BIM-Based Simulation for Safety Management in Railway Infrastructure Construction

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Abstract

The management of safety on railway construction sites represents a particularly complex challenge due to the presence of existing infrastructures, work vehicles, simultaneous work and operational constraints typical of interventions near railway lines. The present work proposes an integrated methodology for the preventive management of safety based on the integration of reality-based survey by UAV, Building Information Modeling (BIM) and simulation of construction site activities. The workflow begins with the acquisition of existing conditions through drone photogrammetry, the generation of a point cloud and the creation of an interoperable BIM model of the railway infrastructure. The model is subsequently integrated with parametric models of the work vehicles, their operational envelopes and with the time planning of the works, allowing 4D simulations and clash detection analysis for the preventive detection of spatial and temporal interferences. The methodology was applied to a case study relating to a real railway section, demonstrating how the integration of reality-based survey, parametric modeling and time simulation makes it possible to identify critical issues that are difficult to detect using traditional planning tools. The results highlight the potential of the proposed approach in supporting the planning of site activities, the comparison of alternative operational scenarios and preventive safety management. The main contribution of the research consists in the development of an interoperable workflow that integrates reality-based surveying, Scan-to-BIM modeling, 4D simulation and semantic representation of safety information through BIM objects, laying the foundations for future automatic rule checking procedures and for integration with Digital Twin environments.

1. Introduction

Managing safety on railway construction sites is a significant challenge due to the operational complexity that characterizes these contexts. Construction and maintenance activities are frequently carried out near active rail lines, in limited operating spaces and in the presence of numerous interferences between construction site vehicles, existing infrastructures and simultaneous work. In these conditions, the preventive assessment of construction conflicts and operating conditions plays a fundamental role in the planning of activities and in the reduction of risks during the construction phases. In recent years, the digital transformation of the construction sector has promoted the adoption of Building Information Modeling (BIM) as a methodology for the integrated management of information throughout the entire life cycle of works (Bevilacqua et al., 2020; Hjelseth et al., 2023; International Organization for Standardization, 2018a, 2018b; Karlshoj and Scherer, 2018; Semenov and Scherer, 2021). In addition to three-dimensional representation, BIM allows the structured organization of geometric and information data to support the design, construction and management processes (Bevilacqua et al., 2020; Hjelseth et al., 2023; Inzerillo et al., 2023a, 2023b; Sacks et al., 2018; Semenov and Scherer, 2021).

At the same time, the integration with digital survey technologies and geospatial data has made it possible to generate accurate three-dimensional models of existing infrastructures and the territorial context (Colomina and Molina, 2014; Nex and Remondino, 2014). Despite this potential, the use of BIM as a tool for preventive safety assessment on infrastructure construction sites is still limited. In many cases, information models are mainly used for project coordination purposes, while analyses relating to safety and operational construction conflicts are often managed through separate tools or through evaluations that are not integrated with the digital model (Guo et al., 2017; Volk et al., 2014).

Despite the progress in the application of BIM to safety management, there are still limited studies that integrate reality-based surveying, railway BIM modeling, 4D simulation and representation of safety information according to openBIM standards in a single interoperable workflow. This aspect is particularly important in the railway sector, where the simultaneous presence of existing infrastructures, work vehicles and simultaneous activities makes it necessary to carry out a preventive assessment of geometric and temporal interferences (Guo et al., 2017; Karlshoj and Scherer, 2018; Volk et al., 2014; Zhou et al., 2012).

In this context, the present work proposes an integrated methodology for the preventive management of safety in railway construction sites, based on the integration of reality-based survey using UAVs, Scan-to-BIM modeling, 4D simulation of the processes and parametric modeling of safety information. The main contribution of the research consists in the development of an interoperable workflow that allows the digital reconstruction of the existing railway infrastructure, the modeling of work vehicle operational envelopes, the representation of risk areas as autonomous BIM objects, and the export of this information according to the IFC 4.3 standard, the latest evolution of the IFC schema, which provides dedicated support for railway infrastructure modeling and has become the reference standard for information exchange in railway projects. The proposed approach therefore aims to support the preventive assessment of spatial and temporal construction conflicts, establishing the basis for future applications that automate safety checks and support integration with Digital Twin environments.

