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ScienceDirect

Transportation Research Procedia 45 (2020) 803–810

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 2nd International Congress on Transport Infrastructure and Systems in a changing world (TIS ROMA 2019), 23rd-24th September 2019, Rome, Italy

BIM And GIS Data Integration: A Novel Approach Of Technical/Environmental Decision-Making Process In Transport Infrastructure Design

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Abstract

The European Directive 2014/24/EU and its recent Italian transposition law DM 560/2017 encourage an extensive use of BIM-based practices in transport infrastructure design. Therefore, a shift from the traditional design approach towards a shared and highly integrated model, capable of including the various design phases along with economic, operational and environmental concerns, is observed. In such a framework, this work evaluates the benefits returning from the integration between geospatially-referenced data and the BIM models for a more aware design approach.
The major aim of this study is to underline the potential of an interoperable and shared model supplemented by GIS data, in minimizing or definitely removing the possible conflicts that typically arise between the infrastructure design and environmental constraints.
Particularly, thanks to both the simultaneous assessment of each environmental component and the evaluation of the different project configurations, this methodology can provide an integrated technical/environmental overview of the design.
As a result, it allows for immediately verifying the project to comply with the national minimum environmental criteria, which are mandatory for contractors according to the Italian environmental law n° 221/2015 and the new Italian Public Procurement Code.
The proposed approach was finally tested on an airport infrastructure. Preliminary results have shown viability of the data management model for supporting designer's choices in the various project phases, thereby proving this methodology to be worthy for implementation in infrastructure design procedures.

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Peer-review under responsibility of the scientific committee of the Transport Infrastructure and Systems (TIS ROMA 2019).
10.1016/j.trpro.2020.02.090

Keywords: BIM; GIS; Infrastructures; Airport; Environment; Data Integration.

1. Introduction

The use of Building Information Modeling (BIM) method is becoming a strategic tool in civil engineering both in infrastructure design, construction process and management. The Italian transposition law DM 560/2017 (MIT, 2017) adopts the European Directive 2014/24/EU (EU, 2014) on public procurement, encouraging and establishing an extensive use of BIM-based practices in large transport infrastructure issue. In fact, the European Commission had already intervened on the matter in 2004, through the former Directive 2004/18/CE (EU, 2004). Recently, although BIM has gradually grown and it is well-implemented for structure projects, it remains currently uncommon for transport infrastructure projects, due the higher complexity of application. At the same time, both infrastructure designs and infrastructure works are often those involving the highest complexity, risks, as well as most significant costs. In this context, the application of a novel integrated approach provided by BIM could produce drastic advantages in terms of project quality and effectiveness. The DM 560/2017 (MIT, 2017) defines the methods and times for the gradual introduction of the compulsory use of specific electronic methods and tools for the design, execution and management of construction works. From 1 January 2019, in fact, the BIM have become mandatory for tender equal or higher than 100 million euros, while it is expected to become integral part of any construction work starting from 1 January 2025. Accordingly, the use of BIM is strictly actual and urgent for expensive public contracts that mainly concern the realization of large civil infrastructures such as roads, railways and airports. In this context, a focus should be emphasized on two principal issues related to the technical assessment of built environment sustainability (Manzone et al., 2019) and to the integration of the Geographic Information System (GIS) techniques (Basir et al., 2018; Zhu et al., 2018; Zhu et al., 2019). Another relevant issue is the realization of a sustainable civil infrastructure environment under the technical, legislative and serviceable points of view; in fact, all these aspects should meet each other in a system of reciprocal communication and input-output relationship.

As a result, this comprehensively sustainable environment is expected to provide who is in charge for decision-making process with a system to collect, organize, quantify and report information.

In order to make the infrastructure sustainable at each phase of its life cycle such as design, construction, operation life and end of life (reuse, recycling or demolition), a large quantity of data should be known and integrated into the preliminary phase of the project. The relationship between these information and other several aspects of the project must be possible at every stage of the life cycle to optimize the knowledge and the effectiveness of the related choices.

In addition, the application of GIS in the decision-making process is generally required to manage the georeferenced information on the project, to match information from different sources and formats and to include environmental issues. Besides, GIS can generally use combinations of data sets to build and analyze integrated information and can convert the existing digital information into a form that meets the user's need. At this stage, GIS can complement the BIM approach in order to develop a systematic platform for both design, construction and operation life.

