Integration of BIM and Environmental Planning: The CityGML EnvPlan ADE

Laura Wilhelm[1], Andreas Donaubauer[2], Thomas H. Kolbe[2]

[1]Chair of Geoinformatics, Technical University of Munich/Germany · laura_wilhelm@outlook.com
[2]Chair of Geoinformatics, Technical University of Munich/Germany

Abstract: While disciplines such as architecture, structural design or technical building equipment have already integrated their processes, data structures and tools well into Building Information Modeling (BIM), this has not yet been sufficiently achieved in environmental planning and landscape architecture. Problems that make integration difficult arise from differences in the scope and scale of the models needed for building construction on the one hand and environmental planning on the other: while building construction models focus mainly on the structure itself, environmental planning also considers natural objects such as habitats and protected areas within a larger radius of the structure. Data about such objects are typically maintained in GIS, so the integration of BIM and environmental planning is a matter of BIM-GIS integration. Based on a requirements analysis and an evaluation of existing standardized information models, this paper presents CityGML EnvPlan ADE, a new 3D information model for integrating BIM and environmental planning. As a proof of concept, the information model is tested in a real railroad construction project.

Keywords: Environmental planning, BIM, LIM, 3D GIS, CityGML, spatial-temporal modeling

1   Introduction

Building Information Modelling (BIM) has become mandatory in construction processes in many countries. BIM pursues the goal of integrating all disciplines working in a construction process in an overall integrated data environment. While disciplines such as architecture, structural design or technical building services have already integrated their processes, data structures and tools well into the BIM process, this is not yet sufficiently achieved in environmental planning and landscape architecture (FRITSCH et al. 2019, JUPP 2017, PETERS & THON 2019). This paper presents a novel approach to integrate BIM and environmental planning on the level of information models.

In the context of this paper, the term environmental planning serves as a collective term for the development and implementation of spatially related objectives of environmental policies. Based on geospatial data, such as protected sites and the mapping of species and biotopes, conflicts with planned technical constructions like buildings or infrastructure works are identified and environmental measures are derived. The results of this process are documented and visualized on plans, that describe all conflicts and measures related to a specific construction project.

Consequently, integrating environmental planning into the BIM process means to integrate digital representations of planned buildings or infrastructure work and the digital representation of their environmental context. Whereas the construction data originates from BIM authoring tools, the environmental context including environmental conflicts and planned environmental measures is maintained using Geographic Information Systems (GIS). A major characteristic of the BIM method is that planning is carried out at least in 3D with time and cost as two additional dimensions. For environmental planning this leads to a shift from 2D-

planning to a multidimensional planning approach, which has to be reflected by an appropriate information model. In general, the construction process requires data at different levels of detail. Environmental data in GIS is mainly represented at the macro level whereas the building data in BIM is at the micro level. Therefore, information models from these two domains have been developed independently and the respective standards differ strongly in their structure as BIM and GIS are treated as two separate scopes (ZADEH et al. 2019, KOLBE & PLÜMER 2004). Topographic 3D GIS data can be represented using the City Geography Markup Language (CityGML), a standardized information model for semantic 3D City and Landscape models. BIM models can be standardized via the Industry Foundation Classes (IFC). Since the two standards were developed for different purposes, they have different structures. IFC comprehensively maps the building structure, CityGML focuses on the 3D and semantic representation of topography and thus includes thematic domains such as terrain, buildings, streets, vegetation or water bodies (KOLBE & DONAUBAUER 2021, OPEN GEOSPATIAL CONSORTIUM & buildingSMART INTERNATIONAL 2020, STOUFFS et al. 2018).

Taking into account the information requirements of environmental planning, our investigations show that neither CityGML nor IFC is capable to represent all the information required and produced in the environmental planning process.

However, as many tools, data sets and digital methods in environmental planning are based on GIS, the aim of the integration concept presented in this paper is to use a model from the geospatial domain as integration platform. Furthermore, there is a wide range of software for BIM and GIS. So the second aim of the integration concept is to enable a solution, which is defined independently of a specific software platform. By the standardization of the information model, interfaces can be created, which facilitate and simplify the subsequent management and processing of the data in their respective authoring systems. Consequently, the integration approach is designed on the level of a standardized, comprehensive information model.

