BIM Applications to Transport Infrastructures Assessment. IFC development for railways.

M.J. Falcão Silva & P. Couto
Buildings Department, LNEC, Lisbon, Portugal

S. Fontul
Transportation Department, LNEC, Lisbon, Portugal

ABSTRACT: Transport infrastructures such as roads, railways and runways are under increased traffic loading and their rehabilitation has to be performed in an efficient way, structurally and financially. In this process, monitoring of structural and functional capacity of transport infrastructures using nondestructive tests is performed in a systematic way. It is important to take advantages of these measurements to plan a future rehabilitation.
Using the BIM methodology, it is possible to obtain a model that, besides containing the three-dimensional graphic representation of the pavement or rail track and its physical and mechanical characteristics, also has information regarding the structural condition resulting from the continuous inspections.
The authors developed case studies of Building Information Modelling (BIM) applied to roads, runways, and railways. In the road and airport pavements cases, the integration of structural capacity in the modelling was studied. Regarding the railway's cases, a construction of a transition zone was addressed and its behavior during the first three years after entering in service was modelled. For both roads and railways, rehabilitation of existing infrastructures was modelled using BIM. To minimize compatibility problems between the various software based on this methodology, a standard format called IFC (Industry Foundation Classes) has been developed. This allows the user to have access to all the information without being limited to the source software of the model.
In this paper IFC has been evolving in railways. Therefore, basic criteria that allow IFC to store all the essential information for the railway design were developed in this study. Their implementation is presented in a case study of a railway structural assessment. The main troubleshooting and consideration reached so far are presented herein, identifying the advantages of BIM approach.

KEY WORDS: BIM, IFC, structural elements, railways.

1 INTRODUCTION

The AECO sector (Architecture, Engineering, Construction and Operation) is considered inefficient, with the repetition of tasks being frequently verified, as well as the increase in costs or extension of the deadlines for completion of projects, making it uncompetitive and sustainable.

Building Information Modelling (BIM) is seen as something innovative, which allows for complete collaboration and compatibility, being pointed out as the solution for increasing the competitiveness and sustainability needed by the construction sector (CEN/TC 442, 2020). BIM is a construction approach methodology, created with the aim of facilitating integration and interoperability in the construction industry. For the above motivations to be verified, it is essential that the coordination be precise and coherent, so as not to jeopardize the project's viability or the productivity of those involved. In recent years, BIM has had a dizzying development, with an increasing need to interact with this methodology on a daily basis, thus demanding a re-education of designers.

Transport infrastructures are critical for society. Mainly, in case of railways a rigorous interaction between several intervenients is required. There are various areas that are crucial to railway user's safety such as signaling, electricity supply, communications and, one of the most important, the infrastructure condition. The railway presents increased complexity in terms of maintenance due to the interdictions needed for maintenance actions. Therefore, it is important to monitor the rail track condition in a systematic way (Solla et al, 2021) and to follow its deterioration in time to be able to plan maintenance actions efficiently. BIM represent a essential tool to reflect track condition evolution in time.

It is common knowledge that the various actors in the AECO sector, both at the project level and in the different phases of work and exploration, sometimes do not use compatible applications in carrying out their work, others often need inputs from different specialties, which they are not always available with the necessary quality and brevity, others still have different levels of knowledge and mastery in relation to the BIM methodology. In this sense, the study of interoperability is a topic of the greatest relevance and timeliness, considering several types: i) interoperability between applications; ii) interoperability between different actors and specialties; iii) interoperability between people with very different levels of education and/or knowledge of the area. The issue of interoperability is inseparable from BuildingSmart, which has as main objective to contribute to the effective interconnection between the different players in the construction industry, throughout its life cycle, and contributed to the creation and dissemination of protocols for information exchange.

Throughout this work, the way of sharing information based on standardized data of the IFC (Industry Foundation Classes) type for railways will be presented, which were created and developed to enhance the interoperability between different applications and BIM software, being a format of open file with free access, which allows to describe the different components of a construction.

