Chapter

BIM and Advanced Computer-Based Tools for the Design and Construction of Underground Structures and Tunnels

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Abstract

Technology and digitalization are continuously producing changes in sectors and fields of human activities. Infrastructure industry needs this support in various and extensive ways, since it affects involved parties and society overall. Even though many individual branches have been transformed, design and construction show some kind of reluctance on encouraging and implementing comprehensive digitalization. A major reason is the significantly high complexity of infrastructure projects and the extended chains of work procedures and activities that are produced. All those are applying through the whole time scale of buildings' existence. Considering that safety and durability remain always the ultimate goal, every new method and concept shall be exhaustively tested, in order to prove its value and efficiency. The current chapter aims to define and prove technology contribution all along the infrastructure sector, concentrating in tunnels and underground structures. Since evolution is proceeding in accelerated rates, future perspectives are also analyzed to provide broader visions and set indicative standpoints for potential and incentives.

Keywords: building information modeling, tunnel construction, design tools, automatism, clash detection, decision-making, digitalization, disciplines, IFC, interoperability, tunnel monitoring, operation and maintenance, sustainability, semantics, simulation, virtual construction, artificial intelligence

1. Introduction

Tunneling projects and underground structures compose infrastructure projects including a variety of aspects concerning disciplines, scientific domains, faculties, required skills, implemented rules, and requirements. All those, as well as the included further features, are executed and applied through the entire projects' chain, that is, from the initial perception and planning, to design and development, realization, and building of structures, ending up to operation and maintenance for the whole life cycle. In order to accomplish the above, a vast variety of tools and software and hardware items are used, aiming to combine and simultaneously fulfill all the scientific knowledge, standardized criteria, and respective codes.

The overall outcome consists of a complicated combination which is actually the core of many engineering projects. The differentiator factor is the fact that tunnel and underground structures are realized and function on a widely diverging scale (from km to detailed cm scale). More specifically, projects are realized and extended through multiple domains: survey and alignment, excavation and retaining measures, tunnel model and engineering, and detailed parts over the life cycle, such as boring machines, mechanical-electrical equipment, utilities, and many other components according to the tunnel's type and usage. Another distinctive side is the strongly interdisciplinary nature of tunnel infrastructure, resulting to a variety of specialties, stakeholders, suppliers, etc.

In combination with the uncertainty of ground properties and behavior, there is a clear necessity to detect and utilize all available and advanced design tools, with the aim to combine semantic, geometrical, and constructional aspects up to the final projects' accomplishment.

2. BIM and advanced design tools: definition from conception to development and future growth

Building Information Modeling (BIM) presents an infrastructure project in the form of three-dimensional representations of elements, which can be further associated with information about other characteristics and properties [1]. The created intelligent 3D model enables document management, coordination, and simulation during the entire life cycle of a project (plan, design, construction, maintenance, and operation). The evolution of technology-digitalization and the continuous progress in software and hardware equipment provided multiple capabilities to BIM. As a result, BIM has been converted from a design tool to a separate concept affecting all areas of engineering, and nowadays, it has been altered to define a whole industry applying to fields apparently irrelevant from engineering yet using the same technology and tools, focusing on similar goals, and sharing common inspiration.

It constitutes a main principle that *BIM as a term is not defining a specific and single software or process*. BIM is the *fundamental concept* which has absolutely dominated in infrastructure. *All possible branches of engineering and infrastructure could be effectively realized through BIM processes*. The three main processes *modeling*, *analyzing*, and *monitoring* are executed and integrated through BIM. Even at cases, where conventional methods are used, BIM provides methods and tools in helping to incorporate and use the available data and output in terms of structures' completion and integrity.

Initially, BIM started from 3D representations and gradually has ended up to communicating design intent in 7D terms. All dimensional aspects are defined and accordingly updated through the whole life cycle of a project (**Figure 1**):

3D aspect: Geometry, semantics, physical visualization, clash analysis

4D aspect: Time scheduling, project phasing simulations, activity progress, virtual construction

5D aspect: Cost-budget tracking, cost analysis scheduling, estimations for materials, equipment, man power

6D aspect: Sustainability, energy consumption analyses, infrastructure performance

7D aspect: Facility management, operation, maintenance, scheduling, project phasing simulations, activity progress, life cycle

Since BIM has dominated, several standards, codes, and terms have been established in order to provide rules and guidelines and to facilitate design and