The main goal of the paper is to demonstrate the potential of a unique BIM model in integrating several environmental aspects implemented with a GIS, in order to facilitate the environmental compatibility assessment of the transport infrastructure, complying with the main relevant environmental regulations.

2. Background and literature review

The implementation between BIM and GIS largely relies on data exchange between the two systems. Despite the two systems and platforms may actually seem different in terms of focus and scope, the integration of the GIS in BIM has attracted the attention of researchers from both fields due to the potential relative benefits (Alsaggaf and Jrade, 2015; Ma and Ren, 2017, Zhu et al., 2018). In order to overcome the limitations of the stand-alone use of the technologies, the integration of BIM and GIS is indeed required. As an instance, according to Irizarry and Karan (2012) GIS provides topological (georeferenced) data, which allows for 3D analysis, spatial analysis, and queries such as the calculation of the distance between two points, the calculation of travel route and the definition of the optimal location. BIM is incapable of such analysis, but it provides a detailed database of object-oriented parametric information for the building and represents it in a 3D model, a feature that in GIS is lacking (El-Mekawy and Ostman, 2010). The BIM-

GIS integration can operate both for fundamental and application levels. Fundamental level essentially refers to data transformation between the two systems, which is required for a comprehensive information exchange. A geometry transformation and a semantic information transfer represent key examples of this level to shift information from one system to the other, specifically, from BIM to GIS or from GIS to BIM. For example, the representative data format for BIM is the Industry Foundation Classes (IFC), which is, on the one hand, an open, neutral, object-based data format for describing building and construction activities in the Architectural, Engineering, Construction, and Facility Management (AEC/FM) domain and for information exchange (Vanlande et al., 2008), and on the other hand it is an official international standard registered by the International Organization for Standardization, ISO 16739 (2016). Again, in the GIS framework, there are two main data formats available, City Geography Markup Language (CityGML) and shapefile. Currently shapefile is mostly used in application-oriented studies and some options are available for users to transform IFC to shapefile.

Regarding the progress of the use of BIM for transport infrastructure a wide, exhaustive and critical analysis of scientific literature has been carried out by Costin et al. (2018). More than 180 publications were reviewed, to provide a comprehensive, up-to-date literature review and to furtherly facilitate research and applications in the domain area of BIM for transport infrastructure. Moreover, one of the main scopes of this paper consists in discovering more efficient and cost-effective techniques for managing the construction and maintenance the transportation infrastructure for both academia and industry stakeholders. The main results of the research have shown that the use of BIM for transport infrastructure has been increasing, but have also revealed a major need for a standard neutral exchange format and scheme to promote interoperability. Furthermore, the authors suggested the continuing collaboration between academia and industry to mitigate most challenges and to realize the full potential of BIM for transport infrastructure. As an instance, the authors have stated that using BIM for the assessment of environmental impacts of infrastructure development is an important area that has received only few attention. The paper by Costin et al. (2018) represents one of the largest, actual and complete work for the evaluation of the state of the art for the application of BIM approach to transport infrastructure.

Moreover, the literature review has stressed out that some progress has been made for the development of BIM application to the relationship with design, construction and management actions for transport infrastructures. This paper proposes a contribution for both the relationship between BIM and GIS and for the useful aspects related to a technical/environmental decision-making process.

From the environmental point of view, in the last 30 years, the regulations that influence the design of transport infrastructures have increased significantly according to several Directives such as 92/43/EEC (1992), 97/11/EC (1997), 2011/92/EU (2011) and 2014/40/EU (2014). It is well known as in the EU countries, the design process of infrastructures is subjected to the principles of Sustainable Development, as defined by numerous international agreements and environmental regulations such as Treaties of Maastricht (1993), Treaty of Amsterdam (1999) and Treaty of Lisbon (2009). Among the most important instrument to regulate the sustainable principle in design process is the Directive 2014/52/EU (2014) that defines the main aspect of Environmental Impact Assessment. This Directive, transposed by the Italian Legislative Decrees n°152/06 (MATTM, 2006) and n°104/2017 (D.Lgs, 2017), represents the regulatory act with which member states evaluate the environmental compatibility of a project and, therefore, its actual feasibility.

In the Legislative Decree n°152/06 it is well specified that the environmental assessment of plans, programs and projects aims to ensure the human activities to be compatible with the sustainable development of the area and, therefore, with the respect of the regenerative capacity of ecosystems and resources, the safeguarding of biodiversity and a fair distribution of the advantages associated with economic activity.

