IFCALIGNMENT FOR RASTER-TO-VECTOR GIS RAILWAY CENTRELINE: A CASE STUDY IN THE SOUTH OF ITALY

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ABSTRACT:

Built environment Asset Management (AM) is evolving and renewing itself through the development of new technologies. Building Information Modelling (BIM) is the main methodology for the digitisation process of existing data and information. Although BIM was originally intended for buildings, in the last few years Infrastructure Building Information Modelling (I-BIM) and Civil Information Modelling (CIM) are emerging to manage civil infrastructure. The interaction of infrastructure with the surrounding environment is a fundamental aspect and it requires data-sharing between different sources and systems. Geographic Information Systems (GIS) is used to store and elaborate Earth's surface information, and it is, therefore, necessary to achieve a complete BIM/GIS interoperability. This paper aims to test the popular BIM open-standard Industry Foundation Classes (IFC) capabilities and potentialities in storing GIS data. A case study of a disused railway in the south of Italy was used to test the methodology presented: rail-centreline (alignment) extraction from GIS raster data, and a conversion of the alignment to an *IFCAlignment* element. The possibility to export a rail alignment in IFC was confirmed.

1. INTRODUCTION

New technologies and digitisation processes are changing the built environment Asset Management (AM). In the Architecture, Engineering, Construction and Owner Operators (AECOO) industry, Building Information Modelling (BIM) is the main methodology for the digital conversion of existing documents and data. Even though the term BIM, coined in 1970 by Professor Charles M. Eastman (Sacks et al., 2018), originally just indicated a general digital model of a building construction, now its usage is ever-expanding. The expansion concerns both model uses and objects: the digital model is built to follow the entire lifecycle of a project, from design and construction to operation and management. This is not only about buildings but encompasses all forms of the built environment (buildings and civil infrastructures). Abbreviations I-BIM (Infrastructure Building Information Modelling) and CIM (Civil Information Modelling) are referred to BIM at the infrastructure scale, considering: transportation infrastructure, energy infrastructure, utility infrastructure, recreational facility infrastructure, and water management infrastructure (Cheng et al., 2016). The main difference between a building (vertical) model and an infrastructure (horizontal) model is the extension. A road or a railway often extends for several kilometres, and it can present lots of interferences with other elements of the surrounding environment (Vignali et al., 2021). Therefore, a fundamental part of a digital infrastructure model is the interaction with the geographic context that can be handled using GIS (Geographic Information Systems) techniques.
A comprehensive database composed of parametric objects from BIM and geographic information from GIS requires a strong focus on interoperability issues. Due to their different nature and modelling approaches, in terms of semantics, geometry and level of detail, the integration is a complex task, and there is no optimal conversion between them. The information flow always involves different data formats, being Industry Foundation Classes (IFC) and City Geographic Markup Language (CityGML) the most relevant. IFC, a BIM open data standard, was developed by buildingSMART for data exchange (3D geometry), (buildingSMART, 2005). CityGML, an XML-based standard approved by Open Geospatial Consortium (OGC), is used for environmental information exchange (3D models of the city), see Zhu et al. (2018).
The principal BIM-GIS integration methods are (Song et al., 2017):

1. extract data from BIM to GIS;
2. integrate GIS data to BIM systems; and
3. integrating both BIM and GIS data on a third-party platform.

From the infrastructure AM point-of-view, the capacity of BIM and GIS for the management, analysis, and visualisation of data may provide more insights for increasing the value of assets, detecting and reducing risks and optimising decision-making in assets management (Wang et al., 2019). The implementation of the BIM/GIS integrated approaches to address multidisciplinary problems in AM is gaining momentum and is particularly important for infrastructure (Garramone et al., 2020).
The main topic investigated in this research is how IFC could be used to store GIS data and information. The objective is to output an IFC file that represents the centreline of the rail (the alignment). The main contributions of this research are:

- rail alignment extraction from GIS raster data;
- a conversion of the alignment to an *IFCAlignment* element, the IFC entity used to store alignment information.

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The structure of this paper continues as follows: Section 2 shows the results of bibliometric analyses about the research topic, Section 3 briefly describes IFC capabilities, Section 4 presents the case study data, and Section 5 outlines conclusions and future developments.

