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City Information Model for the Optimization of Urban Maintenance Cost

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Abstract. Public authorities address issues related to urban maintenance management on a daily basis. Maintenance is vital for preserving efficient architectural and functional quality, but the economic resources that can be invested in it are increasingly limited. Thus, authorities tend to carry out maintenance works only when effective emergency situations occur. On the contrary, adopting a preventive maintenance plan would allow a better management of the available budget and savings of resources. The paper aims to present a methodology to optimize maintenance costs by integrating GIS and BIM systems in order to create a City Information Model (CIM). It is meant to optimize management and monitoring of urban maintenance works assisting public authorities in their effort in making a more efficient use of the economic resources allocated.

Keywords: Urban Maintenance Cost; GIS; BIM; CIM

INTRODUCTION

Urban maintenance management plays a fundamental role in the public authorities' activities as it compensates for the inevitable degradation of urban elements through specific strategies to maintain functional, structural and architectural quality [1].

However, economic aspect is one of the major limitations of maintenance procedures as they involve different technical sectors such as buildings, roads, lighting, sewerage and green public areas on a large scale. Thus, experts must develop programmed maintenance plans identifying specific intervention thresholds to reduce costs that otherwise would not be sustainable. Programmed maintenance consists of preventive interventions carried out with constant frequency and it is based on an appropriate knowledge of the reliability and durability of systems, subsystems, components and materials.

Since land conservation and transformation is a complex and multidisciplinary issue and economic resources are increasingly limited, public authorities need a method to optimize urban maintenance management procedures.

In the literature, there are many researches related to the City Information Modeling for smart city [2–5], city planning [6–8] also through spatial analysis [9],the promotion of the sustainability mobility [10, 11], the transport network capacity [12]

The paper aims to present a methodology to optimize maintenance costs by integrating GIS and BIM systems in order to create a City Information Model (CIM). It is meant to optimize management and monitoring of urban maintenance works assisting public authorities in their effort in making a more efficient use of the economic resources allocated.

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MATERIALS AND METHODS

City Information Modeling (CIM): Interoperability between GIS and BIM

Geographical Information Systems (GIS) and Building Information Modeling (BIM) are the most widely used tools in the design and management of urban facilities and infrastructures as they allow quantitative and qualitative analyses and improve the knowledge base in decision-making process.

GIS allows to acquire, manage and visualize georeferenced data through 2D thematic maps [9] allowing spatial analyses based on functional and physical relationships of the external environment on a large scale. However, there is a lack of a detailed and complete digital repository of information on buildings and infrastructure [14, 15].

Within the AEC (architecture, engineering, construction) industry, Building Information Modeling is a consolidated approach both for the sustainable design of new construction and the management of existing buildings and cultural heritage. BIM model is an interactive data archive containing both geometric data and non-graphic information, such as materials, energy characteristics, solar analysis, costs and maintenance instructions. It consists of a central informative and shared model, integrated among every project participant, and it is configured as a dynamic system particularly helpful for the building's facility management (FM). BIM models allow to collect a lot of information in a single database, link it to 3D geometrical features of buildings and export it to specific software for different purposes [16]. However, BIM technology does not include information about the surrounding environment, so it is insufficient when used alone in the field of urban planning and management [17]. Thus, for their intrinsic characteristics, GIS and BIM are complementary tools [18].

Nowadays, there is no integration of the BIM and GIS tools, but there are several studies on the integration of their data exchange formats.

Open Geospatial Consortium developed the CityGML. It is an information model dedicated to the representation of sets of 3D urban objects. Its purpose is to give a common definition of the basic entities, attributes and relationships that constitute a 3D city model. To do that, CityGML organises the information by describing city objects with their geometrical, topological, semantical and appearance properties [19, 20]. It is structured to represent cities and buildings features with a different Level of Detail (LoD) [21].

