BIM AND GIS FOR LOW-DISTURBANCE CONSTRUCTION

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ABSTRACT: *Construction and maintenance activities of bridges often bring negative impacts to the urban environment in terms of disturbance, traffic jams and disruptions, noise, dust, and air pollution. Lack of coordination between the stakeholders in strategic, tactical and operational construction planning process has been identified as a key factor behind these negative impacts. Attempts to solve this issue critically depend on an effective interoperability between ICT tools from the building domain (based on Building Information Model or BIM) and the urban planning domain (based on three dimensional Geographical Information System or 3D GIS). Research on the interoperability between BIM and GIS requires knowledge of Open BIM as well as Open GIS and their interconnection. Unfortunately, Open BIM and Open GIS have been developed separately and they have pursued different standards and technologies. Open BIM for civil infrastructure projects is still limited, especially due to the fact that the IFC open standard currently targets the building sector. Open GIS mainly relies on the use of GML/CityGML standard.*

This paper focuses on research to develop a solution for the interoperability of BIM and GIS, especially for the purpose of low-disturbance construction. It reports the on-going EU FP7 collaborative research project PANTURA. The preliminary achievements include a prototype solution that consists of: an architecture for the integration solution between BIM and GIS data and tools; an Application Domain Extension (ADE) that connects BIM data from the bridge with the computational parameters on disturbance in a GIS-based planning tool Urban Strategy; a configuration of open-source Deegree 3D model server; and a query interface between the model server and the decision-support tool. The prototype solution is verified using two case studies: on-site assembly of a new bridge on La Palma island, Spain; and refurbishment of existing bridges in Rotterdam, the Netherlands.

KEYWORDS: *BIM, GIS, interoperability, decision-support tool, low-disturbance construction, bridge project, urban environment.*

1. INTRODUCTION

Lack of coordination in strategic and operational construction planning process has been identified as a key main factor behind the negative impacts of urban infrastructure projects (Sebastian et al., 2013). In order to enable the clients, designers, builders, and project managers to explore all possible planning, design and engineering solutions for low-disturbance construction, there is an urgent need for integrated modelling and analysis of the construction objects (e.g. bridges) and the surrounding areas that will be affected by the construction or maintenance activities. There are many existing tools and software applications (e.g. urban planning tool, risk management tool, building design tool, structural engineering tool), yet each of them only addresses a particular scale level and supports a specific process. Most existing tools are not compatible with each other, and the users are facing either great redundancy or crucial loss of information when attempting to integrate the knowledge across different domains and project stages. Solving this issue critically depends on the interoperability between information modelling tools from the building domain and the urban planning domain. Unfortunately, certain gaps in the interoperability of data and tools between Building Information Model (BIM) and Geographical Information System (GIS) still remain.

This paper addresses research on the interoperability of BIM and GIS for low-disturbance construction, especially regarding bridge projects in the city. It reports an on-going EU collaborative research project titled PANTURA in the 7th EU Framework Program for Research and Technology Development. It mainly discusses research on ICT instruments focusing on the development of interoperable BIM and GIS based solutions by connecting: 1) an existing tool Urban Strategy for interactive spatial planning based on meta-data of urban situation; 2) the Building Information Model (BIM) of a bridge that contains project-specific technical and planning data; and 3)

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a decision-support tool to be used by the project stakeholders when considering the priorities and consequences of possible decisions in relation to low-disturbance sustainability indicators.

The structure of the following sections of this paper reflects the research methodology as adopted in the PANTURA project. It can be summarized as follows.

- First, state-of-the-art review is carried out with the focus on issues of GIS and BIM interoperability; functionalities and required further development of an existing tool Urban Strategy; and comparative analysis to select the feasible and most optimal solution for the interoperability of BIM and GIS based on open standards.
- Second, the user requirements for the BIM-GIS instruments for low-disturbance construction are defined. The definition is made based on interactive feedback from the other research work packages in the PANTURA project. Then, the development of the new prototype solution is described particularly with regards to the four abovementioned main aspects.
- Third, the preliminary outcomes are verified and demonstrated in two case studies of real bridge projects in Spain and the Netherlands. The case studies address the design and planning for new and existing bridges.
- Finally, conclusions and discussions are presented regarding the current achievements and remaining issues (both technical and user-related), and the applicability of the proposed solutions for other projects.

2. STATE-OF-THE-ART REVIEW

2.1 Urban Strategy tool for interactive planning

Supporting ICT tools have an important role during the planning and design of low-disturbance construction projects. A number of interactive urban planning tools are currently available, for instance: Urban Simulation, Interactive Urban Design, Value Lab, Urban Explorer, and PlanYourPlace, StrateGIS Urban Developer, AGISwlk, SEMANCO, and tools for environmental impact assessment (Chan, et al. 1998; Vries et al., 2005; Halatsch et al., 2008; TII, 2012; Steiniger, 2012; Seijdel et al., 2011; Yaakup et al., 2004; Madrazo, 2012; Gontier, 2010). These tools rely on GIS almost entirely and have very limited interference with BIM of the buildings or other construction objects.

