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BIM FOR RAILWAY INFRASTRUCTURE: THE CASE STUDY OF THE OGLIASTRO–SAPRI HIGH-SPEED RAIL

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Abstract. The Infrastructure-BIM is constantly growing in all the main European countries. The focus of this research is the digital twin creation of the Ogliastro-Sapri High-Speed rail in Italy. The entire project was carried out using Bentley Systems® BIM-based tools such as OpenRail Concept Station and OpenRail Designer. The advantages and limitations of the methodology applied to a real railway project are highlighted. As the main result, a specific interoperable asset manager is proposed for maintenance purposes.

Keywords: design standards, I-BIM, maintenance, railway, railway asset management system.

JEL Classification: O2 Development Planning and Policy.

Introduction

Building Information Modelling (BIM) is a methodological approach for managing information related to an engineering project for each phase of its entire operational life (Bormann et al., 2018).

BIM history starts in the '70s with the works of Charles Eastman (Eastman et al., 1974), even though the term Building Information Modeling was used for the first time in 1992 by the researchers van Nederveen and Tolman (1992).

BIM was first introduced for vertical building projects. Thus, BIM for the so-called linear or horizontal infrastructures came in a second moment, providing the main tool for innovation in the civil infrastructure industry, whereby the construction and academia-industry are currently putting great effort into infrastructure BIM study and implementation (Md Zaid et al., 2021).

In the wake of this, the present research work aims to explore the potential of Infrastructure-BIM (I-BIM) in more detail, by developing the railway model of an Italian case study and implementing a monitoring system with an international scope. For this reason, an overview of the European, Italian and Irish regulatory status will be briefly outlined.

1. State of the art

Incorporated into the legislative system by more and more nations and supranational structures (Charef et al., 2019), BIM opens up a multitude of possibilities and applications to different sectors, reducing errors, highlighting problems, involving all actors and professionals, thus improving the process as a whole (Azhar et al., 2015). With regard to horizontal civil infrastructures, and in particular railways, the research world is committed to finding workflows that are a synthesis of needs and purposes that complete an overall picture of all phases of the asset's life (Costin et al., 2018). There are an increasing number of examples of BIM applications to railways (Matejov & Šestáková, 2021), for the three-dimensional parametric design of the typological section (Biancardo et al., 2021a), for the digitization of existing tracks (Biancardo et al., 2021b), or of specific works of art (Abbondati et al., 2020), also in relation to other transport infrastructures (Pasetto et al., 2020). Interest in railway BIM is growing due to proven benefits from its implementation (Shin et al. 2018), and in relation to the need for railway network expansion (Bensalah et a 2019; Lu et al., 2019), or reconstruction (Alnoor, 2021), or modernization (Neves et al., 2019). In addition to design, railway BIM is also effectively applied for the management phase,

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for both urban and suburban infrastructure (Xu et al., 2020). In addition, BIM constitutes a useful platform for monitoring compliance with regulatory constraints, before and after project realization (Häußler et al., 2021), as well as for predicting the occurrence of conflicts and technical problems, thanks also to the combination with state-of-the-art technologies related to Artificial Intelligence (Sresakoolchai & Kaewunruen, 2022).

Railway infrastructure must meet safety requirements concerning its construction and operation. Railway traffic loads the rails with strong vibrations that on the long term cause some defects that can be dangerous for safety. Thereby, correct maintenance planning is fundamental. Railway infrastructure maintenance consumes very large budgets, being a complex task to undertake with numerous challenges. In particular, the coordination with trains traffic operation is of crucial importance.

Lidén (2015) gave a comprehensive overview of the railway infrastructure maintenance field, the planning problems it contains and the research that has been conducted so far. Track geometry monitoring is one of the most important activities in maintaining the steady technical conditions of rail infrastructure (Skrickij et al., 2021). The Standard UNE EN 13848–1:2020 (European Standard, 2020) defines the method of measurement for railway tracks using track recording vehicle (TRV) in Europe. The standard also defines the approach for evaluating track condition by means of various safety-related limits associated with each of the parameters measured so that maintenance interventions can be planned. For this purpose, track inspection vehicles or TRV are used to measure several track diagnostic parameters (Shah et al., 2021). An example of best practice is what reported by Hebib-Albinovic and Albinovic (2018), on the use of an "FMK-004" TRV for the railway monitoring in the Federation of Bosnia and Herzegovina, and the comparison with an "FMK-007" TRV, that works on the principle of non-contact measurement.