While, BuildingSmart developed the "Industrial Foundation Classes" (IFC). It is an ISO standard that defines all objects of a building in a civil engineering project. IFC includes object specifications and provide a structure for data sharing among AEC applications and stakeholders. In an IFC, object specifications are categorized in Levels of Development (LoD) [22].

City Information Modeling (CIM) is the result of the integration of these two data exchange formats (Fig.1).

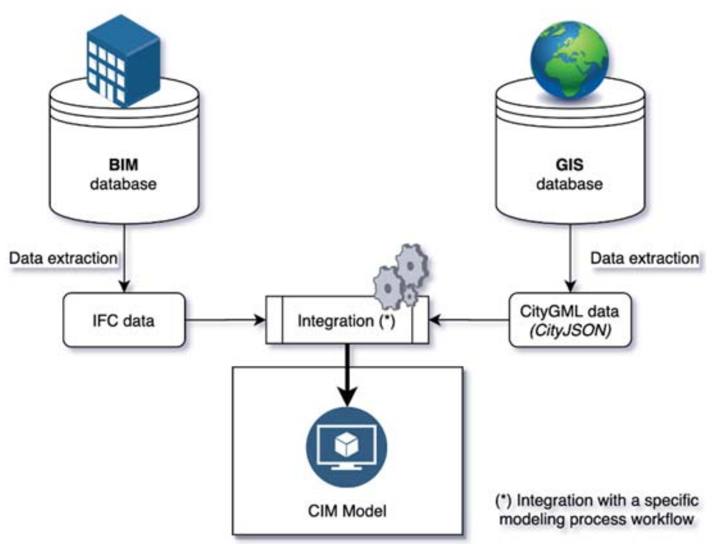


FIGURE 1. Integration between IFC e CityGML formats (made by authors)

It uses 3D numerical models of the city which represent the different types of urban objects (buildings, road system, urban furniture, vegetation, water bodies among others), relationships and behaviors. Each of the objects that constitute these city models have characteristics: geometric (form), graphic (appearance), topological (relationships) and semantics (properties / behaviors) coming from IFC and cityGML formats [5].

The researchers have tested different software for the integration of data exchange formats. The most used ones are shown in Table 1.

TABLE 1. Main software used in literature to create a City Information Modeling

Features	Software available
Dashboard Maps Query and search	Esri ArcGIS Qgis (*) Leaflet JS library (*) DaviCal (*)
Database	PostGIS (*) Postgres (*) GeoServer (*) ESRI Geodatabase
Data Analysis	Esri ArcGIS Qgis (*) Autodesk Revit Graphisoft Archicad OpenBuilding Designer

(*) Open Source software

Methodology

In urban planning and management, maintenance is one of the most complex activities for public authorities. Thus, this paper aims to present a methodology to optimize maintenance costs by integrating GIS and BIM systems in order to create a City Information Model (CIM). It is meant to optimize management and monitoring of urban maintenance works assisting public authorities in their effort in making a more efficient use of the economic resources allocated.

The method is divided into three stages:

1. *Data Collection*. Data collection requires significant effort in terms of time-consuming to have relevant information. Useful data can be collected in the technical offices of public administrations or alternatively on the websites of the administrations themselves, which make available opendata files. The sectors of urban maintenance concern roads, lighting system, sewerage, green areas, etc.. Table 2 shows general data that can be collected for each sector.

TABLE 2. Collection data list

Data	Description	Notes
Spatial localization	Defining the administrative territory on which maintenance is to be carried out	City/District/Area
Intervention category	Establishing maintenance sector	Road, lighting system, sewerage, green areas, etc.
Intervention labelling	Identification of the technological system	Work Breakdown Structure of the system

Data	Description	Notes
Description of intervention	Identification of anomalies in the technological system	Digital data or text
Intervention times	Chronoprogram data	Frequency of control and maintenance for an interventions schedule
Economic amount	Data containing the economic aspects of the interventions	Maintenance costs (economic frameworks, final expenditure, etc.) for a financial planning.