The Urban Strategy tool is considerably unique compared to other existing tools. It is a tool that combines the 3D interactive planning functionality with impact analysis capability. It can visualize two or three dimensional model of the urban area including the graphical information of traffic, noise, air quality, CO2, ground quality, and safety condition. It is able to analyse and compute across the various urban aspects. Each aspect is computed using a specific model, e.g. traffic model, noise model and air quality model. The data regarding the various aspects are integrated by means of: a 3D data store and a communication layer that bridges between the various computational models. This will enable the decision-makers to take the necessary measures before, during, and after the construction of the new bridge (Duijnisveld et al., 2010). The 3 main components of the Urban Strategy are shown in Fig 1.

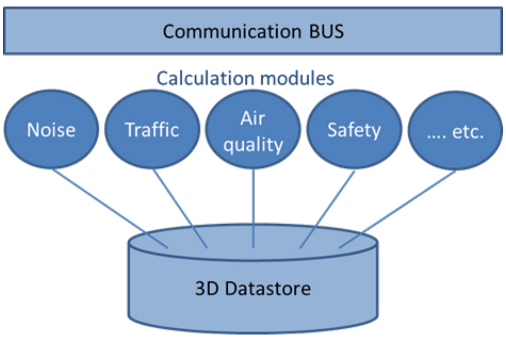

Fig. 1: The main components of Urban Strategy tool.

These components are: 1) the communication layer (BUS); 2) a set of calculation modules for different parameters (e.g. calculation module for traffic, calculation module for noise, calculation module for air quality); 3) the data store. The BUS works following the principle of trigger mechanism. After a computing process, the BUS received a signal regarding the changes made to certain types of data, and subsequently notifies the subscribed calculation modules that the relevant data have been changed or renewed. The data store is basically an Oracle database. It is also possible to store simple geometric data, for instance based on import from CityGML, but these cannot contain the CityGML structure. Despite its already comprehensive functionalities, further developments are needed to make possible the input-output relation with BIM model (e.g. the BIM model of a bridge). Moreover, an improved mechanism to retrieve and represent the relevant information for certain stakeholders is needed to support multi-actor decision-making and coordination processes that is crucial to achieve the low-disturbance objective.

2.2 Open-standard based approaches for connecting BIM, GIS and Urban Strategy

Research and discussions on the interoperability between BIM and GIS require knowledge of the interoperability between different BIM models –the so-called "Open BIM", as well as the interoperability between different GIS models –the so-called "Open GIS". Open BIM has a long history in ISO STEP (Standard for the Exchange of Product model data) and buildingSMART IFC (Industry Foundation Classes). At this moment, many experts acknowledge that IFC is the best available standard information structure that uses ISO STEP languages (EXPRESS, SPFF) for its compliant content representation (ISO, 2004; ISO, 2002). Current effort under the term IFCforInfra aims to broaden the scope of IFC to cover civil infrastructure (Yi et al., 2011). Practical solutions for civil infrastructure are currently sought by modifying the existing IFC models for AEC. Another option is to use proprietary interfaces on top of advance technologies like web services (W3Schools, 2013). Regarding the platform for BIM data, an examples of open-source software (OSS) applications for BIM servers is the BIMServer as an OSS variant on top of the highly scalable OSS Berkeley key-value DBMS by Oracle (BIMServer, 2013; Seltzer et al, 2012).

Open GIS mainly relies on the use of GML/CityGML standard from the Open Geospatial Consortium (OGC, 2013). GML/CityGML is completely built in the mainstream web/XML-technology: the content is in XML that is compliant to XSD (XML Schema Definition) information structures. GML also provides a very flexible extension mechanism known as Application Domain Extension (ADE). In the latest CityGML version 2, existing ADEs can be integrated – in other words: some parts in the earlier version of CityGML that were only available as ADE are now an integral part of the standard. Regarding the platform for GIS data, compliant client software applications and tools are available, for instance the OSS Deegree Server that can store GML features and support open-source database engines PostgreSQL/PostGIS as well as relational DBMS/Spatial Engine (PostgreSQL, 2013).

Based on the existing concepts, in principle, in the PANTURA research project, three main strategies were identified for the interoperability of Open BIM and Open GIS data:

- Keep them separate: Essential integration between BIM and GIS to meet minimum requirements will reply on the capability of the end-user applications, i.e. import/export between BIM and GIS.
- Consolidate in Open BIM and use Open GIS as an open data provider: Open GIS is used as the provider for data to be included in BIM.
- Consolidate in Open GIS and use Open BIM as open data provider: GIS represents 'the bigger picture' wherein a variety of data sources –among others BIM with regards to building objects– can be integrated.

When open-standard based approach is used (thus, relying on Open BIM and Open GIS), in theory, there are three possible scenarios to connect the Urban Strategy tool with Open BIM and Open GIS for the purpose of low-disturbance construction projects (Fig 2).