2. BIBLIOMETRIC ANALYSIS

2.1 Methodology

A bibliometric analysis of the literature collected from Scopus database was carried out in order to understand trends and opportunities relating to the use of IFC in the infrastructure field. The research was conducted at the end of 2021. The keywords used to define the research boundaries are:

((‘IFC’ OR ‘Industry Foundation Class’) AND ‘Infrastructur*’)).*

Considering ‘article title’, ‘abstact’ and ‘keywords’, a set of 584 pieces of literature was obtained. Then, to remove references not connected to this study, the results have been filtered out:

- by *language*, considering only the references in English, that is the academic language. Subtotal: 566 results;
- by *source type*, considering only the journal articles to reduce the database's complexity. Subtotal: 288 results;
- by *year*, considering articles published from 1994 when the IFC initiative began. Subtotal: 285 results;
- by *subject area*, considering the articles related to the engineering field (excluding, e.g., medicine, genetics, etc.). Subtotal: 204 results.

2.2 Results

At the end of the filtering phase, the final set of articles was analysed using the R package Bibliometrix, (Aria and Cuccurullo, 2017), version 3.1, and VOSviewier software, version 1.6.18 (van Eck and Waltman, 2010), in order to visualise historical data trends and conceptual, intellectual and social structures. Looking at the annual scientific production, the interest in using IFC is increasing with an annual growth rate of 15.66% (see Figure 1).
The highest growth is registered in 2018, when 20 articles were published, with a peak of 41 articles in 2020. To better understand how the database is structured, a co-occurrence network analysis for author’s keywords was carried out (see Figure 2), considering a minimum number of occurrences of a keyword of 5. The map, made by vertices (the size is proportional to the item occurrence) and edges (the size is proportional to the items co-occurrence), is composed of four main clusters:

- the blue cluster, led by ‘bim’ and ‘ifc’, contains links to ‘gis’ and ‘citygml’, demonstrating that format and software integration is a central topic;
- the green cluster, again led by ‘bim’ and ‘ifc’, is more oriented toward the use of open standard formats for BIM;
- the red cluster, led by ‘industry foundation classes’, is similar to the previous one and it is BIM-oriented; and
- the orange cluster shows the centrality of ‘interoperability’, a key issue in this analysis.

To narrow down the sample of articles by only considering transportation infrastructure, the results were further filtered out through a set of sub-keywords: ‘bridge*’ (59 articles), ‘road*’ (62 articles), ‘rail*’ (27 articles) and ‘tunnel*’ (37 articles). The results are plotted in Figure 3. Venn diagram allows to identify if a link between sub-keywords exists and its strength. Considering that bridges and tunnels can be found in both ‘road*’ and ‘rail*’ classes, the diagram demonstrates that railway is the asset class less investigated (Costin et al., 2018). The references about railways were further analysed through an in-depth review of title and abstract, selecting only the documents with high research relevance. A total set of 9 articles was selected.

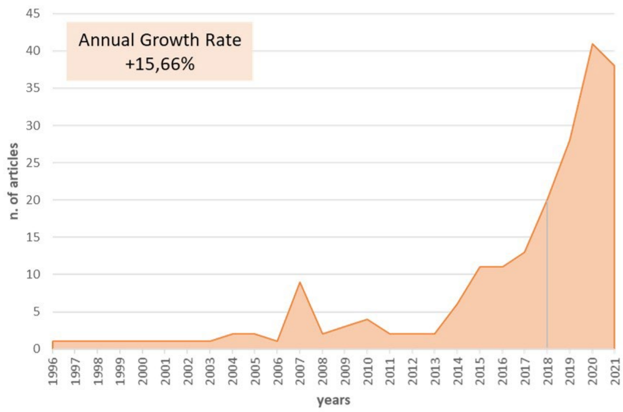

Figure 1. Annual Scientific Production (1996-2021).

