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To cite this article: L Barazzetti 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **364** 012084

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Duality between BIM and GIS: an example related to the medieval bridge Azzone Visconti

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Abstract. The paper presents the work carried out on the medieval bridge Azzone Visconti in Lecco, Italy. The project required the use of both BIM and GIS technologies to assess the loading capacity of the bridge. First, a detailed geometric survey was carried out with laser scanning and photogrammetric techniques. The aim was the generation of a BIM. Displacements were then measured via geometric levelling during loading tests carried out in different days. Such data were integrated and stored in the BIM. Finally, the simulation of traffic conditions was used to investigate the usability of the BIM for a geographic area around the bridge. Results highlighted that the BIM used in the first stage of the work had to be replaced with another integrated BIM-GIS solution more suitable for analysis based on geospatial data.

1. Introduction

This paper presents the different geospatial data collected and processed during the project related to the medieval bridge Azzone Visconti, in Lecco (Italy). A multi-disciplinary team of specialists carried out several analysis to assess the loading capacity of the bridge with both experimental and numerical analyses. More details are described in [1].

The work described in this paper wants to underline the contribution of Geomatics techniques (surveying, modelling monitoring, etc.) and the different types of geospatial data acquired and processed. Different instruments and techniques were integrated to (i) measure very small displacements during loading tests (precision of about ± 0.1 mm), (ii) create a detailed BIM [2] and drawings at a scale 1:50 (precision of about $\pm 2-5$ mm) for condition assessment and finite element analysis, and (iii) produce a new integrated BIM-GIS model for advanced traffic simulations (metric precision of about $\pm 200-400$ mm). In the case of analysis (i) and (ii), a Cartesian reference system was established, which became suitable for most analysis at the local scale (the scale of a construction). The integrated BIM-GIS model required a cartographic reference system (UTMWGS84-ETRF89) and preliminary georeferencing via GNSS of specific information collected in the local reference system. Additional existing geospatial data, such as DTM, shape files, and orthophotos, were added as well.

A clear definition of the work in complete and integrated BIM-GIS projects is still not very clear at the present. In some cases, processing is carried out in independent software with a continuous import/export, which usually results in loss of information. Another approach consists in a BIM imported in a GIS environment, which is also able to perform basic BIM processing, and vice versa.



Nowadays, several authors have described different experiences for a variety of projects where both technologies were discussed (e.g. [3-15], among the others).

It could be said that Geographic Information System (GIS) and Building Information Modelling (BIM) can be very useful when the work requires different scales. For instance, BIM sw are mainly designed for the scale of the building, and GIS for the district, city, regional, national and international scales. On the other hand, such distinction is not always valid since many examples with GIS sw were carried out also for small objects. Another distinction could be based not only on the type of data, but also on the type of operations. GIS engines have advanced functions for geospatial analysis, whereas BIM sw have advanced parametric modeling tools. A common feature of both technologies is the database connected to the graphic representation of specific objects.

The previous similarities and differences are just an overall indicator to understand why BIM and GIS could be intended as different technologies. It is the author's opinion that (at the present), BIM and GIS sw have to be simultaneously exploited to solve related but different problems. An integrated approach in data processing requires a continuous transition through specific software packages. It could be said that BIM and GIS can be used together as they are complementary.

2. The first model of the bridge: working in a local reference system

The project started with the acquisition of photogrammetric and laser scanning data to create a BIM of the bridge in Autodesk Revit. In addition, a set of 2D measured drawings (plans, sections, elevations) at the scale 1:50 was requested. The survey was carried out with these basic requirements in mind. A geodetic network was measured with a Leica TS30. The network was adjusted via least squares obtaining an average point precision of about ± 1.5 mm. Points of the network provide the local reference system used for the generation of the model.

A set of 77 scans was acquired with a Faro Focus 3D laser scanner. Scans were registered in the local system with an average accuracy of about ± 3 mm. Then, the project was integrated with several photogrammetric blocks. Most instruments and techniques allowed us to achieve a metric accuracy better than ± 5 mm, which is more than sufficient for the creation of deliverables at the scale 1:50.