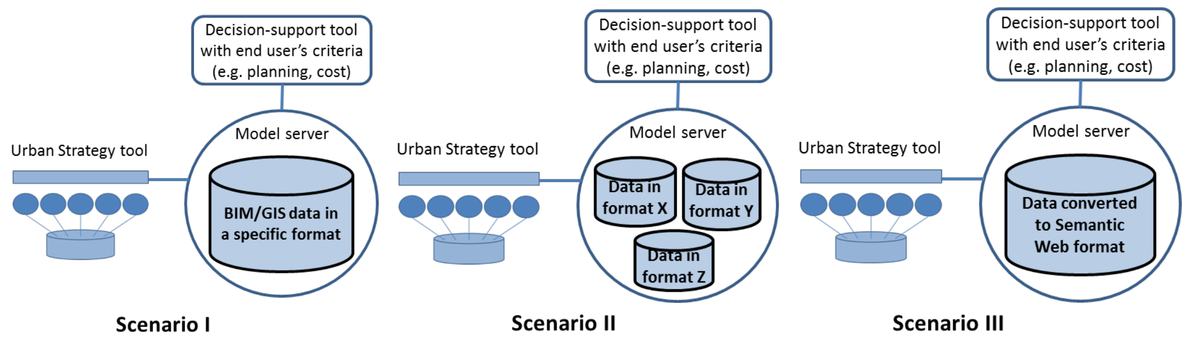

Fig. 2: Investigated scenarios to connect the Urban Strategy tool with Open BIM and GIS data.

In the Scenario I, all available and relevant BIM and GIS data are converted based into a certain format on a selected open standard. The converted data are then stored in a server. This scenario can be further specified into:

- Scenario I-a where IFC is the selected open standard and the open-source BIMServer or similar is used as the model server for data and applications (BIMserver, 2013).
- Scenario I-b where CityGML is the selected open standard and the open-source Deegree 3D server or similar is used as the model server for data and applications (GeoServer, 2013).

In the Scenario II, the data are stored in their original formats. The conversion only takes place when specific subsets of data are required to be used by certain calculation modules. This scenario can be based on COINS open standard. Here COINS serves as the controlling mechanism over different data formats. COINS is a Dutch initiative to develop a flexible BIM open standard applicable to improve the object-oriented content of the communication transfers according to Systems Engineering (SE). SE is used to formulate the functional specification with explicit specified requirements that can be matched with the expected or measured performances of the actual construction object (COINS, 2013).

In Scenario III, all relevant data are upgraded towards a semantic level. An RDF data server (W3C, 2013) can carry out this conversion to generate a semantic model. In this scenario, various open standards can be used and the interactions between them can take place on the semantic level. For instance, BIM IFC data can be converted to ifcOWL and then stored in the RDF server. Similarly, GIS CityGML data could be converted to the so-called CityRDF.

3. DEVELOPMENT OF BIM–GIS–URBAN STRATEGY INTEROPERABILITY SOLUTION FOR LOW-DISTURBANCE CONSTRUCTION

3.1 User requirements

The PANTURA research project aims to support the stakeholders to plan a low-disturbance bridge construction project by using an ICT tool. These stakeholders are thus considered as the end-users of the ICT tool. This ICT tool mainly consists of 2 parts: the End-User Application (EUA) and the integration platform of BIM – GIS – Urban Strategy. The EUA thus becomes the interface that is visible for and operational by the end-users, and therefore should be able to support the end-users in defining and combining their decision criteria, and assign the weighing factors when necessary, referring to the generic set of Key Performance Indicators (KPIs) for low-disturbance construction and the decision level (i.e. political, strategic, tactical, operational). Based on the development of the KPIs and the priority list derived from Europe-wide benchmarking (PANTURA, 2011), the EUA focuses the following KPIs, for which the input is provided by the BIM and/or GIS data:

- Worker safety, which is asserted in BIM as the “WorkerSafety” property in the bridge model.
- Resident safety, which is asserted in BIM as “ResidentSafety” property in the bridge model.
- Noise, which is calculated based on noise source points in Urban Strategy dataset as “MaxNoiseLevel” property for each building in the surroundings of the bridge construction site.
- Mobility, which is calculated based on the information of capacity and Intensity of roads at the construction site and surrounding areas. This information is derived from traffic intensity level, which serves as input to the Urban Strategy dataset.

3.2 Architecture for interoperability

After the exploratory research on three possible scenarios for open-interoperability as discussed in previous section and shown in Figure 3, in the PANTURA research project, it was decided to elaborate solutions based on Scenario I-b, i.e. CityGML is the selected open standard and the open-source Deegree 3D server or similar is used as the model server for data and applications. Three main preferences behind this decision are:

- The preference to convert all types of data to one open-standard format for compatibility with the from the EUA; and therefore, Scenario II where various original formats are maintained was excluded.
- The preference to rely on an operational (‘up-and-running’) open-standard; and therefore, Semantic Web format has been excluded since much research is still needed.
- The focus on multiple civil infrastructure objects integrated in their urban areas; and therefore, CityGML has been considered more practical than IFC. Moreover, export to CityGML format from Urban Strategy model is already supported.