2. Methodology

The proposed methodology integrates UAV photogrammetric survey, BIM modeling and simulation of construction processes with the aim of supporting the preventive assessment of safety conditions in railway infrastructure construction sites. In this framework, the information model is not considered simply as a geometric representation of the infrastructure, but as an integrated digital environment for the analysis of the interactions between existing infrastructure, construction vehicles and equipment, and construction site configurations.
Previous studies have shown how BIM can contribute to the improvement of prevention strategies on construction sites through the integration of design, planning and operational safety management (Fargnoli and Lombardi, 2020; Guo et al., 2017; Zhou et al., 2012).
For linear infrastructures, an accurate representation of existing conditions is a fundamental prerequisite for reliable construction and operational conflicts analyses. Digital survey technologies and UAV photogrammetry enable the rapid acquisition of high-density three-dimensional data, allowing the generation of detailed geometric models of both the infrastructure and the surrounding context (Colomina and Molina, 2014; Nex and Remondino, 2014). This data is integrated into BIM environments, where the point cloud provides a metric reference for model construction and validation.
The BIM model was structured according to openBIM standards, such as the IFC 4.3 Rail scheme, developed for the interoperable representation of linear and railway infrastructures (IFC Rail Project, 2020, 2019a, 2019b, 2019c). This facilitates the representation of the railway infrastructure as an integrated system and supports the sharing of information between the stakeholders involved in the project. The model includes representations of construction site machinery, equipment, and operational envelopes, allowing to analyze the possible interactions between mobile assets and existing infrastructure.
Clash detection tools and 4D simulations allow the assessment of the compatibility between operational configurations and the infrastructure context, supporting the early identification of potential interference and risk situations. The integration of the time dimension into BIM models also allows the analysis of the interactions between simultaneous activities, which represent one of the main causes of accidents on complex construction sites (Szóstak et al., 2024). The BIM model was further enriched with information related to construction site safety, enabling the representation and management of hazard zones, safe routes, operational areas, and safety requirements associated with the different phases of the construction process. This allows both risk conditions and related mitigation measures to be visualized and analyzed within the digital environment.
By integrating digital surveying, parametric modeling, and time-based simulation, the BIM model was used as a virtual construction site planning environment, where different operational configurations were analysed and compared before their actual implementation. This approach enables the identification of spatial and organizational conflicts that are difficult to detect using traditional two-dimensional planning tools (Zhang et al., 2013).

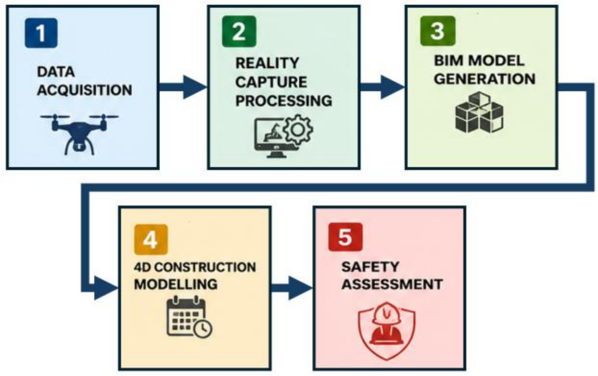

Figure 1. Workflow of the proposed methodology, from UAV photogrammetry and BIM modeling to 4D simulation and railway construction site safety analysis.

3. Case study

The proposed methodology was applied to a section of railway infrastructure of about 750 m, selected as a case study for the development of the digital model and for the experimentation of safety analyses. The site was selected as representative of a railway context characterized by high facility density, the presence of conflicting objects along the rail line and operating conditions compatible with the typical problems of complex railway construction sites. The area includes a multi-track railway system with the railway superstructure, the civil platform works and the appurtenant areas, representing a significant context for the assessment of interferences between existing infrastructure and construction site activities.
Starting from the aerial photogrammetric survey, carried out using a DJI® Mavic 3 UAV equipped with a 20 MP 4/3 CMOS camera, a high-density point cloud was generated which constituted the metric reference for the reconstruction of the BIM model of the infrastructure. The flight was planned with an average altitude of 40 m above ground level, guaranteeing a Ground Sampling Distance (GSD) of about 1.58 cm/pixel, with longitudinal and transverse overlap of 80%.
A total of 178 nadiral images were acquired along the railway axis, ensuring high data redundancy and continuous coverage of the study area. Photogrammetric processing was performed using Agisoft Metashape® Professional software, following a Structure-from-Motion (SfM) and Multi-View Stereo (MVS) workflow for the generation of the dense point cloud (Figure 2) (Remondino et al., 2017).

