

## EXPLORING 4D AND 5D ANALYSIS IN BIM ENVIRONMENT FOR INFRASTRUCTURES: A CASE STUDY

L. Inzerillo<sup>1</sup>, F. Acuto<sup>1\*</sup>, A. Pisciotta<sup>1</sup>, K. Mantalovas<sup>1</sup>, G. Di Mino<sup>1</sup>

<sup>1</sup> DIING, Department of Civil Engineering, University of Palermo, Italy

### Commission II

**KEY WORDS:** BIM, Infrastructures, 4D, 5D, Railway station.

### ABSTRACT:

Building Information Modelling (BIM) has emerged as a focal point in the construction industry, garnering substantial attention due to its capacity to elevate product quality, facilitate accurate quantity determination, and enhance scheduling efficiency. The inherent complexity of construction projects necessitates the integration of BIM models endowed with automation functionalities for schedules and cost estimation. This integration ensures that updates seamlessly occur throughout the construction process, thereby mitigating project uncertainties and reducing overall costs. While the potential benefits of BIM are recognized, a substantial challenge persists in the Architecture, Engineering, and Construction (AEC) field defining workflows for the automated generation of optimized 4D/5D BIM simulation and analysis. The effective utilization of BIM as a transformative tool requires addressing this challenge to unlock its full potential in project management. BIM serves as a pivotal conduit for project data, providing a structured approach to elevate overall product quality, streamline processes, and minimize contingencies and costs associated with construction projects. Consequently, the successful implementation of BIM with automated 4D/5D simulation and analysis stands as a critical milestone in advancing the capabilities of the AEC industry, ensuring greater efficiency, accuracy, and cost-effectiveness in construction projects. According to these aspects, the time-cost analysis (4D/5D) of a project for the North-South railway station in Riyadh, designed by Architect Engineer Dia Hilal, was investigated.

### 1. INTRODUCTION

Building Information Modelling (BIM) plays a pivotal role in reshaping the conventional approach of the construction industry, transitioning from two-dimensional (2D) drawing information systems to three-dimensional (3D) object information systems. This paradigm shift transforms the documentation methodology in building design and construction, replacing manual, human-readable practices with digital descriptions of building elements seamlessly integrated with time and cost, which are computer-readable (Arjun R. Pandey and Farzad Shahbodaghlu, 2016; Kelly et al., 2013; Mihindu and Arayici, 2008; Vacanas et al., 2016). This evolution is encapsulated in the concept of n-dimensional (n-D) modelling, where diverse informational "dimensions" are merged into a comprehensive digital building model (Kagioglou, 2003).

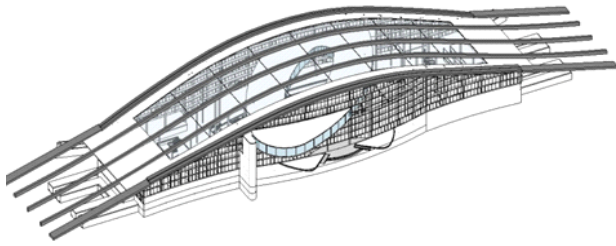
The BIM framework, developed to delineate deliverables for Architecture, Engineering, and Construction (AEC) stakeholders, aims to achieve Integrated Project Delivery (IPD) (Akinci et al., 2002). Notably, time, a non-material but crucial element in construction projects, is presented through various perspectives, including time-space conflicts and construction schedule visualization (Chau et al., 2004; Heesom and Mahdjoubi, 2004). The incorporation of time into project assessment is exemplified by 4D Computer Aided Design (CAD), forming the foundation for 4D BIM and construction progress measurement (Kim et al., 2013).

In the realm of cost estimation, accuracy during the early stages of construction projects is widely acknowledged. Historically, cost estimation relied on user experience due to the absence of comprehensive information in the early project phases (Kaming et al., 1997). The advent of 5D BIM bridges this information gap, offering improved project financing and cash flow control. The integration framework of cost and schedule, evolving rapidly, shapes management systems and repetitive construction processes (Hegazy, 2022; Trost and Oberlender, 2003).