The creation of the BIM was carried out dividing the bridge into its constructive elements. Specific objects were generated and assembled. They include stones, ashlars, sprinters, decks, floor beams and stringers. The complexity of the bridge, with irregular shapes not available in existing object libraries, required the development of specific procedures for parametric modelling. This was necessary to overcome the lack of commercial software able to provide detailed geometric reconstructions which preserve the level of detail encapsulated into laser scanning point clouds [16-17]. For this reason, a procedure based on surfaces made up of NURBS curves and NURBS surfaces [18] was used to create new parametric BIM objects. Some images of the model are shown in Fig. 1.



Figure 1. The first BIM in Autodesk Revit.

A condition assessment was carried out using the orthophotos generated via photogrammetry, vector data were instead used to run structural simulations. As mentioned in the introduction, it is not the author's intention to describe such operations, for which the reader is referred to [1]. On the other

hand, the work carried out to measure the vertical displacements of the bridge deserves to be mentioned. Vertical movements were measured via geometric levelling, after mounting a set of benchmarks on the bridge. Different loading tests were carried out and least squares adjustment provided the displacements of benchmarks with an average accuracy of about ± 0.15 mm (Fig. 2). Specific “benchmark” objects were added to the Revit Model to identify the location of the measured points. Then, graphs and tables were connected to the model, which enriched the existing database.

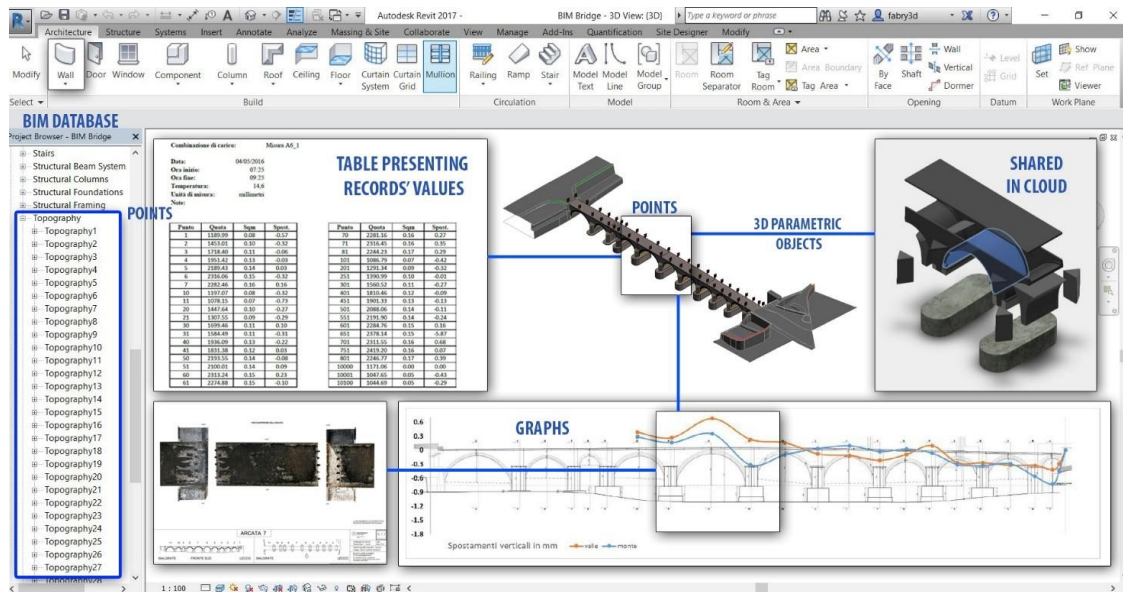


Figure 2. Integration of monitoring data in the BIM.

3. The second model of the bridge, towards BIM-GIS

The second phase of the work was a traffic flow simulation in the area around the bridge, assuming different configurations:

- (i) Bridge with 2 lanes;
- (ii) Bridge with a single lane;
- (iii) Bridge closed.

