

## Article

# Building Information Modeling (BIM) Application for a Section of Bologna's Red Tramway Line

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**Abstract:** New technologies such as the I-BIM (Infrastructure Building Information Modeling) are radically changing the infrastructure design and construction sector. In this study, the I-BIM approach has been used for the design of a portion of the future Bologna's Red Tramway Line. Starting from the topographical survey of the area, a "federated" model was created, aggregating in a single digital environment all the models inherent to the individual disciplines involved. Interference analysis (Clash Detection) between the various disciplines was performed, subject to the preparation of a coordination matrix and the temporal simulation of the worksite phases (BIM 4D). The results have shown that the I-BIM approach represents a powerful tool for optimizing and validating infrastructure design, allowing users to see how the infrastructure integrates and fits into the real 3D environmental context.

**Keywords:** building information modeling (BIM); infrastructures building information modeling (I-BIM); tramway; road; clash detection; 4D simulation



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## 1. Introduction

The design of large-scale works is focused increasingly on the frequent use of methodologies and technologies aiming to simplify and automate the management, planning and coordination of construction processes; this is leading the civil engineering sector to continuously evolve. Considering the time-consuming nature of traditional two-dimensional drawings, the Building Information Modeling (BIM) approach shows an innovative change to the design and construction practice by increasing the archived information concerning the entire life cycle of the structure, from the project to the construction, up to its demolition and disposal. The term BIM was coined by Professor Charles M. Eastman in 1970. Although this acronym was originally used for buildings, the International Organization for Standardization has recently proposed updating the definition of the term to "the use of a shared digital representation of a built asset to facilitate design, construction and management processes to form a reliable basis for decisions". This new definition thus makes it possible to extend the methodology to all types of digital design, regardless of the type of asset requiring BIM [1]. This acronym indicates an integrated process in which through simulations of the real construction of a project within a digital environment it is possible to manage its physical and functional characteristics [2]. However, these definitions are united by four key elements of the BIM methodology (collaboration, representation, process, and life cycle) that interact with each other to create an innovative and efficient project environment.

Among the major advantages that the introduction of the BIM approach has brought to civil engineering practices are the optimization of the production process through better control of all design components and more efficient collaboration between all the professionals involved, digitizing the entire life cycle of work from conception and construction to management, monitoring and operation [3,4]. In recent years, the demand from public administrations for the use of this software has extended its application to the infrastructure

sector. In particular, this study aims to highlight how I-BIM's design allows users to optimize the design process, considering time, cost and resources in a complete and real vision in a 3D context. It aims to analyze a case study concerning a part of the Red Line of the Bologna tramway. The discussion has an innovative connotation: a "federated" model has been created, aggregating in a single digital environment all the models inherent in the individual disciplines involved and, subsequently, performing interference analysis (Clash Detection) between the various disciplines themselves. By performing preparation of a coordination matrix and status, it has also been possible to simulate the construction site phases (BIM 4D). In this regard, the application of BIM was carried out in three successive phases: the creation of the three-dimensional design model, the planning of the construction process (4D) and the extraction of information from the model. For these three phases of work, several software packages were used: Autodesk Civil 3D and Revit proved to be suitable for 3D modeling, while Navisworks Manage was used to create the model in four dimensions.

## 2. Theoretical Background

At the present time, infrastructure and structure modeling is entrusted increasingly to emerging technologies, such as 'Scan to BIM' or 'Field to BIM' [5,6]. They enable the capture of a points cloud with high definition and cause it to coincide with the BIM modeling. In this way, in addition to operating between interventions in present constructions and the insertion of new ones, it allows the foundations of a future connection artificial intelligence (AI) to be established. In fact, the AI, thanks to a series of algorithms, allows the cohesion of heterogeneous sources within the same scenario [7,8]. The development of BIM technology, therefore, helps to realize of the first step of automation, including in the field of design. The first clear advantages of using this methodology lie in the assessment of the time and resources available [9–11]. Numerous studies have shown an increase of 75% in productivity, as it tends to optimize the time of realization of the elaborations and bring under control the whole structure tied to the plan, from the total costs to the number of necessary resources. Using BIM 4D, one can also compare different design alternatives by visualizing the work sequences and duration of each task. In addition, BIM 4D simulations can be transformed into 5D BIM simulations by incorporating information on the quantities and cost of materials used [12]. Potentially the use of the methodology can extend up to the seventh dimension (three new dimensions are currently being studied) and, given the recent trend towards "Smart city" design, BIM can also provide practicality in construction management (including construction, operation and maintenance) and provide technical support for future urban intellectualisation [13–15]. Many studies, in fact, report the application of this methodology to various infrastructure elements, including energy (energy production plants, storage/distribution terminals, refineries, wells and mines) and service (networks/pipelines), known as Infrastructure Building Information Modeling (I-BIM) [16–18]. For example, the application experience of BIM in the design, construction and management of thirteen different projects, including ten infrastructure projects and three building projects, was analysed. The study was carried out concerning indicators such as clarity of design solutions, number of conflicts, quality of work, control/predictability of costs, requests for changes, etc. The results showed that BIM resulted in 38.5% quality improvement, 38.5% conflict reduction, 61.5% clearer design, 23.1% fewer changes and 30.8% more accurate cost estimates [19,20]. However, the management of I-BIM is affected by considerable constraints linked to the single geometry that makes up the various infrastructure elements, hence the lack of standardization of products [21]. Although many efforts have been made to ensure the interoperability of data with the development of open source standards and object-oriented models, such as the Industry Foundation Classes (IFC) for so-called vertical BIM (buildings), there is a huge lack of open data standards for the exchange of information suitable for the horizontal case (infrastructure), thus limiting the adoption and effectiveness of the integrated BIM in the latter case. In this sense, several measures have been promoted in recent years to improve the integration of BIM in the infrastructure sector, promoting greater development in terms of