The isolated presentation of construction project data, such as time and cost, often lacks meaningful insights. The integration provided by 5D BIM, incorporating building information (3D), time (4D), and cost (5D), aligns with this framework, transforming isolated data into intelligent information with diverse applications (Forgues et al., 2012; Liu et al., 2014). Multi-disciplinary performance models of 5D BIM, utilized through Virtual Design and Construction (VDC), enhance information sharing, comparison, and project integration among stakeholders (Lu et al., 2018; Venturini et al., 2018). VDC ensures consistency and accuracy checks for various dimensions of information, offering graphical coordination of design, operation, and construction. Employing BIM software, this process combines 3D building components, 4D time scheduling, and 5D cost estimation, presenting a comprehensive and intuitive approach to project management (Fischer et al., 2004; Kunz and Fischer, 2020, 2012).

An efficient control technique should incorporate a systematic recording method that encompasses substantial information from various sections of the project. Therefore, the development of integrated modules for cost assessment and control is essential to advance the field of building control (Hardin, 2009). This integrated approach facilitates informed decision-making with proactive measures, addressing cost-related challenges throughout the entire construction process (Solnosky, 2017; Solnosky and Luth, 2015).

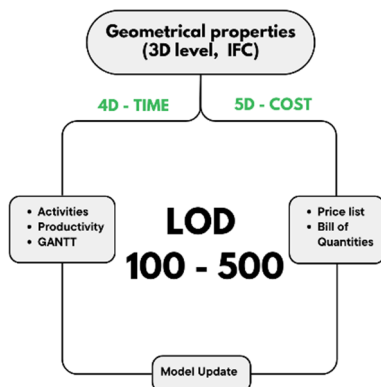
In this study, following the 3D parametric modelling, a time-cost analysis (4D/5D) of a project for the North-South Riyadh railway station designed by Architect Engineer Dia Hilal was investigated. Operating as a crucial element in the Riyadh railway network, the station exemplifies a meticulous application of design principles to optimize both functionality and spatial efficiency. Architect Hilal's design strategy for the North-South Riyadh Railway Station underscores a focus on a rationalized layout, enhancing passenger flow and operational efficiency without compromising a cohesive aesthetic.



**Figure 1:** 3D Revit model of the North-South Riyadh Railway Station.

## 2. METHODOLOGY

Cost estimation involves forecasting the probable costs of a project with defined future scope, position, and completion point. The accuracy of estimates, crucial for business decisions and budget definition, is directly linked to the precision of the project scope. Reliable cost analysis relies on the accuracy of quantitative metric computation, construction methods, and physical project parameters. The Building Information Modeling (BIM) Level of Development (LOD) reflects the accuracy of information, ranging from LOD 100 to 500. Throughout different phases of the project life cycle, LOD influences model characteristics for accurate cost estimation. Initial phases (LOD 200) allow preliminary budget estimates, while the final design (LOD 300) provides more precise estimates. In the bidding phase, accuracy depends on the procurement process, with design-build projects requiring LOD 350 or higher. BIM expedites quantitative computations, facilitating cost analysis and providing real-time design and cost exploration. Owners benefit from illustrated design ideas and detailed building data, reducing long-term operational and maintenance expenses. The BIM model, reaching LOD 500, ensures quality, subcontractor interfacing, project commissioning, and continuous operation and maintenance (Venturini et al., 2018). The integration of the 4D BIM dimension links project plans with 3D model components, facilitating the comparison of different proposal plans. This visual representation of work sequences and activity durations offers various advantages: i) identification of issues not apparent in traditional schedules; ii) the ability to run scenarios to assess execution feasibility and find optimal solutions; iii) 3D visualization of impact after updating the Gantt chart.