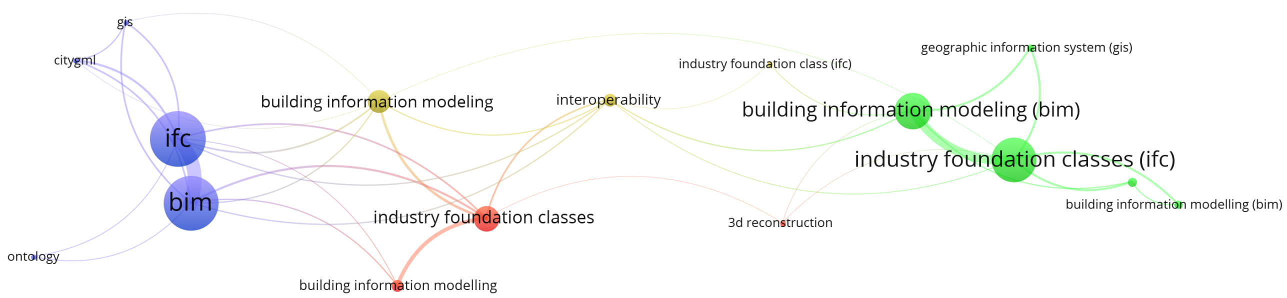

Figure 2. Author's keywords co-occurrence network (conceptual network): of the 612 keywords, 16 meet the threshold.

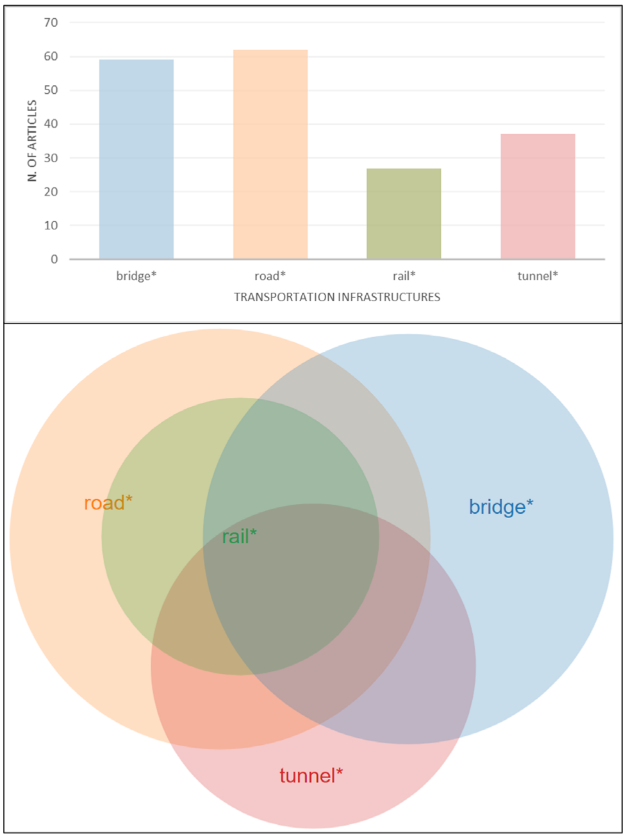

Figure 3. Number of articles considering the transportation infrastructure and Venn diagram (realised on meta-chart.com).

2.3 Discussion

The selected set of articles shows that the use of IFC for transportation infrastructure has been growing, although highways, roads and bridges are the asset classes more investigated. The use of new technologies for infrastructure design and management can improve the network performance while decreasing maintenance risks and costs (Costin et al., 2018). The design process of railway networks could start from survey data, in particular from point-cloud data, defining a methodology to automate railway masts detection from airborne LiDAR (Barazzetti et al., 2020) and then export in IFC format (Ariyachandra and Brilakis, 2020), as well as describing a Cloud-to-IFC workflow that extract rails from 3D point-cloud data and generates IFC files (Soilán et al., 2021). The 'reverse engineering' approach and international standards are also used to model a railway underpass in Slovenia (Abbondati et al., 2020), comparing different BIM-based tools to highlight pros and cons (Biancardo et al., 2021). *Deep learning* models (MVCNN and PointNet) are tested to classify infrastructure BIM elements in order to automate the prechecking of BIM-to-IFC mapping (Koo et al., 2021). IFC-based models are proposed to apply BIM to railway tracks and manage information based on 3D alignment (Kwon et al., 2020) and to address the problem of information isolation in metro protection (Zhou et al., 2018). Geographic capabilities and IFC schema are analysed in order to consider how scale distortion for large longitudinal construction projects is managed (Uggla and Horemuz, 2018). Two major issues were found by analysing the references:

1. Interoperability. Data conversion and lack of information decrease model reliability;
2. IFC improvement. IFC is deeply developed for vertical models (buildings), while infrastructures need a specific schema.