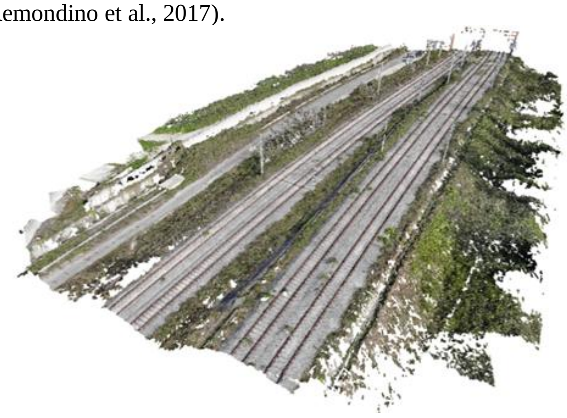

Figure 2. Three-dimensional point cloud of the railway section, generated by photogrammetric processing of UAV images.

The approach adopted followed a Scan-to-BIM procedure, in which the point cloud was used as a geometric basis for the parametric modeling of the main elements of the railway infrastructure (Murphy et al., 2013; Tang et al., 2010; Volk et al., 2014).
The BIM model was developed through an integrated process that involved the combined use of Autodesk® Revit® and Civil 3D®. In particular, the modeling of the elements constituting the railway infrastructure, such as civil works, accessory elements and context components, was carried out in the Revit® environment (Figure 3), while the railway superstructure, including the route and the characteristic elements of the superstructure, was modeled using Civil 3D®, exploiting the specific functionalities for linear design (Figure 4).
Instead, the terrain model was reconstructed in Revit from the point cloud data, allowing a consistent representation of the morphology of the study area.

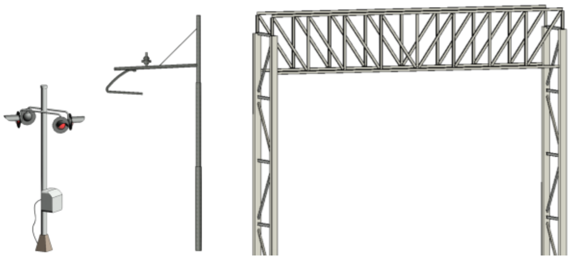

Figure 3. Point BIM elements of signalling and electric traction systems (signal poles, overhead contact line supports and support portals).

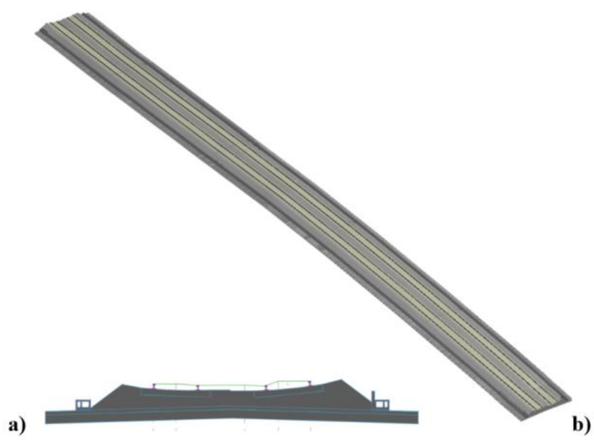

Figure 4. a) Double-track railway section developed in Civil 3D® environment; b) IFC 4.3 model of the double-track railway section generated from the parametric modeling of the railway route.

The entire modeling process was conducted using a Scan-to-BIM approach, based on the overlapping of the point cloud within the modeling environments. This integration made it possible to continuously verify the geometric consistency between the parametric model and the survey data, reducing approximations and ensuring high geometric accuracy of the final model (Figure 5).

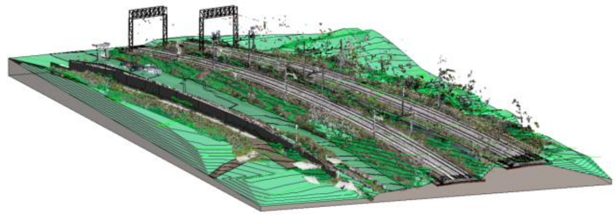

Figure 5. View of the federated BIM model of the railway section with overlapping of the point cloud, used as a metric-geometric basis for the construction of the BIM model and for the verification of consistency with the digital survey.

In this way, the BIM model does not represent exclusively a three-dimensional reconstruction of the infrastructure but constitutes an accurate information environment consistent with the current state, suitable for subsequent safety analyses (Figure 6).

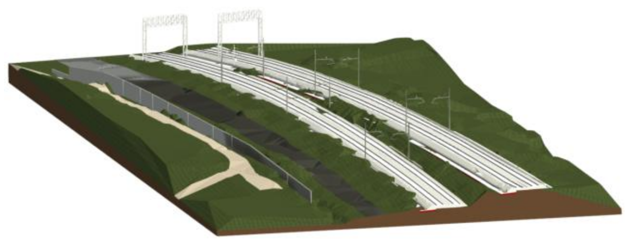

Figure 6. Federated BIM model of the railway section, consisting of the terrain model made in Revit® and the tracks modeled in Civil 3D® and exported in IFC 4.3 format, integrated in a single coordinated environment.