interoperability and increasingly using the signal approach [22,23]. In this regard, much new software is being developed in relation to BIM for infrastructure, such as the Nano Pi 2 Fire, which allows highlighting in depth the supervision of buildings and locating them in the best way through a GPS Locator [24]. In the literature, it is possible to find few examples in which the I-BIM methodology is already adopted in several countries and outside national borders, in particular as regards the railway sector. In Germany, the railways have applied the BIM methodology to manage their network; an example of Deutsche Bahn's use of the methodology is the excavation of a railway tunnel at Rastatt. In Morocco, the Office National des Chemins de Fer (ONFC), the national operator of the railway network, plans to build 1500 km of high-speed railway lines by 2035. The team that led this project consisted of 15 designers and engineers from different disciplines, integrating the BIM methodology into the design process. This integration, however, has differentiated from one discipline to another: while architectural and structural aspects have been more likely to take the approach, other disciplines have encountered difficulties, in particular as regards interoperability with other dedicated software. The Norwegian National Rail Administration has published the "Digital Design Manual" on 3D modeling, BIM and infrastructure design. In particular, the first major investment was the interurban rail project around Oslo, which began in 2016. The 3D/BIM initiative has proved to be a fundamental requirement for designers, with significant advantages in the form of fewer errors in on-site rework, significant savings and improved overall quality of the final product. In Portugal, a 35 km section of railway infrastructure was restored in 2016. In Austria, meanwhile, BIM was also introduced for the analysis of the requirements and performance of the line, to then evaluate its actual safety and possible implementation. This is an important example to highlight the interoperability of the program, as it has enabled international cooperation between Austria and Slovenia [24–26]. In Italy, the use of BIM in road infrastructure projects has so far been used exclusively in academic environments or international programs in the transition from traditional methods to BIM (the so-called CAD to BIM), which required several years of study and application. Today many engineering companies have adopted the method in pilot projects to involve their specialists in implementing their ability to develop a complete BIM-based project [27]. In recent years, great attention is paid to academics and professionals in this field, especially after the implementation of the national law DM 560/2017 and the subsequent update DM 312/2021. The Decree defines the timing and manner in which the requirements are to be implemented through the appropriate electronic means in relation to the scope. In addition, it requires the use of these methods and tools in all aspects of the design and operation of civil engineering structures and infrastructure (bridges, buildings, etc.). Among the latter, there is ample space for infrastructure dedicated to Rapid Mass Transport (MRT), which in Italy is currently promoted by national plans, such as the National Recovery and Resilience Plan (PNRR) launched following the COVID-19 pandemic, and municipal plans such as Urban Plans for Sustainable Mobility (PUMS). Tramway networks are one of the biggest bets for the next phase in infrastructure and transport at the national level. For this type of project the features of MRT engineering include large application spaces, long lead times, complex interfaces and complex management and coordination tasks. In light of these characteristics, the use of BIM technology is necessary and useful to improve the management of the entire design process, even if this has not yet been demonstrated [28–31].

### 3. Materials and Methods

The case study object is a section of the future Red Line of the Bologna city tramway. The path analyzed is divided into three main areas:

- North-West area, in correspondence with Via della Pietra, where a single double-track tram platform is planned (BD\_L2 section);
- Central area, in correspondence with the "Fiorini" stop, where a fork is foreseen for the tracks serving the stop itself (BD\_L2\_FC section);

- South-East area, in correspondence with Via del Triumvirato, where the two tram tracks join to form a single one (BS\_L2 section).

Throughout the entire stretch of line considered, the tracks are bordered by two road lanes of variable width, one in each direction. The tramway is raised 7 cm above the road axis, thus allowing the transit of vehicles at intersections and in emergencies.

The designed modeling has been focused on the “Fiorini” stop, located in Via Emilia Ponente (SS9) between the MRS station (metropolitan railway service) of Borgo Panigale and S. Viola, close to the Pontelungo crossing of the Reno River (Figure 1). In particular, a section of the red line with a length of about 355 m was examined, mostly between the intersections of Via Emilia Ponente with Via della Pietra to the north-west and Via del Triumvirato to the south-east of the case study stop.

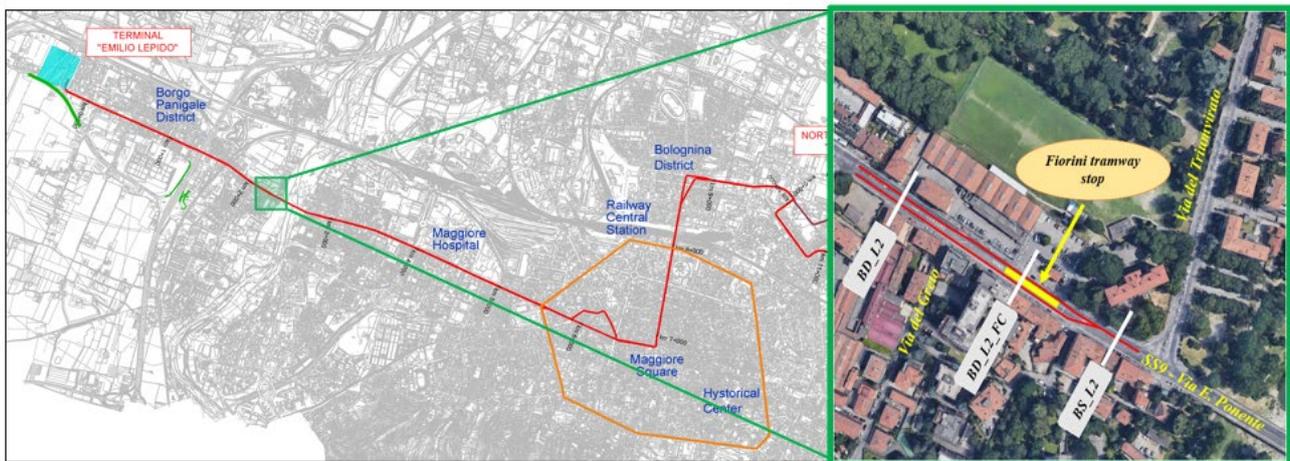


Figure 1. “Fiorini” tramway stop’s location along the Bologna’s Red Tramway Line.