In order to assess the sustainability of design process of infrastructures, many tools and certification systems have been developed. As an example, the study from Muench et al. (2010) provides the readers with an instruction manual for measuring and managing sustainability on infrastructure projects as roads, highways, bridges and railways. The rating system is based on a set of indicators that evaluate the sustainability approach in the design process (e.g. reduction of construction waste, reuse of the existing pavement structure, evaluation and improvement of roadway safety, minimization of transportation impacts, etc.). Each indicator provides associated credits (with a range from 1 to 4) and the sum of all credits defines the Greenroads rating of the project. Another example of these certifications is the ISI Envision Rating System discussed by McWhirter and Shealy (2017). The general methodology is quite similar to Greenroads: there is a checklist of 60 criteria to introduce sustainability principles and should be used both in a self-assessment (during the design process) and as final audit to give the final rating to the project. Also, the Italian government, in transposition of the various European regulations and international agreements, has begun to implement criteria for analyzing sustainability in projects, with specific reference to green procurement. With the Law 221/2015 (MATTM, 2016) the "Minimum Environmental Criteria" have been defined and their application, by all the contracting stations in public works, has been made mandatory by the Legislative Decree 50/2016 (MIT, 2016). These criteria concern all environmental issues in relation to public services or works. In order to investigate this topic, it is possible to analyze the criteria defined for "Assignment of planning services and works for the new construction, renovation and maintenance of public buildings". Among the environmental criteria, mandatory for the design of the buildings, it is possible to highlight the "prevention of soil sealing". This criterion specifies how, in construction of new buildings, there must be:

- a permeable territorial surface not less than 60% of the project surface (e.g. green surfaces, paving with open meshes or grid elements, etc);
- an area to be allocated to green areas equal to at least 40% of the non-built project area and 30% of the total area of the lot.

By analyzing this example and the new sustainability methodology developed in the last years, it is emphasized the importance to use tools that can analyze the territorial-environmental and design-related aspects in a complementary way. This can be reached by a GIS-BIM integrated approach.

3. Methodology

The methodology consists in evaluating the potentials of the systems, providing an integrated solution to allow the implementation of the environmental criteria by means of GIS applications, also respecting the approach suggested by Italian BIM application rules and standards UNI 11337 (2017). In particular, the part 4 of the Technical Standard UNI 11337-4 (2017) called "*Evolution and development of information within models, documents and objects*" focuses on the definition of the level of information detail, intended as the classification of the information contents of an asset, generated through the information process of construction, which allows for the measuring of the information model, of the graphic parametric model and the documental relational model. It describes a classification system based on the Level of Detail (LOD) of the information content of the model.

Moreover, the methodology considers the environmental standards to comply in the design process of an transport infrastructure, as described before. Finally, as shown in Fig. 1 below, the methodology is aimed to link all the cited aspects in an integrated model with the possibility of being applied to all the types of transport infrastructures. In the specific case, to test the feasibility and effectiveness of the process, an application is proposed on a case study represented by an airport infrastructure.

4. Case study

The choice of developing the methodology on an airport infrastructure comes from the high complexity that typically characterizes this system. The airport is constituted of several parts such as terminal, flight infrastructures, service facilities, accessibility infrastructures and technological buildings; each of them has different technical and functional features, thus involving a plurality of technicians and datasets involved during both the design process and whole life-cycle. Even the usage of the stand-alone BIM methodology might greatly simplify the management of the complexity of the system, as it allows to merge in a single model all the features of the infrastructure, so reducing possible mistakes and conflicts occurring during the design phase and, hence, saving a significant amount of resources. The authors propose to make a step further by integrating the BIM methodology with GIS. Indeed, such an approach would allow to leverage in a synergic way both the characteristics of the BIM model and those of a GIS environment, to exploit this union as a support for the decision-making and design process.

