technical and institutional aspects are not straightforward, and this work is a first step towards a more practical application of GeoBIM for building permission. Based on the above workflow, it is now possible to tackle these challenges in a more systematic way, more in depth and with multiple beneficiaries.

The ultimate outcome of the project will be guidelines for best practices when using geoinformation in BIM applications and vice versa, allowing BIM to fully exploit geoinformation and geoinformation to fully exploit BIM.

Notes

1. In particular, BIM could effectively exploit the representation of the geographical context in which the building will be designed, by directly importing the geospatial context into the design software, or by making use of powerful analysis provided by Geographical Information Systems (GIS) relating both to the city and to the building itself, thus testing the impact of the building on the city and of the city on the building.
2. e.g. avoiding adjusting the building design after a negative check, less rules-breaking in the zoning with negative consequences for the city and other buildings, no loss of time in checking non-compliant designs, etc.
3. In addition to checking urban regulations with an integrated GeoBIM approach, BIM offers the possibility to automatically check building regulations such as minimum area of toilets or maximum distance from each location on a floor to the stairs. Since these building rules only require a model of the building and no geoinformation, they fall outside the scope of our research.
4. As an example, 'Planning Portal' (which is a collaboration between the UK Ministry of Housing, Communities and Local Government and TerraQuest Ltd setup to make the planning process easier) notes that nationally a site plan (map of the site) and a block plan (showing the development in detail) are required.
5. In this summary, the calculation of fees and construction costs are not considered. However, the possibility to use BIM data would offer great advantages (e.g. accurate evaluations) even in this case.

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References

'*Smart built environment*' Swedish project [online]. Available from: https://www.smartbuilt.se/in-english/ [Accessed 5 April 2019].

Allmendinger, P. and Sielker, S., 2018. *Urban planning and BIM - final report*. Department of Land Economy, University of Cambridge.

Amirebrahimi, S., *et al*., 2016. A framework for a microscale flood damage assessment and visualization for a building using BIM–GIS integration. *International Journal of Digital Earth*, 9 (4), 363–386. doi:10.1080/17538947.2015.1034201

Atazadeh, B., *et al*., 2017. Extending a BIM-based data model to support 3D digital management of complex ownership spaces. *International Journal of Geographical Information Science*, 31 (3), 499–522. doi:10.1080/13658816.2016.1207775

BIM loket [online]. Available from: www.bimloket.nl [Accessed 5 April 2019].

Boyes, G.A., Ellul, C., and Irwin, D., 2017. Exploring BIM for operational integrated asset management – a preliminary study utilising real-world infrastructure data. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 4 (4W5), 49–56. doi:10.5194/isprs-annals-IV-4-W5-49-2017

Brasebin, M., *et al*., 2016. A generic model to exploit urban regulation knowledge. *ISPRS International Journal of Geo-Information*, 5 (2), 14. doi:10.3390/ijgi5020014

Brent, n/d. *Supplementary planning guidance - buildings in gardens within conservation* areas, *London Borough of Brent* [online]. Available from: https://www.brent.gov.uk/media/154770/SPG20%20Buildings%20in%20gardens%20in%20conservation%20areas.pdf [Accessed 5 April 2019].

buildingSMART industry foundation classes [online]. Available from: https://www.buildingsmart.org/ [Accessed 5 April 2019].

Casey, M.J. and Vankadara, S., 2009. Semantics in CAD/GIS integration. *In*: A. Karimi and B. Akinci, eds. *CAD and GIS integration*. Auerbach Publications, 146–173.

Chapron, P., *et al*., n/d. *Exploration de l'influence de la réglementation urbaine locale sur la morphologie des formes bâties par simulation distribuée* [online]. Available from: https://iscpif.fr/wp-content/uploads/2017/06/Presentation-SimPLU.pdf and https://iscpif.fr/projects/17808/ [Accessed 5 April 2019].

DCLG, 2015. *Plain English guide to the planning system*, Department of Communities and Local Government. Available from: https://assets.publishing.service.gov.uk/government/uploads/sys