The stop is studied on the basis of the technical drawings of the final design, exploiting the three-dimensional representation of the work and the surrounding environment for the identification and resolution of any interference between the various disciplines (structures, plant engineering and infrastructures) and for the management of construction site timing (4D temporal simulation).

Figure 2 defines the analysis performed step-by-step.

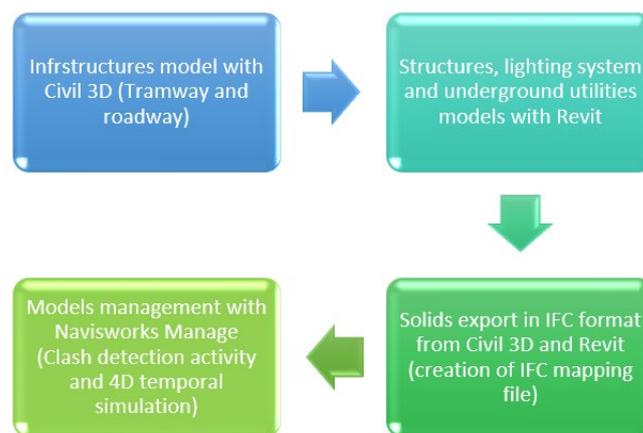


Figure 2. The structure of the analysis.

### 3.1. The BIM Design

The case study was approached with three software packages: “Autocad Civil 3D”, “Revit” and “Navisworks Manage”. The starting point is represented by the three-dimensional

modeling of the main entities, using the first two software packages in relation to their characteristics: while for linear works (such as road and rail-train infrastructures) “Autocad Civil3D” was adopted, while for punctual works (such as the stop structure) it was considered appropriate to refer to “Revit”. The only exception was the modeling of underground utilities and the public lighting system, which, despite being linear works, were also realized with “Revit”. Once the individual models inherent in the various disciplines involved in the case study had been performed, a multidimensional model was created on “Navisworks Manage”, obtained by merging the aforementioned discipline models in a single digital environment. In this way, it was possible to study possible interferences between the individual entities and the succession of construction phases as time changes, thus constituting a model in four dimensions (where the time variable is added to the three spatial variables).

In the transition from three-dimensional modeling to the management of the aggregate model on Navisworks, a brief focus is proposed on a fundamental aspect of the BIM methodology which is seldom addressed in the literature, relating to structured data management and implementation, in particular the effective use of model management activities such as the activity of interference detection (Clash Detection) and temporal simulation (BIM 4D). The latter, in fact, represent two innovative aspects of the advent of BIM in the construction world as they allow 360-degree management of the construction process. Whereas in the former case the errors that would normally be discovered only on-site during processing (with consequent high costs due to the resolution of these in that design step) can be identified in the office even before someone sets foot on the site, in the latter case, 4D models have demonstrated significant advantages over the entire life cycle of a project, including collaboration with stakeholders, assessing the buildability of the project and identifying spatial conflicts in construction, through multidimensional visualization of the construction process and the sequence of works [32–34]. The quantity and quality of the information content of the objects that make up digital information models, defined by the acronym LOD (Level of Development), assume crucial importance. Every single element of the model is expressed in a verified representation in terms of size, shape, position, quantity and orientation of the actual installation and placement in the project. The LOD of an object is therefore determined as “the set of all geometric and non-geometric information (normative, economic, etc.) that can be represented in graphic form (2D and 3D) and alphanumeric form, defining the usability of the model and thus its adherence to the real-world characteristic” [35].

Since this is a model based on a definitive design, in the case under consideration it was considered appropriate to use an object Level of Information Development of type C [LOD C (IT), equivalent to a LOD 300 according to the US standard or LOD 3 according to UK legislation] for structures and type D [LOD D (IT), equivalent to a LOD 350 according to the US standard or LOD 4 according to UK legislation] for road infrastructures and plants, concerning the LOD scale required by Italian UNI 11337-4/2017.

In order to create a three-dimensional model of the main road infrastructures present in the case study, it was necessary to define a base surface, that is a 3D representation of the existing road surface. In correspondence with the planned Fiorini tram stop, there is currently a category C road with a single carriageway consisting of one lane in each direction and a central accumulation lane, an area for which a topographical survey is available as part of the documentation for the final design of the red tram line (Figure 3).



necessary to customize the content of infrastructure BIM models by creating new parametric components of the model section, as in the case study in question. In particular, the road sections were created using the “Sub Assembly” (parametric components) present in the aforementioned “Country Kit”, modifying them appropriately in terms of stratigraphy and structure (lanes, sidewalks, docks); the road pavement is composed of 4 cm of surface course, 7 cm of binder course and 10 cm of base course, all in bituminous mixture with a transversal slope of 2.50%, that lean on 35 cm of granular foundation (Figure 5). For the construction of the typological cross-sections of the railway-tram system the Civil 3D application “Subassembly Composer” was used, capable of creating new Sub-Assemblies, with which the Assemblies (assemblies), or the standard sections, are constructed.

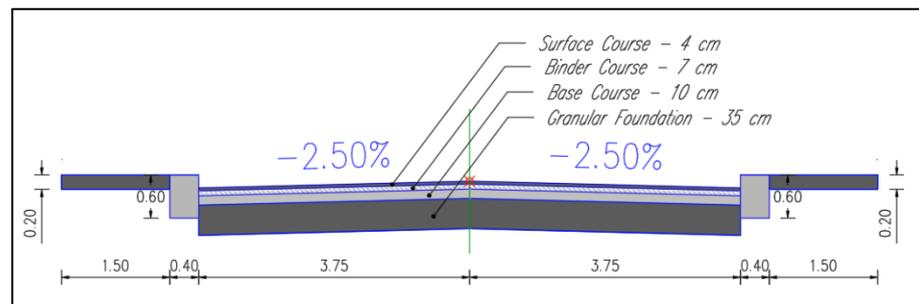


Figure 5. Typological Road section composed of Italian Country Kit subassemblies.