In order to proceed with the selected Scenario I-b, four key steps are necessary to achieve the solution for data/model interoperability. These steps are shown in Fig. 3.

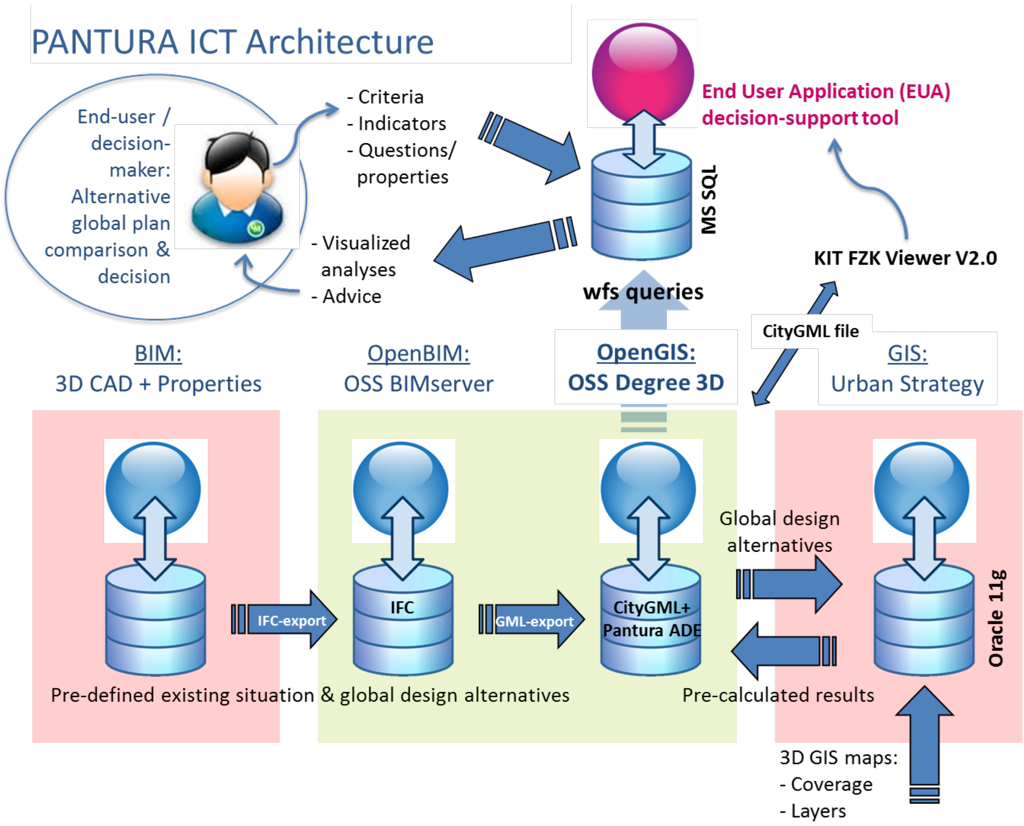

Fig. 3: BIM – GIS interoperability architecture developed in the PANTURA research project.

A set of design and construction solutions for the bridge, including their properties, are modelled in BIM using different software as selected by the client, designer, engineer, or contractor. The 'native' BIM models are exported to open-standard IFC models. These IFC models are then then transformed into CityGML format. The properties are handled by the PANTURA ADE (which is explained in the next section). This CityGML models and other GIS data are stored in the Deegree 3D model server (an open GIS server, which is explained in the next section). All information structures and semantics are based on CityGML, and the used syntax is XML. The Urban Strategy tool can use CityGML data in the Deegree 3D model server to make calculation/analysis of disturbance impacts. The calculation results are then fed back to the model server. The EUA accesses the information in the Deegree 3D model server via fully-standard queries of Web Feature Services (WFS) and stores the data in its native data storage (Microsoft MS SQL) for further processing. The EUA performs analysis of the data based on the KPIs, decision-making criteria and weighting factors as selected by the end-users.

3.3 Open standards and Application Domain Extension (ADE)

Operationalizing the architecture for interoperability requires interfacing solutions utilizing open standards (i.e. IFC and CityGML) as well as Application Domain Extension (ADE). As mentioned in previous section, CityGML is used in the PANTURA research project as the intermediate language for all data derived from various sources (BIM, GIS and Urban Strategy dataset). CityGML is an extension of GML (Geography Mark-up Language), which is a language using a XML structure for describing geographical information. CityGML contains more detailed geographical information, and particularly describes urban objects in three dimensions including the inter-relations between these objects. For the purpose of supporting decision-making in low-disturbance bridge construction projects, CityGML 2.0 is chosen. In CityGML 2.0, a bridge has become part of the standard; this is not the case in the 1.0 or 1.1 version.

In order to 'connect' CityGML and IFC, an ADE is needed. The level of taxonomy and semantics in CityGML is lower than in IFC, and hence, directly translating (exporting) the data from IFC to CityGML will result in loss of information. By extending the CityGML standard via an ADE to match IFC data types and hierarchy, the loss of information can be reduced significantly. In the PANTURA research project, the BIM IFC model of a bridge is translated to a CityGML model with help of the PANTURA ADE.