Configuration (i) reflects the conditions before the beginning of the work. Configuration (ii) is the actual conditions. In fact, after completing the work described in section 2, it was decided to (permanently) close 1 lane. The last configuration (iii) was the case of a limited time period (1 week + another week later), when the bridge was temporarily closed to allow specialists to collect all the technical data to assess the loading capacity.

It is clear that the different configurations have direct impact on the traffic in the area around the bridge. In such case, data analysis must be moved from the local scale of the bridge to a wider area, which includes also the existing road network.

Traffic analysis tools are available in GIS software and could be used to simulate traffic flows at specific hours of the day. On the other hand, we decided to carry out the traffic simulation via BIM to reuse (as much as possible) the data already processed in section 2. The BIM of the bridge as well as the raw data (geodetic network, laser point clouds) were georeferenced in the cartographic system UTM-WGS84 ETRF89 and integrated with additional geospatial data. Georeferencing was carried out with some points measured with GNSS receivers in RTK.

Existing geospatial data include both raster and vector layers from the geospatial database of the province and municipality. An additional LiDAR (aerial) point clouds was also integrated. Such

dataset was acquired in 2005 using the Optech ALTM3033 altimeter. The theoretical density of the points was 0.2–1 points/m² (without taking into account the overlapping area of different strips) while the real density in the considered area is about 1.7-1.8 points/m². Such resolution is significantly lower than the point cloud acquired via terrestrial laser scanning, but it provides a coverage for the entire city.

Fig. 3 shows a detail of the vector layers used for traffic simulation: the existing road network, buildings, and water bodies. As can be seen, the bridge was removed from GIS data, since the idea is to replace the corresponding shapefile with the model in Revit.

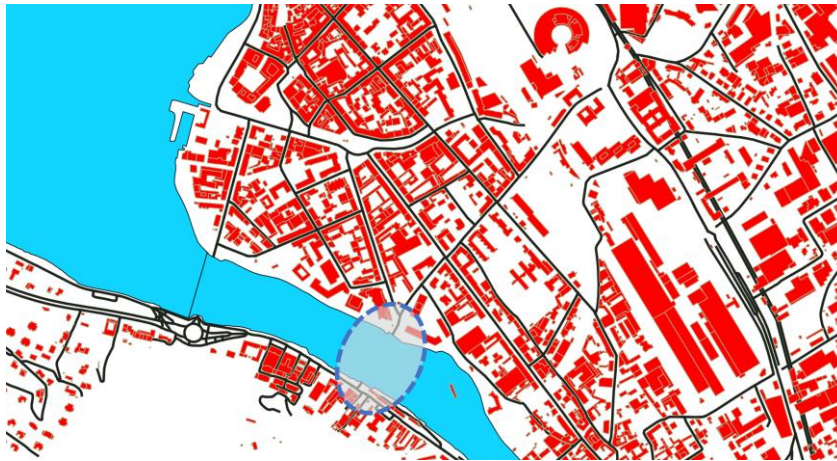


Figure 3. The different shapefiles used to simulate traffic conditions. The bridge was removed and replaced with the BIM in Revit.

The software used for traffic simulation is Autodesk InfraWorks, which is designed for BIM of infrastructures. It has instruments able to simulate traffic conditions starting from a BIM that encapsulate geospatial data. The road shapefile was imported in Infraworks and projected on the digital terrain model. Additional information about intersections (e.g. stop signs) was added manually. Buildings were also integrated (the height of each building is available in the shapefile) since they provide visibility occlusions during traffic simulations. Buildings are basically represented as boxes. Then, data from OpenStreetMaps were superimposed to the available cartographic layer to check their consistency. Such operations were carried out in QGIS, where a spatial subset in the considered areas was extracted to limit the amount of data. Since the road networks from OpenStreetMaps was consistent with the geospatial database, we decided to use such dataset because it is more recent.