Specifically, the projected tramway substructure is defined by several components: 60R2 rails covered with rubber profiles to minimize the transmission of noise and vibrations to the ground (ERS system—Embedded/continuous Rail System) are fixed in place with a 30 cm thick blocking concrete cast in turn resting on a further 7 cm thick reinforced concrete Rck 30 N/sq mm layer with a protective function against an anti-vibration mat (3 cm thick) placed below it. This mat is protected at the bottom by a PET sheet, which separates it from a foundation with a thickness of 20 cm in reinforced concrete Rck 30 N/sq mm.

The typological section is completed at the top by a screed of slopes with the function of protecting the lower layers and removing rainwater, and by an external curb that divides the tramway from the road (Figure 6).

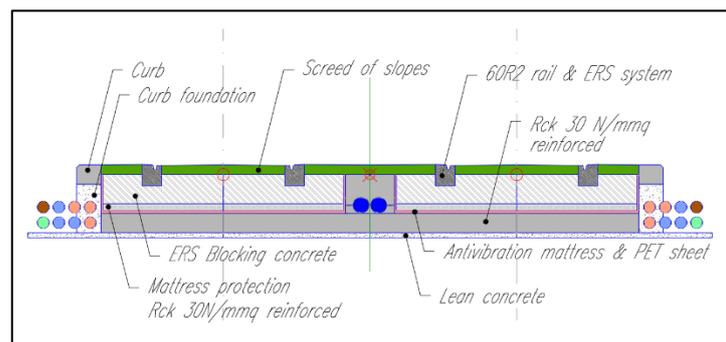


Figure 6. Typological Tram system BD\_L2 section by Subassembly Composer.

### 3.2. Tram Stop’s Design

Following a suitable georeferencing of the model, obtained by linking it to the topographic survey file, it was possible to create the structure of the tram stop platform using Revit. The stop is characterized by a width of 3.5 m and a length of 42 m, to which are added the two access ramps each 4 m long with a 7.50% slope.

The different structural components of the raised platform were modeled through objects characterized by stratigraphies consistent with the typological section shown in the final design drawings. Since the design level at the stop is inclined from the horizontal

with an average longitudinal slope of 0.51%, it was necessary to use “inclination arrows” to provide the same slope to the above objects.

The two access ramps to the platform were created with the aid of a small Revit “local model” (Figure 7a), used to create a geometry that would allow the two different slopes to be reconciled, that of the entire platform raised (relative to the design level) and that of the access ramp. This geometry, created ad hoc for the specific case, was then inserted into the model, solving the problem effectively (Figure 7b).

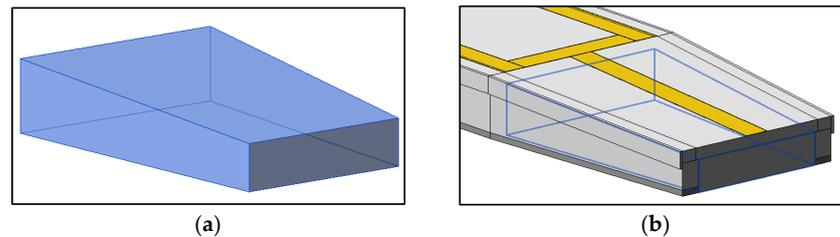


Figure 7. (a) Local model by Revit. (b) Access ramp with local model.

Despite BIM modeling being carried out for “objects” with geometric and informative characteristics that are well suited to standardized contents (as happens in construction), with this case study it can be deduced that this is not entirely extensible to the case of infrastructures, for which ad hoc objects are often used due to the uniqueness of the components to be built. Following the construction of the platform paved component, the shelter was conceived, which according to the final design rises above a surface foundation in reinforced concrete on plinths, tied by a connecting beam. The planned structure has a frame 12.80 m long and 3.80 m high with a mixed steel-concrete section with a portal type structure, containing a wooden surface that acts as a continuous seat for users of the waiting infrastructure, and laminated glass sheets, fixed to the intrados of the same through an anchoring system with a roofing function (Figure 8).

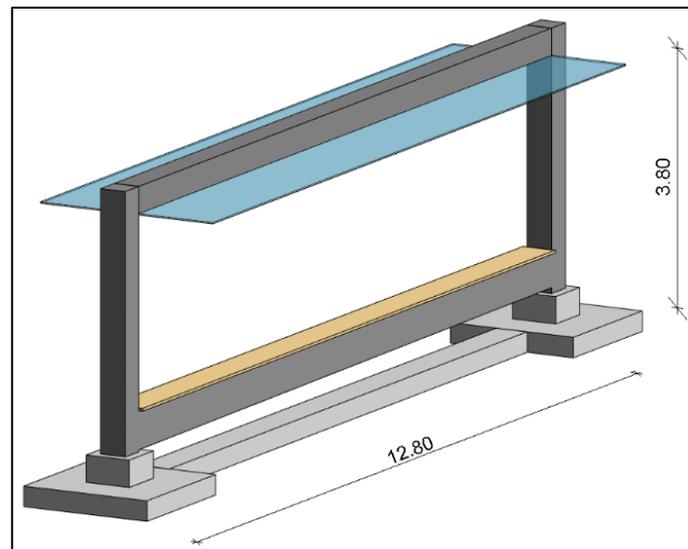


Figure 8. Shelter geometry by Revit.

Revit’s default “families” (parametric objects) were used to define the individual components of the shelter, such as beams, pillars, floors and foundation plinths, appropriately calibrating the objects from a spatial point of view in relation to the final design section.

Among these, it is considered interesting to investigate the case of the “Floor” object used to model the tram stop platform.

The typical stratigraphy of the stop platform is defined by a 0.10 m concrete lean on which rests a layer of gravel 0.85 m thick; above this, a concrete screed of 0.10 m and a thickness of sand and cement equal to 0.06 m have been provided, on which the flooring in “Crescentone” granite slabs with a thickness of 0.04 m is then laid. The lateral part of the quay and the edges are of the same granite worked suitably to maximize the visibility of height jumps; the LOGES orientation systems, on the other hand, are made of artificial stone with a light/dark contrast with respect to the quay pavement.