Along with its function to support the translation from IFC data to CityGML data, the PANTURA ADE also contains dedicated properties that are relevant for analysing disturbance impacts during bridge construction. This is needed to overcome the limitations of CityGML in supporting custom properties of an object-type. Using the PANTURA ADE, certain values –depending on the design and construction scenarios– can be assigned to the properties of the bridge models. The Urban Strategy tool can then be used for analysing and comparing the disturbance impacts of these scenarios.

3.4 Open-source model server

Based on the proposed architecture and the use of open standards in the PANTURA research project, the model server should meet the following criteria: is open-source, able to handle CityGML models, able to facilitate queries by the Urban Strategy tool and the End-User Application, and accessible via the internet. The available open-source model servers, which fulfil these criteria, are Deegree 3D and GeoServer (Deegree, 2013; GeoServer 2013). Both servers can store geospatial (CityGML) data, can be queried via the internet using Web Feature Service (WFS), and are java-based software. Since the functionalities and performance of both servers keep growing and changing along with the on-going development, it is hardly possible to draw a scientific comparison before selecting the most optimal solution. In the PANTURA research project, it was decided to experiment with the Deegree 3D server. Configuring the Deegree 3D server to support CityGML models and the Urban Strategy dataset was done through the following steps:

- Creating a database: The Deegree 3D server is capable of using different types of geospatial databases, but a database has to be created manually before use. For the purpose of disturbance analysis during construction in the PANTURA research project, a Postgres database (an object-relational database management system which can hold multiple databases) with the addition of PostGIS (for the geospatial part) is set-up.
- Setting up a Java Database Connectivity (commonly known as JDBC, which enables Java programs to execute SQL statements) within the Deegree 3D server: This connection will rely on the location of the server as well as the port that holds the database, database name, username, and password of the database user. When the database is available, the Deegree 3D server needs to be further configured to use this database as the location where 'features' (i.e. objects and properties of the GIS models) are stored.
- Setting up a feature store within the Deegree 3D server: A feature store can take a database as its storage containers. Transactional queries can also fill the database with new features. During the creation of the feature store, the Deegree 3D server generates a set of SQL statements to configure all necessary tables, based on a schema that identifies all existing feature types. This schema is the CityGML schema as described in the previous chapter along with the ADEs (i.e. PANTURA ADE). After these SQL statements have been performed, it is then possible to upload a CityGML file to fill the feature store.
- Adjusting the used WFS version (an optional step, only when necessary).

4. CASE STUDIES TO VERIFY THE PROTOTYPE SOLUTIONS

4.1 Case study of on-site assembly of a new bridge in Los Sauces, La Palma, Spain

A relevant case for the application of BIM and GIS to plan low-disturbance construction project was provided by ACCIONA and Government of the Canary Islands, both from Spain, which are partners in the PANTURA consortium. The case of the new bridge in Los Sauces town was to construct a new pedestrian bridge along the main road at a key location in the Los Sauces town. Since there was only one main road which connected the two parts of the town, the construction of the pedestrian bridge should be done in such a way without closing this main road; or if road closing is inevitable, then the closing time and disturbance should be minimized. For this reason, as well as other long-term sustainability considerations, it was decided to build a lightweight bridge of Fibre Reinforced Composite (FRP) material through off-site prefabrication. ACCIONA was the selected contractor, and it prefabricated the FRP beam of the bridge at its factory in Madrid. The FRP beam of the bridge was then transported to La Palma, prior to the on-site assembly process. The case study focused on deciding the most optimal scenario for the one-site assembly of the FRP bridge.

Two scenarios for on-site assembly were defined in the case study:

- On-site assembly scenario I: The FRP beam is transported from the port to the project site by truck. When the truck arrives to the project site, a crane located next to the road and in one side between the abutments is ready to lift up the beam from the truck and to place it on the abutments. In order to carry out this activity, one of the two road lanes is closed temporarily because the truck parks on the road lane next to the construction site. Once the beam is placed on the abutments, the truck can leave and the road can be opened again. The whole process would take maximum 2 hours. The noise level is reasonably low, but there would be some traffic disturbance during the transport from the harbour to the construction site.
- On-site assembly scenario II: Scenario II differs from scenario I by the use of a helicopter for transporting the FRP beam the harbour to the construction project site. The distance from the harbour to the project site by helicopter is about 14 km. No traffic disturbance would be experienced during the transport, yet standard and additional safety factors when transporting a load with helicopter must be taken. The noise level is high, and the road needs to be closed completely during the process for safety reasons.

The experimental application of BIM, GIS and Urban Strategy tool in this case can be summarised as follows.