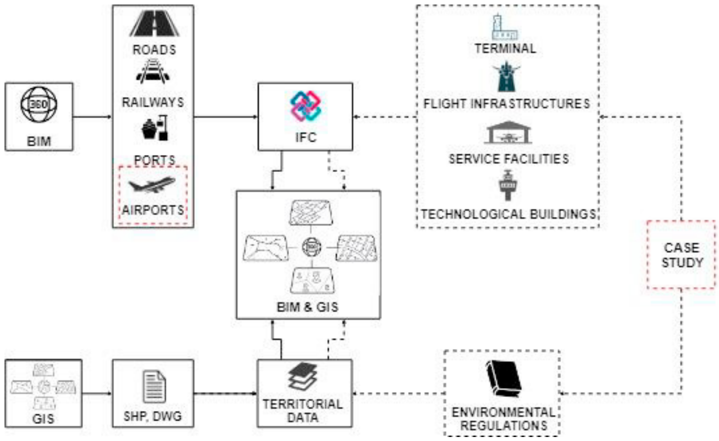


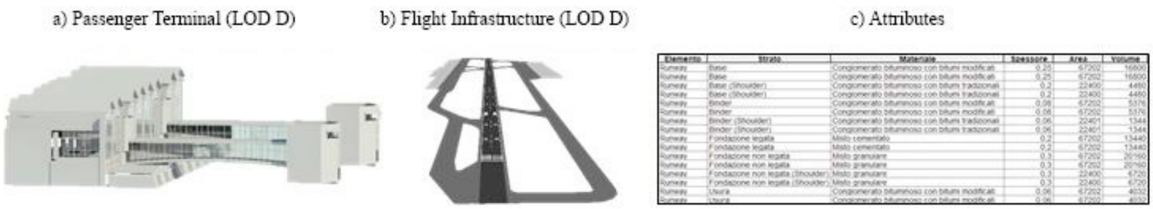
Fig. 1. Methodology and case study flowchart.

More in detail, to introduce the design process of an airport infrastructure, and thus evaluate the best alternatives, the authors suggest to run simultaneously the activities related to design with those related to the environmental impact assessment. In this way, it is possible to remove, prevent or reduce environmental impacts, therefore avoiding and minimizing the planning of mitigation and compensation measures. Regarding the practical aspect of the case study, the process shown in Fig. 1 is established. The process starts with the development of the information model of elements within a generic aerodrome's boundary using BIM oriented software such as Revit ® (2019) and Civil3D ® (2019).

It is important to note that the information model, according to Italian standard UNI 11337-1 (2017), encompasses graphical, documentary and multimedia contents. Specifically, for the considered works it has been realised a technical model with a different LOD for each component of the system. More in detail, the models implemented are: Passenger Terminal with LOD D, Flight infrastructure with LOD D, Service facilities with LOD B, Adjacent buildings with LOD B. Each model is accompanied by data and information needed to perform successive analysis and is summarised and provided by an output file named Industry Foundation Classes (IFC), an international open file, that allows exchanging and sharing activities among software applications used in the process.

As widely known, the airport infrastructure produces several impacts that require to develop an accurate environmental analysis to prevent it. For this reason, GIS technology can be useful; indeed, GIS joins database features that allow to memorize data and to get graphs, with those of a map that provides spatial data and geographic representations.

While the technical design model is developed, an environmental model is produced, where the spatial data needed for the environmental impact assessment have been collected. It has been useful to exploit inputs from various sources for the definition of the environmental model. Currently, Italy is trying to increase the use of open data; in particular Public Administrations are making data available to be easily consulted and processed in order to realise territorial maps and improve statistical analysis. Thanks to data in regional databases, it has been possible to get files, mostly in Shapefile format (SHP), together with the characterization of the site where the building is located. The shapefile is an essential format in the BIM-GIS integration, as it is the most used format for data exchange in GIS and it can be displayed in many modeling software.



Elemento	Strato	Materiale	Spessore	Area	Volume
Runway	Base	Conglomerato bituminoso con bitumi modificati	0.25	67202	16800
Runway	Base	Conglomerato bituminoso con bitumi modificati	0.25	67202	16800
Runway	Base (Shoulder)	Conglomerato bituminoso con bitumi tradizionali	0.2	22400	4480
Runway	Base (Shoulder)	Conglomerato bituminoso con bitumi tradizionali	0.2	22400	4480
Runway	Binder	Conglomerato bituminoso con bitumi modificati	0.08	67202	5376
Runway	Binder	Conglomerato bituminoso con bitumi modificati	0.08	67202	5376
Runway	Binder (Shoulder)	Conglomerato bituminoso con bitumi tradizionali	0.06	22401	1344
Runway	Binder (Shoulder)	Conglomerato bituminoso con bitumi tradizionali	0.06	22401	1344
Runway	Fondazione legata	Misto cementato	0.2	67202	13440
Runway	Fondazione legata	Misto cementato	0.2	67202	13440
Runway	Fondazione non legata	Misto granulare	0.3	67202	20160
Runway	Fondazione non legata	Misto granulare	0.3	67202	20160
Runway	Fondazione non legata (Shoulder)	Misto granulare	0.3	22400	6720
Runway	Fondazione non legata (Shoulder)	Misto granulare	0.3	22400	6720
Runway	Usura	Conglomerato bituminoso con bitumi modificati	0.06	67202	4032
Runway	Usura	Conglomerato bituminoso con bitumi modificati	0.06	67202	4032

