Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 45 (2020) 850–857

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

Integrated railway design using Infrastructure-Building Information Modeling. The case study of the port of Venice

Marco Pasetto[a,*], Andrea Giordano[a], Paolo Borin[a], Giovanni Giacomello[a]

[a]*Department of Civil, Environmental and Architectural Engineering, , University of Padova, via Marzolo, 9, Padova 35131, Italy*

Abstract

The Infrastructure Building Information Modeling (I-BIM) is a digital information management system utilized in the transport infrastructures construction, becoming increasingly important. BIM modeling aims at bringing improvements to all design stages. The use of BIM modeling will also provide cost reduction and control, increase awareness to data, design information availability and usability in each phase of infrastructure life cycle. Although the advanced modeling of the building components and systems leads to advantages well highlighted by practice and literature, in case of transportation infrastructures a critical analysis could show if this design methodology carries out the same benefits. The limited availability of infrastructure components libraries and the difficulty in assigning parameters to the geometries of the objects (many of them with unique characteristics) have been frequently quoted as main obstacles to the BIM use for the transport infrastructures. With this background, the problem is to understand which BIM-for-building features must be preserved in the production and management practices of each infrastructure model (classes, information exchanges and relationship between the classes and the spatial decomposition). This work is focused on the study of the I-BIM methodologies for the transport infrastructures (in particular railway infrastructures), analyzing a case study related to the port of Venice. The upward trend of goods quantity daily passing through the port infrastructures, led to the need to expand the container loading/unloading ship areas and, at the same time, to find a new and faster goods exit from the port areas, compared to the existing railway infrastructures. The authors developed a pre-feasibility study to identify the railway connection between the new port station and the existing line Padova – Mestre and to evaluate the difficulties and the ripeness of available means for an integrated design with the BIM tools

Keywords: Infrastructure Building Information Modeling; railway; infrastructures; integrated design.

* Corresponding author. Tel.: +39-049-827-5569; fax: +39-049-827-5220.
E-mail address: marco.pasetto@unipd.it

10.1016/j.trpro.2020.02.084

1. Introduction

Thanks to a recent ministerial decree the Italian government declared as mandatory the use of electronic tools and methods in case of design and construction of public works, characterized by high complexity and innovation, whose value exceed 100 million Euro. Within a range of 5 years, all public works are supposed to follow the same directive. Divided into 6 economic steps (2019-2025) the process of design, construction and management of civil infrastructures represent the first category of public works in which these methods will be used as standard.

The last five years showed an overall competition to find practical applications on using Building Information Modeling (BIM) for transportation infrastructure, which is a critical component to a nation's economy, security, and sustainability. Few papers over the years provided literature reviews and critical research on both academic publications and industry case studies (Bradley et al., 2016; Cheng et al., 2016; Costin et al., 2018; Dell'Acqua et al., 2018; Kim et al., 2016; Obergriesser e Borrmann, 2012; Shou et al., 2015). Academic institutions seem to play a minor role, comparing to the major engineering firms which adopted BIM methodologies and software in their projects, although the latter focused only on the outcome without underlining the workflow as well. At the same time, contracts overload engineering firms in delivering the design of infrastructure facilities as a highly complex task, in which numerous constraints and boundary conditions have to be taken into account. This includes the connection with the existing transport network as well as the technical characteristics of the infrastructure facility itself. Agdas and Ellis (2010) already described the difficulties in implementing Information Technology (IT) in the transportation construction industry: public ownership in infrastructures, fragmentation of the construction industry, combined with protracted length of construction site and standardization issues.

The recent update of the definition of Building Information Modeling by International Organization for Standardization (ISO) shows how its concept has been evolving as "the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" (ISO, 2018). The definition overtakes the specification about which type of asset the BIM is applied for, as a methodology for all kind of digital design. This concept leads to delete any use of other acronyms for BIM when is related to infrastructure, as heavy-BIM, horizontal-BIM, infrastructure BIM, Construction Information Modeling (CIM). What should be clear to all actors in the Architecture Engineering and Construction (AEC) industry is that BIM shares principles among different assets, not software or modeling techniques.

There are two principles in Building Information Modeling and Management to implement in other disciplines (Eastman, 1975): use of classes of objects, to manage properties and methods; parametricity, to simplify objects change during the design process.