In order to correctly model the structure configuration, four different floors with different stratigraphy were created and were then placed side by side to manage the thickness variations of the materials along the cross-section (Figure 9).

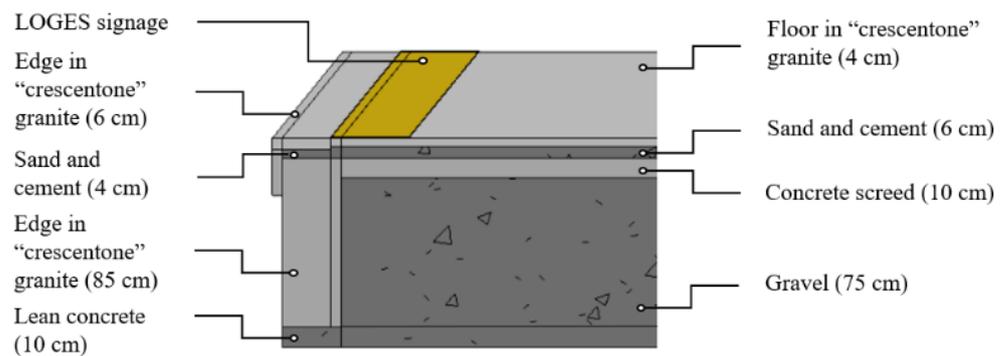


Figure 9. Tram stop platform model by Revit.

In this way it was possible to intelligently recreate the articulated stratigraphy proposed in the design phase, making the most of the available default geometries and minimizing computational costs. In Figure 10 it is possible to observe the final result of the structural modeling of the tram stop platform.

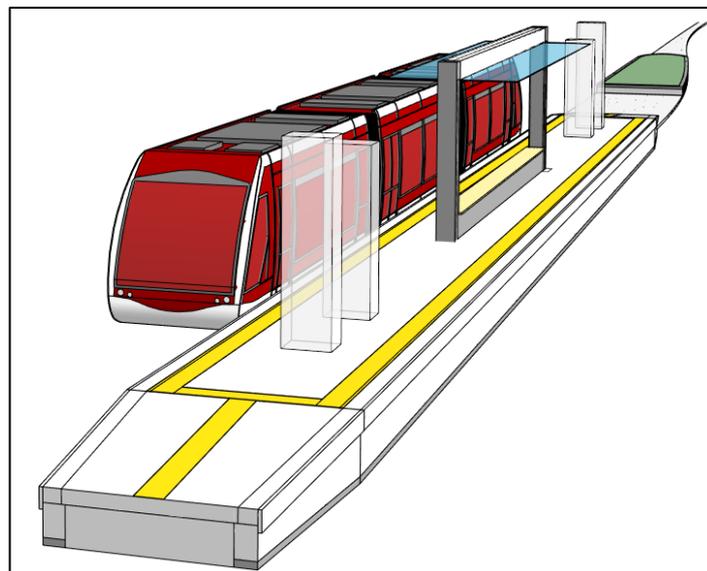


Figure 10. Tramway stop 3D model on Revit.

### 3.3. MEP Design

In parallel to the structural modeling, “Revit” was also used for the representation of the public street lighting system (Figures 11 and 12) and some existing underground utilities (aqueduct, low-pressure gas pipeline and sewer network).

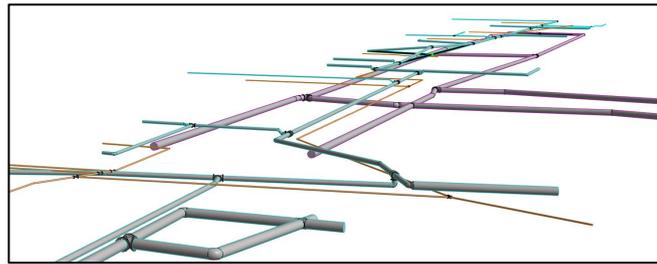


Figure 11. MEP model on Revit.

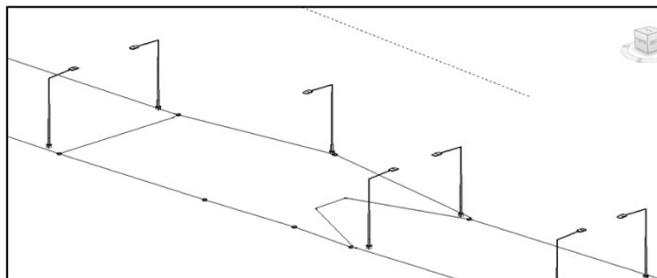


Figure 12. Public street lighting system model on Revit.

A decidedly interesting aspect that the BIM methodology has allowed in relation to existing subservices is inherent in the three-dimensional modeling of these, allowing one to study their interaction with the other entities of the work in question. It should be emphasized that this is a considerable advantage if one considers that the managing bodies rarely have them, providing only planimetric and often obsolete information.

Carefully following the indications on the two-dimensional design tables, it was observed that these underground utilities were not in any way interfering with the works foreseen in the case study; with the sole purpose of carrying out an interference analysis (Clash Detection), two levels were varied within the aqueduct and low-pressure gas systems, purposely leading to coarse interferences that could be correctly identified by the management analysis software and consequently resolved.

### 3.4. “Clash Detection” Structure

One of the most interesting practical implications of the arrangement of a multi-disciplinary model is expressed in the possibility of carrying out detection of possible interferences through the so-called “Clash Detection” activity.

In this regard, in Italy, the voluntary regulation UNI 11337-5/2017 indicates how the data and information contained in different graphic models belonging to a specific digital construction process must be coordinated with each other; in particular, it defines this activity as second level coordination (LC2) which can take place through the simultaneous aggregation of the information content of multiple graphic models, as indicated by Figure 13.