The case study presented in this paper is about the creation of the digital model of the high-speed railway line Ogliastro–Sapri, two cities located in Southern Italy. The model was enriched with a dynamic asset management tool in which maintenance data acquired by means of a track geometry car was entered.

In this way, it is intended to further investigate the potential of BIM in the railway sector, the level of interoperability achieved by some of the main and most widely used BIM-based software, and to carry out a comparison of international standards and best practices.

2. BIM regulation overview for Italy and Ireland

In Italy, the latest provision allowing engineers and designers to use BIM in their project is the Simplifications Decree, 2021, that provides for the contracting authorities the possibility of awarding a reward score for use in the design phase of specific electronic tools such as modelling tools for construction and infrastructure (Presidente della Repubblica, 2021).

Looking at the Irish standards, there is no defined reference legislation on BIM.

McAuley et al. (2018) realized a study in which was highlighted that Ireland is mature for modelling processes, but the government had primarily chosen a passive approach with little or no assertive activities.

Sometimes it is done reference to the standards adopted in the BIM Protocol used in the United Kingdom. The BIM Protocol was first commissioned by the Construction Industry Council (CIC) in 2013 as part of its response to the UK Government BIM Strategy. The Protocol was drafted for use with all common construction contracts (i.e., contracts for design and construction in respect of an asset) and supports BIM working at Level 2.

Referring to the ISO 19650 standard, Italy, UK and Ireland work for the infrastructure sector with a maturity level 2 (International Organization for Standardization, 2018). This level promotes collaborative working by giving each of the stakeholders its own 3D CAD model.

3. Case study

The 2011 Italian railway state company (Italferr) feasibility study provides the upgrading of the Battipaglia–Reggio Calabria (Italy) route by creating a new pair of rails along the link Ogliastro–Sapri (Italy) with the aim to reduce the journey time.

There are three design solutions identified for the connection between Ogliastro and Sapri, named as "Solution A", "Solution B", and "Solution C". Each of the three alternative solutions presents in the last stretch of about 10 km two possible hypotheses of entry to Sapri, called "Sapri variant" and "Villammare variant". In this case study the "Villammare variant", being 9 km long, starting from North-West of Ispani and then grafting on the historical line, was analyzed.

The digital reproduction of the case study was carried out in seven phases: a) creating digital terrain model; b) creating horizontal and vertical alignment; c) creating templates; d) modelling the 3D corridor; e) adding rails and sleepers; f) implementing the features; g) building the asset management system; h) exporting in Industry Foundation Classes (IFC) format.

3.1. Digital Terrain Model

To obtain the railway I- BIM model the first step was creating the Digital Terrain Model (DTM) using the software OpenRail ConceptStation, embedded within the BIM software suite by Bentley. The DTM obtained was manipulated in order to have a "3D seed" lighter and easier to manage. It was very helpful to cut the extreme part of the area which appeared to be non-compliant with the actual geometry of the terrain.

A seed file is an empty pre-set file in which there are proper settings to define the appropriate size, units and origin to guide designers in their work.

3.2. Horizontal-vertical alignment

In this phase, the horizontal alignment and vertical profile of the line were modeled and then it was possible to obtain the parametric 3D model of the infrastructure.

In this phase of the modeling, it was possible to compare the horizontal-vertical elements standards adopted in Italy and in Ireland. As it is showed in Table 1, for the horizontal alignment the values of the transition curves and the circular curves are very similar. The main difference is found in the definition of the single element's length: both the standards prescribe different values in relation to the speed. Choosing the same speed, the Italian standards proposes smaller length values (Agostinacchio et al., 2010; National Transport Authority, 2018).

Table 1. Horizontal alignment standards

ITALY		
Speed [km/h]	Length Range [m]	
$V \leq 200$	$\frac{V_{max}}{5}$	$\frac{V_{max}}{3}$
$200 < V \leq 300$	$\frac{V_{max}}{2.5}$	$\frac{V_{max}}{1.5}$
Circular Curves	Radius > 275 m (for new lines)	
Transitions	Clothoid and Cubic Parabola	
IRELAND		
Speed [km/h]	Length minimum value [m]	
75	41.667	
100	55.556	
120	66.667	
The absolute minimum element length is 30 m, regardless of speed value		
Circular Curves		
Radius > 200 m (for new lines)		
Transitions		
Clothoid and Cubic Parabola		

As the elevation profile, it seems that the Italian standard prescribes that the gradings and the elevation curves are related to the speed chosen for the track, in contrast to the requirements of Irish legislation in which the parameters are linked to the slope to be assigned to the track (Table 2).