Fig. 2. Example of different LOD application for Passenger Terminal (a), Flight Infrastructure (b), Attributes (c).

More in detail, in the definition of the relationship building-environment it has been useful to gather information about geology, hydrography, risk maps, land use and coverage, resident population and other aspects.

Regarding the airport infrastructure it has been necessary to produce SHP files to perform specific analysis, such as the evaluation of noise pollution caused by the airport or analysis concerning the computation of areas.

The connection between informative models and the GIS is ensured through the spatial relation guaranteed by the position and depending on the shared reference system. The most used reference systems in Italy are Roma40 Gauss-Boaga and ED50 UTM systems. For the analysed scenario it has been adopted the Roma40 Gauss-Boaga system, that is based on datum Roma1940 referred to the Hayford (1924) international ellipsoid oriented to Monte Mario. All the IFC and the SHP files use this reference system and all the objects are then localized in the correct position, to allow an effective integration. Once the IFC of the several parts are done and the SHP files of the spatial data are drawn up, in analogy with the above, it is possible to make the BIM models interact with the GIS data. Actually, there are many software GIS differenced by their functional features. The choice of software to use is influenced by a large number of variables, therefore, the objective to be achieved and data format available to perform the analysis must be considered. Each software has its peculiarity; some software are specialised in the data raster management, others enabling to work with three-dimensional geometries. According to the overall objective of this paper, it has been chosen to develop the study using the ArcGIS® (2019) platform, that offers tools enabling to import IFC format, thereby facilitating the integration of BIM and GIS. As shown in Fig. 3, BIM-GIS integration supports the choices in the design phase or whenever an airport expansion plan is envisaged and allows easier monitoring of the airport complex during its operational phase.

To understand the advantages offered by the interaction of these two systems, a series of analysis conducted and still improving and developing, are described hereafter. Having regard to the decree of 11 October 2017, as detailed in previous chapters, the authors used the model to performs a quick analysis of the permeable surfaces, surfaces covered with buildings and surfaces designated as public green areas. In this way it is possible to verify compliance with the limits imposed by the mentioned decree through visual and numerical feedback.

Further analysis and applications of the model are aimed at verifying the acoustic compatibility of the airport. An integrated IFC model file, containing the buildings potentially exposed to the effects of noise and suitable properties such as the intended use of the building and the resident population, allows a quick identification of the buildings classified as sensitive receptors. Moreover, it is possible to calculate indicators that relate the main variables, including the area of the noise contour and population resident within or close to the individual areas of the acoustic footprint. By examining the results of this analysis, it is possible to evaluate the effects of the acoustic impact related, to a new runways configuration. It is also possible to match this new configuration, implemented in the IFC model file - which involves an increase in aeronautical traffic issue to a corresponding noise curve configuration and consequently define the measures to be implemented.

Especially during the construction phase, other relevant aspect is related to the network analysis own of GIS. Thanks to the model it is realistically possible to visualize the territorial context in which the airport is located and therefore optimize the routes of the construction-site vehicles, main responsible for the impacts on air quality.

The case study allows to experiment the BIM-GIS integration and to demonstrate the versatility of the model created. The analysis and applications presented, are a few of the many that can be implemented using functions already integrated in the GIS platform or using scripts specifically written to perform more complex ones.

5. Conclusions and future developments

Transport infrastructures play a fundamental role in the growth and development of countries, but at the same time, if not effectively constructed and managed, they can constitute the weak link in the system. Given the complexity and the many factors involved in works of this type, it is necessary to implement strategies that can simplify the process that goes from planning to infrastructure maintenance. A novel BIM approach provides a complete and integrated view of the system and allows to store a considerable amount of data, especially useful for the operation phase. At the same time, GIS allows to analyse the geographic entities both from a graphical and symbolic point of view and for the information content. The advantages of the methodological process described in this paper can be highlighted both for the design phases and for the maintenance phases.