2 CONCEPTUAL FRAMEWORK

2.1 Level of Development (LOD)

It is understood by Level of Development (LOD) the level of development that defines the minimum requirements at a dimensional, spatial, quantitative, qualitative level, among others, that are necessary and authorized. There are 5 LODs: LOD100, LOD200, LOD300, LOD400, LOD500, and LOD350 was later added. The higher the LOD, the greater the associated requirements. In LOD 100, the element can be graphically represented in the model through a symbol or other generic representation, but it does not satisfy the requirements that make it a LOD 200. Information related to the element can be obtained through other elements of the model. In LOD 200 the element is graphically represented in the model as a generic system, object or assembly with approximate quantities, dimension, shape, location, and orientation. Non-graphical information may also be associated with the modelled element. In LOD 300 the element is graphically represented in the model as a specific system, object, or assembly in terms of quantity, dimension, shape, location, and orientation. Non-graphical information may also be associated with the modelled element. In LOD 350 the element is graphically represented in the model as a specific system, object, or assembly in terms of quantity, dimension, shape, location, orientation, and encounter with other systems. Non-graphical information may also be associated with the modelled element. In LOD 400 the element is graphically represented in the model as a specific system, object, or assembly in terms of quantity, dimension, shape, location, and orientation with information on detailing, fabrication, assembly, and installation. Non-graphical information may also be associated with the modelled element. Finally, in LOD 500 the modelled element is a representation verified on the ground in terms of dimension, shape, location, quantity, and orientation. Non-graphical information may also be associated with the modelled element. The information required in each IFC is a function of the required LOD (Eastman et. al, 2008) (Carmali et. al, 2018), (BIM Forum, 2020).

2.2 OmniClass

The OmniClass Building Information Classification System (CICS) was developed by the association of the International Alliance for Interoperability (IAI) with companies in the AECO sector, to respond to the need to organize databases in an electronic way. This classification system is based on ISO 12006-2:2015 and two other classifications, UniFormat and MasterFormat. The OmniClass classification system can cluster, unify, and update several existing CICS, making it easier for everyone involved to use. Even so, knowledge of the CICS is necessary, to use the most appropriate table, which is not an easy task for people outside the process (Secretariat, 2006).

Omniclass is a system that consists of the combination of tables. The purpose of a table system is to facilitate communication between the intervening parties, assigning a clear and simple code to each element, with all elements having an associated code that is detailed throughout the levels. Its main use is in the initial phase of the project before there is a concern with the type of material or construction method to be used. Like so many other classification systems, it has advantages, including: i) Attribution of detailed information about the project, cost data and information about specifications; ii) Allow exchange of information between stakeholders; iii) Compatibility with standard systems: Masterformat and Uniformat. However, OmniClass has some associated inconveniences, which should be remembered, namely: i) Number of levels of variable analysis; ii) independent numbering system between different tables; iii) no direct correspondence with the tables proposed in ISO12006-2:2015.

Omniclass tables can be grouped into three main categories: Organization of construction results (Tables 11 to 22); Classification of construction processes (Tables 31 and 32); Organization of building resources (Remaining Tables). According to (Weygant, 2011), the most relevant for BIM are Table 21, Table 22, Table 23 and Table 49. Regarding Table 49 (Properties), this is difficult to elaborate and update, as it concerns manufacturer-specific information, which is generally not defined, nor is there a standardization system (Secretariat, 2006).

2.3 Industry Foundation Classes (IFC)

BuildingSMART defines Industry Foundation Classes (IFC) as a data schema that makes it possible to contain data and exchange information between different BIM software. The IFC is currently recognized, in its version 4 (IFC4.3) dated 2020 through the ISO 16739:2020 standard, for Data Sharing in the Construction and Building Management Industries, which defines the concept of data structure, as well as the format of the exchange file to be used in BIM (ISO, 2020).

The IFC schema is a standardized data model that codifies, in a logical way: i) the identity and semantics (name, machine-readable unique identifier, object type or function); ii) the characteristics or attributes (such as material, colour, and thermal properties); iii) the relationships (including locations, connections, and ownership); iv) of objects (like columns or slabs); v) abstract concepts (performance, costing); vi) processes (installation, operations); vii) people (owners, designers, contractors, suppliers, etc.). The schema specification can describe how a facility or installation is used, how it is constructed, and how it is operated. IFC can define physical components of buildings, manufactured products, mechanical/electrical systems, as well as more abstract structural analysis models, energy analysis models, cost breakdowns, work schedules, and much, much more.