Literature review shows extensively the research developed by BuidingSmart to align building model creation to civil transportation assets, typically divided into 5 categories: bridges, roads, railways, tunnels and airports (Cheng et al., 2016). Some researches were carried by national chapter, in order to evaluate Industry Foundation Classes (IFC) extension, such as IFC-Bridges (Yabuki e Li, 2006) and IFC-Roads (Lee e Kim, 2011). BIM for buildings is related to organize the object by a vertical framework, structured by a typical hierarchical organization offered by IfcProject, IfcSite, IfcBuilding, IfcBuildingStorey. Linear infrastructures need a structure organized by the curve representing their layout, as a series of segments, circular curves and transition curves. Therefore, BuildingSmart developed the IfcAlignment (a subtype of the new class IfcPositioningElement) to define the position of elements by a linear referencing geometry, only potentially linked to IfcSpatialZone, in order to manage construction and operation. A complete representation of IfcAlignment is offered by a single horizontal and vertical curve (IfcAlignment2DHorizontal, IfcAlignment2DVertical) and a 3D alignment, as a valid computation from the 2D alignments provided by the authoring software. Since there are numerous transition curves in practical use, integrating them explicitly in the data model is not a feasible option. Amann and Borrmann (2016) brought to light the necessity to describe more transitional curves for the standard, now provided by the class IfcClothoidalArcSegment2D, thanks to the proposed IFC procedural language (IFCPL).

For transportation assets, the alignment track corresponds not only to the spatial framework for objects (classes), but it characterized the design within a BIM environment in terms of agility, ability to reply to design changes (parametricity), early-stage alternatives finding and multi-scale purposes of design criteria. This is represented by the analogic design process, which needed a path and a series of sections to complete the model representation (Amann et al., 2015). In this sense Huang et al. (2011) defined differences between spreadsheet design methods and those offered by Autodesk software; some authors (Borrmann et al., 2015; Kim e Chen, 2015; Kurwi et al., 2017) discussed the uses of GIS and BIM integration in railway design in order to integrate past best practices with the new methodology.

Differently from the past, thanks to the way BIM methodology manages information, classes and relationships among classes and spatial structures are pre-defined. In the field of railway design, the experience offered by the BuildingSmart Chinese chapter shows a possible framework (China Railway BIM Alliance (CRBIM), 2015). Gao et al. (2016) proposed the introduction of continuous railway elements (i.e. IfcTrackRail, IfcCable) with a geometry representation by profile, and discrete elements, (i.e. IfcTrackSleeper, IfcRailwaySignalDevice) described as B-Rep geometry. The Korean chapter proposed to complete the solution offering a complete understanding of the designed extension (Seo et al., 2017).

2. Methodologies

The design of a transport infrastructure needs different geometrical and functional requirements, that in some cases (especially for roads and airports) are mandatory by laws. The railway design process is composed of different phases: operating schedule/plan, preliminary project, detailed project, construction project and the final project. In the first phase the designer defines kinematic and geometrical parameters (e.g. railway maximum and minimum speeds, not-compensated centrifugal acceleration for cant defect, centripetal acceleration for cant excess, etc.) based on the requests of the client, such as traffic type, localities served by the infrastructure, capacity (e.g. passengers per kilometers) and quality of the service. These parameters allow fixing the service and the infrastructure types (as light, high-speed and freight rails). Based on these kinematic and geometrical parameters, before defining the railway line layout, the designer evaluates the key points (e.g. minimum planimetric radius of the circular curves, the maximum cant, the length of the transition curves, etc.).

Nowadays, an infrastructure project is created using design software (or computer-aided design method for infrastructures) specialized to develop a specific engineering work (roads, railways, surveying, groundworks, pipe water, etc.). This kind of software can design a three-dimensional alignment representing a simple line or complex railway layouts. They can also be used to design railway stations or goods yards or to improve and to modify existing railway lines. The software provides many tools helping the designer to calculate vertical and horizontal alignments, meet site constraints, multilayer digital terrain modeling, design the subgrade, compute the earthworks and produce the design drawing. The geometric position of the track can be defined through the use of survey crews, aerial surveys, and graphic elements. The software is often able to provide a regression analysis which makes it easy to design under highly constrained conditions (particularly in re-alignment projects). The user can also create slew diagrams (representing the geometry of the elements that compose an alignment, such as straights, circular arcs, and spirals) to help verifying the alignments. The software package promptly indicates the validity of the proposed geometry, providing an interactive environment for placing single elements or chains of elements. Some tools utilities allow the user to generate cross-section along the designed track, editing the section with different options (in particular the parametric law allow to move the infrastructure sections according to the rule of the transversal slopes). On a different scale, other software packages can create the rail track (sleepers, rails, fastenings and joints) and the switches (simple turnover, diamond crossing and crossover) to design passenger and freight station or an intersection between lines, showing the constructive details.