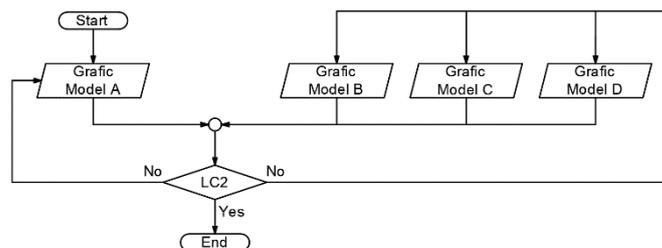


Figure 13. Level 2 Coordination workflow.

The co-ordination activity is not limited only to the automatic detection of geometric interferences between the various information models produced, but extends to controlling the activity of the information present in the models. This way all missing information, design inconsistencies, wrong decisions and inadequate use of resources emerge during the design phase, before starting the works, allowing one to anticipate problems before they occur as delays and increased expenditure during construction. The most evident advantage is found in a saving of time and resources that would otherwise be required to rework new design solutions, revisions and variants in advanced stages of the design or even during construction. In order to perform a Clash Detection analysis for the presented case study, an ad hoc parameter was created to distinguish the different elements of the individual sub-models by discipline; in particular, the following categories have been assigned:

- Structures (existing buildings and tramway stop structure);
- Tram substructure (from lean concrete to ERS/CRS blocking);
- Armament (60R2 rails and ERS/CRS system);
- Roads (lanes, curbs and sidewalks);
- Tram subservices (MV, fiber, traction ground, LV, feeder);
- Lighting (light poles, protective tubes and junction boxes);
- Existing systems (aqueduct, low-pressure gas and sewage system).

The grouping of objects by discipline is fundamental for the drafting of the so-called “coordination matrix”, which is a double-entry table linking the categories listed above to each other, to indicate the types of collision (clash) that could develop in the project, allowing to anticipate unsolvable problems on-site and to reduce the number of variations during construction. In this regard, two types of clashes are analyzed in the case study, such as:

- HARD “H” → by intersection;
- SOFT “S” → for space margin (Clearance clash).

The first type represents two or more objects occupying the same physical space or two objects that interpenetrate to an equal or greater extent than a certain assigned tolerance. The second represents an object that can hinder the movement of other objects or instances when objects need more spatial or geometric tolerances due to movement, space, installation and connection requirements, identifying situations in which two objects do not physically overlap but their proximity is such that it is impossible or excessively difficult to assemble and/or maintain them, and therefore the minimum distance between them is not respected.

A tolerance expressed in the order of centimeters is also attributed to the type of interference, which is established according to the design level, the degree of priority assigned, and the type of element being analyzed: as the design level increases, the accepted tolerance will decrease.

#### 4. The Managing Phase

The concept of a “federated” model is characterized by its interdisciplinary nature, as it involves the integration of several three-dimensional sub-models relating to the various building disciplines (architecture, structure, plant engineering and infrastructure) which are united by correct geo-referencing and which can be managed simultaneously in a single digital environment. The first step in creating such a model in Navisworks is to export the sub-models relating to the different disciplines in an open format that allows interoperability, such as the IFC (Industry Foundation Classes), which is expressed in a particular open file format that allows the interchange of an information model without loss or distortion of data and/or information, maintaining unaltered the structure of the whole and of the individual parts: the objects will have a precise location in space and will be distinguished by categories, characteristics and function [36,37]. Following the assembly of the sub-models inherent in the various disciplines, it is possible to approach various other activities, including the search for interference (Clash Detection) and the preparation of a

temporal simulation in four dimensions. The results of both these activities are presented in the case under study.

#### 4.1. Data Organization

For the correct and optimized management of the aggregate model, a structured data implementation is vital. For this reason, it is useful to build a data and information mapping file, which allows the obtaining of correspondence between the entities when switching from any authoring software to an open format such as IFC [38].

This aspect represents one of the foundations of the BIM methodology, which differs from three-dimensional modeling activity precisely because of the attention paid to the data and its implementation within the model with a view to interoperability.

Firstly, it carried out Clash Detection and 4D simulation activities following the aggregation of sub-models, and an IFC mapping file was created for the presented case study, or a grouping and filtering sheet information, viewable in the objects in open IFC, called PSet, aiming to convert information in the import/export phase into IFC format and allowing the entities produced with the various authoring software to be recognized.

In particular, the three-dimensional objects were characterized within both modeling software used (Civil 3D and Revit) by creating ad hoc parameters necessary to optimize the management of the aggregate model, such as:

- WBS coding;
- CLASH category;
- Type of plant (in the MEP case);
- Creation phase;
- Demolition phase.

It should be emphasized that the construction of the information model is in analogy with the structuring of an information database. The more coherent, codified and well-structured this information is, the better the BIM uses can be made of it.

Through this parameterization, in fact, regardless of the intrinsic characteristics of the individual entities of the different sub-models, an optimization is obtained in the selection and grouping of objects, enabling the performance of filters on the data aiming to carry out a specific management activity [39–41].

The implementation of a model information database proved to be the most effective way of collecting the properties of objects, allowing them to be defined in any aspect that is considered important for design purposes, avoiding the dispersal of data. A model defined in this way, therefore, is easily accessible and readable even by those who have to carry out the work in the project, eliminating a whole series of paper documents which, although referring to the same object, would be unconnected and difficult to read as a whole.

#### 4.2. Clash Detection Activity

Based on the types of collision, the co-ordination matrix in Table 1 was constructed based on the clash categories assigned about the various disciplines in the model; in Table 2 it is possible to consult the legend of the degrees of priority of the clash.

The preparation of these matrices is necessary for the definition of the clash activities within the coordination software, in this case, Navisworks Manage, obtaining for example a list of analyzes to be carried out as shown in Table 3.