Each urban sector (road, sewerage, lighting, green area, etc.) has a programmed maintenance plan containing most of the data. Analysis, inspections or surveys on site are the alternatives for collecting missing data. An example, maintenance plans do not contain the costs related to inspections and interventions. They may refer to Regional Pricing List or specific price analysis.

2. *Editing and Validation.* The editing and validation phase consists of uploading the data collected from maintenance plans and on-site inspections or specific analyses into a digital repository. BIM models allow to collect a lot of information in a single database and link it to 3D geometric features. When the BIM model is ready, it can be exported in the IFC data interchange format. Regarding georeferenced city data, some public administrations provide open data on their online platform. Otherwise, this data can be extracted from GIS software in CityGML format. Since the IFC and CityGML data show structural differences (geometries, objects and relationships, etc.), adaptations and subsequent validations are necessary.
3. *Modeling.* The last stage consists of the integration between BIM and GIS in order to create the City Information Modeling. Geo-referenced 3D city model will include not only geometric information, but also maintenance information of the structures and infrastructures. The CIM will be moved in a cloud or local system in order to be consulted by the public administration [23].

Fig.2 shows the workflow described above.

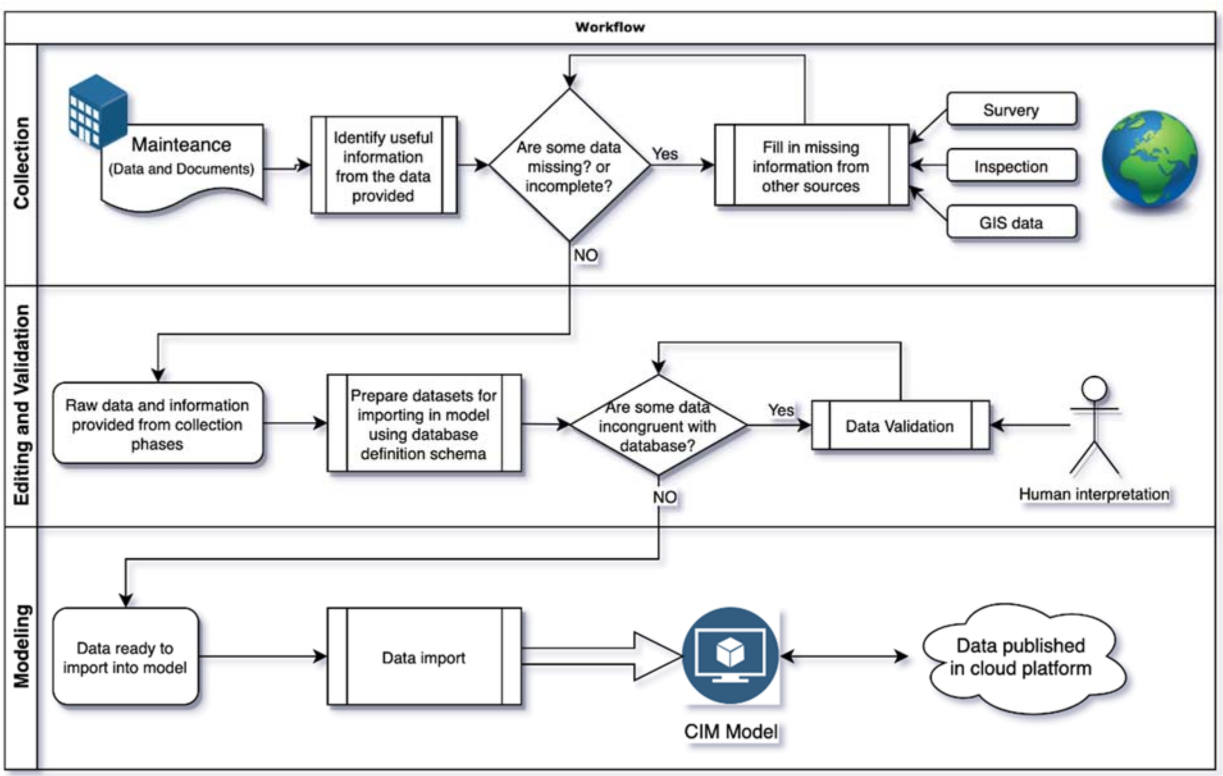
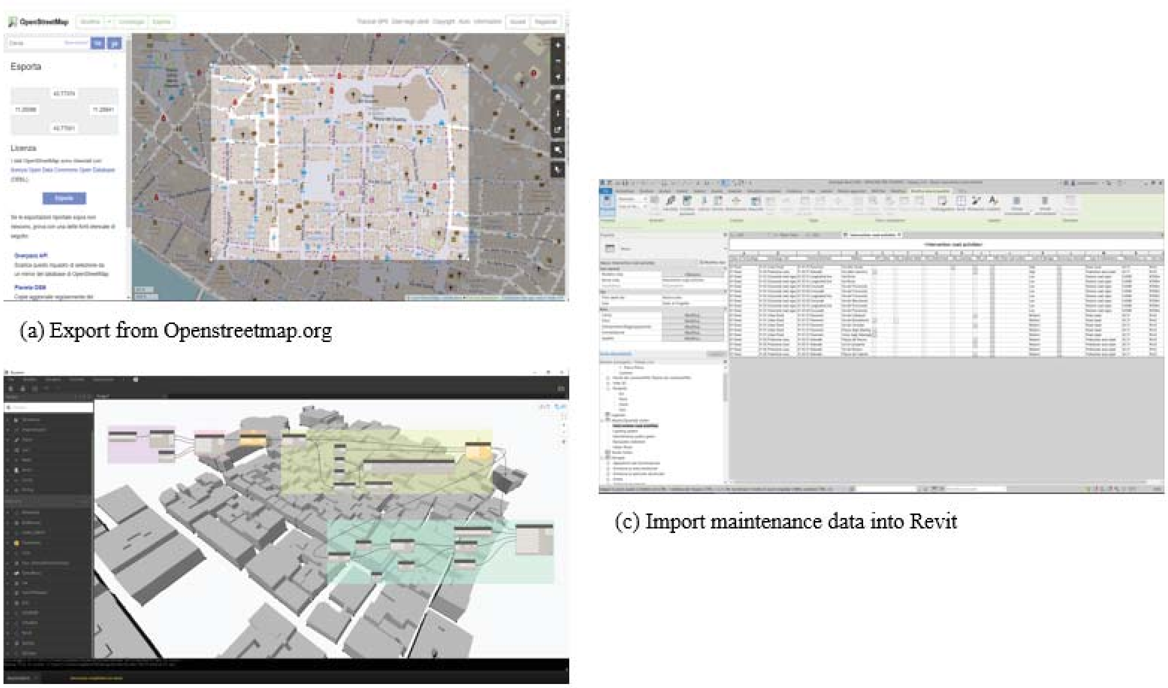


FIGURE 2. Modeling process workflow (made by authors)

RESULTS

To check the feasibility of the process of data integration between GIS environment and BIM, a test has been performed on a sample area.