Next step in infrastructure design is the implementation of the information in a BIM authoring tool. From a software point of view, BIM contains a series of rules and relationships and a structure that link a model with multiple information: the geometry of the railway layout, the data of the infrastructure materials, the model of the terrain, the costs of the infrastructure, the maintenance activities during the infrastructure life, etc. Many software provides a good database of information, containing both drawings and other modeling data (life cost, maintenance cost and activity, safety check, etc.).

Using specific software to design the infrastructure alignment (in both horizontal and vertical planes), the information is then exchanged with the BIM software, in order to specify the objects/entities composing the railway infrastructure. Generally the infrastructure project is drawn in the design software only with a line (the axis of the railway line), composed by straights, transition curves and circular curves lying in the horizontal plane and by grade lines (i.e. straights with a constant slope) and vertical junctions (i.e. vertical circular arcs), in the vertical plane. The tools (or packages) in the BIM software use three-dimensional objects to create the virtual infrastructure, such as rails, switches, sleepers, ballast, catenary poles, overhead line equipment, vertical signs, signaling systems, channels (for telecommunication cable or for water drainage).

A BIM software needs specific goals for its use: to quickly understand if these methodologies meet the goals of the designer, the some BIM uses are implemented, i.e. key factor to achieve of one or more goals once inserting the infrastructure project into a BIM software. Based on previous studies (Bradley et al, 2016; Cheng et al, 2016), BIM uses are defined in many ways and for different goals. In this work, the authors found two classes of BIM uses linked with the scale of analysis: "geographic" and "object-level". The two classes and the relative BIM uses are shown in Table 1.

Table 1. BIM uses.

BIM uses	"Geographic"	"Object-level"
Visualization	X	X
Design review	X	X
Lifecycle information management (maintenance)	X	X
Clash detection	X	
Quantity takeoff	X	X
Schedule modeling	X	X
Cost estimation	X	X
Traffic flow simulation	X	
Virtual inspection (safety and visibility clash detection)		X

The "visualization" and the "design review" can be done for each class. They consist in visualizing the actual state of the area (using a GIS or a file with a Digital Terrain Model - DTM) and checking that all parts are designed correctly. At this stage, the design takes advantage of BIM concepts and methodologies to review design, by linking issues and request of information to instances of the model.

The "lifecycle information management" consists of the information introduced within the model for the future maintenance activity of the infrastructure. In a railway can be distinguished physical-mechanical maintenance to assess the objects wear and integrity (rails, sleepers, etc.) and geometrical maintenance to care about the correct track position (twist, gauge, planimetric track position, altimetric track position, etc.) (Liu e Gao, 2017). As for building and services management, the as-built model could serve as a database to predict any intervention on any object within the model. This differs from the past digital methods, defined only by the layout and cross sections.

The "clash detection" is the evaluation of the interference during the infrastructure design with existing objects in the territory (buildings, other transport infrastructures, bridges, hydrographic network, etc.) (Huang et al., 2011). The "quantity takeoff" is, at the "geographic" scale, the computation of the amount of material relative to the railway line (e.g. embankments, cuttings, expropriations, etc.). At the "object-level" scale, it represents the counting of objects to assembly in order to build the railway (e.g. rails, sleepers, joints, etc.) (Arashpour et al., 2018). The costs of these materials (movement of soil and objects) are assessed with another BIM software tool ("cost estimation"), that allows the user to have the list of objects and their costs.

The "schedule modeling" is the time scheduling of the construction site. It indicates the different steps of the design and the required information for a specific phase (railway line plan, preliminary design, line capacity/ traffic demand check, definitive design, work plan, etc.). In order to benefit from the BIM methods in this phase, a key point is implementing a classification for railways parts and project.

Moreover, the BIM software can provide a tool, "traffic flow simulation", to simulate the capacity of the line and to evaluate if schedule timetable meets the demand of traffic. Lastly, the "virtual inspection" (i.e. safety and visibility clash detection or analysis of vulnerability) is the tool that allow to check the safety boundaries between the different vehicle clearance gauge and the designed railway line (vertical signs and signaling system included), especially in the case of overpasses and intertrack distances in the stations.