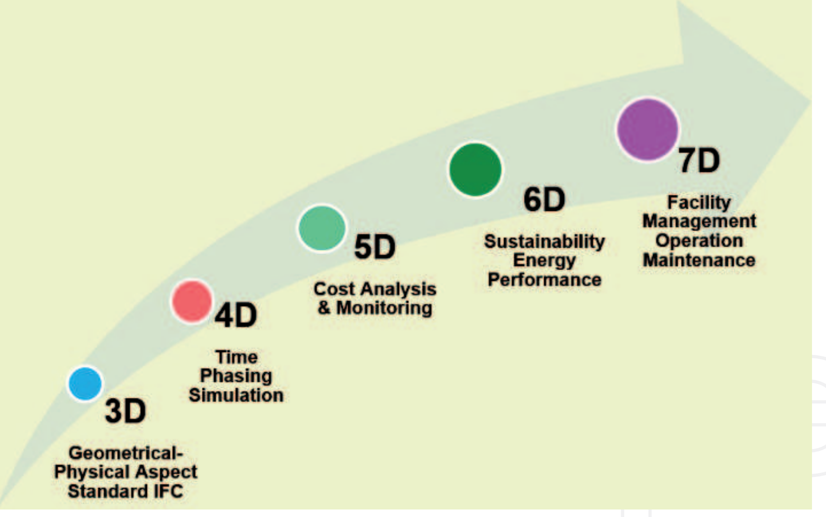


Figure 1.
BIM dimension terminology.

construction, while securing consistent and efficient processes. According to requirements, several indicators could be used.

BIM maturity level is used as a term, in order to describe the ability of the whole infrastructure chain to manage and exchange information. *Levels vary from 0 to 3* indicating low collaboration up to full integration [2] (**Figure 2**).

BIM level of information (*LOI*) indicates the information content provided through elements' attributes. Regarding tunnels, attributes could range from the definition of alignment up to describing materials for mechanical equipment. LOI of models describe semantics of relevant elements, and it depends from the type of structure, discipline, submission procedure, etc. (**Figure 3**).

BIM level of development (*LOD*) indicates the degree of completion and specifies the level of clarity and reliability regarding the information we could extract for an element. It is actually a measure for the achieved refinement of models at a specific stage [1] (**Figure 4**).

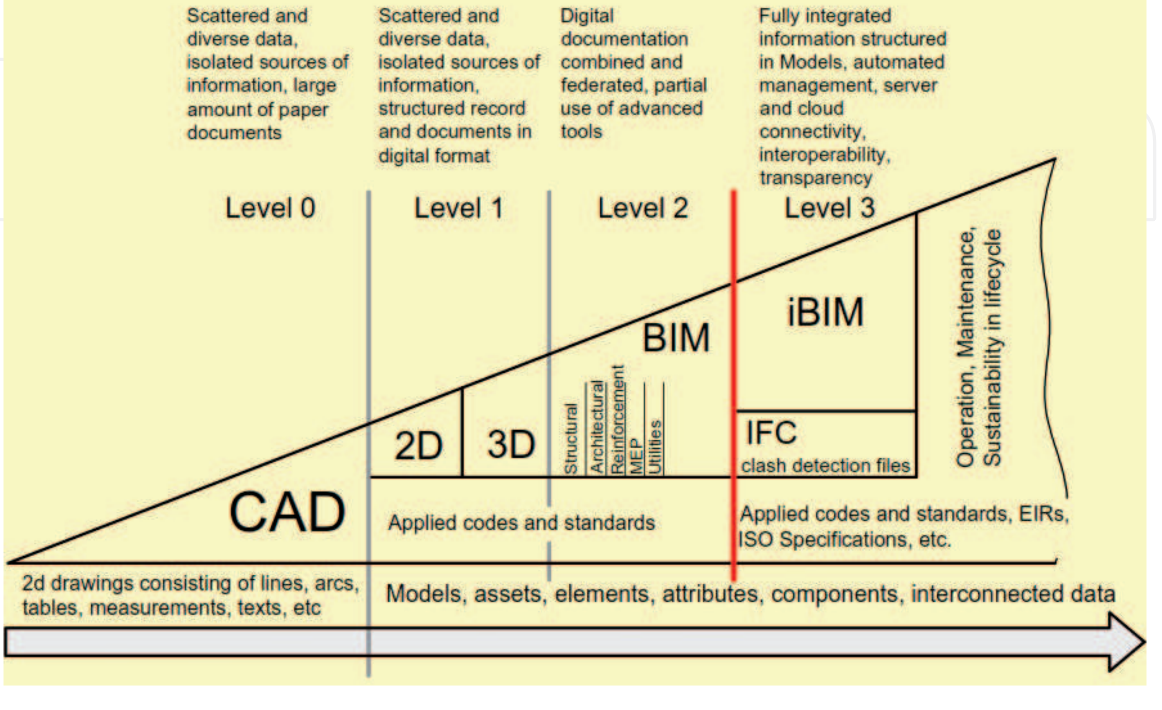
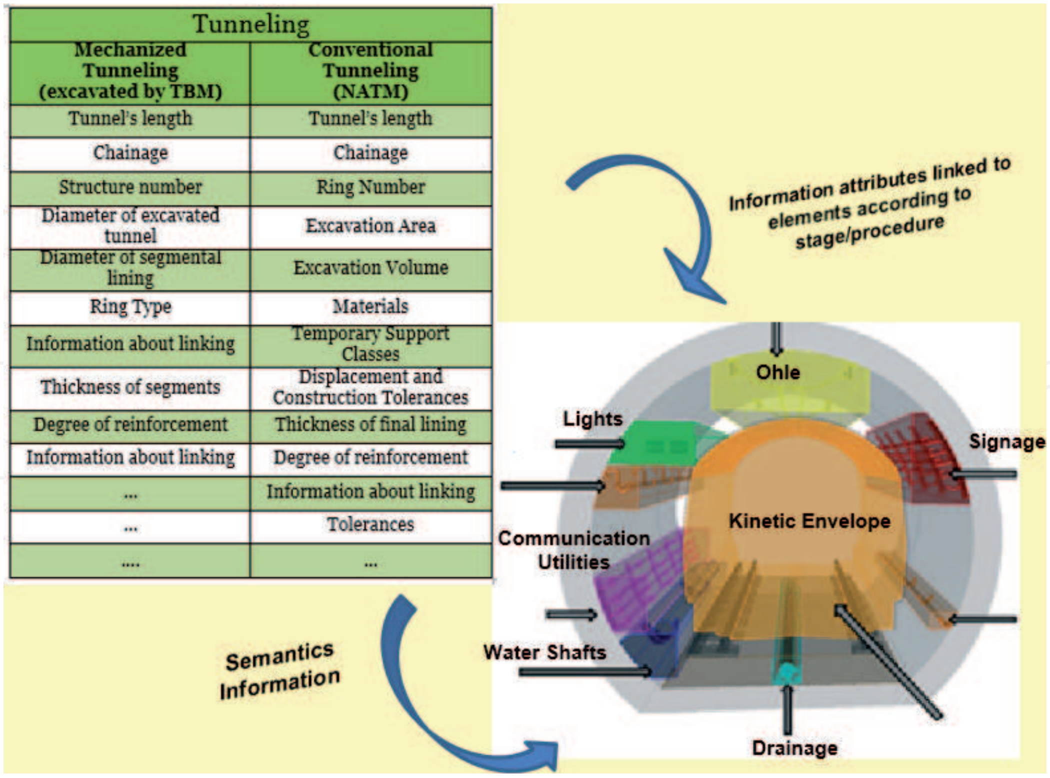


