

GIS and BIM Integration Approaches for Early Railway Planning Phases

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Abstract

While there have been developments to integrate both domains of Geographic Information Systems (GIS) and Building Information Modelling (BIM), approaches on GIS-to-BIM conversion operations do not address early-modelling scenarios. Furthermore, current approaches are often limited to or around buildings, given their nature as the classic common denominator between both systems. Railway projects, however, have different constraints from those of building projects, given their extensive nature and complex conditions. In this paper, the authors summarise available and open data approaches on the topic of context modelling and conversion between GIS and BIM systems in order to give an overview of promising developments for the field of early-modelling railway planning. The authors propose a process for consecutive data use including early pre-planning surveys in GIS and bringing them to the BIM domain for railway planning. A case study shows a low-threshold context modelling using open geographic data and open GIS and BIM formats, creating a much needed planning basis for BIM-based railway planning.

Introduction

It is common sense that the use of Building Information Modelling (BIM) implies above all the idea of the continuous use of data throughout the entire life cycle of a building (Sacks et al. 2018). In practice, it is evident that the process of collecting and evaluating information for railway projects begins well before the start of the construction project, specifically before the actual planning process begins (Bundesministerium für Verkehr und digitale Infrastruktur 2018).

Early studies are of particular interest for the entire railway project process, as they involve a high degree of uncertainty and many possible design variants. Decisions made on the basis of early studies have a wide range of effects at a later stage: On the environment, on residents, on financing and schedules, and even on politics (Flyvbjerg et al. 2008). Studies show that subjectiveness and insufficient evaluation (e. g. of risks) at early stages lead to wrong decision-making later (Flyvbjerg 2009). The German Federal Government and German Railways (Deutsche Bahn) plan to invest three billion euros in new and the extension of existing railway infrastructure in Germany until the year 2027 presumably still not enough to cover the need for railway transportation (Frankfurter Allgemeine Zeitung (07.07.2022)). To reduce uncertainty and additional costs potential, especially in a densely populated and built area as Germany compared to other countries, it is necessary to obtain a holistic overview of

the project area, the built environment and aspects of the natural environment, and surroundings.

In order to do so, input data for context modelling must be collected. A lot of that data comes from Geographic Information Systems (GIS) and later is being included in the planning process. Since the wider use of Building Information Modelling the BIM and GIS integration has become more interesting both for praxis and science. A growing interest can be derived also from the number of publications regarding BIM and GIS integration as will be shown in a later section within this article.

However by the nature of both worlds, the approach of a BIM-based planning process working on a highly detailed building level contradicts the need of early studies in railway infrastructure, as those focus on a higher scale level and not on the component scale (Amirebrahimi et al. 2016, Borrmann et al. 2015). Therefore, it is necessary to include the use of Geographic Information Systems (GIS) to pay tribute to the needs of early conceptual surveys, especially when it comes to spatially (and politically) big projects with a high need for accuracy.

To create a consecutive information flow, the information from the GIS-based surveys has to be fed into a BIM-compatible way of working. Due to the different premises of both disciplines, BIM and GIS, this is still a subject of research with many challenges to overcome; one of them being the insufficient interface between GIS and BIM, especially regarding railway-specific objects and information.

In contrast, many studies focus mostly on BIM-to-GIS, not vice versa (Sani et al. (2019), Donkers et al. (2016)). But at that early point in time there is usually no BIM model yet, yet BIM models need to be created at some point based on data coming from GIS.

The goal of the present article is to identify suitable open data formats and or Application Domain Extensions for the conversion of context data from GIS to a BIM environment for the requirements of early studies in railway projects. The hypothesis stated in this article is that GIS to BIM integration can help create a low threshold context model that supports decision making in a very early stage, when there is no BIM model and only only few, if any, survey data available. Even though there might be commercial solutions, this article focuses on open formats to ensure a continuous use of data throughout the life cycle. Furthermore, railway planning (e. g. in Germany) is mainly a responsibility of public administration and therefore includes the need

for documentation in open formats in order not to depend on (software) company decisions and to guarantee legal non-discrimination rules (Paragraph 97 GWB, German Act against Restraints of Competition).

For this purpose, relevant open data standards for BIM and GIS integration have been identified through first quantitative and then qualitative literature review. Besides scientific publications, publications and norms from standardisation organisations such as Open Geospatial Consortium and BuildingSMART have been considered. The findings have been accumulated and been put into context to gain an overview of existing solutions and their suitability for railway purposes.