**Figure 2:** 4D/5D BIM implementation flow chart

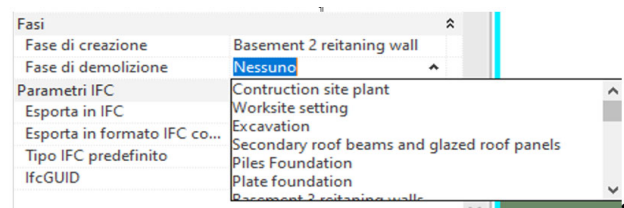
Furthermore, 5D simulation generates models that assess how changes to materials, layouts, and construction methodologies impact the infrastructure layout and costs. This aids in identifying resource utilization over time, with construction costs adjusting automatically in real-time with model changes. The "what-if"

functionality becomes a productive solution for project teams to explore and identify the optimal design layout. In summary, the combined use of 4D and 5D technologies enhances (Abdel-Hamid & Abdelhaleem, 2023) project planning, visualization, and cost analysis, providing a comprehensive set of tools for efficient decision-making throughout the construction process.

## 3. CASE STUDY

The case study on the use of BIM in the Revit® software for the design of the North-South railway station in Riyadh highlights the potential benefits of adopting this technology in the infrastructure sector. The use of BIM in Revit has improved project efficiency, reduced errors, and facilitated coordination among various disciplines involved in station design. The success of implementing BIM in Revit underscores the importance of using software with advanced features for seamless BIM integration (Figure 1) (Carneiro et al., 2019; Inzerillo et al., 2023b, 2023a).

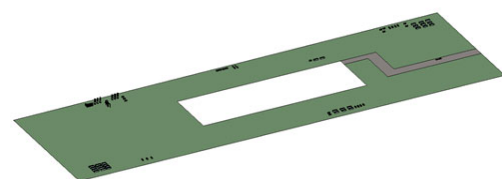
The case study has reached the maximum Level of Detail (LOD), following a path independent of other elements in the BIM. The research aims to create a BIM model that evolves from a 3D model to 4D and 5D. The management of work phases can be carried out directly in Autodesk Navisworks®, but it is more convenient to parameterize the phases in Revit during the design to simplify the selection of elements (Figure 3). The creation of work phases in Revit already allows for a 4D management of the model, with the possibility of extrapolating temporal information of the elements through the creation of schedules.



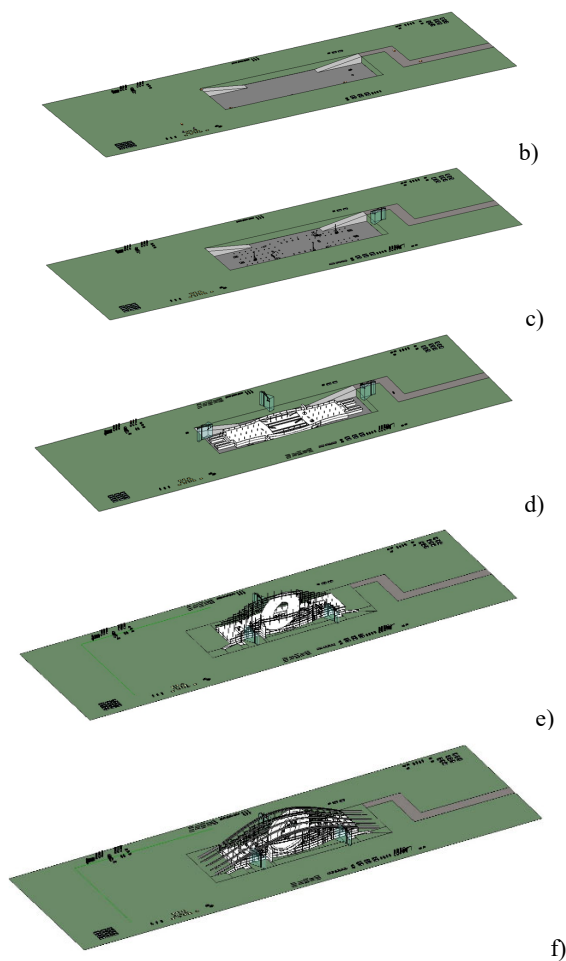
**Figure 3:** Parametrization of phases in Revit.

Each phase generated comprises a designated selection element with assigned time parameters in Navisworks. The Revit model needs meticulous creation to accommodate temporal construction, with the 4D approach initiating during the design phase.