The IFC scheme houses information about the life cycle of an asset: from conception, design, construction, operation to demolition. The need to adopt this type of formats is a consequence of the large number of software that intervene throughout the lifecycle and in which the model will be used. According to (Oliveira J., 2016), BuildingSMART's ambition to make the IFC a complete and comprehensive format is conditioned, given that the defined variables are insufficient to accommodate all the properties necessary for the building elements. The organization of the IFC data structure includes four levels (Figure 1): Resources, Core, Interoperability and Domain.

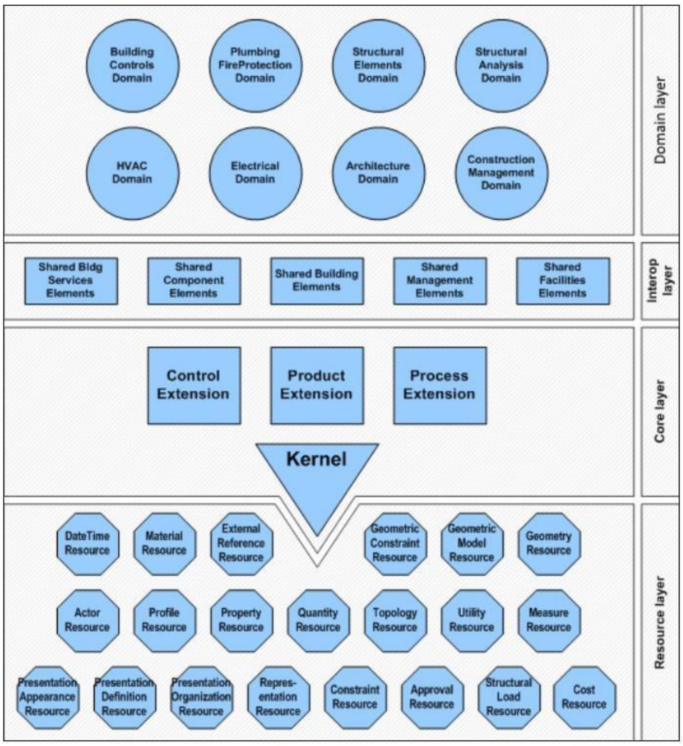

Figure1: Schematic IFC4 Structure, adapted from (buildingSMART,2021a)

The lowest level, the Resources level, includes all structures that contain definitions relating to resources, does not have a globally unique identifier and should not be used separately from the definition established at the top level. Regarding the Core level, this covers the most generic definitions of entities, which are defined at this level or higher, comprise a unique global identification, and may contain information relating to the owner. The Interoperability level gathers the entities definition structures that are specific to a generic product, process or resource used in various specialties; these definitions are normally used in the exchange and sharing of construction information between different domains, and within the scope of this work, a particular focus is given to this level. The highest level, the Domain level, encompasses all structures and definitions of entities that are not specializations of a specific product, process, or resource inherent in a particular specialty. These definitions are commonly used in exchanging and sharing the construct within the domain itself. In general, these levels can describe geometric and non-geometric elements, properties, performance, processes, among other elements (buildingSMART, 2021a).

IFC files use the STEP structure, in which each object that is described has a unique identifier that ensures compatibility between the IFC files and the possibility of completing the object's information. There is currently a lot of information on IFC transport developed by buildingSMART, including reports with the codes, with some still to be developed and published (Figure 2).