A case study has been conducted creating a context model for early studies, including relevant geo data from open sources. Throughout that they have been processed in certain ways in order to first consolidate them in GIS and then convert them to the BIM environment. Due to the focus on open standards and the exchange they allow, Application Programming Interfaces and proprietary data formats were not regarded in the case study.

This paper includes the description of the methodology used to identify relevant publications, the results with findings in a qualitative form, the conducted case study as described above, and finally a discussion of the present work and the validity of the hypothesis. In the last section an outlook to future research is given.

Methodology

This section introduces briefly methodology of the literature review as well as of the performed case study.

Literature review

The aim of the literature review was to find suitable open data standards for use in early modelling of railway projects and therefore classifies as a qualitative, as opposed to a quantitative review. Mainly, three data banks have been included in the search: Scopus, ScienceDirect and Google Scholar.

First, keywords were identified, in this case, "BIM", "GIS" and "railway", as well as "integration" to begin with. Second, those keywords were combined by Boolean operators to form search expression. Title, abstract and keywords were browsed for the combination of defined keywords. To analyse the results, the upcoming number of publications were documented and plotted in a graph to derive the timely course of publication activity on the browsed topics. Subsequently, the results were looked at in more detail on a qualitative level, identifying the papers fitting the search scope. After going through the most relevant ones, a snowball method was used, taking a closer look to the list of references of relevant papers and through that, identifying more potentially suitable ones.

Case study

The aim of the implemented use case was to test the hypothesis, that open GIS and BIM formats are indeed suitable for creating context models for early studies in railway. The process of creating a low-threshold context model for early studies in railway is repetitive and applies generally to almost any kind of input geodata.

As displayed in Figure 1, firstly, the necessary data has to be collected. The data can be of varying nature, the focus here lies on geographic data. Secondly, it is usually necessary to preprocess it in some way. This can imply for example coordinate transformation, cleaning (e. g. when using point clouds or other extensive data sets with redundant information) or editing (e. g. merging or splitting). Thirdly, if the content of the data is not sufficient yet, they might be upgraded and/or semantically enriched with further information (e. g. implicit knowledge, information from external sources such as reports etc.). Eiwelait et al. (2021) state that the process of pre-processing and upgrading information is highly dependent on the initial quality of the input data. In practice it appears that a lot of data, especially when including historical data, is often not even digitised or only available in poor accuracy. Has the processing of data finished, the collected data can then be consolidated in a context model and subsequently converted through open formats from the GIS environment to the BIM planning environment for further usage.

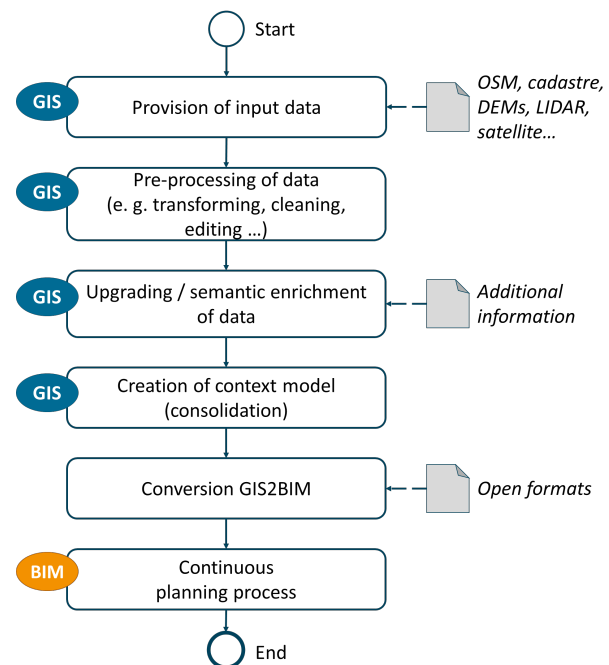


Figure 1: Consecutive information pre-processing from GIS to BIM for early surveying in railway

Results of literature review

When conducting first a quantitative search for relevant publications, it became evident that the topic of BIM and GIS integration, also in combination with railway, gets growing

attention within the last years, peaking in 2021. The exemplary results from Scopus can be seen in the following Figure 2. The described search method has been applied showing correlating results also with a focus on railway.