Subsequently, the modeling of the work vehicles and construction site equipment was developed as a preliminary phase with respect to their integration into the infrastructure model. The machinery was reconstructed with reference to the manufacturers' technical data sheets, which provided the necessary dimensional and functional information, and following the indications of the UNI 11337-4 standard regarding the level of detail and information of the BIM objects (Figure 7) (Ente Italiano di Normazione, 2017).
Each vehicle has been modeled not only in terms of static geometric footprint, meaning the rectangular area enclosed by the four wheels of a stationary vehicle, but also considering its operational envelope, defined as the maximum volume occupied during different working conditions, such as handling, rotation and extension of the mechanical parts (Figure 8). This envelope, developed by parametric modeling, represents the reference element for subsequent interference analyses and allows to describe the operating conditions in a more realistic way, supporting a reliable evaluation of the interactions between vehicles, infrastructure and work areas. Following this, the resulting models were integrated into the infrastructure model, enabling the creation of a federated digital environment for subsequent analysis.

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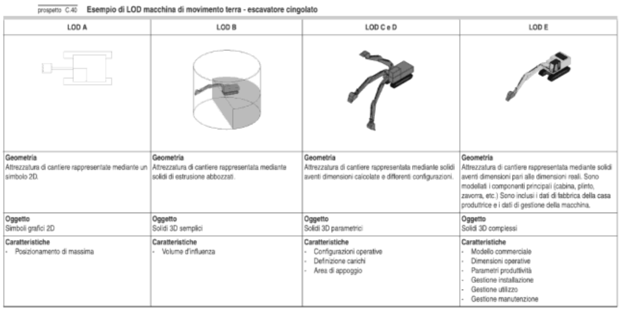

prospetto C.40 **Esempio di LOD macchina di movimento terra - escavatore cingolato**

LOD A	LOD B	LOD C e D	LOD E
Geometria Attrezzatura di cantiere rappresentate mediante un simbolo 2D.	**Geometria** Attrezzatura di cantiere rappresentata mediante solidi di estrusione abbozzati.	**Geometria** Attrezzatura di cantiere rappresentata mediante solidi aventi dimensioni calcolate e differenti configurazioni.	**Geometria** Attrezzatura di cantiere rappresentata mediante solidi aventi dimensioni pari alle dimensioni reali. Sono modellati i componenti principali (cabina, plinto, zavorra, etc.) Sono inclusi i dati di fabbrica della casa produttrice e i dati di gestione della macchina.
Oggetto Simboli grafici 2D	**Oggetto** Solidi 3D semplici	**Oggetto** Solidi 3D parametrici	**Oggetto** Solidi 3D complessi
Caratteristiche - Posizionamento di massima	**Caratteristiche** - Volume d'influenza	**Caratteristiche** - Configurazioni operative - Definizione carichi - Area di appoggio	**Caratteristiche** - Modello commerciale - Dimensioni operative - Parametri produttività - Gestione installazione - Gestione utilizzo - Gestione manutenzione

Figure 7. Example of LOD earthmoving machine – crawler excavator (Ente Italiano di Normazione, 2017).

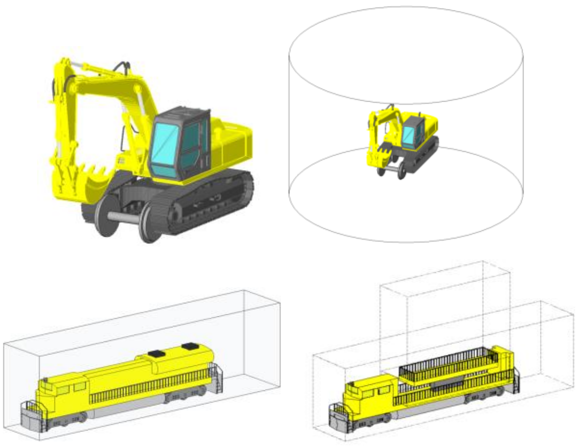

Figure 8. Examples of BIM models of railway construction vehicles with representation of the relative operational envelopes for the verification of the overall dimensions during construction site activities.

4. Results and discussion

The application of the methodology to the case study made it possible to evaluate the effectiveness of the integration between reality-based surveying, BIM modeling and 4D simulation as a support for safety planning in railway construction sites. The availability of an accurate three-dimensional model of the infrastructure, integrated with the work vehicles, the operational envelopes and the time schedule of the activities, has made it possible to perform different types of analysis aimed at the preventive verification of the operating conditions.