Figure 2.
BIM maturity levels [2].



Tunneling	
Mechanized Tunneling (excavated by TBM)	Conventional Tunneling (NATM)
Tunnel's length	Tunnel's length
Chainage	Chainage
Structure number	Ring Number
Diameter of excavated tunnel	Excavation Area
Diameter of segmental lining	Excavation Volume
Ring Type	Materials
Information about linking	Temporary Support Classes
Thickness of segments	Displacement and Construction Tolerances
Degree of reinforcement	Thickness of final lining
Information about linking	Degree of reinforcement
...	Information about linking
...	Tolerances
....	...

Figure 3.
BIM level of information [3].

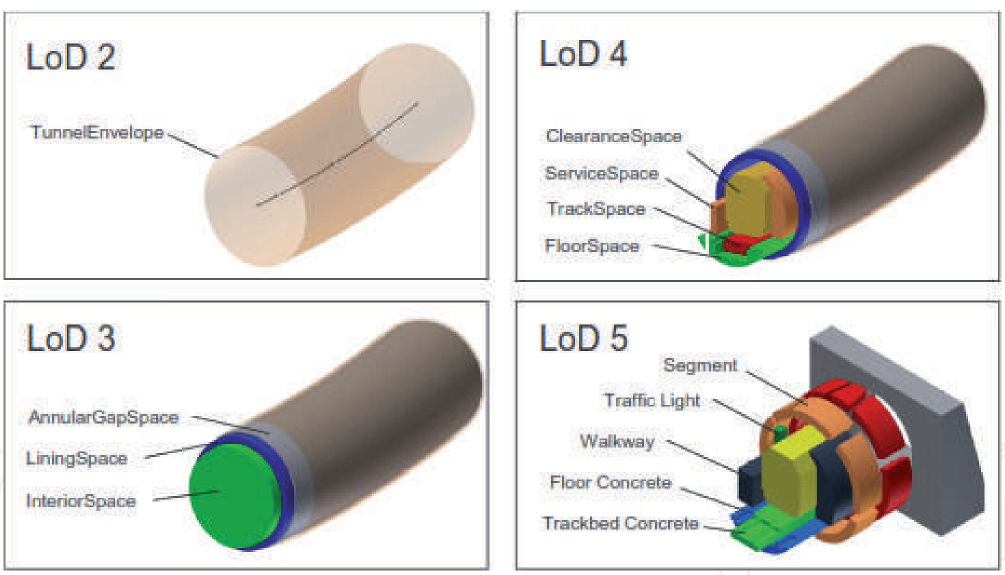


Figure 4.
BIM level of development, shield tunnel case [1].

3. Why BIM?

3.1 Tunneling complexity in terms of conventional tools

Through the years, many tools and products have been used for the realization of underground infrastructure projects. The efficiency and produced relations of quality, time, value, and integrity vary at each case accordingly. The continuous and significant development of software and hardware and upgraded technology are the regulators of growth. Obstacles are overpassed, and solutions are detected and applied for repetitive and common issues. However, available conventional products do not support the multi-scale and multidiscipline aspects required to properly handle large infrastructure projects or smaller specialized ones. Moreover, the nature of underground and tunneling engineering is clearly distinguished by the degree of scientific data interpretation, which is spread along the time and size extents of the projects (**Figure 5**).