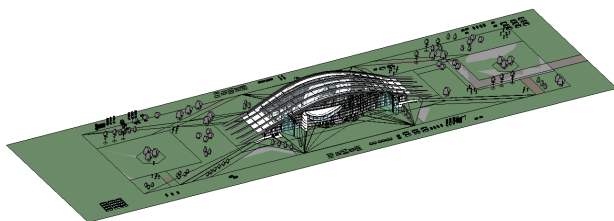
In the initial modelling stage of the railway station in Revit, the process initiates by defining the construction area, establishing boundaries and parameters to guide subsequent development phases. Transitioning to the construction phase, the model undergoes a site division process, delineating distinct areas and integrating pertinent structures. The subsequent excavation phase forms the foundation of the station, identifying excavation routes and equipment and incorporating them into the model for a comprehensive representation. Progressing to foundation work, the groundwork is laid for the structural elements supporting the station. As the model evolves, construction advances to the multi-story structure, capturing the distinctive features of each floor (Figure 4).



a)



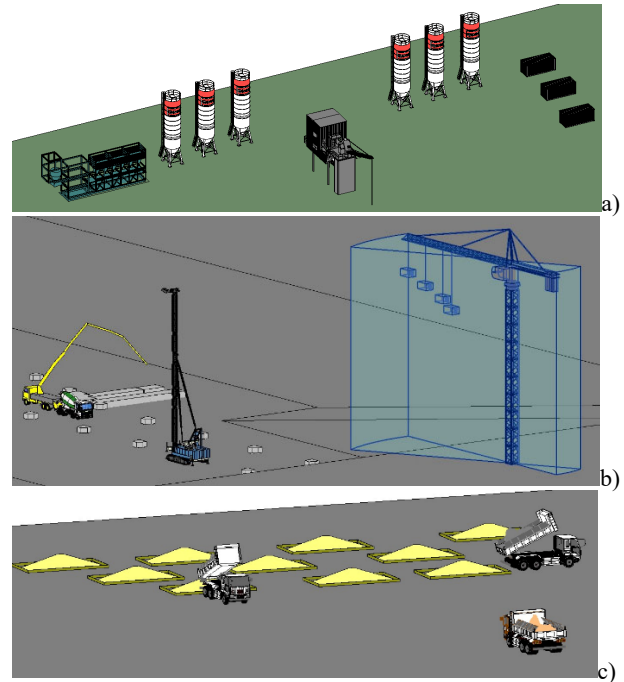
**Figure 4:** Visualization of selected construction phases modelled in Revit: site organization and installation of systems (a); excavation phase (b); foundation works (c); construction of the structure floor by floor (d); erection of elevated structures (e); installation of roof beams (f).



**Figure 5:** Visualization of completed infrastructure.

Ultimately, a comprehensive representation of the railway station is crafted, seamlessly integrating all elements and intricate details to faithfully mirror the finalized infrastructure (Figure 5).

Within a BIM model, elevated levels of detail concerning construction logistics were achievable. The identification of spaces and pathways was carefully assessed by considering the actual footprint of installations, machinery, and equipment within the model (see Figure 6).



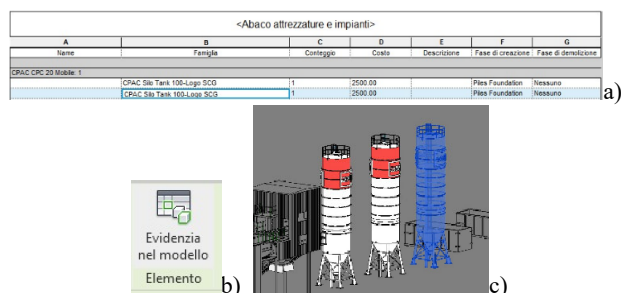
**Figure 6:** Display of specific families of systems, equipment, and machinery modelled in Revit for the construction phase: inert and concrete production plant (a); machinery used for drilling and casting piles (b); identification of temporary waste deposits for excavated soil (c).

Precise integration of facilities, equipment, and machinery at each construction phase in the BIM model also enabled the generation of comprehensive schedules and quantities through the Revit software (Figure 7). By creating these schedules, a cost computation for all model elements, including construction equipment, has been effortlessly obtained within Revit. The computation process involved incorporating the cost parameter and manually inputting the cost value for each element to be assessed. Utilizing this approach for cost extrapolation proved beneficial in the initial stages of economic computation and served as a fundamental reference in the development of bill of quantities for the project.