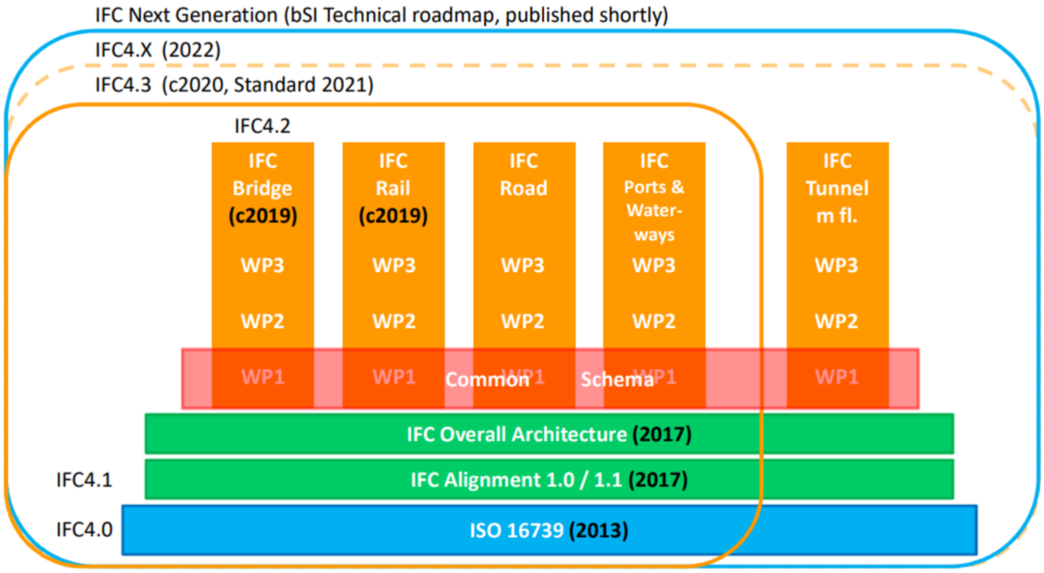

Figure2: IFC developed and to be developed, adapted from (buildingSMART,2021a)

2.4 NATSPEC Element matrix

NATSPEC BIM, a division responsible for the Standardization of Practices for the Exchange of Digital Building Information in Australia, has created several written documents that define how BIM should be implemented in a project, the so-called National BIM Guides, among which stand out, as it is of particular interest for the elaboration of this work, the BIM Element Matrix (BIM Object/Element Matrix). This matrix consists of a set of tables developed with the intention of being used in the identification and chaining of BIM information throughout the life cycle of the work (NATSPEC, 2011). The information listing is referenced according to the OmniClass classification system and according to the level of development (LOD) for the different phases of the life cycle.

The matrix organization (Figure 3) includes a logical sequence of columns, from left to right: i) Definition of development levels (5LODs); ii) Categorization of information with colour code in which information is grouped according to the level of development required, and the objectives defined in the project. The corresponding OmniClass classification system tables are also referenced: iii) Properties of the element or construction system; iv) Responsibility matrix for each item related to the element; v) Information of the data required by the customer; vi) Relation of the information in the second column with the corresponding IFC variable. An illustrative image and a general description of the element are also requested. According to (Oliveira J., 2016), NATSPEC's BIMObject/Element Matrix presents greater development in associated information, to the detriment of the element's geometric characteristics.