- Preparing BIM and GIS data, including: development of BIM model of the bridge in a native 3D CAD software (ArchiCAD); inclusion of properties related to disturbance, i.e. construction time; export to IFC, based on the agreed IFC structure; and import and adjustment of 3D GIS map of La Palma into Urban Strategy tool.
- Generation of construction planning including 2 possible scenarios for on-site assembly process, inclusion of properties related to disturbance, i.e. worker safety and resident safety.
- Defining the disturbance parameters and stakeholders' decision criteria in the Urban Strategy tool, i.e. noise, traffic; and in the EUA, including the data source to compute these parameters, based on 3D GIS map, BIM IFC model, and statistics.
- Facilitating the data and application interoperability by developing and implementing an ADE that connects BIM data from the bridge with the computational parameters on disturbance in Urban Strategy; and facilitating the inter-connection between Urban Strategy tool and EUA on Deegree 3D server.
- Calculation and analysis through: executing Urban Strategy calculation process on each of the 2 possible scenarios for on-site assembly process; analysing the Urban Strategy calculation results (i.e. the disturbance impacts of each scenario) based on the end-user criteria using the EUA; and presenting the analysis results at a decision-making meeting involving the stakeholders (demonstration session involving other PANTURA consortium partners).

4.2 Case study of refurbishment of existing bridges in Rotterdam, the Netherlands

As partners in the PANTURA consortium, the City of Rotterdam from the Netherlands provided a relevant case for low-disturbance construction project, and NCC AB from Sweden provided a BIM model of an existing bridge to be used for experiment of BIM and GIS interoperability in this case. The Willems Bridge, which contained a series of bridges, was one of the key connections between the Northern and Southern city parts. There was a real plan to improve the Willems Bridge due to mid-life refurbishment; the fulfilment of European requirement of the passage height under the bridge for water transport; the increase of traffic load; the extension of public transportation route; and the area development agenda of the City of Rotterdam. Low-disturbance construction was of a high –if not the highest– priority considering the strategic location of the Willems Bridge for both shipping and road transportation, any disruption due to the bridge refurbishment project will bring huge negative economic, social and political impacts to Rotterdam.

For the case study of the PANTURA research project, the city of Rotterdam developed three conceptual scenarios, which were assessed using BIM, GIS and Urban Strategy tool in order to recommend a strategy for low-disturbance construction.

- Scenario I covers refurbishment and strengthening of existing two bridges (the Willems Bridge and the Koninginne Bridge), including a new public transport route over the existing bridges.
- Second II comprises renovation of an existing bridge (the Willems Bridge) and construction of a new bridge next to the Koninginne Bridge.
- Scenario III proposes relocation and extension of an existing bridge (the Willems Bridge) and construction of a new bridge. This proposal aims to introduce a new and efficient public transport route simultaneously with elevating, extending and relocating the Willems Bridge.

Regarding scenario II and III, a BIM model based on an existing bridge was used as a fictional example of a new bridge to be positioned parallel to the Koninginne Bridge. This BIM model was originally developed by NCC AB using Tekla software. The actions taken during the experimental application of BIM, GIS and Urban Strategy tool in this case were similar to the first case study (La Palma case). The difference was that the project scenarios affected the choice for design solutions –instead of choice of assembly solutions as discussed in the first case.

5. CONCLUSIONS AND DISCUSSIONS

This paper reports on-going research in the EU collaborative project PANTURA, especially addressing investigation of BIM and GIS interoperability for the purpose of planning and decision-making of low-disturbance bridge construction projects in the city. The research started with a literature study to examine the possible concepts. The main result of this literature study was ICT architecture to solve BIM-GIS interoperability as shown Fig. 3 in the Section 3. This architecture was then verified using two case studies as described in Section 4. During the experiment, new or improved solutions to facilitate the interoperability were developed and technical issues were resolved. The research activities, which reflected the conceptual ICT architecture, are shown in Fig. 4. The achievements and issues at each research step are concluded in Table 1. Within the PANTURA project, these activities were part of Work Package 3 (WP3), which sub-divided into 2 tasks, i.e. T3.1 and T3.2.