<Abaco attrezzature e impianti>						
A	B	C	D	E	F	G
Nome	Famiglia	Connessione	Costo	Descrizione	Fase di creazione	Fase di demolizione
Architectural Hardware_... BOM 138_ASSAABLOY Israel_89103030_95	CPAC CPC 15 Star Type	1	10000.00		Pile Foundation	Nessuno
10000.00	CPAC CPC 15 Star Type	1	15000.00		Worksite setting	Nessuno
15000.00	CPAC CPC 15 Star Type-2	1	20000.00		Worksite setting	Nessuno
20000.00	CPAC CPC 20 Mobile-1	1	2500.00		Pile Foundation	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Pile Foundation	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Pile Foundation	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Worksite setting	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Worksite setting	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Worksite setting	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Worksite setting	Nessuno
	CPAC Site Tank 180-Logg SCG	1	2500.00		Worksite setting	Nessuno
2500.00	CPAC Site Tank 180-Logg SCG-9	1	2500.00		Worksite setting	Nessuno

**Figure 7:** Excerpt from a construction equipment and facilities schedule generated using Revit software.

The simplification of element identification in the estimate was enhanced through the creation of schedules in Revit, offering a visual reference to each element within the model (Figure 8). The development of schedules not only facilitated tracking cost progression directly in the software but also allowed for the filtering of costs based on designated construction phase parameters established for the model. This modeling approach fostered connections between individual elements and their corresponding materials, streamlining construction projects and elevating estimate accuracy through intelligent data linkages.

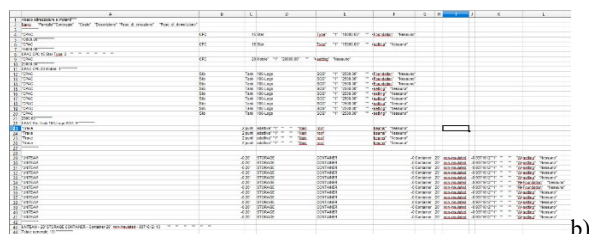


**Figure 8:** Dynamic presentation of selected elements in the Revit schedule: selection of the element in the schedule (a); Revit command to highlight the element in the model (b); visualization of the selected element in the schedule (c).

The schedules produced in Revit were exported as \*.txt files, providing the ability to open them in spreadsheet software for a direct extraction of quantities and descriptions of various elements within the BIM model (see Figure 9). While the export feature facilitated data modification and integration, there was a need for formatting adjustments in the exported text file when accessed in a spreadsheet. Additionally, any subsequent changes to the model only refreshed the Revit schedules, necessitating the re-exportation of data for further computations.

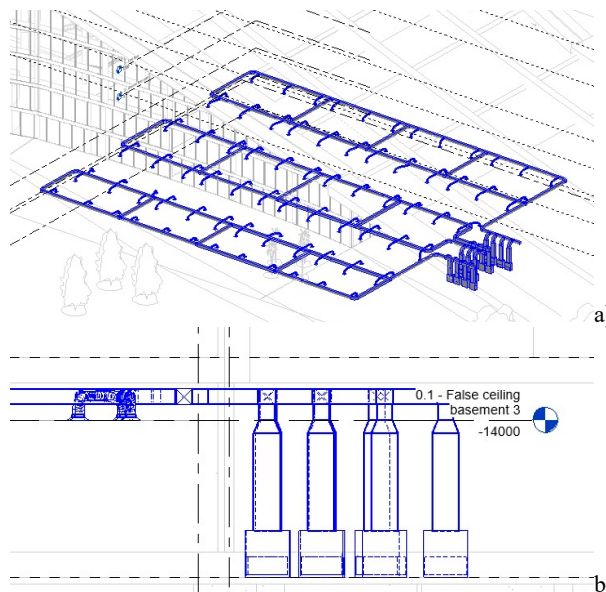
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<Abaco attrezzature e impianti> ***
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***
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"18000.00" "" "" "" "" ""
"CPAC CPC 15 Star Type: 1" "15000.00" "" "Worksite setting" "Nessuno"
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**Figure 9:** Excerpt of text file exported from the Revit schedule (a); conversion of the text file into a spreadsheet (b).