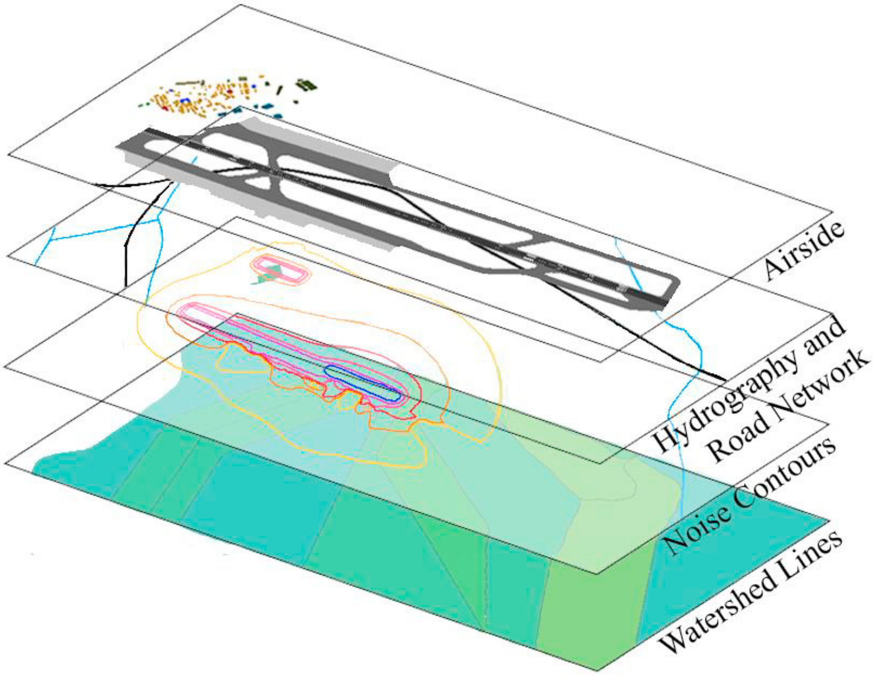


Fig. 3. Model integrated by BIM and GIS features.

In the first case, the integration of the design data (BIM) with the environmental data (GIS), allows realising a tool able to integrate the "environmental analysis" already in the design phase, increasing the effectiveness and efficiency of the design process. As an example, the case study of a new airport gate and taxiway. BIM data allow to know the soil volume of "cut" and "fill" that the project requires. Through the overlap of this design element, with the layer of environmental characterization of the soil quality, already in the design phase, it will be possible to evaluate the portion of land that can be reused as a "by-product", thus limiting the consumption of raw materials and maximizing the material balance, following the principles of "sustainable design". In the second case, the integration of maintenance data, included in the BIM, with environmental data, allows having a "priority of intervention" in maintenance program. This approach differs from the traditional ones because it allows to analyse the maintenance process not only in a technical point of view, but in a more complex "sustainable approach".

Moreover, in this case it is possible to make a practical example in order to better clarify the concept. Take as a case study the assessment of the maintenance status of the water collection channels from the surface of taxiways, gates and runways. In the BIM environment, many information about the maintenance status (i.e. cracking, breaking, etc.) can be collected. By the overlay of these information (i.e. from which untreated runoff water can infiltrate) with the environmental layer relative to the permeability and to the sensitivity of the groundwater, a priority scale of maintenance can be defined. This approach can optimize the maintenance investment, anticipating maintenance to those elements that show structural and environmental criticalities simultaneously. Future developments of this approach involve the automation of the methodological approach proposed. This facet will allow the designer to have an effective guide towards a sustainable design approach. To ensure the efficiency of transport infrastructures over time, the next step is to develop processes and applications able to automate aspects related to the operation of infrastructures. Finally, using these methodologies right from the planning phase of the work and continuing to integrate the models through the subsequent phases of design, construction, management and maintenance, it is possible to simplify the complexity of the transport infrastructure project. However, it is possible and should tend to use these methodologies also on the existing infrastructural heritage, implementing the process with additional tools for surveying and modeling, useful for faithfully reproducing the built infrastructures.

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