2 Related Work

2.1 General BIM GIS Integration Research

There are different ways to integrate BIM and GIS. WANG et al. (2019) distinguishes three typical types: (1) BIM leads and GIS supports, (2) GIS leads and BIM supports, (3) BIM and GIS are equivalent. HIJAZI and DONAUBAUER (2017) identify four main approaches for integrating BIM/GIS at the standardization level: converting IFC to CityGML, CityGML/GIS to IFC, a unified model, or linking BIM and Urban Information Model (UIM). BECK et al. (2020) call for a differentiation between integration efforts in the field of "BIM-GIS Integration", as this term serves as an umbrella term. The authors introduce three main categories, "information characteristic", "solution characteristics" and "purpose", the integration approaches can be differentiated according to their challenge and purpose. A CityGML application domain extension (ADE) – i. e. an extension of the standardized CityGML information model – for example, is located under the "solution characteristics" with sub category "integration method" and "extension".

Several studies show that data exchange between GIS and BIM can be useful for both sides (e. g. CHOGNARD et al. 2018). In the field of automatic conversion from CityGML to IFC a workflow for the conversion of the different properties for representing real world entities of

both standards (semantics, geometry, topology, encoding, georeferencing) has been developed (SALHEB et al. 2020). Integration of BIM and GIS can also be achieved with generic triple graph grammar: TAUSCHER (2020) introduces workflows for the generation of IFC and CityGML metamodels specified as ECore. The workflow for the creation of integration rules allows its application to future schema extensions, too. LIM et al. (2020) developed a Web-based viewer, which is able to visualize CityGML ADE-enabled files, as several ADEs for the BIM to CityGML conversion have been developed.

2.2   BIM GIS Integration in the Environmental Planning Domain

Several integration concepts in the discipline of landscape architecture and landscape planning are based on the further development of IFC (BRÜCKNER et al. 2019, PETERS & THON 2019, SHILTON 2018, WIK et al. 2018). The Norwegian BIM for Landscape Initiative has developed a set of definitions, parameters and code lists to represent 44 landscape objects. The goal is to thereby obtain a uniform standard for landscape objects (WIK et al. 2018). The UK is developing a BIM for Landscape at the Landscape Institute with Product Data Templates (PDT) to provide uniform product information. The BIM in Landscape Architecture Section of the German Chapter of buildingSMART is currently discussing an Information Delivery Manual for plants and paved surfaces. For example, the PDT will integrate plant metadata, planting instructions, service life, and process engineering and maintenance (PETERS & THON 2019, SHILTON 2018). In addition, an Activity Proposal IFC for Site, Landscape, and Urban Planning by Jeffrey Ouellette proposes the extension of the IFC schema for Site, Landscape, and Urban Planning (BRÜCKNER et al. 2019).

The literature emphasizes the importance of 4D-BIM for environmental planning. JUPP (2017) highlights two interlocking processes for a 4D platform to improve environmental planning and management. On the one hand, the cooperation of all disciplines of environmental planning and environmental management must be ensured and on the other hand it must be possible to monitor the environmental impact on site. In order to meet both requirements, a 4D model must guarantee five prerequisites: "scheduling and simulation, environmental equipment modeling, construction site layout modeling, environmental impact significance modeling and visualization, rule-checking capability". SHEINA et al. (2019) also proposes a 4D BIM for engineering and environmental planning. The technical model should be integrated into a map displayed using a GIS software. SCHALLER et al. (2016) extended the phases in the life cycle of a building with environmental planning as BIM-GIS-Cycle. They emphasize the required data transfer and data exchange at certain points in time during the lifecycle of a building. For a holistic model, the interfaces between BIM and GIS are seen as a requirement. EGGER (2020) sees semantic 3D City and Landscape Models based on CityGML as basis for an integrated planning model. All relevant geodata are mapped onto the CityGML data model. The BIM planning is carried out in the imported GIS environment and then integrated in the CityGML overall model. The work presented in this paper extends this approach focusing on the specific requirements of environmental planning, which are not fully covered by the related work described above.