3. INDUSTRY FOUNDATION CLASSES (IFC)

Interoperability between various software and data formats is a key aspect considering the digitisation process of the built environment (Guillen et al., 2016). Different *data format* has been developed and tested for this purpose. A data format is a precise protocol of how the data is structured and organised, and the majority of them are:

- eXtensible Markup Language (XML), a markup language;
- EXPRESS language, based on standard information exchange (ISO, 2004). It is the formal language of Standard for the Exchange of Product model (STEP); and
- Construction Operations Building Information Exchange (COBie), that can be supported by an Excel spreadsheet (XLS).

IFC defines an EXPRESS based entity-relationship model composed of many hundred entities organised into an object-based inheritance hierarchy (ISO, 2018). IFC provides multiple data formats:

- IFC-SPS (ISO, 2016), a text format that uses the STEP physical file structure where each line consists of a single object record;
- IFC-XML (ISO, 2007), an XML format used to share information with other XML tools; and
- IFC-ZIP, a compressed format of the IFC-SPS or IFC-XML.

The IFC initiative began in 1994, then in 1996 IFC 1.0 was published. In about thirty years of ongoing development, in 2021 IFC 4.3 was released, and it is the latest version to date. Although originally aimed for vertical objects, a great effort has been made to include horizontal objects (transportation infrastructure) in the last years. To do this, buildingSMART has created different Rooms (IFC Bridge, IFC Road and IFC Rail) in order to implement IFC standards for infrastructure (buildingSMART, 2017a). IFC Rail project, which started in 2017, has been developing the IFC standard for rail. Phase 1, the definition of a candidate standard, ended in March 2020. In April 2020 started Phase 2, the implementation and validation of the candidate standard to turn it into the final standard.

3.1 *IFCAlignment*

One of the main critical elements in the infrastructure domain is the *alignment*, which represent the combination of the horizontal and vertical profile. *IFCAlignment* is the entity developed by buildingSMART to store alignment information and data according to the specifications of IFC 4.1 (Soilán et al., 2020). This is a new specification of the IFC schema (buildingSMART, 2017b), and there are not many references on the topic (Stepien et al., 2021).
A single IFCAlignment may have:

- a horizontal alignment in the x/y plane of the coordinate system;

- a vertical alignment that considers the z coordinate of a horizontal alignment; and
- a 3D alignment, the combination of a horizontal and vertical alignment.

4. CASE STUDY

In order to reach the proposed objectives, a railway case study is presented and analysed.

4.1 Case study data

The case study considers 'Potenza Inferiore Scalo' – 'Laurenzana' disused railway line in the Basilicata Region, south of Italy (see Figure 4). The line was created to connect Potenza, the capital city, with the surrounding area, but it was definitively closed after the Irpinia earthquake in 1980. A small part of the line has been converted into a cycleway, while most of it is abandoned (Ferrovie Abbandonate, 2007), to date. Table 1 describes the railway's main characteristics.

4.2 Objectives

This study aims to develop a digital database using the potentialities of new technologies to highlight the value of this path inside the territory.

Length	42.50 km
Opening date	1919-1931
Closing date	1969-1980
Last operator	Ferrovie Calabro-Lucane (FCL)
Electrification	No
Gauge	Narrow - 950 mm
Max slope	60‰

Table 1. Railway description.

The input data used to create the model are railway line (raster data) from National Geoportal (Geoportale Nazionale, 2009), administrative boundaries (shapefile data) from ISTAT (ISTAT, 2021) and digital terrain model (DTM, 5 meters resolution) from Basilicata Geoportal (RSDI Basilicata, 2016). The GIS software QGIS (QGIS Association, 2021), version 3.16, was used to visualise and analyse the data. Railway line raster data was imported into civil infrastructure software Autodesk Civil 3D® (Autodesk, 2021).
Two different types of elements compose the entire network (Scaioni, 2010): *linear* and *punctual*. A linear element is the part of the network between two stations/stops, that are the punctual elements (Papathanasiou et al., 2018).