3.3. Creating templates

The "Villammare variant" is 9.070 km long and it is made by a first section of tunnel 8.402 km long, followed by a bridge for 544 m, and then it ends with 100 m trench.

Table 2. Vertical alignment standards

ITALY		
Minimum Vertical Gradings Length [m]	$L = V / 1.80$	
Vertical Curves Radius [m]		
$R_v = \frac{V_{max}^2}{12.96 \cdot a_v} \geq (R_v)\lim$		
Speed [km/h]	$(R_V)\lim$ ranges [m]	
$V \leq 200$	$0.250\ V_{max}^2$	$0.350\ V_{max}^2$
$200 < V \leq 300$	$0.175\ V_{max}^2$	$0.350\ V_{max}^2$
IRELAND		
Minimum Vertical Gradings Length [m]	$L = 15$ m	
Vertical Curves		
Acceleration Rate	Radius [Km]	
Desirable – 0.01g	$R = V^2 / 1271$	
Acceptable – 0.02g	$R = V^2 / 2543$	
Limiting – 0.03g	$R = V^2 / 3814$	

For the definition of the type sections the specific geometries were reproduced with reference to Italian previous case studies. The tunnel template was developed using the standards of the Italian double track Ronchi – Trieste, while the bridge and the embankment respect the current Italian standards of design of civil works (Italferr, 2010).

Fulcrum of the OpenRail Designer template are the points that are colored differently based on the constrains, in relation to the way they are bound to the other points to obtain a single coordinated geometry. The color range goes from red, meaning point heavily constrained to green point without any constraint.

The case study is a double track railway, so in OpenRail Designer it was required to define only one of the two axes as the main one for all types of section to relate all the other points.

3.4. Rails and sleepers

To obtain a double track railway model rails specific sleepers were added.

In Italy the Unit Identification Code UIC 60 rail is used. It is a robust rail that is excellent for supporting track speeds up to 300 km/h. The UIC 54 rail, on the other hand, is lighter and smaller to meet the low speeds required for interconnections between Irish cities. For the sleepers too is proposed a technological comparison, as it is shown in the table the dimensions are very similar, but the substantial difference is the gauge. The Irish

Table 3. Rail and sleeper type

Rail type	Weight [kg/m]	H [mm]	Area [mm^2]	Sleeper type	Speed [km/h]	Weight [kg]	Length [mm]	Width [mm]	Gauge [mm]
UIC 60	60.21	172	7686	RFI -240	300	315	2400	300	1435
UIC 54	54.77	159	6977	TIR6	160	307	2600	289	1602

sleeper TIR6 is created to meet a gauge of 1602 mm, a size rare in the world, instead of the Italian standards, which prescribes a gauge of 1435 mm in accordance with other European railways lines (Table 3).

3.5. Features implementation

One of the cornerstones of BIM is the parametric solid modelling and its information content. For example, the features, geometric and semantics, allow the inclusion of material specifications in the model. In this way it is possible to achieve a smart model. The material "limestone" was used for the stones composing the ballast, being a very common type in the Irish ballast.

The parametric solid modelling allows, therefore, a fast and dynamic management, allowing team members to collaborate on a single model.

3.6. Asset management system

The asset management comprises all systems, methods, procedures, and tools to optimize costs, performance and risks for the complete rail infrastructure life cycle. The aim is to realize the best "value for money". These optimizations shall address all infrastructure activities (building, maintenance and renewal, including machines and materials) over the whole life cycle as well as the consequences of these activities for the government as owner and for the train operators and passengers as users.

In the wake of this, BIM seventh dimension (i.e., maintenance) plays a key role; as an example, in this case study two main railway defects have been considered: "Gauge" and "Top". The Gauge is the distance between two running rails, while the Top is the longitudinal level of the rail measured from the rolling surface.

Maintenance of track gauge guidelines (Civil Engineering Conference, 2001) explains that correct gauge is important for three reasons: (a) tight or wide gauge will adversely affect the ride of trains. On occasions tight gauge has been known to cause severe hunting resulting in emergency stops. Variations in gauge also trigger rough riding conditions especially in switches and crossings (S&C). Consequently, the service to rail customers is affected with discomfort and delays; (b) correct track gauge extends the life of track components and train wheelsets. This is because the forces involved are minimized; (c) gauge defects are the most common cause of derailments.

While in Italy the gauge size is 1435 mm, in Ireland is 1602 mm.

The track longitudinal level measures the deviation in the vertical direction of the running surface on rails from the smoothed vertical position, which indicates the vertical smoothness of a track (Wang et al., 2021).