The successful execution requires the use, exchange, and "translation" of data in different formats, in order to be used as input, parameters, factors, and constraints. In the majority of cases, small differentiations, omissions, and lack of parameters have a decisive influence at design and construction, varying from favorable to conservative, according to the case. A quite common issue for engineers is dealing with data in a form difficult to be handled, such as reports, measurements, and observation results. There is a particular variety of input from boreholes, scanned documents, earthwork reports, mapping layers, photographs, geo-referenced files, etc. Additionally and according to each case, we have to include water designs and surveys, drainage network connections, road networks, underground and superficial deposits, linear features, and so on. Consequently, the overall performance could include disputable error margins, unclear parts, liabilities, underestimation of risks, or creation of fake ones.

In few words, the conventional and traditional tools, even at their most updated versions, provide us a theoretical simulation of tunneling projects, directing us to several debatable assumptions. The final results and output from reports to drawings and calculations are actually representations on the ideal basis that the taken assumptions are fully satisfied. This is due to the fact that engineers have to deal with a heavy use of 2D information and large volume of static documentation and descriptive data. Consequently, there is deviation from the real behavior of the structure, especially in the part of interaction between the real structure and the physical world. The necessity of a liaison concept is fulfilling and indivisibly connecting design, calculations, construction, monitoring, and so on has been forcibly revealed. BIM tools and procedures act determinedly providing not just particular solutions yet reforming and expanding procedures, strategies, and possibilities.

3.2 BIM's role between common and new challenges

Isolation is the critical key to maintain data integrity and security, while linking is the productive key. BIM stands from its own definition to be the effectual key connecting those two concepts. This is the defining factor for the effective use of BIM on a project [4]. Translating and interoperability of information, while keeping a continuous access to the native form of data, and transformation from one software to another are basic parts of BIM's core.

In modern era, *value engineering* has been established as a major demand. Projects need to prove value and performance and achieve specific targets and rates from conception to operation and maintenance. Projects are no longer considered as single and separate entities, but they are incorporated into the wider economic and social environment, interacting with other structures—and not only during the construction phase. New needs of resources' savings are revealed, and new terms such as waste management, energy performance, etc. are introduced. Engineers are dealing with the process outcome and transformative business before even starting the actual work. More than ever before, we are asked not just to construct but also to deliver the services that a project is intended to provide. Associated risks and hazards are also transferred to engineering. The output and the overall footprint must be clearly *defined, measurable, and documented*. The realized design logic shall optimize a combination of tools and solutions, in order to address those outcomes.

To continue to further aspects, urbanization, failing infrastructure, and increased risk of natural disasters underscore the need for a stable, fit-for-purpose built environment [5]. Considering the contribution of infrastructure to the global economy, the produced energy footprint, in combination with required natural and human resources and respective produced waste for the realization of the projects, we are at a point where we have to include aspects previously considered as elaborate and exaggerated yet now totally necessary in order to be competitive and effective. Growing of population and incessant accumulation of people in urban areas are incrementally feeding the necessity of building new structures. Numerous work sites are running at the same time, requiring detailed time and cost schedules to be planned and actually followed without deviations. It would not be an overstatement to say that our world is a living evolving construction site continuously requiring updated tools and ways to exist and run.

Tunnels, in addition to the above, have the particularity to influence and interact both in-ground and underground conditions and environment. This interaction is dynamic, especially during the construction phase, and it consists of the critical concept, demanding a constant reflection at every single part of the life cycle. Thus, additional parameters and difficulties are created, definitely directing us to proceed further to nonconventional methods and procedures.

The fundamental strength of BIM entails on being a process that runs over the entire asset life cycle, providing a digital and actual representation of physical and functional elements, continuously contributing to decision-making. BIM proposes *a general methodology for creating and building multi-scale product models which combine semantic, geometrical, and engineering aspects* in a steady, coherent, and reliable manner.

Since tunneling is actually a link between ground and underground, BIM allows to be closer to an ideal final design, created and fit to frame existing site conditions and socioeconomic and environmental requirements and specifications. Besides tunneling, the design and building of truly complex, interconnected systems carry huge *risks*, unlike other industries and projects. A risk, not always noticed, is the one of delivering assets and systems designed and calculated on time schedules and prices at a time scale of years (or even a decade) ahead of the final product itself [5]. An additional risk refers to implemented techniques and materials' estimation and maintenance.

Another reason, which reveals the necessity of BIM implemented in advanced design tools, maybe even more than the building of new projects does, is the *monitoring, repair, and renovation of existing ones*. In those cases, there is an accountable amount of work, energy, resources, etc. consumed in registering the existing conditions and detecting deviations from the original design—if of course a full documentation is available. We are facing the consequences of data waste, that is, not using the data or recreating data through the project's life cycle. For engineers and parties, already experienced in BIM concept, the waste of time and energy is absolutely obvious, since they can easily identify the parts they could skip and already resolved if the design was generated by BIM.

In order to meet the already challenging demands and the newly created ones, the enhancing of automation capabilities of infrastructure software is a more secure way. This fact is strengthened by the level of automation and technology appearing in every aspect of the modern world; therefore, *we could not serve an upgraded project by traditional and conventional tools*.