3. Case study

The Venice Port (located near to Marghera town, Fig. 1a) and the logistic areas in the Veneto inland play a key role in the economic and infrastructural development of the region and Italy. The increase in the freight traffic in the Venice port highlights the need to upgrade and re-organization of the actual infrastructures to and from the port area in order to comply the future traffic demand.

Nowadays, the railway port station is placed in the north port area (Fig. 1a), near to the center of the actual container and freight shunting area. The south port area is still under redevelopment, after the closure of some areas of the chemical industry, with the construction of a new container and roll-on/roll-off terminals (Fig. 1a). This south port requalified area needs a new railway line linking the new terminals and the actual railway network and this paper focuses on the assessment of the new railway line. The existing railway line, connecting the Venice port north area with the south area, is almost arrived at the final capacity and does not allow a fast movement of the trains between the north and the south port areas.

The area near Marghera town is crossed by some rivers/channels (“Naviglio del Brenta”, “Canale Oriago”, “Scolo Lusore” and “Canale Tron”) and some transport infrastructures (A4 Highway, SS309 “Romea” road, SP81 road, SP24 road, SR11 road, street “dell’Elettricità” – that link SP24 with the new roll-on/roll-off terminals – and two railway lines, a simple track lines between Mestre and Adria and quadruple track lines between Mestre and Padova). In the same site, there is a power plant from which many power lines depart and areas subject to historical constraints (protected areas), such as fortifications (“Forte Tron”) and some Venetian villas along the “Naviglio del Brenta”.

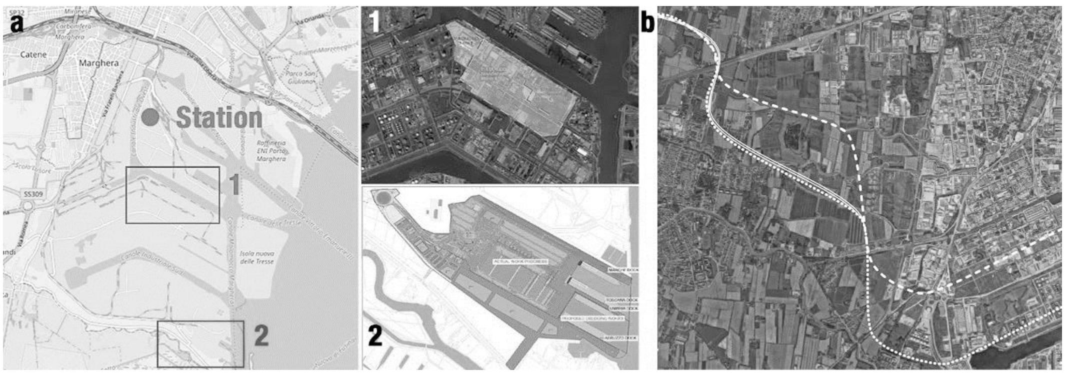

Fig. 1. (a) Geographical context, existing port station and new container (1) and roll-on/roll-off (2) terminals; (b) the three railway layouts.

Starting from three different railway layout options to connect the new south Venice port area with the railway network, the authors use a multi-criteria analysis to define the better layout. The three layouts are shown in the Fig. 1b. The first one (dotted line) starts from the center of the new south Venice port area and intersects “dell’Elettronica” street, SS 309 road, “Canale Oriago”, SR11 road and SP81 road. It runs along the SP81 road passing south of the “Forte Tron” and north of the Oriago town. It connects to the “Mestre-Adria” line, passing under the A4 Highway, and to the “Padova-Mestre”. The second layout (dashed line) starts near the new container terminal and intersects “dell’Elettronica” street, SS 309 road, “Canale Oriago”, SR11 road and SP81 road; it passes north of the “Forte Tron”, connect to the “Mestre-Adria” line, passing under the A4 Highway, and connect to the “Padova-Mestre” line (likewise the first layout). Lastly, the third layout (double continuous line) starts in the same point of the second alignment but, after passed “Canale Oriago”, SR11 road and SP81 road, it covers the first layout. Table 2 describes the construction costs of the three layout alternatives shown in Fig. 1b: the costs were estimated using the Italian Law n. 443 of 2001 (Pasetto et al., 2017).