tem/uploads/attachment_data/file/391694/Plain_English_guide_to_the_planning_system.pdf [Accessed 5 April 2019].
de Laat, R. and Van Berlo, L., 2011. Integration of BIM and GIS: the development of the CityGML GeoBIM extension. *In*: T.H. Kolbe, G. König, and C. Nagel, eds. *Advances in 3D geo-information sciences*. Berlin, Heidelberg: Springer Science & Business Media, 211–225.
Deloitte, 2011. *Resultaten. Workshop Verdiepingsslag processen Stadsontwikkeling/vergunningen 14 juli 2011*. Ketensamenwerking bij vergunningverlening Stadsontwikkeling/vergunningen, Havensteder & DuraVermeerBouw Rotterdam. 1.0, 3-08-2011.
Deng, Y., Cheng, J.C., and Anumba, C., 2016b. A framework for 3D traffic noise mapping using data from BIM and GIS integration. *Structure and Infrastructure Engineering*, 12 (10), 1267–1280. doi:10.1080/15732479.2015.1110603
Deng, Y., Cheng, J.C.P., and Anumba, C., 2016. Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. *Automation in Construction*, 67, 1–21. doi:10.1016/j.autcon.2016.03.006
Ellul, C., et al., 2017. Towards integrating BIM and GIS—an end-to-end example from point cloud to analysis. In: Advances in 3D geoinformation.Cham: Springer, 495–512.
Ellul, C., *et al*., 2018. Investigating the state of play of GeoBIM across Europe. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42, 4(W/10), 19–26.
El-Mekawy, M.S.A., Paasch, J.M., and Paulsson, J., 2015. Integration of legal aspects in 3D cadastral systems. *International Journal of E-Planning Research*, 4 (3), 47–71. doi:10.4018/IJEPR.2015070103
e-*PROSTOR project*, Slovenia [online]. Available from: http://www.projekt.e-prostor.gov.si/ [Accessed 5 April 2019].
European parliament and council directive 2014/24/EU of 26 February 2014 on public procurement and repealing directive 2004/18/EC.
European parliament and of the council directive 2007/2/EC of 14 March 2007 on the INfrastructure for spatial information in Europe (INSPIRE). Available from: https://inspire.ec.europa.eu [Accessed 5 April 2019].
EuroSDR GeoBIM project [online]. Available from: https://3d.bk.tudelft.nl/projects/eurosdr-geobim/ [Accessed 5 April 2019].
Exeter 2008 *supplementary planning document - housholder's guide to extension design, exeter city council* [online]. Available from: https://exeter.gov.uk/media/1660/household-guide-to-extensions-spd.pdf [Accessed 5 April 2019].
Får jag lov? Swedish project [online]. Available from: https://farjaglovprojektet.wordpress.com/ [Accessed 5 April 2019].
FCC, 2018. *Prototyping the future of planning report, future cities catapult* [online]. Available from: https://futurecities.catapult.org.uk/opportunity/prototyping-future-planning/ [Accessed 4 April 2019].
FCP 2018, *Future city pilot 1 - automating urban planning using web processing service engineering report* [online]. Available from: http://docs.opengeospatial.org/per/16-099.html [Accessed 5 April 2019].
Floros, G., Ellul, C.D., and Dimopoulou, E., 2018. Investigating interoperability capabilities between IFC and CityGML LOD 4–retaining semantic information. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives*, 42 (4/W10), 33–40. doi:10.5194/isprs-archives-XLII-4-W10-33-2018
Fosu, R., *et al*., 2015. Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) – a literature review and future needs. *In*: *Proceedings of the 32nd CIB W78 Conference, Eindhoven*, *The Netherlands*. 27–29.
GCS, 2011. *Government construction strategy*, cabinet office [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/61152/Government-Construction-Strategy_0.pdf [Accessed 5 April 2019].
GeoBIM benchmark project [online]. Available from: https://3d.bk.tudelft.nl/projects/geobim-benchmark/ [Accessed 5 April 2019].

Greefhorst, D., Knibbe, F., and Huisman, A., 2018. *BIM verzamelen, verbinden en visualiseren voor vergunningverlening* [BIM collect, connect and visualize for licensing - Final report] versie 0.2, Eindrapport. The Netherlands: Kadaster.

Hijazi, I., Donaubauer, A., and Kolbe, T., 2018. BIM-GIS integration as dedicated and independent course for geoinformatics students: merits, challenges, and ways forward. *ISPRS International Journal of Geo-Information*, 7 (8), 319. doi:10.3390/ijgi7080319

Hwang, J.R., Kang, T.W., and Hong, C.H., 2012. A study on the correlation analysis between IFC and CityGML for efficient utilization of construction data and GIS data. *Journal of Korea Spatial Information Society*, 20 (5), 49–56. doi:10.12672/ksis.2012.20.5.049

INSPIRE data model [online]. Available from: https://inspire.ec.europa.eu/data-model/approved/r4618-ir/html/ [Accessed 5 April 2019].

Isikdag, U. and Zlatanova, S., 2009. Towards defining a framework for automatic generation of buildings in CityGML using building Information Models. *In*: J. Lee and S. Zlatanova, eds. *3D Geo-Information Sciences*. Heidelberg/Berlin: Springer, 79–96.

Jayakody, A., *et al*., 2013. *The development of the CityGML GeoBIM extension for real-time assessable model (integration of BIM and GIS)*. PNCTM, 2.

Kang, T., 2018. Development of a conceptual mapping standard to link building and geospatial information. *ISPRS International Journal of Geo-Information*, 7 (5), 162. doi:10.3390/ijgi7050162

Knoth, L., *et al*., 2018. Cross-domain building models—a step towards interoperability. *ISPRS International Journal of Geo-Information*, 7 (9), 363. doi:10.3390/ijgi7090363

Laakso, M. and Kiviniemi, A.O., 2012. The IFC standard: A review of history, development, and standardization, information technology. *ITcon*, 17 (9), 134–161.

Labetski, A., *et al*., 2018. A metadata ADE for CityGML. *Open Geospatial Data, Software and Standards*, 3 (1), 16. doi:10.1186/s40965-018-0057-4

Liu, X., *et al*., 2017. A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, 6 (2), 53. doi:10.3390/ijgi6020053

London Plan, 2017. *The spatial development plan for London, Greater London authority* [online]. Available from: https://www.london.gov.uk/sites/default/files/the_london_plan_2016_jan_2017_fix.pdf [Accessed 5 April 2019].