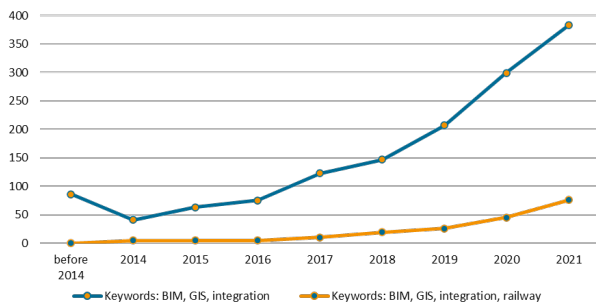


Figure 2: Search results for relevant keywords in Scopus

Both the BIM and GIS domains have predominant file formats for storing structured data, namely IFC and CityGML, respectively (El-Mekawy et al. 2012). Both formats were designed for different uses and are therefore inherently different. Nonetheless, they both share similarities, like their object-oriented nature, and a few similar entities within their classification (Sani & Abdul Rahman 2018). When addressing interoperability, mapping between schemata in both domains is unavoidable.

An overview of available approaches is shown in Figure 3 with focus on established and recently developed standards in both domains as well as relations between them, such as the harmonisation between InfraGML and IFC 4x1 (Open Geospatial Consortium 2016). Extensions of CityGML using Application Domain Extensions (ADE), such as GeoBIM by de Laat & van Berlo (2011) or developments by Stouffs et al. (2018), Donkers et al. (2016) or Kumar et al. (2019) and their relations to both GIS and BIM domains were also regarded (if only exemplary). Approaches considering new and integrated data models, such as that by Amirebrahimi et al. (2016) or El-Mekawy et al. (2012) were also considered.

3D file formats for BIM and GIS

IFC Alignment, as an extension of the IFC data model, was published within the IFC4x1 version and made it first possible to include infrastructural buildings such as roads and railways, harmonising with the Open Geospatial Consortium (OGC) standard InfraGML as an aligned data model. Based on the IFC Alignment, the development of a data model extension called IFC Rail is currently in progress and has recently been released as Candidate Standard. The IFC Rail extension includes domains for representing the track, signalling and level crossing, energy and telecommunication.

It appears that there are already several open-source approaches for the transfer of GIS data, especially for infrastructure, into the BIM environment. These include

the formats LandXML, LandInfra, InfraGML, CityGML, among others, which are based on Markup Languages, e.g., XML and GML. Other less prevalent formats, such as CityJSON, are implementations of a varying data model, based on JavaScript Object Notation (JSON) instead of Markup Languages (Butler et al. 2016).

As described by Open Geospatial Consortium (2021), LandInfra is based on LandXML. LandInfra is a use-case driven subset of LandXML and intended as its successor. LandInfra mostly avoids overlaps with CityGML by focusing on civil infrastructure, like rail and roads as well as cadastre and surveying. Its modelling resolution is not as detailed as that of the IFC extension, including amongst others roads, rails and bridges. Also, LandInfra represents buildings as features of facilities through an outer shape and footprint (Open Geospatial Consortium 2021).

Kumar et al. (2019) have explained how an ADE for CityGML has been created in order to store LandInfra features as well as how to convert bidirectionally between both schemas. To achieve this conversion, a semantical mapping of LandInfra to CityGML has been carried out. Both schemas partly overlap, however, LandInfra lays bigger focus on civil engineering infrastructure. Its OGC encoding standard shows seven dependencies, 'Railways' as one of them, containing classes with specifications about railway elements such as the cant ("Überhöhung"), meaning the height delta between two rails on a curved alignment. Both conceptual models of LandInfra as well as IFC Alignment are aligned and therefore compatible (Open Geospatial Consortium 2016).

The GeoBIM extension by de Laat & van Berlo (2011) proposes an ADE extension to CityGML to support IFC data and using the semantically rich IFC models to enrich the CityGML data. The authors implement the extension in the open source BIMserver in order to export IFC geometry and semantics to CityGML in LOD 4 by querying IFC models.

Zhao et al. (2019) used a BIM and GIS integration in order to optimise highway alignments for planning using semantic web technologies. Information from both domains, GIS and BIM, have been modelled in IFC and CityGML and then have been converted to an web ontology language (OWL) representation. Afterwards both ontologies have been mapped and both data sets have been linked in a GIS environment in order to be queried. Furthermore, the semantic web approach applied enables the possibility for bidirectional conversion.