Then, the georeferenced BIM in Revit was added to the InfraWorks project. On the other hand, such BIM was not recognized as a valid bridge object for traffic simulation. A careful simplification would be needed to provide a model usable for this kind of analysis. We therefore decided to create a simplified BIM directly in Infraworks. Such bridge is still built parametrically and is able to interact with other objects such as roads and water bodies. It is curious that the mediaeval bridge is here replaced with a modern one, which proved to be sufficient for a detailed traffic simulation. After setting specific parameters for the simulation (such as speed, number and type of vehicles, period of the day), a numerical estimate of the traffic flow was carried out. Some example images are shown in Fig. 4.



Figure 4. Some images of the traffic simulation in InfraWorks with different lane configurations: a single lane (top) and two lanes (bottom).

4. Considerations and outlooks

This section tries to compare the work carried out in the previous sections. Two models were generated and handled in different software: Revit and InfraWorks. The first software is surely more suitable for analysis at the local scale of the building, whereas InfraWorks can integrate different geospatial data for projects at a different scale, which could be defined as the scale of the infrastructure.

It is possible to share data between the two software, although specific analyses are feasible only using a distinct workflow. At the same time, data import/export revealed some loss of information.

Fig. 5 shows the different data and techniques for both projects, which are not completely uncorrelated. In the first case, a Cartesian reference system was sufficient for the modelling phase. In the second phase, it is necessary to move to a cartographic reference system. The connection between the two systems is available through some benchmarks measured with total station and GNSS receivers. The transformation used is based on a 2D roto-translation with variation in scale (4 parameters) estimated via least squares, starting from a set of corresponding points $(X, Y)_{LOCAL} \leftrightarrow (East, North)$. Given the size of the bridge (less than 150 m), transformation of coordinates along the vertical line $Z_{LOCAL} \leftrightarrow H$ was carried out with a simple translation. H is the orthometric elevation value, estimated via GNSS and corrected for geoid undulation.

Some operations on the geospatial data have been carried out using a GIS software. Indeed, InfraWorks lacks some instruments for geospatial data analysis available in GIS packages. InfraWorks is more oriented to infrastructure design, where geospatial data have to be incorporated. It provides instruments to model specific typologies of objects such as roads and railways, which becomes parametric objects and their attributes can be modified by working on the database. Here, the work can start from geospatial datasets in both vector and raster formats. Then, additional information has to be added after importing each file in InfraWorks. For instance, information about the typology has to be assigned. A line shapefile that represents a road has to be identified as a road object. Although this is quite obvious, file typologies have to be defined manually resulting in a time-consuming operation. Then, the software provides different basic geometry for roads (such as highway roads, arterial roads, collector roads or local roads), with specific speed limits. Additional parameters are the number of lane forwards and backward, creation date, lifespan, etc.