Door	BIM Object or Element		General Information Use			
	Item Catergory – Door		Basic Tool Features	Derived Data	Selection Agent	Building System
	Description: A 2D and 3D element. A vertical surface element often attributed to the building envelope and egress. An door shall prevent the intrusion of the elements.		Frame and Glazing Information	Material Surface Area	Primary Creator: Architect	Item System Category - Uniformat
					Secondary Creators:	
Level of Development AIA Document E202 – 2008 Developed by Graphisoft 2001	Information Category for Information Item (See Master Information Tab)	Information Item (information about the specific object or element)	Model Element Author	Information Classification Origin	Required by Client Data	IFC Support
LOD 100 – Conceptual						
Overall Building Massing Indicative of Area, Height, Volume, Location, and Orientation.	Building Program & Project Meta Data	Facility ID			File Properties	IfcDoor->IfcBuilding.Name
	Building Program & Project Meta Data	Facility Name			File Properties	IfcDoor->IfcBuilding.LongName
	Building Program & Project Meta Data	Facility Description			File Properties	IfcDoor->IfcBuilding.Description
	Physical Properties of BIM Objects &	Overall Length				IfcDoor->IfcQuantityLength.Name="Length"
	Physical Properties of BIM Objects &	Overall Width				IfcDoor->IfcQuantityLength.Name="Width"
	Physical Properties of BIM Objects &	Overall Height				IfcDoor->IfcQuantityLength.Name="Height"
	Physical Properties of BIM Objects &	Overall Area				IfcDoor->IfcQuantityArea.Name="GrossSideArea"
	Physical Properties of BIM Objects &	Overall Volume				IfcDoor->IfcQuantityVolume.Name="GrossVolume"
	GeoSpatial and Spatial Location of	Position Type				IfcDoor.ObjectPlacement
	GeoSpatial and Spatial Location of	Location Constraint				{clarify} - IfcConstraint
	GeoSpatial and Spatial Location of	Code Constraint				{clarify} - IfcConstraint
	Costing Requirements	Conceptual Cost			X	IfcDoor->IfcCostValue.CostType="Conceptual"
	Costing Requirements	Conceptual Unit Cost			X	IfcDoor->IfcCostValue.CostType="Conceptual" + UnitBasis
	Costing Requirements	Future Cost Assumptions				IfcDoor->IfcCostValue.CostType="Whole life"
	Energy Analysis Requirements	Energy Performance Basis				
	Sustainable Material LEED or Other	Green Assumptions				*IfcDoor->IfcEnvironmentalImpactValue or IfcPropertySet with local LEED agreement*
	Sustainable Material LEED or Other	Green Strategies				*IfcDoor->IfcEnvironmentalImpactValue or IfcPropertySet with local LEED agreement*
	Sustainable Material LEED or Other	LEED Initiatives Bronze,Silver,Gold				*IfcDoor->IfcEnvironmentalImpactValue or IfcPropertySet with local LEED agreement*
	Phases Time Sequencing & Schedule	Phasing (OmniClass Table -32)				IfcProject->IfcTask.Name {stages} + IfcClassificationReference to OmniClass
	Phases Time Sequencing & Schedule	Overall Duration				IfcProject->IfcTask->IfcScheduleTimeControl.ScheduleDuration
LOD 200-Approximate Geometry						
Generalized Systems or Assemblies with Approximate Quantities, Size, Shape, Location, , and Orientation.	Physical Properties of BIM Objects &	Length				
	Physical Properties of BIM Objects &	Width				IfcDoor->IfcQuantityLength.Name="Width"
	Physical Properties of BIM Objects &	Height				IfcDoor->IfcQuantityLength.Name="Height"
	Physical Properties of BIM Objects &	Area				IfcDoor->IfcQuantityArea.Name="Area"
	Physical Properties of BIM Objects &	Volume				
	Physical Properties of BIM Objects &	Maximium Size				
	GeoSpatial and Spatial Location of	Story Number				IfcDoor-->IfcBuildingStorey.Name
	GeoSpatial and Spatial Location of	Zone/Space Name				IfcDoor-->IfcZone.LongName (new in IFC2x4)
	GeoSpatial and Spatial Location of	Zone/Space Number				IfcDoor->IfcZone.Name
	GeoSpatial and Spatial Location of	Room Name				IfcDoor->IfcSpace.LongName
	GeoSpatial and Spatial Location of	Room Number				IfcDoor->IfcSpace.Name
	GeoSpatial and Spatial Location of	Floor ID				IIfcDoor->fcBuildingStory.Name
	GeoSpatial and Spatial Location of	Floor Name				IfcDoor->IfcBuildingStory.LongName
	GeoSpatial and Spatial Location of	Floor Description				IfcDoor->IfcBuildingStory.Description
	GeoSpatial and Spatial Location of	FloorElevation				IfcDoor->IfcBuildingStory.Elevation
	GeoSpatial and Spatial Location of	FloorElevationUnits				IfcUnitAssignment -> assignment of a global length unit [m, mm, inch, feet]
	GeoSpatial and Spatial Location of	FloorTotalHeight				IfcBuildingStorey->IfcQuantityLength.Name="Height"

Figure3: NATSPEC matrix element – Door element (NATSPEC, 2011)

3 RAILWAY FOR THE 21ST CENTURY

The need to implement digitalization in all construction sectors, combined with low productivity in the railway sector and the need to improve the structure throughout the life of these infrastructures, led to the urgent need for digitization in this field, and there seems to be a growing interest in the implementation of the BIM methodology to railway infrastructures. Rail projects are a good example of a multidisciplinary project, in which different specialties use different software and the need for interoperability between them is even more important.