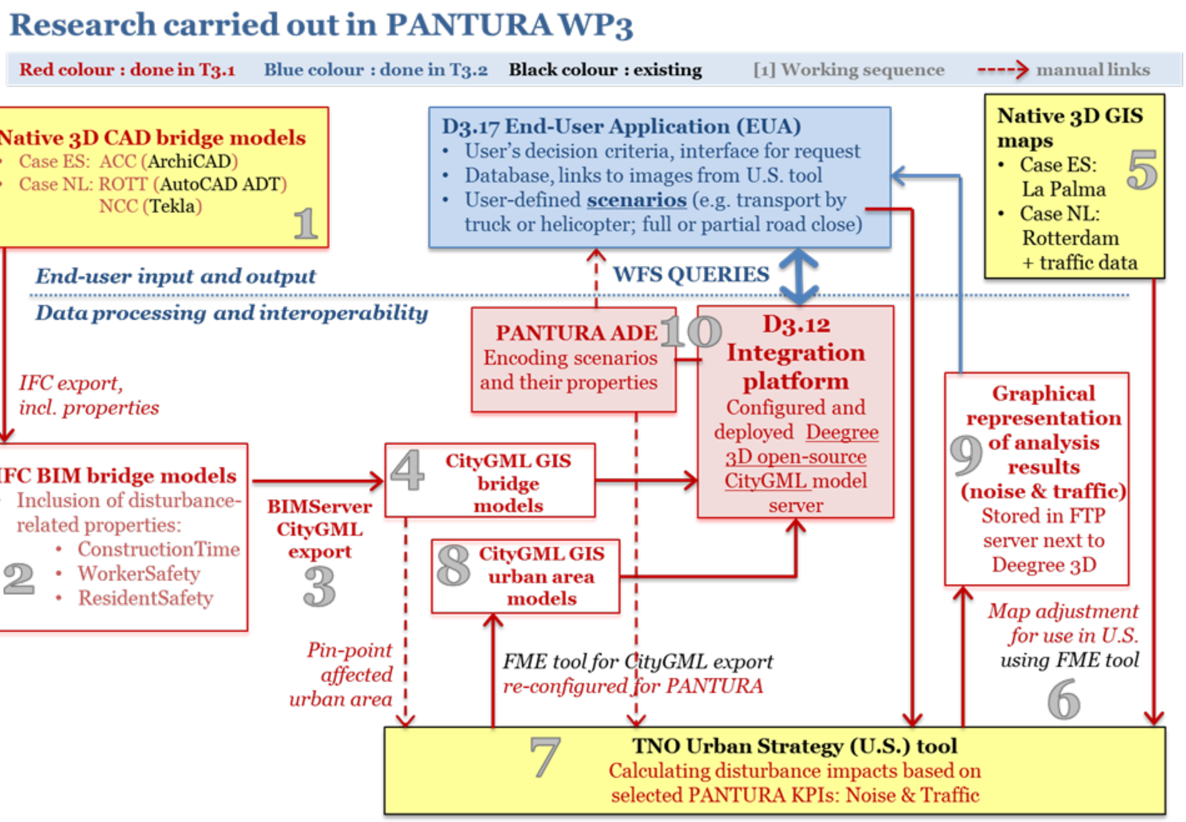

Fig. 4: Current research activities and achievements.

Table 1: Achievements and issues at each research step.

Research step	Achievements made	Issues tackled
1	Consolidated the 3D CAD models of the bridges (new and existing).	Model structure and IFC export from native software.
2	Exported IFC models of the bridges, and inclusion of disturbance-related properties in IFC parameters: ConstructionTime, WorkerSafety, and ResidentSafety.	Naming and consistency of the IFC parameters.
3	Exported CityGML models of the bridges using the PANTURA-CityGML export function that is a plugin for the open-source BIMServer.	Coordinate systems and conversions.

4	Stored CityGML models of the bridges on open-source Deegree 3D model server; pin-pointed affected urban area in the city.	Storage configuration of the model server.
5	Consolidated 3D GIS maps of the cities, including existing traffic data model that was available for Rotterdam.	Completeness and compatibility of the native GIS maps; representation of the explicit shapes involved (like solids or multi-surfaces for objects); availability of relevant data model or statistics for disturbance analysis (e.g. traffic, noise).
6	Adjusted / corrected / combined GIS maps including disturbance-related information as input for Urban Strategy tool – done with help of the existing FME tool (available on market).	Generation of traffic data model for case study La Palma – Spain.
7	Calculated disturbance impacts (i.e. noise and traffic) for 2 case studies.	Determining noise sources and measurements; processing traffic data models.
8	Output CityGML models of the affected urban area including the calculation results from Urban Strategy – export from Urban Strategy model to CityGML model was done with help of the existing FME tool (available on market).	Re-configuration of the FME tool for CityGML export according to PANTURA purposes.
9	Visualised output of Urban Strategy analysis results (e.g. graphical representations of noise level, traffic flow and congestion in the area depending on various construction scenarios).	Storing the images on an FTP server connected with the End-User Application (EUA).
10	Configured and deployed open-source Deegree 3D model server including PANTURA ADE. The PANTURA ADE keeps the configuration and allows users to define queries based on encoding the scenarios and properties.	Configuring the Deegree 3D server for PANTURA schema, data format, and database/storage location; pre-defining the WFS queries; fixing technical bugs in the server; setting-up hardware to host the PANTURA Deegree server (accessible on www.modelservers.org/deegree-pantura/).

Based on the lessons learned from the current research, the following discussions can be presented to address the practical implementation of the solutions and recommendations for future research:

- The PANTURA approach can be used to connect a 3D BIM model and a 3D GIS map. The BIM model can be generated by any CAD/BIM software with IFC export functionality. Thus, this approach can be generalised for implementation in other projects / by other parties.
- The originality of research in PANTURA is found in the attempt for open-interoperability of BIM and GIS, particularly for the purpose of decision-making in low-disturbance urban projects. The challenge of open-interoperability is very high since it must face 4 fronts of complexity at the same time, namely: open BIM; open GIS; connection with an analytical tool, such as the Urban Strategy; and connection with a decision-support tool comprising end-user's criteria and disturbance key performance indicators. Within the context of this challenge, no straight forward connectivity can be found; and therefore, the selected ICT architecture as discussed in this paper consists of a number of export / conversion steps. The selected ICT architecture has been made operational and verified in two case studies, yet neither this paper nor the PANTURA project intends to proclaim that this is the most effective and efficient route towards the BIM-GIS open-interoperability. More research is needed to build scientific arguments to support (or oppose) the selected approach.
- One of the innovative solutions which can be derived from experiment in PANTURA is the use of Deegree 3D server to store and make available CityGML data. The server configuration, including the particular purpose for scenario analysis on disturbance impact, has been registered in the PANTURA ADE. This can become an input for future standardisation regarding properties of data model, server configuration, and standardised query definition.