3 Requirements and Existing Information Models

3.1 Requirements for the Integration of BIM and Environmental Planning

The first step in developing a comprehensive information model based on existing standards was to analyze the general requirements for integrating BIM and environmental planning. Both literature research and discussion with environmental planning experts from the major German railway company "Deutsche Bahn" led to the following main requirements:

1. Fundamental geospatial data such as protected sites, project specific data, such as surveys of vegetation and species, environmental conflicts and measures as well as planned objects from BIM with their attributes/properties need to be represented.

2. The following use cases in environmental planning should be supported:

- environmental impact assessment of the planned building and the construction works,
- clash detection and visualization of conflicts between construction and environment,
- compensation calculation taking into account the BIM data,
- monitoring the construction process from an ecological planning perspective,
- monitoring the environmental impact during the operation and maintenance phase of the building or construction.

3. Special attention must be paid to adequately represent temporal aspects. Four different temporal domains in environmental planning should be represented in the model: (1) time spans with fixed absolute start and end time (e. g. important during construction for a fixed date), (2) recurring regulation time period (e. g. legal time period for clearing woods and scrubs), (3) date/time period with dependencies on actual/planned construction time (e. g. continuous ecological functionality (CEF)-measures have to be implemented before construction start), (4) task depending on predecessor task (e. g. construction of a substitute habitat before the relocation of specific species).

3.2 Assessment of Existing Information Models

In a second step, various standards were examined for their ability to meet the requirements of integrating BIM and environmental planning as described in section 3.1. Six standards were identified to be suitable for modelling environmental planning as they fulfil parts of the listed requirements: CityGML, INSPIRE (Infrastructure for Spatial Information in Europe) and LandInfra (Land and Infrastructure) as international standards, XPlanung and OKSTRA (Objektkatalog für das Straßen- und Verkehrswesen) as German national standards. Furthermore, IFC as BIM standard and approaches to extending IFC by landscape objects were evaluated. The result of the comparison is found in table 1: "++" means that the standard fully fulfills the requirements, "+" means some requirements are fulfilled and "-" means none of the listed requirements were fulfilled. For the specific requirements of environmental planning, CityGML offers a good foundation with the support of vegetation, water and different land use (GRÖGER et al. 2012). IFC as construction standard could map technical components used in environmental planning such as protection fences. Landscape objects could be represented using generic object types like *IFC_Proxy* or (mis-)using other classes like *IFC_Wall*, but the semantics would not be explicitly clear. IFC does not include the mapping of objects, which are important for the definition of project specific environmental data, e. g. protection sites or environmental measures. OKSTRA allows the mapping of landscape planning ob-

jects (landscape, conflict, measure) (HEINS & PIETSCH 2010), but the representation of dynamics is not possible. In XPlanung the core "Landscape planning" (BRENNER 2019) is focused on representing legal landscape plans as part of the zoning of a municipality and is therefore not detailed enough for representing environmental planning of an individual construction project. The INSPIRE data specifications are not specifically adapted to environmental planning, apart from representing protected sites (INSPIRE THEMATIC WORKING GROUP PROTECTED SITES 2010), and, apart from buildings and DTM, 3D objects are not supported. LandInfra covers a few aspects of environmental planning, e. g. vegetation, but not sufficiently, for example regarding the representation of temporal aspects. In relation to the temporal representation, CityGML supports both the static time component (GRÖGER et al. 2012) and dynamics, with the Dynamizer ADE (CHATURVEDI & KOLBE 2016). The comprehensive time representation of IFC (BUILDINGSMART 2020) is inconvenient for environmental planning due to the separate handling of the work calendar (*IfcWorkCalender*), as temporal information should be directly added to the specific object. INSPIRE, LandInfra and XPlanung only support basic static representations of time, which are not sufficient enough for environmental planning. For example the INSPIRE data specification "species distribution" (INSPIRE THEMATIC WORKING GROUP SPECIES DISTRIBUTION 2013) defines no activity period for a species. OKSTRA defines temporal properties for environmental measures (BUNDESANSTALT FÜR STRAßENWESEN 2019), but the specification of time periods is missing.