There is also a *global direction* to incorporate tunnels in larger infrastructure, creating intricate complexes of tunnels, bridges, highways, roads, etc. In addition, many projects are designed with long-term visions aiming to constitute international and cultural points of reference. In such cases, the use of enhanced automation is unquestionable, since it not only speed up the entire workload, but also removes a great amount of it—many times tedious and repetitive—enabling to focus energy to solve more complex problems with creative solutions. Constraints, rules, and challenges are no longer dictated only from engineering criteria, since we are addressed to a global and international market.

The collaboration of modeling, calculation, monitoring tools, the integration of all software parts to a common environment, and the sharing of information in digital data are some of BIM's cornerstones. BIM's technology provides the ability to quickly and cost-effectively capture information about the physical world and make it digital. As this technology is developing and being implemented in projects, we get closer to having a true digital mirror of our physical world [5]. This massive uptake of active collaborative data production demands not only to ensure that we do not neglect any part yet also to guarantee information storage, integrity, and security in our projects. In the world of cloud, mobile, and social connectivity, it is more than obvious that our tools could not remain idle ending up to be obsolete and practically useless (**Figure 5**).

3.3 BIM's role between common and new challenges

Focusing on future directions, many universities worldwide have already included training classes of advanced 3D design and 3D computational modeling. Educational institutions are the core of knowledge, research, and novelty, so it is quite evident that they should actually convert to pioneers of BIM development. Encouraging of investments, fostering faculties' collaboration, and orientated training should already been considered as top priorities. Future engineers must be prepared and skilled to deal with real and demanding problems. The entire direction of their education must be reformed and make clear that engineering faculty requires a wide diversity of knowledge and continuous edification.

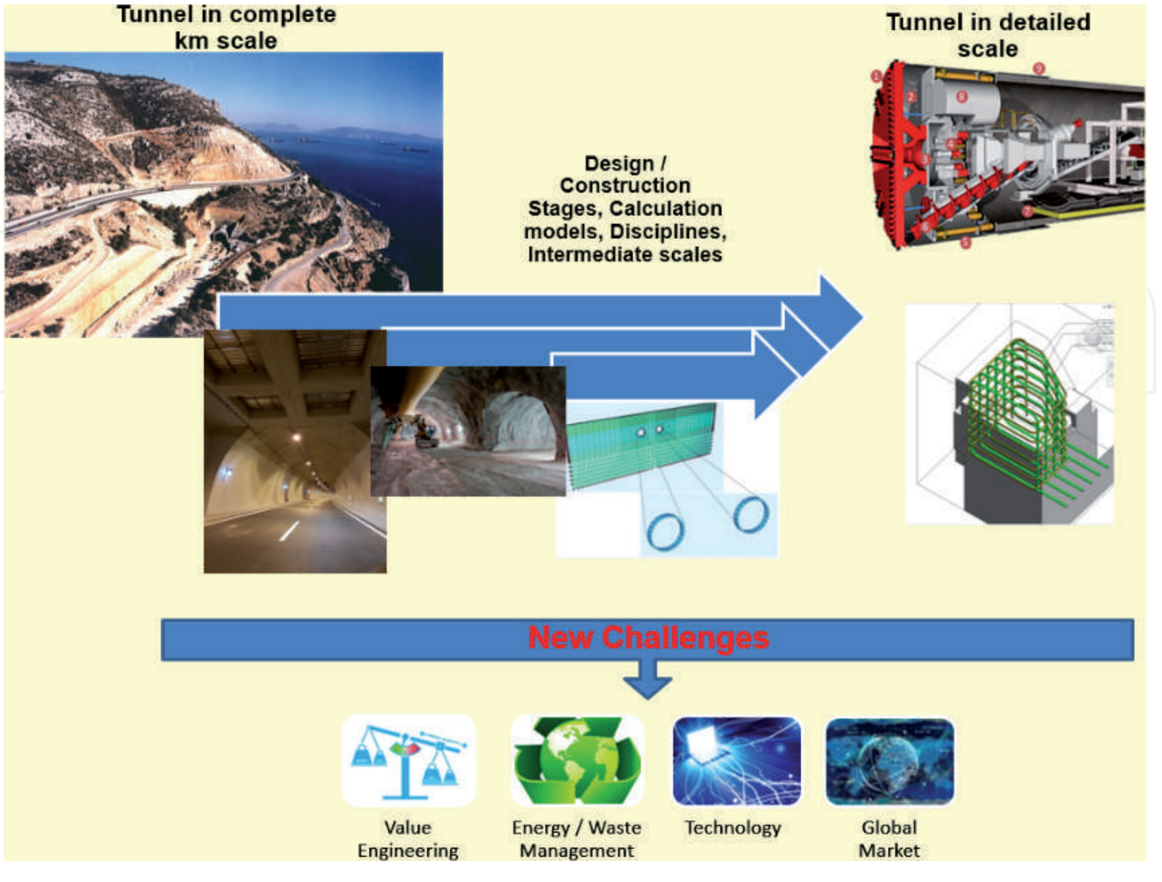


Figure 5.
Tunneling design/construction demands—new challenges [8].