The Revit software was employed to create a model depicting the MEP (Mechanical, Electrical, Plumbing) manufacturing design, with the aim of sharing it with construction detail drafters. Utilizing the architectural and structural building models already in place, the mechanical ventilation system for Basement 3 of the station was meticulously developed. This approach enabled the early identification of notable challenges related to interferences between the ventilation system and other components during the design phase. Modelling the ventilation mechanical system in Revit facilitated the seamless integration of all essential components necessary for the system's implementation (Figure 10).



**Figure 10:** Visualization of the modelled mechanical ventilation system in Revit: Basement 3 system view (a); detailed technical view of the ventilation system (b).

Concerning the systems, it was also possible to generate quantity schedules directly, delineating the costs associated with different components (see Figure 11). These schedules allowed for the extraction of cost values for the system components by inputting pertinent information into the cost parameter.

<Abaco dei condotti>					
A	B	C	D	E	F
Famiglia e tipo	Lunghezza	Quota altimetrica in	Dimensioni	Nome sistema	Costo
Condotta rettangolare: Raggio gomiti / T	9660	5500	500x500	Meccanica Aria di mandata 6	
Condotta rettangolare: Raggio gomiti / T	18946	5500	500x500	Meccanica Aria di mandata 6	
Condotta rettangolare: Raggio gomiti / T	12345	5500	500x500	Meccanica Aria di mandata 1	
Condotta rettangolare: Raggio gomiti / T	18946	5500	500x500	Meccanica Aria di mandata 1	
Condotta rettangolare: Raggio gomiti / T	10610	5500	500x500	Meccanica Aria di mandata 6	
Condotta rettangolare: Raggio gomiti / T	18860	5500	500x500	Meccanica Aria di mandata 6	

<Abaco dell'attrezzatura meccanica>				
A	B	C	D	E
Famiglia e tipo	Nome sistema	Livello	Produttore	Costo
M_Unità di gestione deFaerazione - Split Syste	Meccanica Aria di mandata 1	0 - Basement 3		
M_Unità di gestione deFaerazione - Split Syste	Meccanica Aria di mandata 124	0 - Basement 3		
M_Unità di gestione deFaerazione - Split Syste	Meccanica Aria di mandata 6	0 - Basement 3		
M_Unità di gestione deFaerazione - Split Syste	Meccanica Aria di mandata 5	0 - Basement 3		

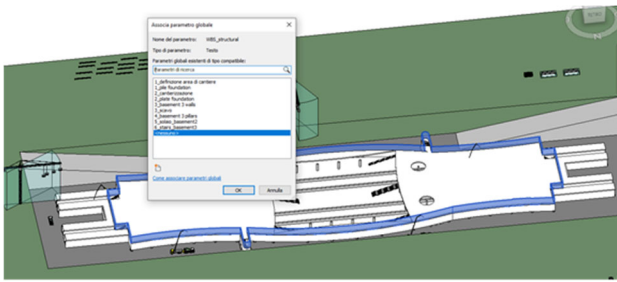
**Figure 11:** Excerpts from schedules of the mechanical ventilation system obtained with Revit: ducts schedule (a); mechanical equipment schedule (b).

## 4. RESULTS

### 4.1 4D Outputs

The implementation of 4D analysis using Navisworks® involves a comprehensive approach that extends beyond conventional project management. The process commenced with the development of a 3D model in Revit, incorporating diverse project elements and speculating on their respective temporal sequences. To streamline element selection in Navisworks, relevant shared parameters of a textual nature were established in Revit. These parameters, linked to the various elements within the 3D model, facilitated the creation of selection filters in Navisworks for associating the temporal parameters of different activities (Figure 12). The optimization of assigning shared parameters to the various model components was achieved through the prior establishment of work phases.





**Figure 12:** Linking the shared parameters created in Revit to the different elements constituting the model.

The choice of components constituting composite elements, like walls, in Navisworks, had to be made explicitly within the model selection structure. An alternative option would have involved creating the wall directly in Revit as individual, separate layers rather than as an element composed of different layers (Figure 13).