Meijer, F. and Visscher, H., 2016. *QuickScan van buitenlandse stelsels van kwaliteitsborging in Engeland, Ierland, Duitsland, Frankrijk, Noorwegen, Zweden en Australië*. Delft: Quick Scan of Quality Control Systems for Building in Germany, England & Wales, France, Ireland, Norway, Sweden and Australia, Delft University of Technology.

Meijer, F. and Visscher, H., 2017. Quality control of constructions: European trends and developments. *International Journal of Law in the Built Environment*, 9 (2), 143–161. doi:10.1108/IJLBE-02-2017-0003

Meijer, F., Visscher, H., and Sheridan, L., 2002. *Building regulations in Europe*. Delft NL: DUP Science. ISSN 0926-6240; 23 ISBN 90-408-2373-7.

MHCLG, 2018. *Guidance: neighborhood planning*, ministry of housing, communities and local government [online]. Available from: https://www.gov.uk/guidance/neighbourhood-planning–2#what-is-neighbourhood-planning [Accessed 5 April 2019].

Noardo, F., *et al*., 2019. GeoBIM benchmark 2019: design and initial results. *In*: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives*. Proceedings of Geospatial Week, Enschede, 10–14 June 2019.

OGC CityGML. http://www.citygmlwiki.org [Accessed 5 April 2019].

Ohori, K., *et al*., 2018. Processing BIM and GIS models in practice: experiences and recommendations from a GeoBIM project in the Netherlands. *ISPRS International Journal of Geo-Information*, 7 (8), 311. doi:10.3390/ijgi7080311

Ohori, K.A., *et al*., 2017. Towards an integration of GIS and BIM data: what are the geometric and topological issues. *In*: *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*, Proceedings of ISPRS 12th Geoinfo Conference, Melbourne, Australia. 26–27.

Olsson, P.O., *et al.*, 2018. Automation of building permission by integration of BIM and geospatial data. *ISPRS International Journal of Geo-Information*, 7 (8), 307. doi:10.3390/ijgi7080307

Pedro, J.B., Meijer, F., and Visscher, H., 2011. Comparison of building permit procedures in European Union countries. *RICS Construction and Property Conference*, 356–375.

Portal Prostor Slovenia [online]. Available from: http://www.e-prostor.gov.si [Accessed 5 April 2019].

Pouliot, J., *et al.*, 2018. Exploring schema matching to compare geospatial standards: application to underground utility networks. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives*, 42 (4/W10), 157–164. doi:10.5194/isprs-archives-XLII-4-W10-157-2018

Rgd, 2012. *Rgd BIM standard, version 1.0.1, 1 July 2012*. The Netherlands: Dutch Ministry of the Interior and Kingdom Relations.

Rizal, R., Bohms, M., and van den Helm, P., 2013. BIM and GIS for low-disturbance construction. *In*: *Proceedings of the 13th International Conference on Construction Applications of Virtual Reality*. London, UK.

Snowball sampling in Wikipedia [online]. Available from: https://en.wikipedia.org/wiki/Snowball_sampling [Accessed 5 April 2019].

Song, Y., *et al.*, 2017. Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: a review from a spatio-temporal statistical perspective. *ISPRS International Journal of Geo-Information*, 6 (12), 397. doi:10.3390/ijgi6120397

Stoter, J., Commandeur, T., and Ledoux, H., 2017. 3D BGT: waarom, wat en hoe?. *Geo-Info* 14(2), 2017–2.

Tashakkori, H., Rajabifard, A., and Kalantari, M., 2015. A new 3D indoor/outdoor spatial model for indoor emergency response facilitation. *Building and Environment*, 89, 170–182. doi:10.1016/j.buildenv.2015.02.036

Tekavec, J., *et al.*, 2018. The slovenian building cadastre as the basis for a 3D real property cadastre. *Vi. Hkk*, 2018, 61.

Uggla, G. and Horemuz, M., 2018. Geographic capabilities and limitations of IFC. *Automation in Construction*, 96, 554–566. doi:10.1016/j.autcon.2018.10.014

Van Berlo, L.A.H.M., Dijkmans, T., and Stoter, J.E., 2013. Experiment for integrating Dutch 3D spatial planning and BIM for checking building permits. *In*: *ISPRS* Archives *of the Photogrammetry*, Remote Sensing *& Spatial Information* Sciences, *II-2/W*. 18th 3DGeoInfo Conference & WG II/2 Workshop, Istanbul, Turkey, 27–29 November 2013. ISPRS.

Vanlande, R., Nicolle, C., and Cruz, C., 2008. IFC and building lifecycle management. *Automation in Construction*, 18 (1), 70–78. doi:10.1016/j.autcon.2008.05.001

Zhu, J., *et al.*, 2018. A critical review of the integration of geographic information system and building information modelling at the data level. *ISPRS International Journal of Geo-Information*, 7 (2), 66. doi:10.3390/ijgi7020066