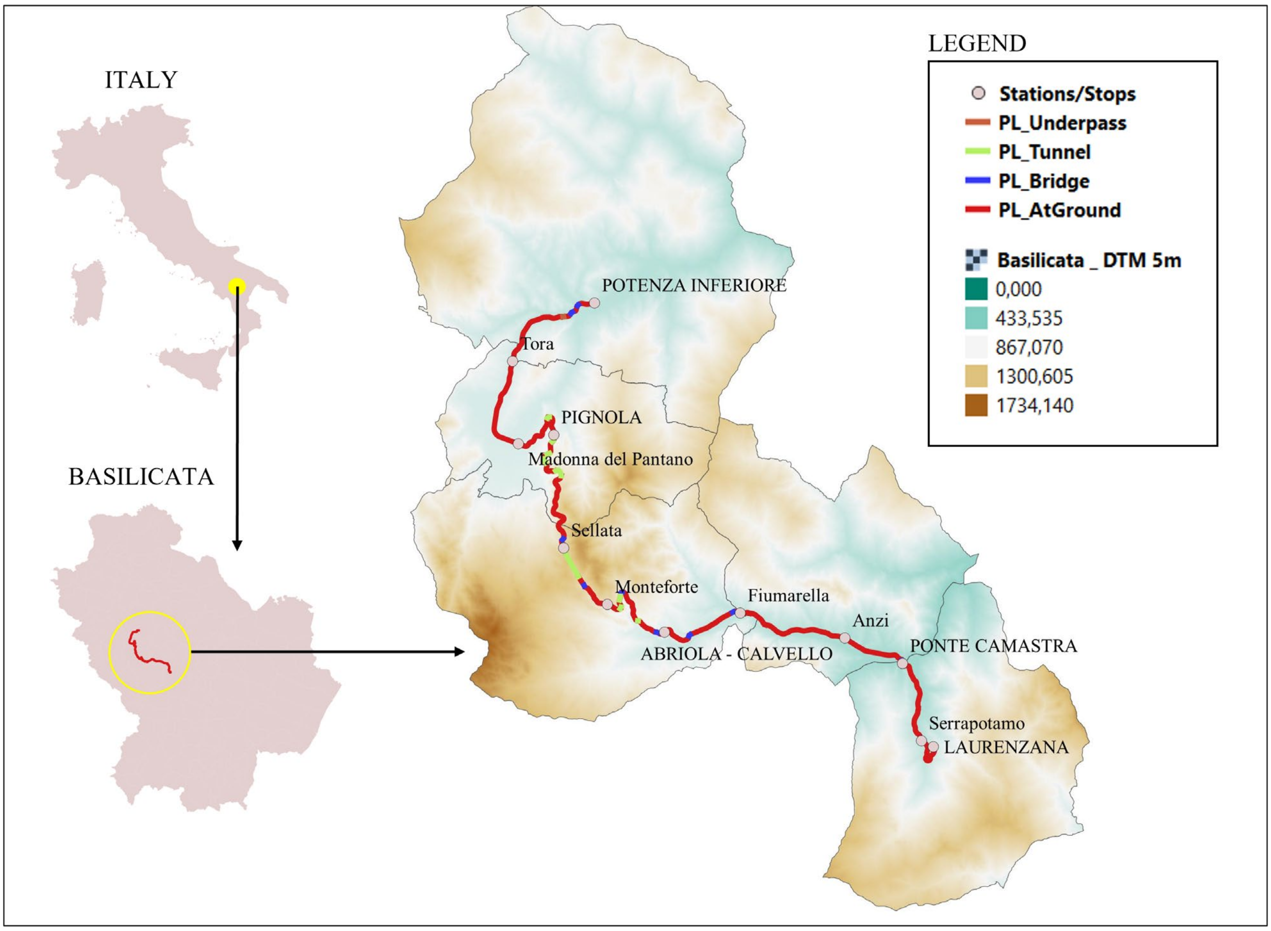

Figure 4. 'Potenza Inferiore Scalo' – 'Laurenzana' railway line. (Reference system: EPSG 32633 WGS 84 UTM 33N). Data sources: rail line from National Geoportal, administrative boundaries from ISTAT and DTM 5m from Basilicata Geoportal.

Linear elements can be further divided into *section* of homogeneous categories (tunnel, bridge and underpass), see European Parliament (2012). A 2D polyline (*x-y* plane) was drawn in order to create a vector element of the line. Four layers were defined to identify different rail locations: at ground level, tunnel, bridge/viaduct, and underpass. Table 2 synthesises railway elements divided by category. In order to add the *z* coordinates, the polyline was loaded into QGIS and saved as shapefile format.

	number	km	%
At ground		39.53	93.01
Tunnel	10	2.33	5.48
Bridge/Viaduct	10	0.61	1.44
Underpass	1	0.03	0.07
Station	5		
Stop	7		

Table 2. Railway elements (linear and punctual).