Table 1: Comparison of different standards according to their integration of requirements regarding BIM and environmental planning

	CityGML 2.0	IFC 4	INSPIRE	LandInfra	XPlanung	OKSTRA
construction data	+	++	–	–	+	+
fundamental geospatial data	+	+	+	+	+	+
project specific environmental data	+	–	+	+	+	+
environmental conflict	–	–	–	–	–	++
environmental measure	–	–	–	–	+	++
impact assesment	++	+	–	–	–	–
ecological construction supervision	–	–	–	–	–	–
monitoring environmental impact	+	+	+	-	–	–
time: static	+	++	+	+	+	++
time: dynamic	++*	+	–	–	–	–
3D	++	++	+	++	–	++
extensibility	++	+	+	+	++	+

*Dynamizer ADE, a CityGML extension to support time dynamic property values
++ comprehensive*, + basic*, – not included*; *according to personal assessment

The comparison in table 1 reveals that none of the selected information models is fully matching the requirements. However, CityGML was chosen as the basis for developing a comprehensive information model for the integration of BIM and environmental planning for the

following reasons: First, the semantic model of CityGML is able to represent many required objects (these are already represented in 3D, as required by the BIM process). Second, CityGML provides the Application Domain Extension (ADE) mechanism, which allows for extending the information model according to the requirements of an application domain. This is a unique property of CityGML compared to the other standards mentioned above, besides XPlanung, which also uses the ADE mechanism, but only supports 2D. For example, IFC can easily be extended by application specific attributes (property sets), however, it is not possible to add new classes to the IFC information model without running through a formal buildingSMART process that involves user consensus and validation. We applied the CityGML ADE mechanism for developing the Environmental Planning ADE (EnvPlan ADE), a comprehensive information model for integrating environmental planning and BIM.
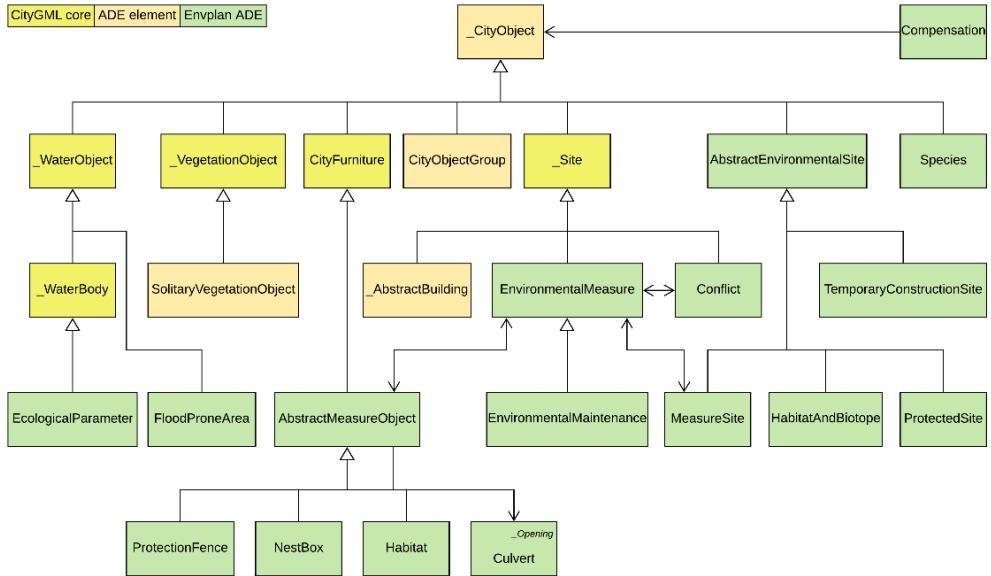
4 The CityGML EnvPlan Application Domain Extension

Figure 1 gives an overview of the CityGML EnvPlan ADE, which was developed based on the requirements described in section 3.1. The extended classes of the CityGML core module are marked yellow. Existing CityGML classes that are extended by attributes are marked in orange. The newly created classes of the EnvPlan ADE are highlighted in green. Concepts of existing CityGML modules as well as from the other standards described in section 3 have been reused wherever possible in order to facilitate data integration from existing data sources.