Conversion

Differences between both GIS and BIM include different definitions for Level of Detail (in GIS and thus in CityGML) and Level of Development (in BIM and therefore in IFC), which must be regarded during conversion. Further,

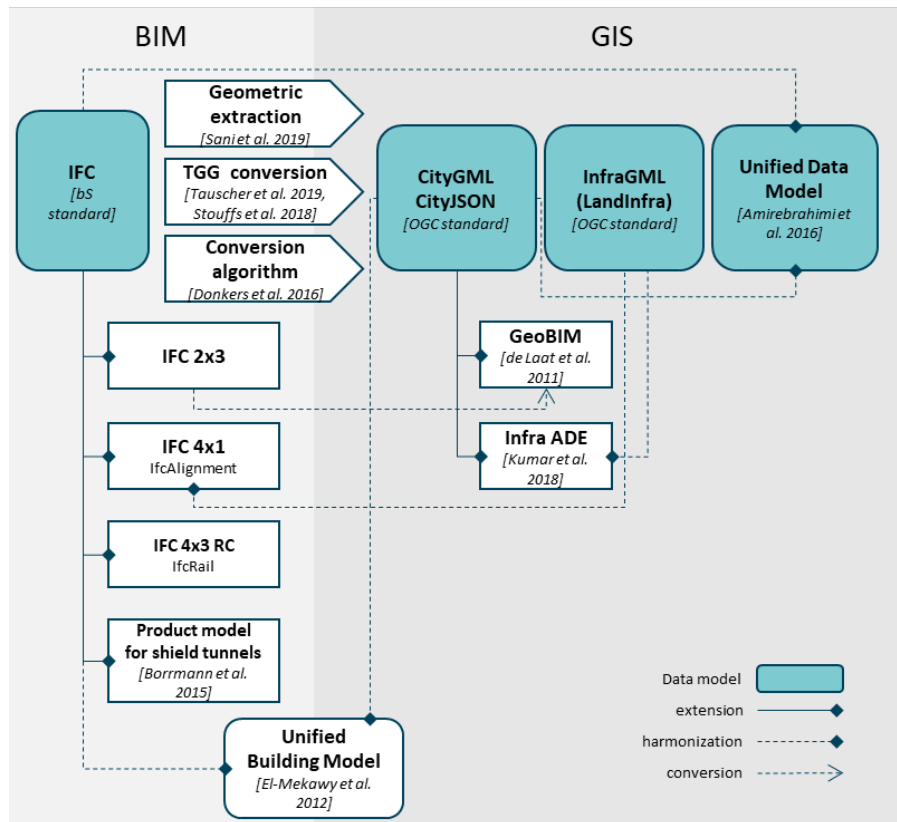


Figure 3: Overview of approaches for BIM and GIS integration

exchange formats in GIS and BIM support geometric representations in different ways (Gilbert et al. 2020). Constraints regarding BIM2GIS integration regard matching, not only the classes within both domains, in which a complete information transfer is not guaranteed, but also the Level of Detail (GIS) and the Level of Development (BIM). Geometric constraints include not only the different geometry representations, but also the mapping of textures, which are rarely used in IFC (de Laat & van Berlo 2011).

Amirebrahimi et al. (2016) defines three levels of attempts in integration: the process, data and application level. Based on that Sani et al. (2019) claims that the challenge of integration GIS and BIM seamlessly depends first on an unhindered data flow between them and proposes an approach to geometrically transform IFC building objects to the equivalent class in CityGML.

One of the challenges lies in the geometric representation of objects. CityGML only represents 3D-objects as the explicit method of Boundary Representations (B-Rep), meaning representing bodies using surfaces, edges and nodes. IFC on the other side is able to use a hybrid approach of implicit and explicit methods including Constructive Solid Geometry (CSG), Sweep Solid (SS) and B-Rep (Borrmann et al. 2021). The work of Borrmann et al. (2015) shows that the geometrical integration of

BIM2GIS, including a transformation from an IFC-based product model to B-Rep is indeed feasible, when using CityGML as the target format.

Based on the conversion direction (GIS to BIM and BIM to GIS) different constraints apply (Sani & Abdul Rahman 2018). Therefore, the next subsections are structured accordingly and summarise both particular constraints and selected solving approaches.

BIM2GIS

Previous work on the interoperability between BIM and GIS systems is abundant. de Laat & van Berlo (2011) propose an extension of CityGML called GeoBIM to support IFC data in the GIS domain, not only with basic geometry, but also semantically, where all IFC classes can theoretically be mapped to CityGML in LOD 4.