Then, the DTM was used as a reference to drape the vector on it. This process allows to set the *z* value of each point of the vector geometry to a value extracted from a raster layer. Stations and stops, dot elements, were placed using the three coordinates (*x, y, z*). Railway line, stations and stops, and terrain model were analysed in Civil 3D. Galleries, bridges and underpasses were checked to remove incorrect *z* values. Figure 5 shows '*Sellata*' gallery: the original line follows DTM elevation points, while the real gallery line is under the terrain. The line was modified considering the gallery's start and end point *z* values. Once all the elements were checked and, if necessary, modified, the alignment was created. Finally, the alignment was exported through *IFCAlignment* (IFC 4.1).

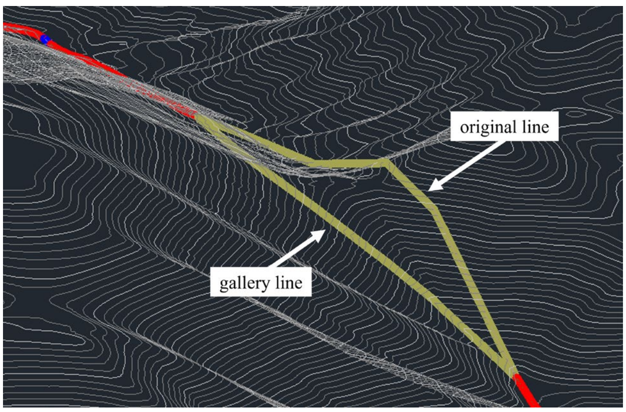

Figure 5. '*Sellata*' gallery (length: 1146 m; altitude: about 1120 m). The 'original line' follows DTM elevation, while 'gallery line' is the correct position.

Figure 6 shows the results: in this case, IFC exported separately vertical profile and horizontal profile, but information is stored in a single file.

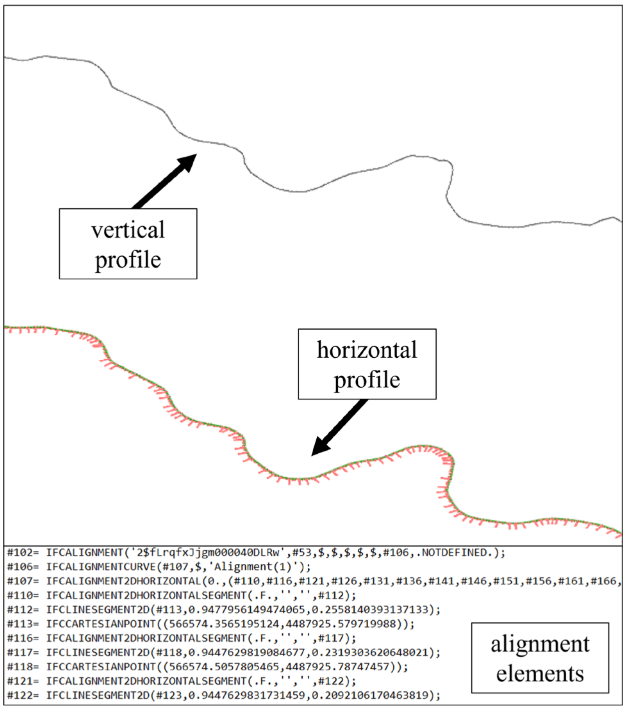

Figure 6. *IFCAlignment* (IFC 4.1) result: graphic visualisation (on the top), and textual visualisation (on the bottom).

5. CONCLUSIONS

The evolution of new technologies is enabling the digital transformation of the built environment. The digitisation of infrastructures requires both the civil infrastructure itself and the geographic context, a single database made by BIM parametric models and GIS information. Interoperability and open standards play a pivotal role in achieving this result.

This ongoing research wants to analyse the use of IFC for transportation infrastructure asset management, highlighting trends and opportunities. The bibliometric analysis shows that only 15% of technical papers dealing with IFC are about infrastructures, and out of those, just a small number concern railways. The analyses highlighted key issues related to data conversion and the need for IFC improvement in the infrastructure field.