**Table 1.** Coordination matrix for Clash Detection activity.

	<i>Strutture</i>	<i>Strade</i>	<i>Sottostruttura tram</i>	<i>Armamento</i>	<i>Sottoservizi tram</i>	<i>Illuminazione</i>	<i>Impianti esistenti</i>
<i>Strutture</i>	-						
<i>Strade</i>	S01	-					
<i>Sottostruttura tram</i>	S005	H01	H01				
<i>Armamento</i>	-	-	H01	H01			
<i>Sottoservizi tram</i>	H001	H001	H001	-	-		
<i>Illuminazione</i>	-	H01	H01	-	-	-	
<i>Impianti esistenti</i>	-	H01	S10	-	H01	-	S20

**Table 2.** Legend of the degrees of priority of the clash.

<i>Legend</i>		
<i>Denomination</i>	<i>Clash Type</i>	<i>Priority</i>
S001	Soft Clash—0.1 cm	High
S01	Soft Clash—1 cm	High
S10	Soft Clash—10 cm	Medium
H001	Hard Clash—0.1 cm	Medium
H01	Hard Clash—1 cm	Low

**Table 3.** Clash Detection activity on Navisworks Manage.

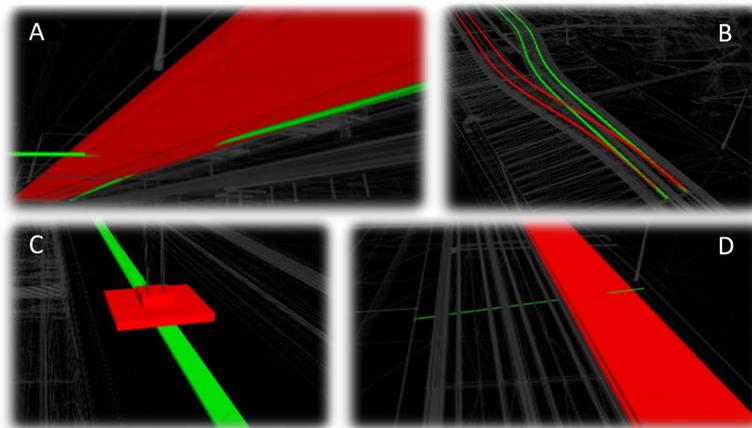
<b>Name</b>	<b>Status</b>	<b>Clashes</b>	<b>New</b>	<b>Active</b>	<b>Reviewed</b>	<b>Approved</b>	<b>Resolved</b>
H01—Armament vs. Armament	Done	2	0	0	0	2	0
H01—Existing Systems vs. Roads	Done	3	3	0	0	0	0
S01—Existing Systems vs. Tram Substructure	Done	1	1	0	0	0	0
H01—Lighting vs. Tram Substructure	Done	2	2	0	0	0	0
H01—Lighting vs. Roads	Done	2	1	0	0	1	0

Some examples of the interferences found are shown in Figure 14, where it is possible to observe a “Hard Clash” between:

- Tram substructure and underground services (Figure 14A,D);
- Armament—heart and frame of the switches needles (Figure 14B);
- Foundation plinth of the bus shelter and underground services (Figure 14C).

When reporting upon design clashes, the main contractor produces periodic clash detection reports that contain information including:

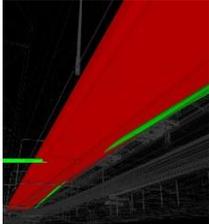
- Thematic groupings of clashes that report upon individual clashes within each compartment category (for example, and in this research “Existing Systems vs. Tram Substructure”);
- Snapshots of every clash identified to aid communication with all designers;
- Clash point coordinates (as x, y and z coordinates) to determine the exact pin-point location of the clash within the federated BIM model;
- The date that the clash was found;
- Clash status (active and unresolved or resolved);
- A written description of the clash;
- A numerical value in meters (m) or millimeters (mm) that quantifies the positional (clash) error [41].



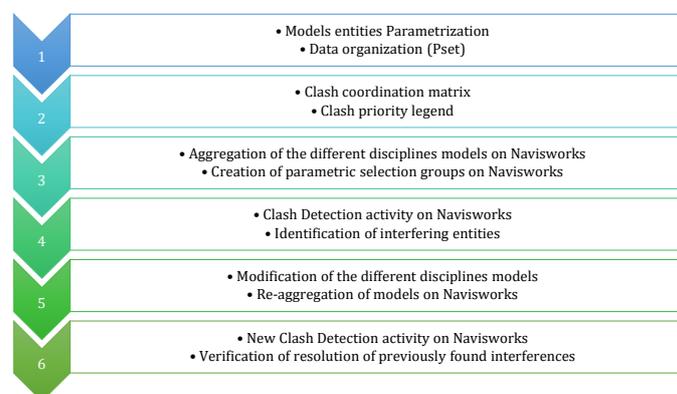
**Figure 14.** Examples of clashes found in the case study. In A and D there is the tram substructure and underground services; in B there is the armament i.e the heart and frame of the switches needles; in C there is the foundation plinth of the bus shelter and underground services.

An example of these periodic reports is shown in Table 4. It defines in detail an interference identified between an existing service and the road alongside the planned tram system.

**Table 4.** Example of Clash Detection report in HTML format.

Image	Clash Name	Status	Distance	Description	Date found	Clash Point	Item 1 ID	Item 2 ID
							Layer Name	Layer Name
	Subservice 1	Active	-0.291	Hard	04/05/2022	x: 682,041.990 y: 4,931,428.177 z: 43,679	Existing Systems	Roads

The detected interferences were then resolved by appropriately modifying the sub-models for the individual disciplines, re-aggregating them within Navisworks and finally re-executing the interference analysis to see if the aim had been achieved. Figure 15 shows a flow diagram of the activities to perform a correct and effective clash detection activity.