In another approach by Stouffs et al. (2018), and further described in Tauscher (2019), information from IFC files was translated into CityGML using Triple Graph Grammar (TGG), consisting of two object graphs (IFC and CityGML) and a correlation graph, in which the conversion data is stored, including a start graph and a set of production rules to transform the graph consecutively. The conversion into CityGML, a topographic geospatial format, is associated with loss of information (Stouffs et al. 2018). The authors propose a mapping approach that promises complete and near-lossless conversion

from IFC to CityGML. The system design of the IFC to CityGML conversion is not bi-directional and allows the transformation from IFC building elements into semantically classified CityGML surfaces. The authors further suggest extending CityGML with its own ADE native mechanism in order to cover information not predefined in CityGML. It is noted in Stouffs et al. (2018) and El-Mekawy et al. (2012), that few extensions to CityGML have been attempted. As de Laat & van Berlo (2011) found, using ADEs might cause difficulties in visualisation, due to the geometric interpretation of different 3D viewers (Sani & Abdul Rahman 2018).

Further developments on the Unified Building Model (UBM), where the schema is derived both from IFC and CityGML, can be found in Liu et al. (2017). Amirebrahimi et al. (2016) apply an attempt using a Unified Data model (UDM) approach in order to visualise flood damage to buildings. The authors carried out a mapping between IFC and CityGML and created a UML data model that unifies both approaches and was implemented in the XML schema.

El-Mekawy et al. (2012) propose a superset model, where concepts from both IFC and CityGML were considered in the semantic and geometric representation and definition of building elements. The authors suggest, that different spatial computations and analyses cannot be performed by only IFC or CityGML. To merge classes from both domains, constraints were defined and sub-types were used, instead of separated feature classes of relationships to super-type feature classes. Furthermore, enrichment functions were implemented to derive semantic information in different cases either from an IFC or a CityGML data set to extract missing information due to the source format. The UBM is validated by a predefined set of queries.

A multi-scale-model approach by the means of enabling different scales (e.g., kilometre scale and centimetre scale) within one representation has been undertaken by Borrmann et al. (2015). To achieve this, an IFC-based product model for shield tunnels has been mapped semantically and geometrically to the CityGML data model. Because of the different methods of representing geometry and different concepts of Level of Detail (LOD), the procedural/implicit geometry representation of the shield tunnel product model has been converted to the Boundary Representation of the target format CityGML, based on parametric modelling techniques.

GIS2BIM

One specific challenge for the conversion from GIS to BIM is the question, which objects classes within the BIM environment the information from GIS should be mapped upon. Sani & Abdul Rahman (2018) found that this is mainly caused by the fact that the GIS format CityGML

has less defined classes than the BIM-specific IFC format. While the integration of BIM2GIS is problematic because of potential data loss, the other way around (GIS2BIM) involves a risk of mismatching object classes. Furthermore, Sani & Abdul Rahman (2018) pointed out several challenges lying within the integration of both domains. Mainly, the authors focused on challenges regarding the geometric conversion, but on the semantic level they also found an urgent need for developing a data model which encloses both approaches of CityGML and IFC.

Meanwhile Tauscher (2019) performed conversion using Triple Graph Grammar, Donkers et al. (2016) presented a conversion algorithm to extract necessary information from BIM models in order to generate CityGML models of LOD3. Although the authors presented a workflow for conversion from IFC to CityGML, the workflow steps (1. Semantic Mapping, 2. Geometric Transformation and 3. Geometric and Semantic Refinement), as well as the carried out semantic mapping, can equally well be applied to a vice versa workflow. Donkers et al. (2016) propose new objects classes as extensions of the IFC in order to better align IFC and CityGML. For CityGML, more detailed and specified rules for defining an object are suggested.

Besides unidirectional approaches, there are also procedures that enable bidirectional conversion, including the approached of unified data models or unified building models (Liu et al. 2017, Amirebrahimi et al. 2016).

Case Study - Context modelling for railway planning

In this section, a case study is carried out, creating a lo-threshold context model from open geodata for early railway studies.

Data preparation process

Because of their spatial extent and the high multidimensional complexity, railway projects must take their geospatial surroundings into consideration. Eiweleit et al. (2021) name several types of data that need to be considered, such as cadastre data, digital elevation models, and ortho photos or surveying flight data, as shown in Figure 4. This kind of geo-referenced data can be used in a GIS environment to put a considered railway alignment into its geospatial context.