The following are indicative references of software-specialized companies and tools, widely used in infrastructure projects for design, model, analysis, monitoring, etc.: Autodesk [9]: Revit, Civil 3D, Navisworks, InfraWorks, BIM 360, ReCap, 3ds Max, Fusion 360; Nemetschek: AllPlan, Bluebeam, SCIA; SOFiSTIK; BIMobject; Plaxis [9]; Bentley Systems; Leica Geosystems; AEC3; Trimble.

BIM stands as a unique concept fulfilling in a verified and upgraded level the rules of engineering in combination with the necessities of the present focusing to the future. The world operates and moves forward requiring the consideration and affiliation of enormous information amount, borders have been eliminated, and projects are performed internationally affecting not only a narrow society and area yet interacting in a global scale. This interaction is fully exposed to socioeconomic criticism, especially on the preliminary and building stages, since we have to deal with investment concerns and unproven performance of an unfinished structure. In our digital world, every engineering construction, regardless of location, size, or cost, is accessible even from mobile devices of affected citizens, at cases long before construction and even regulatory approval [13]. Considering that tunneling projects hugely affect people's daily life, having a direct impact in a time scale of many years, we are not allowed to reject any innovative tool. And above all, infrastructure has to stand solid, safe, and functional through the years, enabling people's prosperity and production of economic value. This necessitates that all involved parties and first of all engineers change the way they work and overcome worries affecting these goals and achievements.

4. Benefits through procedures and workflows and uses and tools from point zero throughout structure's life cycle

It consists of an undeniable fact that BIM's favorable and beneficial impact is not at all isolated in specific parts; however, it extends to every aspect of tunnel and underground projects from the initial inspiration up to the end of construction lifetime. The benefits apply to all involved procedures (modeling, analysis, etc.) and parties, directly and indirectly and similarly to BIM's philosophy of linking, integration, and cooperation; those benefits do not work separately, yet they are interconnected and interacting (**Figure 6**).

4.1 Interoperability achievement

To start with the physical and *geometrical aspect*, BIM creates an absolute and real three-dimensional representation of building components. The meaning of representation may not be so inclusive, since we are talking about a realistic visualization not only for the main structure yet for any other desired auxiliary or interacting part of structures and surroundings. BIM tools are not allowed by default to design with geometrical inconsistencies and errors. In tunnel and underground infrastructure, this is even more valuable, since arched, skewed, and complicated geometries are common. Saving of time and energy is large, not to consider the errors and discrepancies that are avoided. These advantages are even more enhanced considering the combination of all involved disciplines in each project. For example, mechanical and electrical parts are designed in an actual detailed level, in order to facilitate the subsequent construction stages. There is a variety of tools and software, executing clash detections, combining models of different formats into a single project model.

One of the main key words proving the change that BIM has brought to infrastructure is the *interoperability*, which throughout the years and during BIM's usage has been evolved to a whole concept for the engineering faculty. With the aid of network servers, cloud services, etc., the design is executed in an integrated model, which combines all desired disciplines, design-construction stages, and the input from all involved parties. This model could be comprised from an unlimited number of other individual models, organized on a specific structure. Many teams and faculties are able to work on the same model simultaneously. All parties have access to a *common data environment* (CDE). This model sharing accelerates the internal coordination and boosts productivity and project development. The CDE is shared to all parties and stakeholders; therefore, at any time information is accessible to its updated status. We are actually dealing with a totally new and highly upgraded perception about structures' accomplishment.

4.2 Evolution of calculation tools

One of the key breakthroughs that BIM has brought in engineering is the full assimilation of structure's calculations with semantics, geometry, sequence, and any other aspect of the project. Analyses and computations are no longer treated as isolated tasks, yet they are continuously interacting with all parts, generating a realistic representation of structural performance. The geometrical model is directly used from the respective *computational calculation software for the analysis execution*. Upgraded computational tools include geometrical aspects and structural considerations enabling the interpretation and replication of constructive elements and their mutual interaction. Each alteration and adjustment during design-construction from minor ones to complete conceptual modifications are directly reflected to analyses, which are no longer error-prone to manual drafting updates. A direct impact of this linking is obvious in workload, and the required time is rapidly reduced in all stages, from preliminary to detailed and as-built design, including intermediate rework and modifications. Each involved party shares this benefit, and moreover there is not anymore a reason to hesitate for testing alternatives and different techniques. Integration of actual structure and engineering behavior promotes the scientific field, since engineers are more flexible and confident to conduct forensic analyses, enable multiple code reviews, and test many different failure criteria.

Calculation tools have been developed in all directions, offering a vast variety of options and libraries aiming to cover all cases, theories, criteria, etc.

Element types: structural components are completely defined based on geometry, stress-strain conditions and function, critical state, etc. (trusses, beams, interfaces, flat/curved shells, damping points, embedded components, plane/complete strain, anchors, tendons, springs, and so on). Engineers are able to fully define the overall function of the analytical element, in order to ensure the proper simulation of engineering response.