6. REFERENCES

BIMServer (2013). Open source building information model server, www.bimserver.org (last accessed on 1 February 2013).

Chan R., Jepson W. and Friedmann S. (1998). Urban Simulation: an innovative tool for interactive planning and consensus building, *Proceedings of the American Planning Association national planning conference,* Boston, Massachusetts, USA.

COINS (2013). COINS reference manual (Willems, P. and Schaap H. editors), http://www.coinsweb.nl/wiki/index.php/Reference_Manual (last accessed on 1 February 2013).

Deegree (2013). Deegree 3D, http://wiki.deegree.org/deegreeWiki/deegree3/deegree3D (accessed on 1 Feb 2013).

Duijnisveld M., Kievit M. de and Schelling A. (2010). Urban Strategy keeps your city in the move, *Proceedings of Colloquium Vervoersplanologisch Speurwerk, Roermond,* The Netherlands. [in Dutch]

GeoServer (2013). What is GeoServer, http://geoserver.org/display/GEOS/What+is+Geoserver (accessed on 1 Feb 2013).

Gontier M., Mörtberg U. and Balfors B. (2010). Comparing GIS-based habitat models for application in EIA and SEA, *Environmental impact assessment review,* Vol. 30, 8-18.

Halatsch J., Kunze A., Burkhard R. and Schmitt G. (2008). ETH Value Lab: a framework for managing large-scale urban projects, *Proceedings of 7th China urban housing conference,* Chongqing, China.

ISO (2002). *ISO 10303-21:2002 Industrial automation systems and integration -- Product data representation and exchange -- Part 21: Implementation methods: Clear text encoding of the exchange structure,* ISO, Geneve.

ISO (2004). *ISO 10303-11:2004 Industrial automation systems and integration -- Product data representation and exchange -- Part 11: Description methods: The EXPRESS language reference manual,* ISO, Geneve.

Ji Y., Beetz J., Bonsma P., Nisbet N., Katz C. and Borrmann A. (2011). Integration of parametric geometry into IFC-Bridge, *Proceedings of the 23th forum Bauinformatik,* Cork, Ireland.

Madrazo L., Sicilia A. and Gamboa G. (2012). SEMANCO: Semantic tools for carbon reduction in urban planning, *Proceedings of 9th European conference on product and process modelling (ECPPM),* Reykjavik, Iceland.

OGC (2013). CityGML, http://www.opengeospatial.org/standards/citygml (last accessed on 1 February 2013).

PANTURA (2011). *Comparative analysis of best practices: review of existing methods and development of an indicator suite for PANTURA goals, Project report D6.4,* EU FP7 Project PANTURA.

PostgreSQL (2013). About PostgreSQL, http://www.postgresql.org/ (accessed on 1 Feb 2013).

Sebastian R., Claeson-Jonsson C. and Di Giulio R. (2013 forthcoming). Implementation of MEAT for low-disturbance bridge reconstruction projects, *Construction innovation: information, process, management,* Vol. -, No. -, xx - xx.

Seijdel R., Dullemond A. and Schevers H. (2007). StrateGIS 3DSS: collaborative 3D decision support for urban development, *Proceedings of Seminar on the playful city – serious gaming for sustainable urban development,* Delft, The Netherlands.

Seltzer M. and Bostic K. (2012). *Berkeley DB: The architecture of open source applications* (Brown A. and Wilson G., editors), Online Self-Publishing ww.lulu.com.

Steiniger S., Poorazizi M. E., Bliss-Taylor C.A.M., Mohammadi E. and Hunter A.J.S. (2012). PlanYourPlace: merging social networks and participatory GIS for participatory planning, *Proceedings of FIG working week,* Rome, Italy.

TII (2012). Urban Explorer – Applied research project of Swedish ICT Interactive Institute, https://www.tii.se/projects/urbanexplorer (last visited on: 25 January 2013).

Vries B. de, Tabak V. and Achten H. (2005). Interactive urban design using integrated planning requirements control, *Automation in construction,* Vol. 14, 207– 213.

W3C (2013). Reference Definition Framework RDF, http://www.w3.org/RDF/ (accessed on 1 Feb 2013).

W3Schools (2013). Introduction to Web Services, http://www.w3schools.com/webservices/ws_intro.asp (accessed on 1 Feb 2013).

Yaakup A.B., Johar F., Maidin M.A. and Ahmad E.F. (2004). GIS and decision support systems for Malaysian development plan studies, *Proceedings of international conference on spatial planning and decision support systems,* Kuala Lumpur, Malaysia.

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