To illustrate the aforementioned process, the case study has been conducted using open tools and open formats for a context model that is suitable for early studies in railway projects. The following input data has been used:

- Geo-referenced photos from surveying flights (*.tif)
- Point clouds from Airborne Laserscans in 1 m grid width (*.xyz)

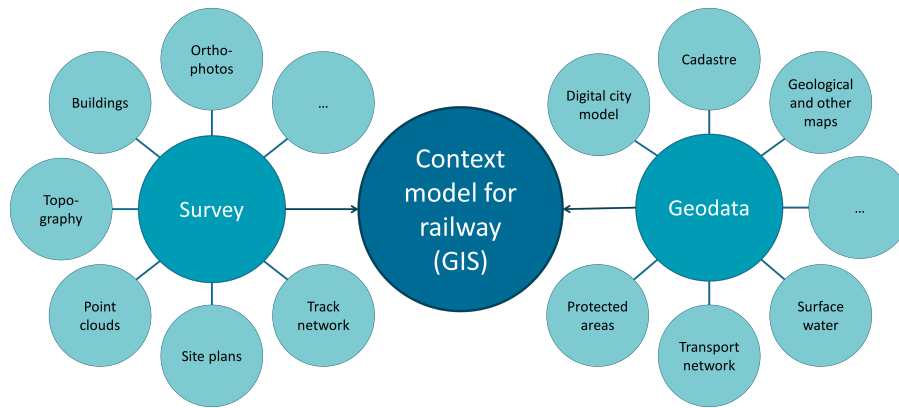


Figure 4: Components of context models for (German) railway, according to Eiwelait et al. (2021)

- Digital City Model (*.gml)
- Cadastre Map (*.shp)
- Existing street and railway infrastructure (*.geoJSON)

Initially, the aforementioned data has been collected. The Free State of Thuringia, one of the administrative county of Germany, provides open geospatial data on a public homepage, administrated by the regional authorities. The data are updated regularly and free for download. In a next step the data were supplemented by Open Street Map (OSM) data, providing information about existing street and railway infrastructure and additional point information on stations and other points of interest for public transportation.

Implementation

The cadastre data and OSM data was brought into the open tool QGIS. In this case, all the data had to be transformed from EPSG:4326-WGS84 to the projected coordinate system EPSG:25832-UTM32. This was done using QGIS. The data was then exported to the *.geoJSON format.

The visualised geo data in QGIS can be seen on figure 5, showing the main station of the city of Weimar, Thuringia. Building contours, as well as railway and street alignments come from Open Street Map (OSM). The underlying OSM-map has been chosen for improving the spatial impression. Cadastre data have been included as well.

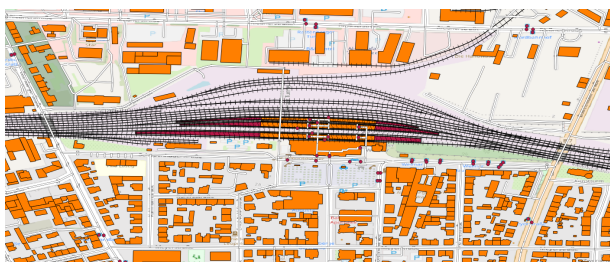


Figure 5: Open geodata from Geoinformation System

To create a 3D-context model, a mesh out of the point clouds was created using CloudCompare in order to generate a digital elevation model. This model could be exported as *.obj into the BIM collaboration software Desite MD Pro. The geo-referenced photos have been added to the software and mapped onto the 3D digital elevation model, now displaying the photo content in the right topography and not as 2D anymore.



Figure 6: Creating a digital elevation model from point clouds

In the next step, the CityGML-data containing the digital city model could be added. In this case, all data provided by the Free State of Thuringia was already available in the projected coordinate system EPSG:25832-UTM32 and did not need a coordinate transformation. The data from QGIS could then be imported to the BIM coordination software. Figure 7 shows the result of the coordinated context data within a BIM collaboration software, including already much of the necessary data for early railway studies. This federated model can now be exported to the IFC format.