Materials and computational criteria: isotropic, homogenous, orthotropic materials. Self-healing concrete behavior and integration in construction. Temperature dependence and energy associated with material's shape. Evolution of Young's modulus in model codes, laboratory curved, or customized subroutine. Crack prediction in linear/nonlinear analysis. Maturity dependence of shear behavior, tension softening, and compression. Creep/shrinkage in transient mode. Material aging, plasticity, hardening, and hysteretic models for steel reinforcement. Viscoelasticity with temperature-dependent Young's modulus. Overall, physical/material properties, engineering criteria, and behavior are explicitly defined and fully incorporated in all computations.

Analysis types: upgraded software is equipped with powerful solvers in order to optimize solution procedures for all types of linear/nonlinear/dynamic complex models with accurate results and fast computations. By this way, engineers have also the option to simultaneously perform more analysis types finding the best structural option and achieving a better understanding of design intent, yielding less errors and omissions. Besides the typical ones, more complex and time-consuming types are added: construction stage analysis, seepage steady or transient, drained/undrained analysis, saturated flow, consolidation, pressure-dependent degree of saturation, porosity, soil swelling, P-delta analysis for second-order effect, dynamic analysis, liquefaction, strength reduction (phi-c), ground stratification from borehole data, use of relaxation factors to model body's 3D behavior during excavation, and frequency response.

A serious impediment that engineers are dealing with in calculations is the generation of an *accurate and representative mesh*. New tools use different input, hybrid mesh, and Boolean operations, generating 3D surfaces and intelligent node-to-node connections; simulating even small, very distorted fissure elements; and eliminating local imprecisions. These effects are extremely essential to obtain a consistent model, since errors, thin faces, and local inconsistencies lead to failures during the simulation, as model's continuity is not guaranteed. Using BIM, mesh follows structure's irregularities, and objects with complex geometry do not require excessive simplification. Complicated geometries, like intersections, junctions, caverns, elevated structures, etc., are not anymore resolved with questionable assumptions. Moreover, 3D meshing procedures of higher order displacement interpolation, 3D inclusive interfaces, and triangulate surfaces for faults and horizons from geological data are feasible.

Another typical however intricate task of calculations is the definition of *boundary conditions*. Similarly with other aspects, different types, values, and theories can be performed to investigate and conclude to the more realistic ones. The definitive advantage is that computational model could be directly compared with field measurements and gives us an assessment of model's reliability.

All those could be further developed using *event simulation* and time history analysis to simulate different stages/events during the life of the structure and model more realistically the stress state at any time, leading to identifying of potential deficiencies, which may cause damage or reduce performance. Phased analyses with load history and sequencing combined with dynamic, thermal, etc. loading-unloading, and material behavior determine worst-case reaction and stresses.

Since multiple cases and scenarios could be analyzed, the form of derived *results and output* acquires major importance. New tools provide useful options for automatically produced and updated diagrams, plots, etc., easily compared and providing possibilities, since it becomes quite easy to visualize the influence of design scenarios/changes across different iterations and isolate specific parts. Software could even provide interpretation of analysis and *solution procedures* through automatic solver selection. Based on the results, preliminary design of other disciplines could be generated, for example, 3D rebar models.

All of the above enable different and realistic decision-making, since engineers are able to identify critical stages, recognize problematic regions, and detect vulnerabilities. Initial hypotheses are tested, evaluated, and progressively adjusted to reach an actual consistence with experimental tests and realized construction. Physical-design-calculation models are interactively reflected from one to the other. Options like shape and material optimization, especially in reinforcement, are evaluated based on reliable and actual data. *The final tunnel infrastructure tends to be more close to the optimum balance between engineering behavior, safety, economy, and functionality*.

4.3 4D and 5D influence joined with digitalization: IFC development

BIM's profits to the whole extents are realized through the incorporation of *4D and 5D perspective*. The nongeometrical and material attributes are interrelated through all processes. Besides, the created construction phases provide a real visualization of the building sequence. The result is a solid and actual chain of the project's entities. Models of different format and discipline are linked, enabling 3D clash detection and 4D construction planning simulation, which allow a better understating of the project, enabling decision-making and efficient resolution of issues. Clash detections are set on a routine schedule, and the execution offers the ability to check and compare the actual design-site conditions at the entire time scale. Data segregation works simultaneously with data integration. It becomes also quite clear that the generated 3D, 4D, and 5D processes provide accurate and real data regarding materials, procurement, quantity takeoffs, and overall cost. In combination with the ability of BIM to elaborate construction drawings (e.g., shop reinforcement), quantities and costs can be extracted at any time, facilitating resources' management and site planning. Procurement is regarded as a part of a broader life cycle, rather than as a stand-alone process, and actually commences from the inception stage finishing when the project is delivered for management. All those are proved to be huge assets for companies and contractors, especially in tender stages. Time and cost records, which previously were considered as approximate estimations are now reflecting reality throughout the work procedure.