The multi-criteria decision analysis helps to find the optimal solution. Solving the system corresponds in choosing the best option (interpreted as “the most preferred alternative” of a decision-maker) between a set of available possibilities. The following steps have been applied to the decision of the project alternative: identifying of the alternatives (three railway line layouts), identifying evaluation criteria, estimation of the weights for every criterion, analysis of the options (assessment of the characteristics of each alternative compared to each criterion and measurement standardization according to a comparable scale) and making a choice.

Table 2. Costs of the three layouts.

Costs (million euro)	Layout 1 (dotted line)	Layout 2 (dashed line)	Layout 3 (double continuous line)
Train control system and other technologies	1.12	1.07	1.08
Embankment/Cutting	6.59	6.20	6.26
Bridge	5.22	5.22	5.22
Tunnel	0.62	0.62	0.62
Railway equipment	44.96	43.02	43.32
Station	1.00	1.00	1.00
Total cost	59.51	57.13	57.50

Table 3. criteria and sub-criteria used in the multiple-criteria decision analysis.

Criteria	Sub-criteria
Environmental impacts	Hydrological aspects, noise, soil consumption, visual/landscape impact, station without electric traction, soil decontamination
Project complexity	Investment and maintenance costs, interference with high voltage lines, construction site issues
Economic Impacts	Impact in the transport/logistics sector, reduction of agricultural land, change in real estate values
Transport efficiency	Line capacity, safety, reliability and regularity, interference with port activities

During the process, the authors applied the analytic hierarchy process (decomposition of the decision problem into a hierarchy of subproblems, evaluation of the relative importance of its various elements by pairwise comparisons, conversion of these evaluations to numerical weights and calculation of a score for each alternative). In Table 3 the authors indicate the criteria used for the multiple-criteria decision analysis. A sensitivity analysis is been carried out on the criterion weights to examine the effects on different scenarios and to find differences to the final overall results.

The multi-criteria decision analysis gives the values to compare the three alternatives: 2.24 for the first layout, 1.86 for the second one and 1.57 for the third one. The results indicate that the third alternative is the best solution. The first two alternatives are more unfavorable since both tracks pass near to the Oriago town. The sensitivity analysis demonstrates that the chosen solution is not subjected to a variation, confirming that the best solution is the third railway layout.

The BIM methodologies have been applied to the third railway layout, as new railway line for the Venice Port. As already stated, any BIM application needs authoring tools in order to create spatial structures, cross sections and the instances at the detail level. The software used in this section is provided by Autodesk, within the workflow proposed through Infraworks, Autocad Civil 3D and Revit. The workflow started by the collection of a typical set of geographical information, to best describe the existing context: terrain modeling, as the surface in which infrastructure is placed; waterways, for construction of bridges at the intersection with the track; decontamination areas, for having different construction costs; existing transportation infrastructures (roads, railways), electricity infrastructures, hydraulic infrastructures, each of them linked to specific objects in case of intersection. Public and private geographical data sets and integration by means of other geometric surveys allow to have a better understanding of the initial condition, expressed within a 3D digital environment, contrary to the typical 2.5D Geographic Information System (GIS) interface.

A second phase is represented by modeling some alternatives using the alignment authoring tools. The layout needs to be linked to national standards and legislation (geometrical and kinematic parameters). This part gives the designer the opportunity to evaluate multiple parameters: length, cut and fill earthwork balancing, types and number of intersections with other structures, etc.

Once the designer selects the preferred solution, the final step is represented by detailed modeling of specific parts, such as bridges, tunnels, stations. Typically, past authoring tools can not integrate multiple information and classes in a 3D environment: the BIM software process allows to rebuild the alignment, as decided after the multi-criteria analysis, within another digital environment.

This step exposed the need for interoperability during the whole design process. Unfortunately, the second software does not comprehend standard components or sections for railways. Thus, the lack of the class "railway" does not allow to give correct methods at the intersection with other infrastructures (i.e. railway-road, railway-railway, railway-terrain, etc.). The same issue is presented during the placement between the section of the railway and the alignment path. As described in the first part, the availability of different classes for railways and roads is linked to the different positioning of the origin of the section. The use of an undefined section for different types of infrastructure can indicate wrong computation of earthworks. Once again, a correct standardization of classes (methods and rules), whose instances remain associated with the designed alignment, represents the necessary condition to develop a BIM methodology for railways.

The case study develops a workflow also valid for an "object-level" detailed study: this step is required to validate BIM tools during the whole railway design process. For distinctive parts of the infrastructure, particularly for stations, the designer specified the planned solution by modeling every object, such as rails, sleepers, switches, signaling systems, vertical catenary poles, etc.