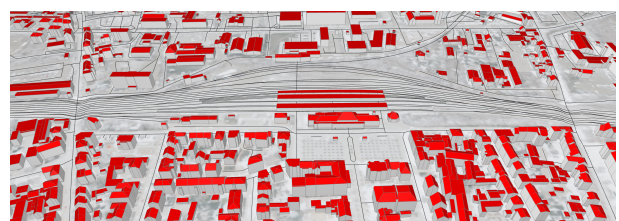


Figure 7: 3D-context model for BIM-based railway planning

Discussion and Conclusions

In the present article, different approaches for the conversion of context data in the field of BIM and GIS integration have been investigated. The interoperability between both worlds is especially relevant for enabling a

seamless railway infrastructure planning due to the fact that early surveys are being conducted on a geospatial scale and should then be brought to the BIM environment for further and more detailed planning. For this a literature review has been conducted, identifying the relevant open data formats and ADEs to do so. In a case study a low-threshold context model for early railway studies was created, including open geo data in GIS and bringing it into a 3D BIM environment, providing the basis for further BIM-based planning.

The literature review shows different promising approaches for early-model-based application in railway projects. Objects of railway infrastructure are partly considered, but only on a very coarse level, which impedes a close analysis of viable approaches and shows an obvious gap. On the side of BIM, specialised extensions for IFC (namely IFC Rail) are currently in progress and are expected to extend the BIM field for relevant information regarding railway infrastructure. The data model of InfraGML, that has been developed in a cooperation between the OGC and buildingSMART, is aligned with the IFC Alignment concept and therefore a promising candidate for future compatibility of object classes.

Regarding conversions and format extensions to support bidirectional information exchange, such as those performed by Kumar et al. (2019), Sani & Abdul Rahman (2018), show promise for enabling the usage of GIS-based early-models in later planning phases as well as the incorporation of available BIM models in the early-modelling phase. A viable approach for the early-modelling railway use-case could be an adaptation of the extension by Stouffs et al. (2018) using ADEs and Triple Graph Grammar (TGG). Overall, the review shows that on the BIM side a basis for representing railway infrastructure is going to be provided with IFC Rail. However, the GIS side shows a lack of granularity regarding railway objects within the common data formats and none of the reviewed papers have shown a validation for the railway domain. Figure 3 gives an overview on the reviewed concepts and how they relate to standards of the BIM and GIS environments.

The review showed furthermore that there is a growing interest in unified approaches in order to enrich each other but also to make use of querying techniques. In this field, it could also be identified that the focus lies mostly on the enrichment of GIS using BIM and not particularly to use GIS in order to enrich BIM for early or pre-planning phases. The conversion from BIM to GIS and vice versa shows a clear focus of reviewed papers on the integration of BIM to the GIS environment, as can also be seen in Figure 3. The other way around though for bringing information from the GIS environment to a BIM-integrated workflow, is only addressed on a theoretical level. The performed validations, and none of them for railway, validate unidirectional conversion from BIM to GIS.

Figure 3 shows that there are several approaches including different conversion methods, which could hypothetically also be used in order to convert railway objects. However, a corresponding data model or an extension of such a model is a necessary prerequisite on the GIS side.

Based on the proposed process for integrated application of information from both GIS and BIM domains in railway projects, the authors were able to conclude that there is a gap regarding the connection of GIS and BIM for early modelling, especially regarding the preparation of railway planning.

The conducted case study showed that for creating early context models for railway, many established open data formats are already more than sufficient to contain the necessary information. What was not regarded in the case study, is the extensive conversion of more detailed railway information coming from GIS. The polylines used in the railway contained exactly the information that were coming from Open Street Map. Therefore the *.geoJSON format was suitable due to the low detailing of source data. For more detailed information and a higher granularity of railway objects, another format might be more suitable, as the literature review showed (e. g. InfraGML). It was therefore possible to already include a lot of important context data.

Outlook

Based on the performed review, future work will address the discussed fields of application regarding GIS and BIM integration as well as semantic enrichment for early-model-based railway surveying and pre-planning. A case study will be used for displaying used methods and findings using a suitable case study, e. g. an early-phase railway project. To include existing railway structure more thoroughly, will be part of future implementation and research.

Furthermore, future work needs to address the relevant prerequisites and particular requirements of early surveys in railway projects more in depth. Depending on that, a decision can be made, in which way an exchange between GIS and BIM can be ensured and which strategy might be the most suitable one. Moreover, direct exchange between vendors should be questioned, especially in early-modelling scenarios, to address all viable solutions.

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