In this paper, a methodology to convert GIS raster data into IFC was tested on a case study: a disused rail line in the south of Italy. Raster to vector transformation was the first step; then, the vertical profile was modified. In the end, the rail alignment was exported using *IFCAlignment* entity (IFC 4.1). Although information is stored in a single IFC file, horizontal and vertical profiles were separately exported.

The obtained IFC model is the first step for future developments following new IFC releases. Moreover, other properties will be added to the alignment, such as cadastral information and rail status, in order to enrich the IFC model.

Creating a digital database for disused railways can help decision-makers understand the value of these paths inside the territory and recover, retrain, and return them to the community.

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REFERENCES

Abbondati, F., Biancardo, S.A., Sicignano, G., Guerra De Oliveira, S., Tibaut, A., Dell'Acqua, G., 2020. Bim parametric modelling of a railway underpass. *Ing. Ferrov.* 75, 443–459.

Aria, M., Cuccurullo, C., 2017. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* 11, 959–975. https://doi.org/10.1016/J.JOI.2017.08.007

Ariyachandra, M.R.M.F., Brilakis, I., 2020. Detection of Railway Masts in Airborne LiDAR Data. *J. Constr. Eng. Manag.* 146, 04020105. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001894

Autodesk, 2021. Civil 3D 2022. URL https://www.autodesk.it/products/civil-3d/overview?term=1-YEAR&tab=subscription

Barazzetti, L., Previtali, M., Scaioni, M., 2020. Roads Detection and Parametrization in Integrated BIM-GIS Using LiDAR. *Infrastructures* 5. https://doi.org/10.3390/INFRASTRUCTURES5070055

Biancardo, S.A., Intignano, M., Viscione, N., Guerra De Oliveira, S., Tibaut, A., 2021. Procedural Modeling-Based BIM Approach for Railway Design. *J. Adv. Transp.* 2021. https://doi.org/10.1155/2021/8839362

buildingSMART, 2017a. IFC Rail Project. URL https://www.buildingsmart.org/standards/rooms/railway/ifc-rail-project/

buildingSMART, 2017b. IFCAlignment. URL https://standards.buildingsmart.org/IFC/DEV/IFC4_2/FINAL/HTML/schema/ifcproductextension/lexical/ifcalignment.htm

buildingSMART, 2005. IFC standards. URL https://www.buildingsmart.org/

Cheng, J.C.P., Lu, Q., Deng, Y., 2016. Analytical review and evaluation of civil information modeling. *Autom. Constr.* 67, 31–47. https://doi.org/10.1016/J.AUTCON.2016.02.006

Costin, A., Adibfar, A., Hu, H., Chen, S.S., 2018. Building Information Modeling (BIM) for transportation infrastructure – Literature review, applications, challenges, and recommendations. *Autom. Constr.* 94, 257–281. https://doi.org/10.1016/J.AUTCON.2018.07.001

European Parliament, 2012. Directive 2012/34/EU. URL https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02012L0034-20190101&from=EN (accessed 3.5.21).

Ferrovie Abbandonate, 2007. Ferrovia Potenza Inferiore Scalo - Laurenzana. URL https://www.ferrovieabbandonate.it/linea_dismessa.php?id=136

Garramone, M., Moretti, N., Scaioni, M., Ellul, C., Re Cecconi, F., Dejaco, M.C., 2020. BIM and GIS Integration for Infrastructure Asset Management: a Bibliometric Analysis. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* VI-4/W1-20, 77–84. https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-77-2020

Geoportale Nazionale, 2009. Infrastrutture Ferroviarie - Tratte Ferroviarie. URL http://www.pcn.minambiente.it/geoportal/catalog/search/resource/details.page?uuid=m_amte%3A299FN3%3Aad5f561e-1e56-4b2b-f504-fe4ff7a9e446

Guillen, A.J., Crespo, A., Gomez, J., Gonzalez-Prida, V., Kobbacy, K., Shariff, S., 2016. Building Information Modeling as Assest Management Tool. *IFAC Pap.* 49, 191–196. https://doi.org/10.1016/j.ifacol.2016.11.033

ISO, 2018. Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema. URL https://www.iso.org/standard/70303.html

ISO, 2016. Industrial automation systems and integration — Product data representation and exchange — Part 21: Implementation methods: Clear text encoding of the exchange structure. URL https://www.iso.org/standard/63141.html