Based on different thresholds it is possible to organize a maintenance campaign, possibly involving the scheduling of maintenance operations in the months following to the immediate closure of the line or the imposition of temporary speed limits.

OpenRail Designer allows to implement the results of the systematic monitoring of rail defects.

In this case study the tool "Item Type" was used to implement the seventh dimension in the model, thus creating a dynamic portal where to enter data for every defect, as the date, the subdivision, the value of the defect and the threshold of alarm (Figure 1).

The mostly adopted surveying modality in Ireland is based on Tracking Recording Vehicle (TRV). The vehicle is equipped with cameras, video equipment, computers and software capable of instantly processing the results detected during tracking.

3.7. Exporting in Industry Foundation Classes (IFC) format

Once the modelling and asset management phase was completed, the file was exported to Industry Foundation

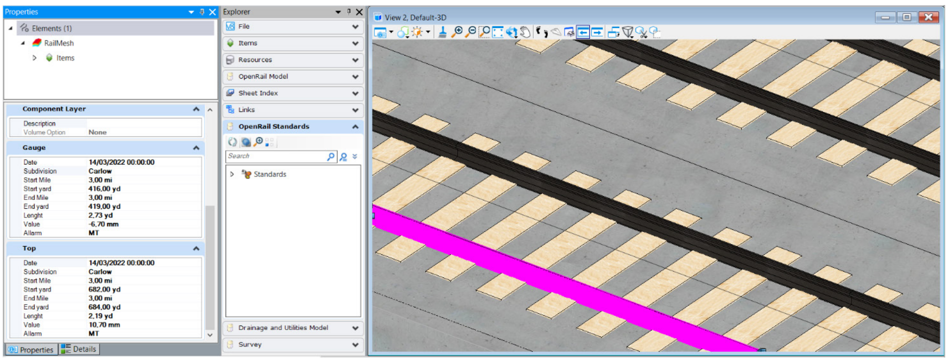

Figure 1. Railway set management system

Classes (IFC) format, to investigate the interoperability between the software of different software houses.

The first step was to import the IFC file obtained by Open Rail Designer into BIMvision. BIMvision is a free software that allows users to open and view virtual models exported to IFC from the most popular CAD (Computer-Aided Design) systems.

Figure 2 shows the successful import result: BIMvision not only shows all the geometrical characteristics assigned to the layout, but also the asset manager tool created with the data related to the detected defects.

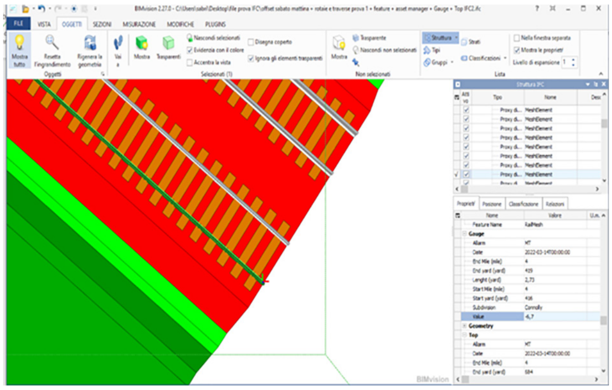

Figure 2. BIMision import

This result is extremely important: OpenRail Designer allows engineers to process and manage open files so this is the beginning of managing a file .dgn with software developed by other software house.

Conclusions

In conclusion, the I-BIM methodology-based software used allows for the modelling of a railway system in an efficient way, giving the possibility to implementing the railway asset management within the digital model.

There has been a sharp improvement over the years to allow users to a complete and easy use; in this perspective a single software is sufficient to implement data from different areas of engineering.

The comparison between Italy and Ireland regulations on BIM faces that Ireland needs an update of the existing legislation to embrace those specific new electronic tools.

At the very end this case study shows how I-BIM can be leveraged as a decision support tool for maintenance and renewals budgets and in the life-cycle management of assets.

In the future it is necessary to improve the interoperability, contributing and expanding buildingSMART work, as a global organization that leads the digital transformation of the construction industry. The association and all the technicians are contributing to the creation of open and international standards for facilities and infrastructures.

Author contributions

Salvatore Antonio Biancardo: Conceptualization, Methodology, Validation, Writing – Review & Editing, Supervision Sabrina Palazzo: Software, Visualization, Writing – Original Draft Mattia Intignano: Formal analysis, Writing – Review & Editing Gianluca Dell'Acqua: Data curation, Supervision.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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