This phase leads to understand the value of building an object library for railways: the high level of standardization in civil infrastructures allows to build short libraries, principally composed by structural and electrical elements. The lack of the class "rail" leads to use the class "beam", which has methods to remain associated with the alignment and to rotate its section in the YZ plane. In order to resolve the clash detection during the construction process, the study highlights the need of a class representing the rolling stock, geometrically defined as the sweep of an area (IfcSweptAreaSolid), based on the alignment (Fig. 2).

Finally, modeling railway signals through electrical equipment components permits using custom analysis in order to check the visibility of the signaling system (Motamedi et al., 2017). Thanks to BIM tools, designers can take advantages of VPL (Visual Programming Languages) to deliver ad hoc scripts which uses ray-trace methods to check and control the visibility of every element (represented by the centroid of the electrical appliance instance) by the driver, as a subclass of the clearance of the rolling stock (Fig. 2).

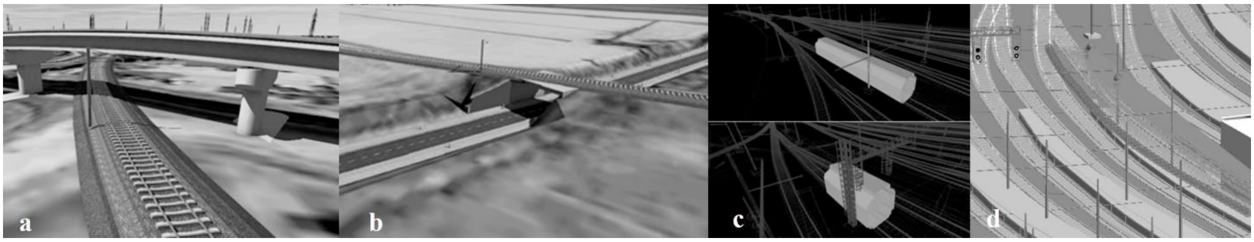

Fig. 2. (a, b) Modeling of different solutions at the intersection between designed railway and existing roads; (c) clash detection between the rolling stock and other elements; (d) visibility analysis using raytrace methods in Dynamo.

4. Conclusion

The case study showed occasions and issues in designing and modeling a railway in the Venice Port. Thanks to a multi-scale approach, derived from both traditional modeling/computation and a new BIM approach, the designer can evaluate the best solution among three alternative layouts. A multi-criteria analysis linked data from the model at the geographic scale, which worked as a link to different 3D information, to information about construction site and costs. Once this analysis provides the selected alignment, another model represented other classes of elements, such as bridges, tunnels, stations. This phase provided a new set of information to check the accuracy of the first analysis. BIM has been applied for modeling detailed elements, such as rails, sleepers, switches, signaling systems, etc. In this phase, the authors demonstrated how existing methods well established for buildings (Virtual Design and Construction, ray-trace analysis, clash detection) helped transportation design. The definition of dictionaries, classes of objects and associated methods represent a mandatory step in order to give effectiveness to the multiscale approach.

References

Agdas, D., Ellis, R.D., 2010. IT in transportation construction: opportunities and barriers to implementation, in: Computing in Civil and Building Engineering, Proceedings of the International Conference. Nottingham University Press, pag. 223.

Amann, J., Borrmann, A., 2016. Embedding procedural knowledge into Building Information Models: The IFC procedural language and its application for flexible transition curve representation. J. Comput. Civ. Eng. 2, 1–14. https://doi.org/10.1061/(ASCE)CP.1943-5487

Amann, J., Singer, D., Borrmann, A., 2015. Extension of the Upcoming IFC Alignment Standard with Cross Sections for Road Design. Proc. ICCBEI 2015.

Arashpour, M., Bai, Y., Kamat, V., Hosseini, R., Martek, I., 2018. Project Production Flows in Off-Site Prefabrication: BIM-Enabled Railway Infrastructure. Proc. 35th Int. Symp. Autom. Robot. Constr. (ISARC 2018) 80–87. https://doi.org/10.22260/isarc2018/0011

Borrmann, A., Kolbe, T.H., Donaubauer, A., Steuer, H., Jubierre, J.R., Flurl, M., 2015. Multi-Scale Geometric-Semantic Modeling of Shield Tunnels for GIS and BIM Applications. Comput. Civ. Infrastruct. Eng. 30, 263–281. https://doi.org/10.1111/mice.12090

Bradley, A., Li, H., Lark, R., Dunn, S., 2016. BIM for infrastructure: An overall review and constructor perspective. Autom. Constr. 71, 139–152. https://doi.org/10.1016/j.autcon.2016.08.019

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

China Railway BIM Alliance (CRBIM), 2015. Railway BIM Data Standard (Version 1.0).