1. *Data Collection*. It consists of three stages:
   - *Geographical data collection.* We pulled a basic data on the layout of the urban district from OpenStreetMap which provides geographical data on streets, buildings, infrastructure, green areas etc.. We chose this procedure because geographical data in OpenStreetMap are available as open data under the ODbL (Open Database License) and thanks to its API it can be selected and exported to both GIS and BIM systems.
   - *Collection of maintenance plans.* As mentioned before, urban maintenance covers several sectors (roads, lighting systems, sewerages, green areas, etc.). In this specific case, we have taken into account urban road maintenance plans. The road system is broken down into technological units and technical elements (roadway pavement, sidewalk pavement, road markings, etc.). For each of these elements the anomalies, control frequency and maintenance frequency have been listed.
   - *Maintenance costs.* Finding the cost of road maintenance is no easy task. For this reason, we determined the road maintenance costs by carrying out a price analysis of the main activities (road surface renovation, cleanliness, road markings renovation, etc.) by referring to the Public Works Price Lists.
2. *Editing and Validation*. It consists of two stages:
   - *BIM model creation*. We chose to build BIM model with Revit Autodesk Software. Since the OSM format of the district is based on 2D vectors, we used Dynamo plugin to create the 3D model. The script implemented in Dynamo aimed to import the OSM file exported from OperStreetMap and read its features and attributes. The polylines were automatically transformed into extruded solids (volumes) and converted into Revit masses. The script automatically associated to these solids all the other parameters coming from OpenSteetMap. We also used Dynamo process to import maintenance data collected in the previous phase from Excel to Revit. The last step concerned the export of data in the IFC data interchange format (Fig.3)



(a) Export from Openstreetmap.org

(b) Import OSM into Revit through Dynamo

(c) Import maintenance data into Revit

FIGURE 3. BIM model process (made by authors)

- *Data integration between the domains IFC and CityGML*. We used the Esri ArcGis and the Data Interoperability Extension plug-in in order to import the features containing inside IFC format. At this point, the Esri ArcGis software allows a first visualization of 3D city modeling. In the same way, Esri ArcGis software exported the CityGML format via the Data Interoperability Extension plugin.
- *Validation*. In order to verify and validate the correctness of the conversion methodology process, the model was imported into the FZK Viewer. This is a free software, developed by KIT (Karlsruher Univerity of Techonology), allowing users to visualize IFC and CityGML data (Fig.4).

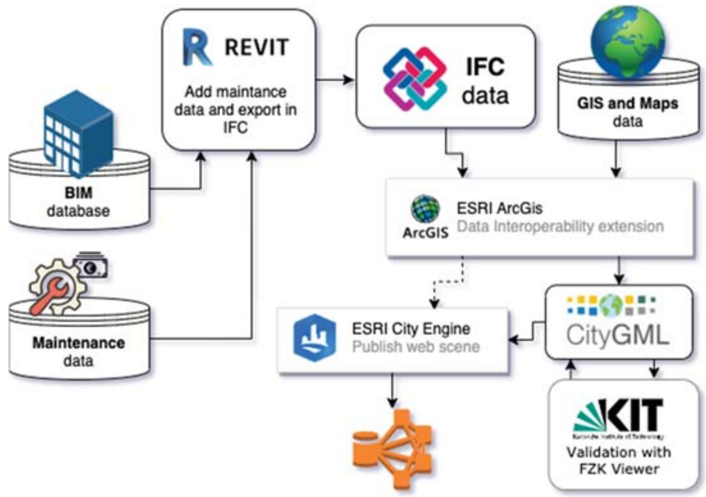


FIGURE 4. Data integration between the domains IFC and CityGML (made by authors)

3. *Modeling.* The final step is to import the CityGML format (including IFC data) into the GIS environment. In this specific case we used the Esri City Engine software to query not only the geometries but also the information related to the road maintenance plans (Fig.5).