Funzione	Materiale	Spessore	Ripiegature	Materiale strutturale	Variable
1 Struttura [1]	Intonaco - Bianco 0,0250		<input checked="" type="checkbox"/>		
2 Contorno del nucleo Strati sopra ripiegat 0,0000					
3 Struttura [1]	Default - Muro 0,7500			<input checked="" type="checkbox"/>	
4 Contorno del nucleo Strati sotto ripiegat 0,0000					
5 Finitura 1 [4]	Intonaco - Bianco 0,0250		<input checked="" type="checkbox"/>		

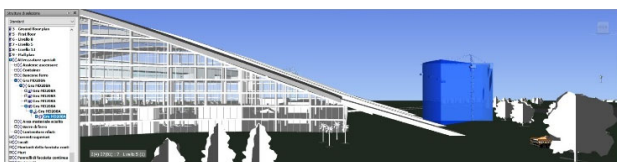
**Figure 13:** Wall stratigraphy in Revit.

Through the implementation of schedules in Revit to quantify materials, the economic computation of individual layers was facilitated, enabling a more detailed cost evaluation. Regarding information about the temporal phases of execution, each individual layer was automatically assigned the same phase for both creation and demolition, thereby hindering a nuanced distinction between the layers themselves (Figure 14).

<Computo dei materiali muro>						
Materiale	Descrizione	Materiale Area	Materiale Volume	Costo	Fase di creazione	Fase di demolizione
Muro di base: Generico - 60 cm						
Intonaco		922,7 m <sup>2</sup>	13,8 m <sup>3</sup>		Basement 3 retaining walls	Nessuno
Parete in CLS armato		473,5 m <sup>2</sup>	262,8 m <sup>3</sup>		Basement 3 retaining walls	Nessuno
Muro di base: Generico - 60 cm						
Intonaco		18133,8 m <sup>2</sup>	453,3 m <sup>3</sup>		Basement 3 retaining walls	Nessuno
Parete in CLS armato		9069,9 m <sup>2</sup>	6690,0 m <sup>3</sup>		Basement 3 retaining walls	Nessuno

**Figure 14:** Materials quantification schedule for a wall, including the identification of individual layers.

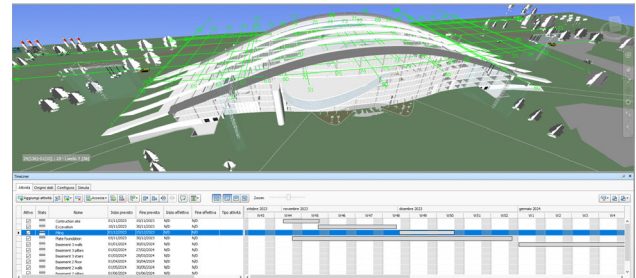
Each element within the imported model on Navisworks encapsulated all the information previously entered into the Revit software. The software organized the elements using a selection structure, allowing for the selection of objects or the identification of the selected object type within the model (Figure 15). Each individual element in the selection structure could be associated with an activity, which had to be reciprocally created in the TimeLiner for constructing the 4D model.



**Figure 15:** Identification of elements in the selection structure of Navisworks.

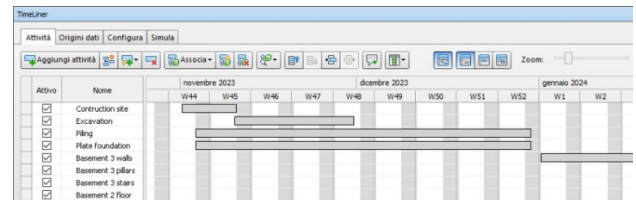
Following the import into Navisworks, the exploit of selections made possible by shared parameters, previously configured in Revit, allowed for the association of times with planned activities, greatly simplifying the creation of the 4D construction

model. Utilizing the assigned times for the model elements in Navisworks also facilitated simulations of the construction process (Figure 16).