New attributes are assigned to the classes *AbstractCityObject*, *AbstractBuilding* and *SolitaryVegetationObject*, for example in order to represent the cost of environmental measures as well as the construction cost for the new buildings or infrastructure works. New classes are derived from *AbstractSite*, *AbstractBuilding*, *CityFurniture* and *AbstractWaterObject*. *AbstractEnvironmentalSite* and *Species* are specializations of *AbstractCityObject*. *AbstractEnvironmentalSite* is a container of common properties of sites where environmental measures are planned for (*MeasureSite*), mapped habitats and biotopes (*HabitatAndBiotope*), sites under environmental protection *(ProtectedSite,* reused from *INSPIRE)* and construction site facilities, that are removed after construction is completed (*TemporaryConstructionSite*).

Information without geometric representation is modelled as specializations of the CityGML class *AbstractSite*: these are measures (*EnvironmentalMeasure,* aligned with OKSTRA), their maintenance (*EnvironmentalMaintenance,* aligned with OKSTRA) and *Conflicts* (aligned with OKSTRA*)*. These objects get a spatial representation when they are actually implemented, which is expressed by relating them to measure areas (*MeasureSite*) or measure objects (*AbstractMeasureObject*). *AbstractMeasureObject* is derived from the CityGML class *CityFurniture*, as measure objects like protection fences or nest boxes are immovable objects and can be geometrically represented by prototypes (e. g. 3D geometries from an object library).

The class *Compensation* has an association with the class *AbstractCityObject*, which allows to assign environmental compensation values (see use case in section 5.2) to each object causing an environmental impact.

Fig. 1: Structure of the Environmental Planning Application Domain Extension (EnvPlan ADE) for CityGML as a UML class diagram
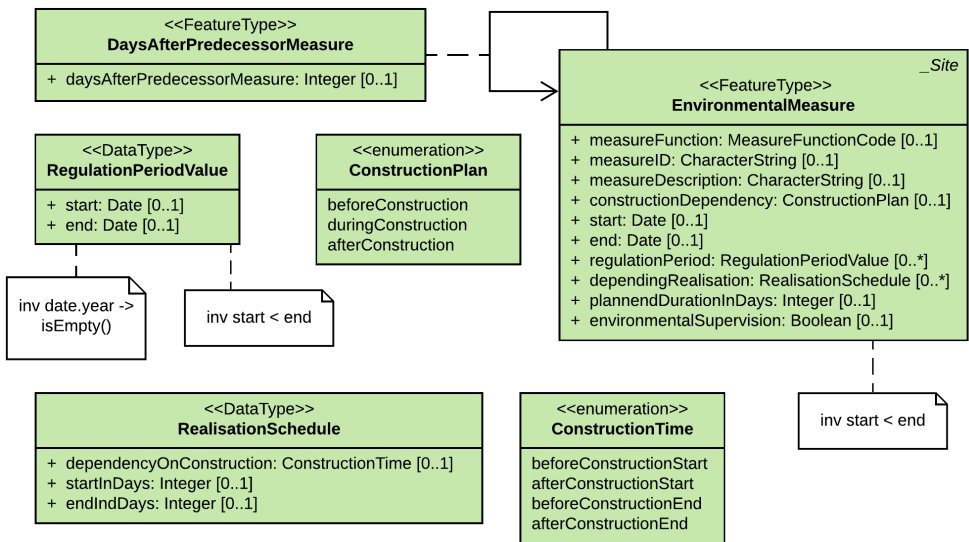
Fig. 2: Implementation of the four different temporal domains in the EnvPlan ADE