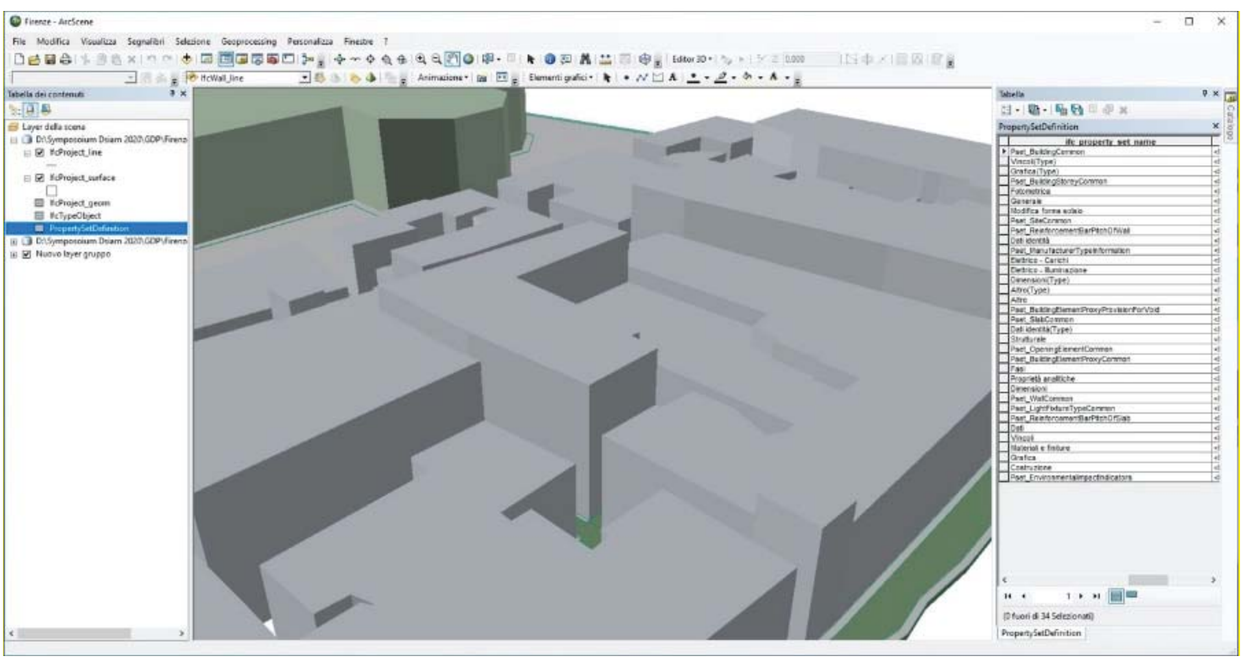


FIGURE 5. 3D visualization of district in Esri City Engine (made by authors)

DISCUSSION AND CONCLUSION

The paper proposes a workflow to optimize management and maintenance activities in urban areas for public authorities in order to save time and costs in decision-making processes. City Information Modeling created by integration of BIM and GIS is useful to visualize and query the system keeping always updated the information about the maintenance activities already carried out and those planned. The proposed workflow allows to import data from projects, constructions and/or maintenance activities into a geographical information system. This approach becomes useful for public authorities as a decision support for the planning and planning of short and medium term interventions while keeping economic expenditures under control.

To achieve this goal, it is important not only the technical quality and robustness of the data collected, but also an accurate attention to the functionalities that allow to query the database and obtain effective reports in terms of useful data and communication of information to decision makers.

The paper shows a case study of City Information Modeling through the integration of IFC and CityGML data interchange formats from Revit Autodesk and ESRI ArchGIS software, respectively. Tab.1 shows many other open source or commercial software that can do it.

The proposed workflow can certainly be improved through full integration between BIM and GIS systems and the use of intermediate standards such as LandInfra [24].

The proposed method can be adopted more generally in the context of transport planning and maintenance. In fact, the CIM can be used as a decision support for public administrations in the management of travel time savings [25–28] or for the urban regeneration of some neglected districts [29, 30]. Moreover, an improvement in urban maintenance management will certainly have positive effects on the satisfaction of residents and especially tourists [31].