According to (BuildingSMART, 2021b), in 2017 China Railway BIM (CRBIM) and the 7 European Rail Infrastructure Managers joined together and formed IFC RAIL, with the objective of drawing up a plan for the digitization of railway infrastructures, for the better design, build, operate, and maintain (Figure 3). BuildingSMART was involved throughout the project to ensure that all BIM modelling processes were respected.

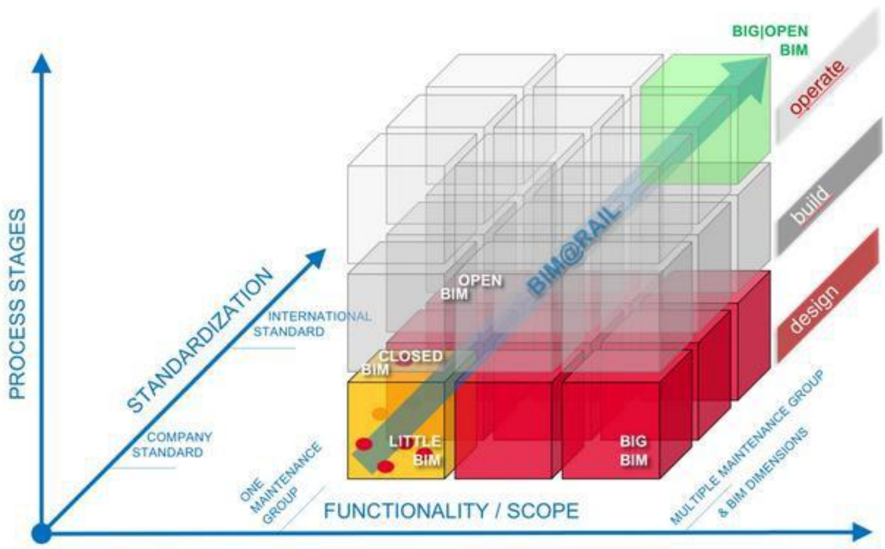

Figure 4: Summary of the strategy applied by IFC RAIL (BuildingSMART, 2021b)

The IFC RAIL team focuses on advancing standardization for railway infrastructure. At the end of 2019, the work that developed the IFC files for the railways was delivered. After completion of the first phase of work, in March 2020, the team started the second phase of work in April of the same year. The second phase of the IFC Rail project has as main objective to implement and validate the IFC 4.3 version, making it a standard for use. After completion, and subsequent validation, the standard is expected to be published in an international ISO standard. Leading to advantages for promoting the digitization of the railway infrastructure sector. These infrastructures are part of the “class” of linear infrastructures, as their size (extent) is considerably larger than the others. The way to design and budget for these infrastructures is to divide the entire railway line into smaller alignments with homogeneous characteristics.

In the following chapter, as an example, IFC structures, obtained based on the NATSPEC matrix, for elements that constitute the railroad type Rail (rails) will be exposed.

4 RAIL IFC EXISTING PROPOSAL

Rail’s function is to support and transfer the concentrated loads from the train wheels to the sleepers, impose the steering on the vehicle's wheels and distribute the forces resulting from the start-up and from the adhesion braking. Generally, just for the sake of designation, the rail is divided into three parts: Head, Web and Foot. In the following are identified IFC proposals for rails elements (considering the example of UIC60E type). The 28 IFC sources considered for rail correspond to the lower level, the Resources level (BuildingSMART, 2020), as identified in Figure 1, considering that include the structures that contain resource-related definitions and can be fixed in the corresponding NATSPEC Matrix, in alignment with what is shown in Figure 3:

i) Space. *Designates the space in which the element fits. In this case the railway infrastructure* (rail type UIC60E). Data type – *Text*. IFC system - *IfcRail.ObjectPlacement*;

ii) Element Name. *Designates the name of the element*. Data type – *Text*. IFC system - *IfcRail->IfcTrackElement.Name;*

iii) Element Type. *Corresponds to the rail type*. Data type – Text. IFC system - *IfcRail->IfcTrackElement.type;*

iv) Element Number. *Corresponds to the identification of the rail number*. Data type – Integer. IFC system - *IfcRail->IfcTrackElement.Number;*

v) Track Gauge. *Corresponds to the rail gauge*. Data type – *Number*. IFC system - *IfcRail->IfcTrack.TrackGauge;*