ISO, 2007. Industrial automation systems and integration — Product data representation and exchange — Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas. URL https://www.iso.org/standard/40646.html

ISO, 2004. Industrial automation systems and integration -- Product data representation and exchange - Part 11: Description methods: The EXPRESS language reference manual. URL https://www.iso.org/standard/38047.html

ISTAT, 2021. Confini delle unità amministrative a fini statistici. URL https://www.istat.it/it/archivio/222527

Koo, B., Jung, R., Yu, Y., Kim, I., 2021. A geometric deep learning approach for checking element-to-entity mappings in infrastructure building information models. *J. Comput. Des. Eng.* 8, 239–250. https://doi.org/10.1093/JCDE/QWAA075

Kwon, T.H., Park, S.I., Jang, Y.H., Lee, S.H., 2020. Design of railway track model with three-dimensional alignment based on extended industry foundation classes. *Appl. Sci.* 10. https://doi.org/10.3390/APP10103649

Papathanasiou, N., Adey, B., Burkhalter, M., Martani, C., 2018. Risk Assessment Methodology. *DESTination RAIL Deliverable D3.6*.

QGIS Association, 2021. QGIS 3.16. URL https://www.qgis.org/it/site/index.html

RSDI Basilicata, 2016. Modello digitale del terreno (DTM) risoluzione 5m. URL http://rsdi.regione.basilicata.it/Catalogo/srv/ita/metadata.show?uuid=r_basili:9EE9C09A-7091-D8A2-A41D-F28191B86C4F

Sacks, R., Eastman, C., Lee, G., Teicholz, P., 2018. BIM Handbook. *BIM Handb.* https://doi.org/10.1002/9781119287568

Scaioni, M., 2010. Evaluation of the uncertainty of the length of energy distribution networks. *Appl. Geomatics* 2, 163–175. https://doi.org/10.1007/S12518-010-0032-Y

Soilán, M., Justo, A., Sánchez-Rodríguez, A., Riveiro, B., 2020. 3D Point Cloud to BIM: Semi-Automated Framework to Define IFC Alignment Entities from MLS-Acquired LiDAR Data of Highway Roads. *Remote Sens.* 2020, Vol. 12, Page 2301 12, 2301. https://doi.org/10.3390/RS12142301

Soilán, M., Nóvoa, A., Sánchez-Rodríguez, A., Justo, A., Riveiro, B., 2021. Fully automated methodology for the delineation of railway lanes and the generation of IFC alignment models using 3D point cloud data. *Autom. Constr.* 126, 926–5805. https://doi.org/10.1016/J.AUTCON.2021.103684

Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J.C.P., Hampson, K., 2017. Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective. *ISPRS Int. J. Geo-Information* 6. https://doi.org/10.3390/ijgi6120397

Stepien, M., Vonthron, A., König, M., 2021. Integrated Platform for Interactive and Collaborative Exploration of Tunnel Alignments. *Lect. Notes Civ. Eng*. 98, 320–334. https://doi.org/10.1007/978-3-030-51295-8_23

Uggla, G., Horemuz, M., 2018. Geographic capabilities and limitations of Industry Foundation Classes. *Autom. Constr*. 96, 554–566. https://doi.org/10.1016/J.AUTCON.2018.10.014

van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 84, 523–538. https://doi.org/10.1007/S11192-009-0146-3/FIGURES/7

Vignali, V., Acerra, E.M., Lantieri, C., Di Vincenzo, F., Piacentini, G., Pancaldi, S., 2021. Building information Modelling (BIM) application for an existing road infrastructure. *Autom. Constr.* 128, 103752. https://doi.org/10.1016/J.AUTCON.2021.103752

Wang, H., Pan, Y., Luo, X., 2019. Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. *Autom. Constr.* 103, 41–52. https://doi.org/10.1016/j.autcon.2019.03.005

Zhou, Y., Hu, Z.Z., Zhang, W.Z., 2018. Development and Application of an Industry Foundation Classes-Based Metro Protection Information Model. *Math. Probl. Eng.* 2018. https://doi.org/10.1155/2018/1820631

Zhu, J., Wright, G., Wang, J., Wang, X., 2018. A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level. *ISPRS Int. J. Geo-Information* 7. https://doi.org/10.3390/ijgi7020066