REFERENCES

1. Acampa, G.: European Guidelines on Quality Requirements and Evaluation in Architecture. Valori e Valutazioni. Semestrale anno XII, 47–56 (2019)
2. Amorim, A.L. de: Discutindo City Information Modeling (CIM) e Conceitos Correlatos. Gest. Tecnol. Proj. 10, 87 (2015). https://doi.org/10.11606/gtp.v10i2.103163
3. Wolisz, H., Böse, L., Harb, H., Streblow, R., Müller, D.: City district information modeling as a foundation for simulation and evaluation of smart city approaches. BSO 2014. (2014)
4. Auci, S., Mundula, L., Quaquero, E.: Bright cities and city information modeling. Real Corp. 143–152 (2019)
5. Simonelli, L., Amorim, A.L.: City Information Modeling: General Aspects And Conceptualization. American Journal of Engineering Research (AJER). 7, 319–324 (2018)
6. Thompson, E.M., Greenhalgh, P., Muldoon-Smith, K., Charlton, J., Dolník, M.: Planners in the Future City: Using City Information Modelling to Support Planners as Market Actors. UP. 1, 79 (2016). https://doi.org/10.17645/up.v1i1.556
7. Kagan, P.B., Kulikov, V.G.: Information Modeling of Urban Planning Development. AMM. 409–410, 951–954 (2013). https://doi.org/10.4028/www.scientific.net/AMM.409-410.951
8. Hamilton, A., Wang, H., Tanyer, A.M., Arayici, Y., Zhang, X., Song, Y.: Urban information model for city planning. Journal of Information Technology in Construction (ITcon). 10, 55–67 (2005)
9. Ignaccolo, M., Inturri, G., Giuffrida, N., Le Pira, M., Torrisi, V., Calabrò, G.: A step towards walkable environments: spatial analysis of pedestrian compatibility in an urban context. European Transport\Trasporti Europei. 76, 1–12 (2020)
10. Torrisi, V., Ignaccolo, M., Inturri, G.: Innovative Transport Systems to Promote Sustainable Mobility: Developing the Model Architecture of a Traffic Control and Supervisor System. In: Gervasi, O., Murgante, B., Misra, S., Stankova, E., Torre, C.M., Rocha, A.M.A.C., Taniar, D., Apduhan, B.O., Tarantino, E., and Ryu, Y. (eds.) Computational Science and Its Applications – ICCSA 2018. pp. 622–638. Springer International Publishing, Cham (2018)
11. Torrisi, V., Ignaccolo, M., Inturri, G.: Toward a sustainable mobility through. A dynamic real-time traffic monitoring, estimation and forecasting system: The RE.S.E.T. project. In: Pezzagno, M. and Tira, M. (eds.) Town and Infrastructure Planning for Safety and Urban Quality. pp. 241–247. CRC Press (2018)
12. Torrisi, V., Ignaccolo, M., Inturri, G.: Analysis of road urban transport network capacity through a dynamic assignment model: validation of different measurement methods. Transportation Research Procedia. 27, 1026–1033 (2017). https://doi.org/10.1016/j.trpro.2017.12.135