The requirements related to the four different temporal domains used in environmental planning were taken into account, for example, by adding a temporal reference to the class *EnvironmentalMeasure* (see Fig. 2). The specific temporal attributes are implemented according to the mentioned prerequisites. Besides the data type "date" for specific start and end times

(case 1 of the temporal requirements defined in section 3.1), the depending time periods are represented. Recurring periods (case 2) are implemented as *RegulationPeriodValue*. Since the duration of the construction project can last several years, the object constraint language (OCL) rules shown in the UML diagram ensure that no year is specified for the periods and that the start time is before the end time. The dependence on the construction time (case 3) is modelled as *RealisationSchedule*. Regarding the actual construction time, the number of days before, during or after construction start/end has to be added. The case of a predecessor measure (case 4) is solved by using a reflexive association and the number of days between both measures.

The UML model EnvPlan ADE is converted into an XML Schema using the software ShapeChange[1]. The UML model, as well as the XML Schema files, are provided on GitHub[2].

5   Proof of Concept

The EnvPlan ADE was tested using BIM and GIS data from a railway project – the refurbishment of a train station and the extension of a train platform, located in Bavaria, Germany.

5.1   Implementation of the EnvPlan ADE as a Spatially Extended Relational Database Schema

The conceptual model as described in section 4 was implemented as a spatially extended relational database schema using the tools provided by the open source project 3DCityDB (YAO et al. 2018). This allows to automatically derive the database schema for any CityGML ADE from the UML model. 3DCityDB is based on the database management systems PostgreSQL with PostGIS extension or ORACLE. In our implementation, PostgreSQL was used. The queries and analyses described in section 5.3 can then be defined using SQL statements.

5.2   Data Integration Workflow

The construction model was exported from the BIM authoring tool Autodesk Revit to the IFC format. For the environmental planning data, different sources were used: fundamental geospatial data from a public Web Feature Service, project related data (format: Shapefiles) and information from the conflict and measure plan (formats: Shapefiles, DWG). The GIS data of the environmental planning and BIM data of the construction planning were transformed into the CityGML EnvPlan ADE using the tool FME (Feature Manipulation Engine, Safe Software). The transformation included a process to lift the 2D environmental planning data to 3D and the data import into the PostgreSQL database with 3DCityDB schema. In this process, fundamental geospatial data, such as protected sites were transformed to planar polygons or line strings floating at a specific height level (the reference height of the construction project). Project specific environmental data, such as measure sites and objects, were draped over the digital terrain model, which results in high resolution triangulated geometries for these objects. All project relevant data from construction and environmental planning was visualized as an overall model (see Fig. 3). The test proved that all relevant planning data can
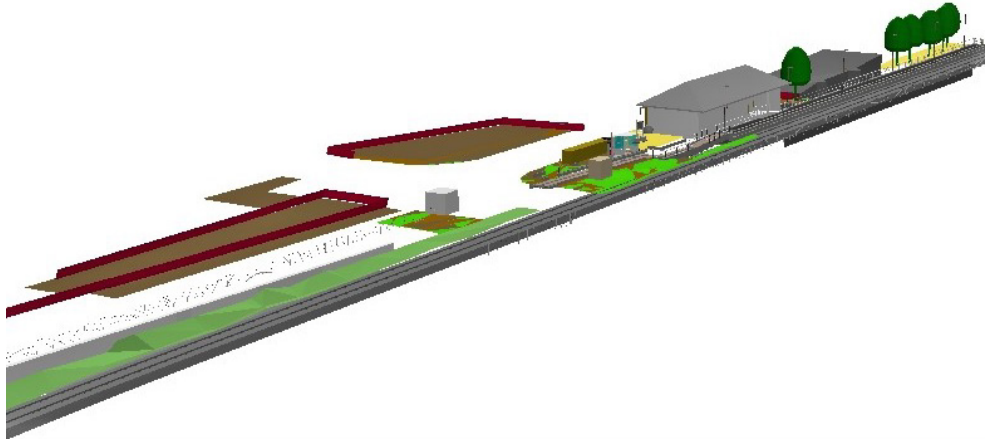
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[1]   https://shapechange.net
[2]   https://github.com/tum-gis/CityGML-EnvPlan-ADE

be successfully transformed to CityGML EnvPlan ADE and thus an integrated data environment for BIM and environmental planning can be realized.