The elaborations developed within the BIM environment concerned the verification of the spatial compatibility between vehicles and infrastructure, the analysis of non-modeled elements through the integration of the point cloud, the detection of static and dynamic interferences and the evaluation of different operational scenarios. These analyses constitute an objective support for the definition of prevention measures, making it possible to identify critical issues that are difficult to detect using traditional planning tools.

One of the first checks concerned the correct definition of the operational envelopes of the work vehicles. The modeling of the volume of influence associated with the different work configurations makes it possible to represent the space occupied by the machinery during handling operations and to verify in advance the compatibility of the processes with the elements presents along the line.

As shown in Figure 9, the analysis highlights the possible interferences between the operational envelope of the vehicle and the elements of the railway infrastructure, such as contact line portals, support poles and other artifacts present in the intervention area. The preventive identification of these critical issues makes it possible to evaluate different operational configurations and to define adequate safety distances before the start of construction site activities. This result highlights how the modeling of operational envelopes is an effective tool to anticipate the identification of incompatible configurations, reducing the dependence on checks carried out directly in the execution phase.

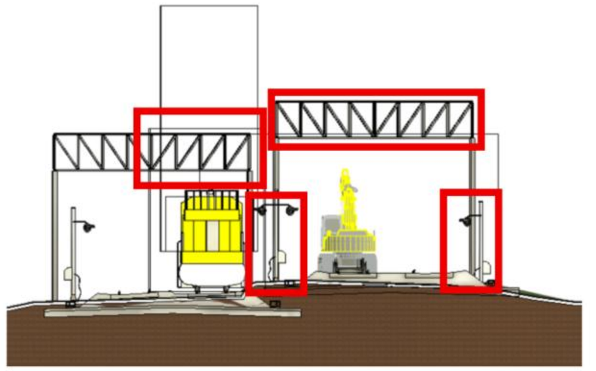

Figure 9. Analysis of possible interferences between railway infrastructure and work vehicles through sections of the BIM model, with visual identification of spatial criticalities between existing elements and operational configurations of machinery.

For the portions of the infrastructure not reconstructed by parametric modeling, the BIM model was integrated with the point cloud deriving from the UAV photogrammetric survey (Figure 10). The overlap between the BIM model and the reality-based data allows the verifications to be extended even to elements that are not explicitly modeled, while maintaining the geometric reference to the current state. This integration increases the reliability of compatibility checks and provides an additional layer of control when planning tasks. In this way, the point cloud not only performs a modeling support function but becomes an additional information layer to verify the presence of elements not explicitly reconstructed in the parametric model.

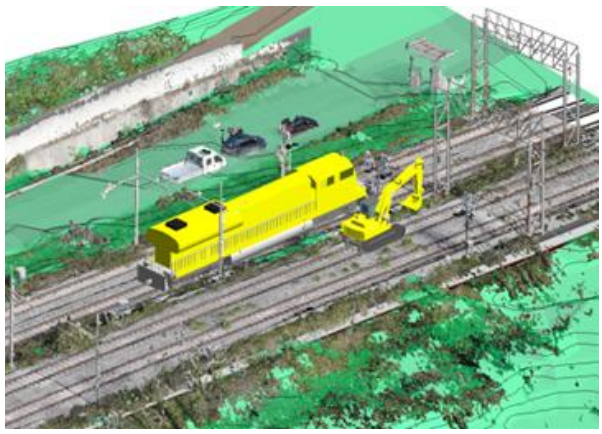

Figure 10. Overlay of the BIM model on the point cloud for interference analysis even in relation to non-modeled elements.

The evaluations carried out also include clash detection analyses in static conditions, aimed at the preventive identification of geometric interferences between the elements of the model (Figure 11). In this type of verification, the dimensions of vehicles, provisional works and infrastructure are compared, regardless of the time sequence of the work, highlighting any

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incompatible overlaps. However, these checks represent only a first level of control, since they do not consider the temporal succession of activities or the changes in the position of the vehicles during the different operational phases.