13. Maarseveen, M. van, Martínez-Martín, J.A., Flacke, J.: GIS in sustainable urban planning and management: a global perspective. (2019)
14. Guarini, M.R., Buccarini, C., Battisti, F.: Technical and Economic Evaluation of a Building Recovery by Public-Private Partnership in Rome (Italy). In: Stanghellini, S., Morano, P., Bottero, M., and Oppio, A. (eds.) Appraisal: From Theory to Practice. pp. 101–115. Springer International Publishing, Cham (2017)
15. Amirebrahimi, S., Rajabifard, A., Mendis, P., Ngo, T.: A data model for integrating GIS and BIM for assessment and 3D visualisation of flood damage to building. Locate. 15, 10–12 (2015)
16. Eastman, C.M. ed: BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors. Wiley, Hoboken, NJ (2011)
17. Rafiee, A., Dias, E., Fruijtier, S., Scholten, H.: From BIM to Geo-analysis: View Coverage and Shadow Analysis by BIM/GIS Integration. Procedia Environmental Sciences. 22, 397–402 (2014). https://doi.org/10.1016/j.proenv.2014.11.037
18. Saygi, G., Agugiaro, G., Hamamcıoğlu-Turan, M., Remondino, F.: Evaluation of GIS and BIM roles for the information management of historical buildings. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. 2, 283–288 (2013)
19. Kolbe, T.H., Gröger, G., Plümer, L.: CityGML: Interoperable Access to 3D City Models. In: van Oosterom, P., Zlatanova, S., and Fendel, E.M. (eds.) Geo-information for Disaster Management. pp. 883–899. Springer Berlin Heidelberg, Berlin, Heidelberg (2005)
20. Campisi, T., Acampa, G., Marino, G., Tesoriere, G.: Cycling Master Plans in Italy: The I-BIM Feasibility Tool for Cost and Safety Assessments. Sustainability. 12, 4723 (2020). https://doi.org/10.3390/su12114723
21. Biljecki, F., Ledoux, H., Stoter, J.: An improved LOD specification for 3D building models. Computers, Environment and Urban Systems. 59, 25–37 (2016). https://doi.org/10.1016/j.compenvurbsys.2016.04.005
22. UNI 11337-4:2017: Building and civil engineering works - Digital management of the informative processes - Part 4: Evolution and development of information within models, documents and objects, http://store.uni.com/catalogo/uni-11337-4-2017?josso_back_to=http://store.uni.com/josso-security-check.php&josso_cmd=login_optional&josso_partnerapp_host=store.uni.com
23. Logothetis, S., Valari, E., Karachaliou, E., Stylianidis, E.: Spatial DMBS Architecture for a free and open source BIM. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLII-2/W5, 467–473 (2017). https://doi.org/10.5194/isprs-archives-XLII-2-W5-467-2017
24. Open Geospatial Consortium & buildingSMART International: Built environment data standards and their integration: an analysis of IFC, CityGML and LandInfra, https://www.ogc.org/docs/discussion-papers?utm_source=phplist737&utm_medium=email&utm_content=HTML&utm_campaign=OGC+and+buildingSMART+International+publish+discussion+paper+on+the+integration+of+BIM+and+GIS, (2020)
25. Acampa, G., Ticali, D., Parisi, C.M.: Value of travel time: An economic assessment for transport appraisal decision-makers. Presented at the Proceedings of the International Conference of computational methods in sciences and Engineering (ICCMSE-2019) , Rhodes, Greece (2019)
26. Campisi, T., Tesoriere, G., Canale, A.: Microsimulation approach for BRT system: The case study of urban turbo roundabout. Presented at the Proceedings of the International Conference of Computational methods in sciences and engineering 2017 (ICCMSE-2017) , Thessaloniki, Greece (2017)
27. Campisi, T., Canale, A., Tesoriere, G., Renčelj, M.: The newest public transport system applied to turbo roundabouts. Proceedings of the Institution of Civil Engineers - Engineering Sustainability. 1–8 (2020). https://doi.org/10.1680/jensu.19.00008
28. Torrisi, V., Ignaccolo, M., Inturri, G.: Estimating travel time reliability in urban areas through a dynamic simulation model. Transportation Research Procedia. 27, 857–864 (2017). https://doi.org/10.1016/j.trpro.2017.12.134
29. Acampa, G., Mattia, S.: Marginal Opportunities: The Old Town Center in Palermo. In: Mondini, G., Fattinnanzi, E., Oppio, A., Bottero, M., and Stanghellini, S. (eds.) Integrated Evaluation for the Management of Contemporary Cities. pp. 441–451. Springer International Publishing, Cham (2018)
30. Barbato, D., Pristeri, G., De Marchi, M.: GIS-BIM Interoperability for Regeneration of Transurban Areas. REAL CORP 2018 – EXPANDING CITIES – DIMINISHING SPACE. Are “Smart Cities” the solution or part of the problem of continuous urbanisation around the globe? Proceedings of 23rd International Conference on Urban Planning, Regional Development and Information. 243–250 (2018)
31. Acampa, G., Grasso, M., Marino, G., Parisi, C.M.: Tourist Flow Management: Social Impact Evaluation through Social Network Analysis. Sustainability. 12, 731 (2020). https://doi.org/10.3390/su12020731