**Figure 16:** Assigning timelines in Navisworks to different elements of the model.

The allocation of time to different elements automatically produced a Gantt chart, facilitating the scheduling of project completion times (Figure 17). Within the model's temporal parameters, it was also feasible to input both the actual and planned dates of tasks, thereby enabling real-time simulations even during the construction phases.



**Figure 17:** Gantt chart generated in Navisworks by assigning timelines to selected elements in the model.

## 4.2 5D Outputs

Beyond temporal planning data, Navisworks facilitated model integration by incorporating cost, enabling a thorough 5D analysis. The association of costs with activities could be performed by considering either total costs or by breaking them down into categories present in the software: material cost, labor cost, equipment cost, subcontractor cost (Figure 18).

Nome	Stato	Inizio previsto	Fine prevista	Inizio effettivo	Fine effettiva	Tipo attività	Associazione	Costo totale
Construction site		01/11/2023	10/11/2023	N/D	N/D		Gruppi->Co...	185.000,00
Excavation		10/11/2023	30/11/2023	N/D	N/D		Gruppi->Ex...	320.000,00
Piling		03/11/2023	30/12/2023	N/D	N/D		Gruppi->PIL...	20.000,00
Plate foundation		03/11/2023	30/12/2023	N/D	N/D			20.000,00
Basement 3 walls		01/01/2024	30/01/2024	N/D	N/D		Gruppi->Ba...	

a)

Costo materiale	Costo manodopera	Costo attrezzatura	Costo subappaltatore	Costo totale
10.000,00	25.000,00	100.000,00	50.000,00	185.000,00
20.000,00	200.000,00	100.000,00		320.000,00
20.000,00				20.000,00
20.000,00				20.000,00

b)

**Figure 18:** Assigning costs in Navisworks to activities (a); categories of costs that can be assigned in Navisworks (b).

From Navisworks, TimeLiner data could be exported in \*.csv or \*.xls format, viewable through electronic spreadsheet software or project management and planning software (Figure 19). However, akin to exporting data from Revit schedules, it was noted that after export, the data were not interpreted correctly and necessitated subsequent corrective interventions.



determining corporate safety charges, and conducting consistency checks—all encapsulated within a unified document directly linked to the Revit BIM model.

Although the Office version of ArchVISION had limited functionalities, it still ensured accurate data export without necessitating manual adjustments, as often required in exports derived from the generation of Revit schedules.

## 5. CONCLUSIONS

The case study examining the application of Building Information Modelling (BIM) in Revit for the design of the North-South railway station in Riyadh underscores the transformative impact of advanced technologies on the infrastructure sector. Demonstrating a successful implementation of BIM in Revit, the study reveals substantial improvements in project efficiency, error reduction, and enhanced collaboration across various disciplines involved in station design. The research's forward-looking approach aims to progress seamlessly from a 3D model to 4D and 5D models. The adoption of Autodesk Navisworks for 4D management, coupled with the strategic parameterization of phases in Revit during the design phase, exemplifies an efficient workflow. This approach not only simplifies the selection of elements but also facilitates the extraction of temporal information through the creation of schedules. The phased approach, spanning from defining the construction area to the final integration of all elements, provides a well-organized framework for construction management. The consideration of construction logistics within the BIM model, including precise identification of spaces and pathways, showcases the software's capabilities in facilitating detailed planning and analysis. The study further extends its application to Mechanical, Electrical, and Plumbing (MEP) manufacturing design, illustrating Revit's effectiveness in early detection of challenges and interferences during the design phase. The incorporation of essential components in the mechanical ventilation system underscores the software's capacity to address interdisciplinary concerns seamlessly within a unified platform. The implementation of 4D and 5D analysis using Navisworks represents a well-structured approach to construction project management. Acknowledging certain challenges, particularly in labor-intensive processes for detailed 4D and 5D representations, the study recommends specialized applications like ArchVISION RP as an efficient solution for detailed quantity takeoff and cost analyses. In conclusion, the case study provides a comprehensive exploration of the transformative potential of BIM in Revit for infrastructure design and construction. It not only emphasizes the software's capabilities in design, construction management, and interdisciplinary collaboration but also recognizes the need for specialized tools to address specific aspects of project analysis.

## ACKNOWLEDGEMENT

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