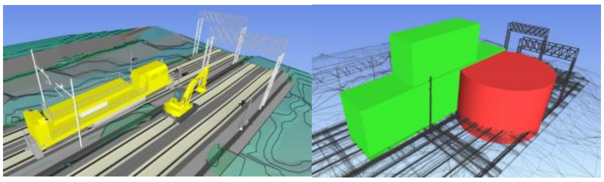
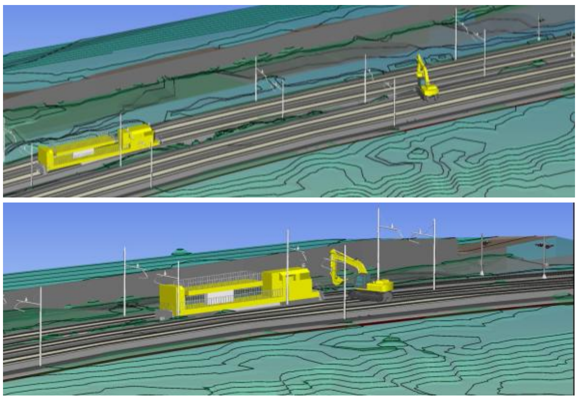


Figure 11. IFC 4.3 model of the railway section in Navisworks® environment for clash detection analysis, with automated detection of static interference between two construction site vehicles.

The integration of the time dimension has made it possible to extend the checks to the dynamic operating conditions through 4D simulations of the processes. In this case, the interferences are evaluated by considering the temporal evolution of the activities and the movement of the vehicles during the different operational phases (Figure 12).
Dynamic simulation makes it possible to identify conflicts that do not emerge in static checks, but that occur exclusively during the performance of site operations (Figure 13). This type of analysis is particularly important in the railway context, where the simultaneous nature of the work, the presence of confined spaces and the proximity to existing facility require a prior assessment of the operating conditions. The 4D simulation therefore makes it possible to identify interferences that do not emerge from static geometric checks alone, but that occur exclusively in specific time windows of the construction process.



a)

b)

Figure 12. Frame of the dynamic simulation of the railway construction site: a) initial configuration of the vehicles; b) subsequent configuration of the timeline.

Overall, the results obtained demonstrate how the integration of reality-based surveying, BIM modeling and 4D simulation makes it possible to transform the digital model into a decision support tool for preventive safety planning. In fact, the BIM environment makes it possible to analyze in a coordinated manner the relationships between existing infrastructure, work vehicles and construction sequences, identifying spatial and temporal interferences that are difficult to detect using traditional planning tools. The possibility of comparing different operational scenarios before the start of work also contributes to the definition of more effective prevention measures and the reduction of risks during the execution phase.

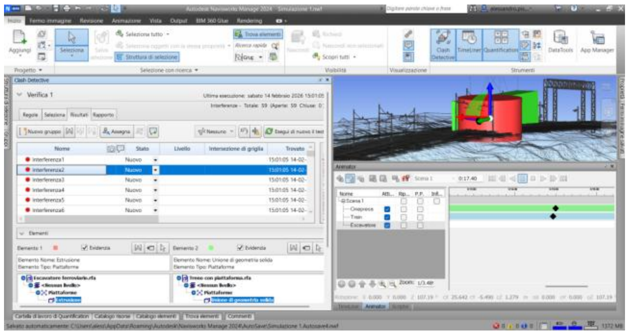
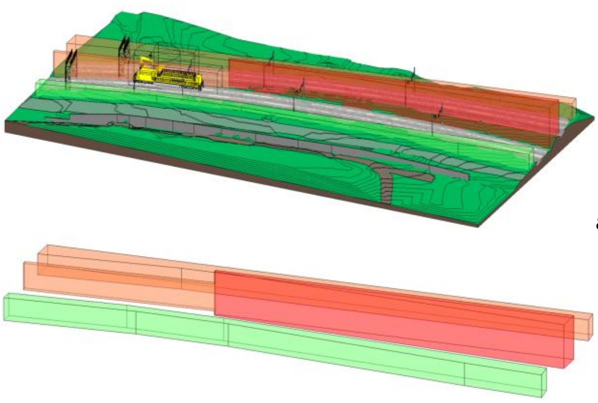


Figure 13. Interference analysis in dynamic construction site simulation, with highlighting of conflicts between moving elements using the Clash Detective function.