vi) Elementar rail length. *Corresponds to rail unit length*. Data type – *Number*. IFC system - *IfcRail->IfcQuantityLength.Name="Length";*

vii) Dimension C. *Corresponds to the rail head width*. Data type - *Number.* IFC system - *IfcRail->IfcQuantityLength.Name="DimensionC";*

viii) Dimension D. *Corresponds to the rail head height*. Data type - *Number.* IFC system - *IfcRail->IfcQuantityLength.Name="DimensionD";*

ix) Dimension E. *Corresponds to the rail Soul Thickness*. Data type - *Number*. IFC system - *IfcRail->IfcQuantityLength.Name="DimensionE";*

x) Relative Position. *Corresponds to the relative position of the rail in relation to the horizontal alignment*. Data type - *Text.* IFC system - *IfcRail->IfcQuantityLength.Name="Relative Position";*

xi) Vertical Moment of Inertia. *Corresponds to the vertical moment of inertia of the rail section.* Data type – *Number*. IFC system - *IfcRail->IfcQuantityLength.Name= "VerticalMomentofInertia";*

xii) Horizontal Moment of Inertia. *Corresponds to the horizontal moment of inertia of the rail section.* Data type – *Number*. IFC system - *IfcRail->IfcQuantityLength.Name= "HorizontalMomentofInertia";*

xiii) Gaps between Rails. *Corresponds to the Type of joints in rail bar joints.* Data type – *Text*. IFC system - *IfcRail->IfcObjects.Rail="GapsBetweenRails";*

xiv) Steel type. *Corresponds to the steel type used in the model*. Data type – Integer. IFC systems - *IfcRailType->IfcMaterial.Type*;

xv) Stainless. *Corresponds to the situation in which it's stainless steel (yes or no)*. Data type – *Boolean. IFC* systems - *IfcRailType->IfcMaterial.Stainless (yes/no)*;

xvi) Technical standard. Identifies the existing standard to be applied relating to railways. Data type – Integer. IFC systems - IfcRail->Pset_ManufacturerOccurrence->Property="Technical Standard";

xvii) Modulus of Elasticity. Corresponds to the módulo de Elasticidade do aço que constitui o carril. Data type – Number. IFC systems - IfcRail->IfcProperty.ModulusofElasticity;

xviii) Density. Corresponds to the Densidade ou massa especifica do aço que constitui o carril. Data type – Number. IFC systems - IfcRail->IfcProperty.Density;

xix) Tenacity. Corresponds to the Tenacidade associada ao aço que constitui o carril. Data type – Number. IFC system - IfcRail->IfcProperty.Tenacity;

xx) Minimum Tensile Strength. Corresponds to the Valor da resistência à tração mínima do aço que constitui o carril. Data type – Number. IFC system - IfcRail->IfcProperty.MinimumTensileStrength;

xxi) Flexural. Corresponds to the Resistência à flexão do aço que constitui o carril. Data type – Number. IFC system - IfcRail->IfcProperty.FlexuralStrength;

xxii) Wear. Corresponds to the Resistência ao desgaste do aço que constitui o carril. Data type – Number. IFC system - IfcRail->IfcProperty.WearResistance;

xxiii) Environmental Corrosion. Corresponds to the suscetilidade à corrosão. Data type – Number. IFC system - IfcRail->IfcProperty.EnvironmentalCorrosion;

xxiv) Electric Conductivity. Corresponds to the Condutividade elétrica do aço que constitui o carril. Data type – Number. IFC system - IfcRail->IfcProperty.ElectricCondutivity;

xxv) Reused rail. Considers if the rail is new or not. Data type – Number. IFC system – Boolean. IFC system - IfcRail->IfcProperty.ReusedRail;

xxvi) Space Usable length. Corresponds to the Extensão ocupada pelos carris. Data type – Number. IFC system - IfcRail->IfcRelSpaceBoundary->IfcSpace : space quantity length;

xxvii) Space Usable length. Corresponds to the Unidade em que extensão é medida. Data type – Text. IFC system - IfcUnitAssignment -> assignment of a global length unit [m, mm, inch, feet] - given consistently to all elements;

xxviii) Manufacturing date. Corresponds to the Data em que se prevê a produção do carril. Data type – Number. IFC system - IfcRail->IfcRelAssignsToProcess->IfcTask->IfcScheduleTimeControl.ActualManufacturing

5 FINAL REMARKS

It is notorious the growing recognition by the construction industry of the predominant role of BIM and the need for digitization of the sector (Industry 4.0). This is justified by the huge investment, both public and private, that exists around the world in this sector. To ensure the success of projects, resulting from the increased use of these methodologies, it is necessary to guarantee complete interoperability between all entities involved in the project. It is necessary to create instruments that allow the definition of the requirements required for the model.