**Figure 15.** Activity workflow for an effective Clash Detection.

### 4.3. 4D Temporal Simulation

The study of the construction site phases is extremely important as it influences many aspects of the design, such as the management of the road network, the movement of materials, the succession of individual processes and the spatial and temporal coordination of activities. In this regard, the addition of the time variable to the three spatial dimensions extends the use of CAD tools from the design phase to the construction phase [39–41]. In fact, 4D modeling allows the combination of planning data (temporal) with spatial data (geometric), facilitating the analysis of different production strategies before the start of on-site work [41]. For this reason, similarly to what has been done for the clash detection activity, in order to create a 4D temporal simulation model for the presented case study ad hoc parameters have been created on the basis of the Work Breakdown Structure of the final design (WBS) of the Red Line, which would allow placing the different elements of the individual sub-models within the specific works of the site. Following the definition of the WBS codes and the timing of each process with any contemporaneity, parametric search groups have been created for the correct association of the objects with the related machining operations. The purpose of this process was to implement the so-called “Time Liner” within the Navisworks software, or the equivalent of the Gantt Chart, the result of which is shown in Figure 16.

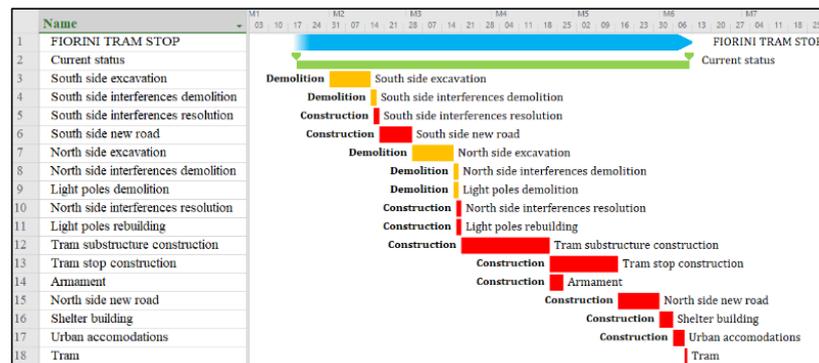


Figure 16. Gantt Chart of construction site phases.

For a clear and correct representation of the single worksite phases, a typical chromatic coding of buildings has been adopted, namely that of yellows and reds for demolitions and new constructions, respectively. To obtain this distinction in the assignment of the work phases to the individual entities of the model, the ad hoc parameters “Creation phase” and “Demolition phase” referred to in the previous paragraphs have been created, thus making data and information management more fluent (Figure 17).

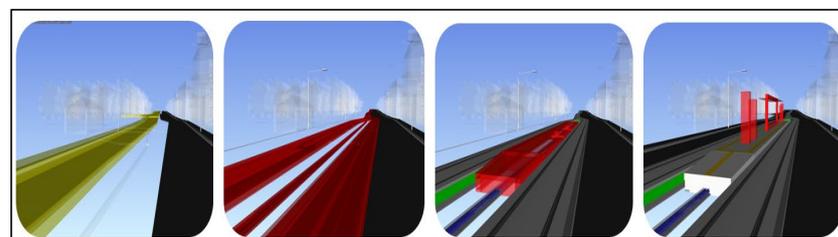


Figure 17. Example of subsequent construction work.

In the specific case study presented, the assignment of the demolition and creation phases to the individual project entities made it possible to obtain a complete view of the work execution process; one of the consequent aspects was the possibility of assigning a resolution schedule to the individual interferences identified between the works already in the design phase, which would have been much more complex and costly in the absence of a single source of data and information to be analyzed. Furthermore, given the completeness

of the model from an information point of view, it is easy to modify it during the project for any requirement, quickly adapting the entire project to the new directives.

## 5. Conclusions

The I-BIM methodology has proven to be a tool with enormous potential for optimizing and simplifying infrastructure design. However, in some respects, it has not yet reached a level of maturity where it can be applied simply and effectively to all types of infrastructure. In this case, the possibility of creating a multidimensional parametric model of the tramway has made it possible to have an overall view of the same, with particular reference to its multidisciplinary nature. It was also possible to perform model management analysis, potentially optimizing time and economic resources. For the effective management of the model and the provision of a range of information that would otherwise be complicated and costly to associate with individual entities, the correct data and information organization proved essential. This process made it possible not only to parameterize the objects, making it easy to modify them, but also to optimize the management processes of the multidisciplinary model.

However, while I-BIM offers considerable advantages such as those described above, it also has some shortcomings, which emerged as a result of some difficulties encountered, particularly with regards to 3D modeling and the use of open interchange formats. The first limitation of Civil 3D modeling concerns the impossibility of using an automated control of compliance with the minimum standards by law for all types of tracks. In fact, the tramway tracks have not actually been conceived according to the Italian Railway Elevation Standards (as assumed in the case study) but refer to other standards (UNI 7156—“Tramways and fast tramways. Minimum distances of fixed obstacles from rolling stock and inter-railway. Height of contact line” and UNI 7836 -“Undergrounds and tramways—Plano-altimetric layout of tracks”), which have not yet been implemented in the software. As Civil 3D is widely used by infrastructure designers, this situation is hopefully a temporary shortcoming on the software side, given the considerable advantage that automated control of regulatory standards entails in the design phase, although manual control by the designer remains essential. Another aspect highlighting the current lack of software such as Civil 3D for tram applications was the need to use the external “Subassembly Composer” module for the construction of typological cross-sections of the tram system; this is because the subassemblies proposed in the Italian “Country Kit” for railways are not sufficient to correctly represent the tramway substructure, thus making ad hoc modeling of the system necessary. However, one of the most discussed shortcomings in the BIM world, also found in the case study presented, is inherent in the insufficient maturity of open formats such as IFC for the interchange of so-called “horizontal” objects; for these entities, in fact, it was necessary to extract the solids for the export of the infrastructural model, effectively losing information relating to the layout and height profile.

In the present case, the I-BIM methodology, through the combination of three-dimensional modelling software (such as Civil 3D and Revit) and model management software (such as Navisworks Manage) used, is considered to be a valid design method at any level (preliminary, final or executive). There remain gaps in the interoperability between the tools required in terms of a direct connection between them: as a result of minor changes to models, a new export in open IFC format from the modelling software was required before the overall model of the work could be re-examined, making the management process disconnected from the modelling process, thus slowing down the entire production process. This can represent the starting point for the future application of this methodology, in full cohesion with innovative artificial intelligence.

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