One of the significant aspects that emerged from the case study concerns the possibility of using the federated model as an environment for preventive experimentation of the construction site. In addition to interference checks, the model makes it possible to compare different operating configurations, verify the compatibility of the equipment with the available spaces, evaluate the operating envelopes of the vehicles and support the planning of activities before the start of work. In this perspective, BIM assumes a role that goes beyond the simple geometric representation of the infrastructure, configuring itself as a decision support tool in line with the principles of Prevention through Design (Fernández et al., 2023, 2021; Rodrigues et al., 2021; Yuan et al., 2019; Zhang et al., 2015).
Compared to approaches based exclusively on the automatic identification of safety rules in building models, the proposed workflow extends the principle of prevention in the design phase to the railway context, integrating reality-based data, infrastructure models and operational envelopes of work vehicles.
The case study also highlighted how the effectiveness of simulations depends to a significant extent on the quality and structure of the information model. The pre-definition of information objectives and use cases is a fundamental element to ensure that the level of geometric and informational detail is consistent with the purposes of the analyses, avoiding both excessively complex models and models lacking the information necessary for safety verifications.
The application of the methodology required a significant initial investment for the creation of the BIM model, the modeling of the work vehicles and the definition of the related operational envelopes. This aspect is consistent with the principle expressed by the McLeamy curve according to which anticipating decisions in the early stages of the process allows to reduce the impact of changes in the later phases (Ilozor and Kelly, 2011; Sacks et al., 2018). In a context characterized by greater digital maturity, the availability of BIM libraries of work vehicles, existing infrastructure models and standardized procedures would make it possible to significantly reduce this initial effort, making the workflow more efficient and easily replicable.
Although the methodology was developed on a railway case study, the proposed approach is potentially extendable to other infrastructural contexts characterized by high operational interference.
A further particularly significant aspect of the proposed methodology concerns the possibility of integrating safety-related information directly into the BIM model, overcoming an approach limited to the geometric representation of the infrastructure alone. In the case study, three-dimensional modeling of the risk areas associated with the overturning of work vehicles was tested, represented by parametric volumes

classified according to the level of danger (low, medium and high). These volumes were developed as independent BIM objects and inserted within the federated model of the infrastructure, allowing the risk areas to be spatially contextualized with respect to the tracks, work vehicles and other elements present on the construction site (Figure 14a). Figure 14b highlights how risk areas can be modeled as autonomous BIM objects, equipped with their own geometric representation and a dedicated information structure (Martínez-Aires et al., 2018; Zhang et al., 2015). This approach makes it possible to integrate risk directly into the information model, transforming it into an entity that can be queried and managed like the other elements of the infrastructure. The availability of dedicated objects is also a prerequisite for associating semantic properties, control rules and useful information for subsequent security assessments. This represents one of the most innovative elements of the workflow, since the risk is not treated as a simple graphic annotation or information external to the model, but as an information object with geometry, attributes and spatial relationships with the other elements of the construction site.

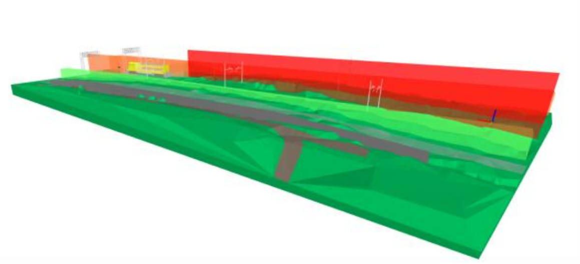


a)

b)

Figure 14. a) Modeling of the areas of overturning risk of work vehicles in the BIM model by means of three-dimensional volumes classified according to the level of danger (low, medium and high); b) Parametric volumes created for the representation of risk areas within the BIM model, developed as autonomous information objects.

To verify the transferability and interoperability of the methodology, the model was subsequently exported according to the IFC 4.3 standard and visualized using the openBIM BIMVision® software (Figure 15a). The tests carried out have shown that the export allows to preserve both the geometry of the risk volumes and the related information properties, ensuring the possibility of sharing this data between different software platforms without compromising the structure of the model.
The preservation of information properties in the IFC environment is particularly relevant because it allows risk areas to be used as a basis for future automatic verification, model querying and compliance control procedures. This aspect is particularly relevant in the railway infrastructure sector, where interoperability is one of the main requirements for the collaborative management of information throughout the entire life cycle of the work.
Exporting to IFC format also preserves information associated with risk volumes, making it searchable even within interoperable platforms (Figure 15b). Through the association of dedicated properties, it is possible to describe the characteristics of the risk through information attributes, such as the level of hazard, the operational requirements, the mitigation measures or other parameters defined according to the needs of the project. Although these properties have been used exclusively for demonstration purposes in this work, they represent the basis for future developments oriented towards the structuring of safety information and the implementation of automatic rule checking procedures, in which the BIM model can be interrogated to support compliance checks and risk assessments.



a)

Properties | Location | Classification | Relations | IFC Green

Name	Value	Unit
Element Specific		
Guid	2aYAdjlur5ORaUKrmg5HGk	
IfcEntity	IfcBuildingElementProxy	
Name	high overturning risk:high overturning risk:316140	
ObjectType	high overturning risk:high overturning risk	
PredefinedType	NOTDEFINED	
Tag	316140	
Profile		
ProfileName	high overturning risk	
Pset_BuildingElementProxyCommon		
IsExternal	No	
Reference	high overturning risk	
Pset_BuildingElementProxyCommon		
IsExternal	No	
Pset_EnvironmentalImpactIndicators		
Reference	high overturning risk	

b)

Figure 15. a) Export of the BIM model in the interoperable IFC 4.3 format and visualization using the openBIM BIMVision® software, with maintenance of the geometries and information associated with the risk areas; b) Example of the information properties associated with risk volumes in the IFC 4.3 model, which can be used for the classification of risk areas and as a basis for future automatic verification procedures (rule checking) and safety assessment.