Fig. 3:   Overall model showing objects from construction and environmental planning; the construction objects are visualized in grey; the colored features are environmental measure sites and objects

5.3   Queries and Analyses Based on the Information Model

In the following, two use cases based on the information model are described as examples.

The first use case shows clash detection and visualization of conflicts between construction and environment. To find space for temporary construction areas, spatial-temporal queries can be performed. These queries check whether this is possible on the start day of the construction period (in the railway project: construction period from 2021-02-01 until 2021-08-31). The query shows which environmental measure affects the areas and whether there are time restrictions related to the start day of construction (2021-02-01). The result of this spatio temporal clash detection is shown in table 2. The temporary construction areas are spatially intersected with the environmental measure areas. The column "possible" shows that the construction site cannot be set up on the 1st of February as environmental measure specifies a time regulation for tree cutting from 1st October until 28th of February.

Table 2:   Clash detection of the date for the setting up of temporary construction site

measureid	measuredescription	startday	startmonth	endday	endmonth	possible
002_VA	clearing woods	1	10	28	2	FALSE

The second use case is about an automatic compensation analysis. By law[3], any intervention in the environment must be compensated. This calculation is an important part of environ-

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[3]   The used railway project takes place in a city in Bavaria, Germany, so the regulation of the state of Bavaria was applied: https://www.lfu.bayern.de/natur/kompensationsverordnung/index.htm.

mental planning and is represented in the EnvPlan ADE by the class *compensation*. The compensation calculation is integrated into the data integration workflow as described in section 5.2 above and therefore carried out using FME, but it could also be implemented using any GIS software, that is able to connect to a PostGIS database or directly in PostGIS using as a set of database queries.

In our railway project, the newly built and thus sealed areas, the temporary construction areas and the cut trees have to be compensated. For calculating the compensation value, a formula specified by law[3] is used. Using this formula, the compensation value is calculated as impacted area times value of the underlying biotope times a factor depending on the type of impact (sealing, planting, construction, operation). To determine the impacted area, the areas affected by the construction (objects of classes *Building* and *TemporaryConstructionSite*) are spatially intersected with the mapped biotopes (objects of class *HabitatAndBiotope* and *SolitaryVegetationObject*). The values of the underlying biotopes are derived from attributes of the class *HabitatAndBiotope,* the type of impact is derived from the type of the object causing the impact (*Building* → sealing, *TemporaryConstructionSite* → construction). The result of this calculation is represented as an object of the class *Compensation*.

The use cases and their implementation are described in greater detail in the master thesis by WILHELM (2020).

6   Conclusions and Outlook

The EnvPlan ADE supports the integration of environmental planning with BIM regarding the following aspects:

- Common standards-based information model and data format including relevant data from different disciplines involved in the BIM process: This enables standardization of interfaces and still being able to use different software tools from the respective domains. In our approach CityGML is used as a comprehensive model combining construction data and environmental data on one platform.
- Combining the requirements of environmental planning for BIM-integration in a comprehensive information model: BIM projects are still lacking environmental context information and the EnvPlan ADE can be used to standardize the required environmental data.
- Spatio-temporal representation: The EnvPlan ADE allows a 4D-BIM for environmental planning. This supports e. g. the generation of construction time tables and spatio-temporal clash detection between construction and environmental planning.

The EnvPlan-ADE extends CityGML and defines a specialized model for environmental planning. Future work will focus on the one hand on testing the ADE with further real world projects and use cases. On the other hand, the round trip BIM authoring tool → CityGML EnvPlan ADE → BIM authoring tool will be investigated.

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