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

Dell'Acqua, G., De Oliveira, S.G., Biancardo, S.A., 2018. Railway-BIM: Analytical review, data standard and overall perspective. Ing. Ferrov. 73, 901–923.

Eastman, C.M., 1975. The Use of Computers Instead of Drawings in Building Design. AIA J. 63, 46–50.

Gao, G., Liu, Y., Wu, J., Gu, M., Yang, X., Li, H., 2016. IFC Railway : A Semantic and Geometric Modeling Approach for Railways based on IFC, in: International Conference on Computing in Civil and Building Engineering. pagg. 1188–1195.

Huang, S.-F., Chen, C.-S., Dzeng, R.-J., 2011. Design of Track Alignment Using Building Information Modeling. J. Transp. Eng. 137, 823–830. https://doi.org/10.1061/(asce)te.1943-5436.0000287

ISO, 2018. ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling -- Part 1: Concepts and principles.

Kim, H., Chen, Z., 2015. Integration of BIM and GIS: Highway Cut and Fill Earthwork Balancing. Comput. Civ. Eng. 2015–Janua, 468–474. https://doi.org/doi:10.1061/9780784479247.058

Kim, J.U., Kim, Y.J., Ok, H., Yang, S.H., 2016. A study on the status of infrastructure BIM and BIM library development, in: International Conference on Computational Science and Computational Intelligence, CSCI 2015. IEEE, pagg. 857–858. https://doi.org/10.1109/CSCI.2015.52

Kurwi, S., Demian, P., Hassan, T.M., 2017. Integrating BIM and GIS in railway projects: A critical review, in: 33rd Annual ARCOM Conference, Cambridge, UK, 4-6 September. pagg. 45–53.

Lee, S.H., Kim, B.G., 2011. IFC extension for road structures and digital modeling. Procedia Eng. 14, 1037–1042. https://doi.org/10.1016/j.proeng.2011.07.130

Liu, Q., Gao, T., 2017. The Information Requirements for Transportation Industry's Facilities Management Based on BIM. Open Constr. Build. Technol. J. 11, 136–141. https://doi.org/10.2174/1874836801711010136

Motamedi, A., Wang, Z., Yabuki, N., Fukuda, T., Michikawa, T., 2017. Signage visibility analysis and optimization system using BIM-enabled virtual reality (VR) environments. Adv. Eng. Informatics 32, 248–262. https://doi.org/10.1016/j.aei.2017.03.005

Obergriesser, M., Borrmann, A., 2012. Infrastructural BIM standards – Development of an Information Delivery Manual for the geotechnical infrastructural design and analysis process, in: eWork and eBusiness in Architecture, Engineering and Construction. pagg. 581–587. https://doi.org/10.1201/b12516-93

Pasetto, M., Giacomello, G., Pasquini, E., Baliello, A., 2017. Feasibility and preliminary design of a new railway line in the dolomites area of veneto region, in: Transport Infrastructure and Systems - Proceedings of the AIIT International Congress on Transport Infrastructure and Systems, TIS 2017. pagg. 119–126. https://doi.org/10.1201/9781315281896-18

Seo, K., Park, S.I., Kwon, T., Lee, S., 2017. Development of Ifc-railway to manage the model data of railway infrastructures, in: 3rd International Conference on Civil and Building Engineering Informatics & 2017 Conference on Computer Applications in Civil and Hydraulic Engineering. pagg. 339–342.

Shou, W., Wang, J., Wang, X., Chong, H.Y., 2015. A Comparative Review of Building Information Modelling Implementation in Building and Infrastructure Industries. Arch. Comput. Methods Eng. 22, 291–308. https://doi.org/10.1007/s11831-014-9125-9

Yabuki, N., Li, Z., 2006. Development of New IFC-BRIDGE Data Model and a Concrete Bridge Design System Using Multi-agents, in: International Conference on Intelligent Data Engineering and Automated Learning. Burgos, pagg. 1259–1266. https://doi.org/10.1007/b99975