In a project environment, the application of new work methodologies such as BIM requires time for analysis, which is not an easy task nowadays. However, competitiveness requires companies to keep up with the evolution of the digitalization of construction. In the field of transport infrastructure, it is possible to state that the IFC variables are still insufficient to define the construction elements, making the application of the BIM methodology difficult. However, numerous advantages are foreseen in its application, either in the design and construction phase, or during the follow-up of the work.

Despite the issue of interoperability being a wide-ranging issue, there is still a long way to go, particularly in the case of railway infrastructure. The standardization of these infrastructures is still just an application proposed by BuildingSmart (IFC Rail) and, therefore, the validity of the correspondence of the IFC variables is not known, nor are these available for the software.

In the specific case of Portugal, there are already some studies carried out for transport infrastructure, and considerable effort is still required, both financially and personally.

Acknowledgements

The authors acknowledge the contributions of Eng. Patrícia Vieira to the development of this research work.

REFERENCES

BIMForum, 2020 - LOD - Mentions of the LOD Specification. BIMForum, 2020. Disponível em WWW: <https://bimforum.org/lod/>.

BuildingSMART, 2019 – IFC Rail Project – WP2 Data Requirements Report.

BuildingSMART, 2021a – IFC Rail Project. Disponivel em WWW: <https://www.buildingsmart.org/standards/rooms/railway/ifc-rail-project>.

BuildingSMART, 2021b - Industry Foundation Classes, Version 4.0.2.1 - Addendum 2. buildingSMART, 2021. Disponível em WWW: < https://www.buildingsmart.org/standards/rooms/railway/ifc-rail-project>

Carmali, S. et al., 2018. Contribuições para a aplicação do BIM a Infraestruturas Ferroviárias. 2º Congresso Português de Building Information Modelling, Instituto Superior Técnico, Universidade de Lisboa.

CEN/TC 442 - Business Plan. CEN/TC 442 Building Information Modelling, 2020. Disponível em WWW: <http://standards.cen.eu/BP/1991542.pdf>

Eastman, C. [et al.], 2008 - Eastman, Chuck; Teicholz, Paul; Sacks, Rafael; Liston, Kathleen - BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. Wiley Publishing, 2008.

ISO 12006-2:2015 - Standardization, International Organization for - ISO 12006-2:2015 Building Construction -Organization of Information about Construction Works. Geneva: International

ISO 16739:2020 –Standardization, International Organization for - ISO 16739:2020 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. Geneva: International

NATSPEC, 2011a - BIM Object/Element Matrix. NATSPEC, 2011. Disponível em WWW: < https://www.bim.natspec.org/documents/natspec-national-bim-guide/NATSPEC_BIM_Object- Element_Matrix_v1.0_Sep_2011.xls>.

NATSPEC, 2011b - NATSPEC National BIM Guide. Australia: Construction Information Systems Limited, 2011b.

NATSPEC, 2021 - About. NATSPEC, 2021. Disponível em WWW: < https://bim.natspec.org/>

Oliveira J., 2016. Normalização BIM – Especificação do Nível de Desenvolvimento e Modelação por Objetivos. Dissertação de mestrado, Departamento de Engenharia Civil, FEUP, Porto.

Secretariat, O., 2006, - Secretariat, Omniclass - OmniClass - Introduction and User's Guide. USA: Construction Specifications Institute, 2006.

Solla, M., Pérez-Gracia, V., Fontul, S., 2021. *A Review of GPR Application on Transport Infrastructures: Troubleshooting and Best Practices*. Remote Sens. 2021, 13(4), 672; https://doi.org/10.3390/rs13040672

Weygant, R. S. (2011). BIM content development: standards, strategies, and best practices. John Wiley & Sons.