The experimentation developed in this work has been limited to the modeling of the risk areas related to the overturning of work vehicles; however, the proposed approach is easily extendable to other types of risk characteristic of railway construction sites. These include areas of interference between operating vehicles, buffer zones near tracks in operation, electrical risk associated with traction systems, the handling of suspended loads, vehicle transit corridors and areas subject to operational constraints. The possibility of representing these conditions by means of parametric objects would allow the development of an increasingly complete safety information model, which can be queried and reused in different infrastructural contexts.
The results obtained confirm the potential of the proposed workflow to support preventive safety planning; However, the methodology still has some limitations. The experimentation has been validated on a single railway case study and requires manual parametric modelling activities for the reconstruction of the work vehicles, the definition of the related operational envelopes and the representation of the risk areas. In addition, the workflow does not yet integrate automatic rule checking procedures or systems for dynamically updating the model using data acquired in real time. These aspects represent the current limits of the proposed implementation, but at the same time constitute the main guidelines for research development.
A further aspect concerns the structuring of security information in interoperable environments. At present, there are no

established guidelines or standards that define shared methods for modeling safety information within IFC schemes, with particular reference to railway infrastructures. The definition of dedicated Property Sets, specific classifications and shared rules for the representation of risk areas is therefore one of the main future research directions.
In this perspective, the proposed methodology represents a first contribution towards the evolution of BIM from a geometric coordination tool to an information platform for safety management. The integration of reality-based surveying, parametric modeling, 4D simulation and IFC interoperability lays the foundations for future applications aimed at the automation of safety checks, the implementation of rule checking procedures and the development of Digital Twins for the monitoring and management of railway infrastructures (Boje et al., 2020; Lu et al., 2020).

5. Conclusions

The research proposed an integrated methodology for supporting the preventive management of safety in railway construction sites, based on the integration of reality-based surveying using UAVs, BIM modeling and simulation of construction activities. The workflow has made it possible to transform the survey of the existing infrastructure into an interoperable information environment, in which geometric, temporal and safety data can be managed in a coordinated manner.
The application to the case study has shown how an accurate BIM model, built from high-resolution photogrammetric data, can support the verification of the operational envelopes of the work vehicles, the identification of geometric interferences through clash detection, the evaluation of space-time interferences through 4D simulations and the comparison between different operational configurations. The integration of the point cloud has also made it possible to extend the checks to elements that are not explicitly modeled.
One of the main contributions of the research concerns the use of the BIM model not only as a three-dimensional representation of the work, but as a digital environment to support decisions, capable of integrating geometry, time planning and safety-related information. In this perspective, the federated model makes it possible to analyse alternative construction site scenarios in advance, verify the compatibility of the works and identify critical issues that are difficult to detect using traditional planning tools, contributing to the application of the principles of Prevention through Design in railway infrastructure management processes.
The research also highlighted the potential offered by the modeling of risk areas as autonomous BIM objects, to which dedicated information properties can be associated. The export of the model according to the IFC 4.3 standard has shown how this information can also be maintained in openBIM environments, confirming the role of interoperability as a fundamental requirement for collaborative data sharing and management. Although this implementation has been developed in experimental form, it constitutes a first step towards the structuring of information models in which risk becomes an integral part of the asset information, laying the foundations for future applications attributable to 8D BIM.
However, it should be emphasized that the effectiveness of this approach depends on the quality of the information model and the prior definition of the objectives of use. Building safety-oriented models still requires a significant upfront investment in terms of data acquisition, parametric modeling, definition of operational envelopes, and information organization. As evidenced by the principle of the McLeamy curve, this investment anticipates decision-making early in the design process, reducing changes, disruptions and costs during the execution of the work. The progressive diffusion of standardized BIM libraries, interoperable infrastructure models and shared procedures will help reduce this initial effort, favoring a wider application of these methodologies in the design and management processes.
Key future developments include the definition of Security Property Sets, the implementation of automated rule checking procedures, integration with Digital Twin platforms and the definition of shared guidelines for the modeling of security information in IFC schemes. These developments will contribute to extending the role of BIM beyond geometric coordination, enabling its use as an information environment for the integrated management of safety in railway infrastructures.

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