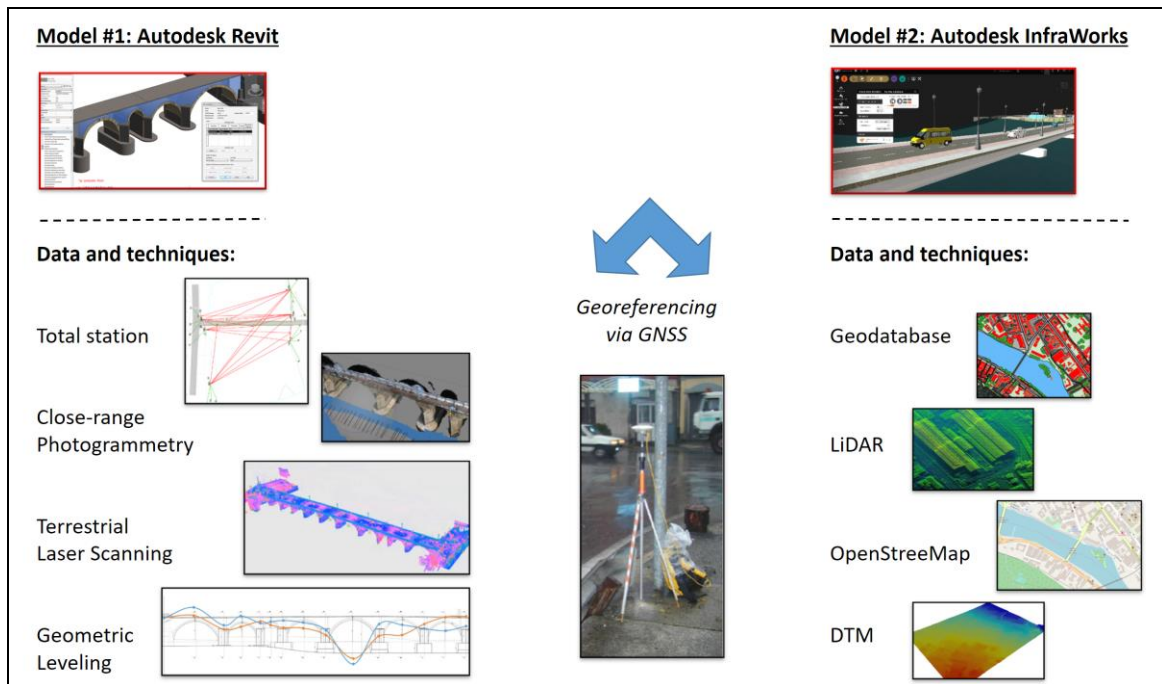


Figure 5. The different data collected and processed in this project.

BIM software like Revit are instead mainly designed to represent the building and its elements. The typical workflow for the generation of a new (as-designed) BIM requires the assembly of predefined objects already subdivided into categories (walls, columns, floors, roofs, windows, doors, ceilings, ramps, etc.). Objects are placed in levels (e.g. foundation, floor, ceiling, roof, etc.), which provide a sort of reference system. Levels can be intended as horizontal planes for the different storeys of the construction. The generation of the BIM of a medieval bridge in Revit was not a simple task because of the lack of parametric objects able to represent the geometry of the bridge. Here, additional tools and functions were developed and used to represent the geometry captured by photogrammetry and laser scanning, as described in [19].

GIS software cannot represent the complexity of the building with this level of detail. A similar consideration is valid also for InfraWorks. It is therefore rather clear that BIM, GIS and BIM-GIS are still complementary solutions, which have to be exploited together. On the other hand, this paper reflects the work achievable with the commercial solution available on the commercial market in 2017. The integration between BIM and GIS is a field of research of primary importance that is developing very fast. For example, Autodesk and Esri have announced a partnership to “put GIS and BIM at the centre of construction projects, driving smarter decisions, optimized designs, accelerated project approvals, reduced cost, creating smarter cities and resilient infrastructure. Building the bridge between GIS and BIM will change the way we plan, design, and build our future” (text copied from <http://www.esri.com/landing-pages/autodesk-esri-strategic-alliance>). It is therefore expected that substantial changes will be available soon.

5. Conclusion

One of the outcomes of this research was the creation of “two BIM” for the local survey and the work in the cartographic reference system. Two software were used to handle the models: Autodesk Revit and Autodesk InfraWorks. In the first case, the model of the bridge was generated considering the requirements of the project: geometric survey, condition assessment, destructive and non-destructive testing, finite element analysis, estimation of the loading capacity. InfraWorks was instead used to

integrate some geospatial data and to run traffic simulations with the bridge in different configurations. Although some data can be integrated, processed, and visualized in both software, specific tools and functions were available only in a specific package. This required a set of import/export operations to take advantages of both packages. At the same time, the use of a “pure GIS software” was mandatory to handle the geospatial data with the typical geospatial tools only available in such packages. In fact, although InfraWorks can exploit geospatial information, the available tools are more oriented to preliminary design of infrastructures. This underlines the dual role between BIM and GIS at the infrastructure level, which makes the simultaneous use of both solutions still mandatory for structure and infrastructure projects based on geographic information.

Acknowledgments

This work has been supported by the GAMHer project: Geomatics Data Acquisition and Management for Landscape and Built Heritage in a European Perspective, PRIN: Progetti di Ricerca di Rilevante Interesse Nazionale – Bando 2015, Prot. 2015HJLS7E.

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