Prior to construction: BIM could act in a precautionary manner, reducing discrepancies and rework costs and preventing constructability issues. Especially, this last feature consists of a valuable asset for engineers, who quite often deal with serious technical issues on site, several of those requiring accountable time, effort, cost, and rehabilitation actions, not to mention cases where problems are irreversible affecting safety, quality, and overall performance of the infrastructure. Due to the project's consistent better understanding, unacceptable and unforeseen circumstances can be detected, analyzed, and resolved. Especially in tunnels, we must not neglect the size factor, which acts incrementally and affects every other part. This is why rectifying problems prior to construction progression is quite beneficial, since at an earlier stage, while corrective measures are still practical, the cost of all kinds is considerably less.

As soon as excavation works and support installation start, engineers are able to make an ongoing follow-up from the already performed simulation of the real construction phases. All federated models, documents, and calculations are continuously updated through all processes, in order to maintain consistent data and conclude to transparent, accurate, and reliable workflows. As a result, site responds quicker to design changes; solution adoption is more feasible, fast, and efficient; and project delivery is apparently improved. Especially in tunneling (e.g., NATM), where engineers have to decide and keep up based on the dynamics of building progress, they are more flexible and confident to test and implement different techniques and solutions. Efficiency is checked and confirmed by simulating the actual geometry with the actual encountered conditions. Unnecessary design and construction challenges are avoided by developing an optimal route and organizing construction sequencing focused on minimizing insecurity and ideally any deficit of infrastructure realization [11]. Furthermore, BIM is the key element to meet aggressive timelines and handle massive coordination. In our days we have to deal with largely extended projects, where a great number of firms, authorities, subcontractors, consultants, and people of various faculties have to work on the same line. This extraordinary level of coordination is practically unfeasible and non-affordable to be achieved with traditional and conventional 2D methods and procedures, even the most evolved ones.

Keeping up with BIM's profit enumeration, we should include the features of *digitalization and automatism* in infrastructure. Those features act with all the already mentioned aspects and benefits, enhancing in an absolute way all capabilities and offering a decisive boost to progress and evolution. Repetitive tasks are

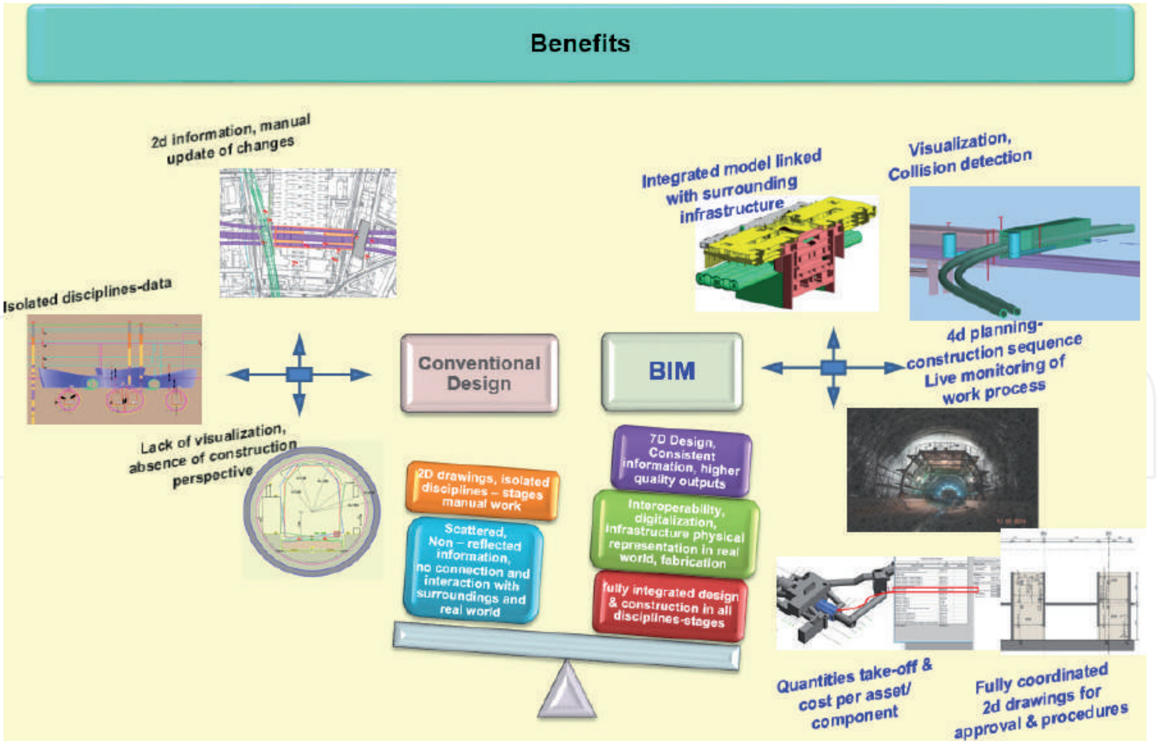


Figure 6.
Conventional VS BIM design [8].

simplified and at cases even eliminated. There are plenty of ways and alternatives to build scripts and conduct routines for complex recurring tasks, quickly and efficiently. Visual programing tools help engineers to analyze and design data, standardize tedious workload, and aid in processing. Easy tasks are now executed automatically and the most complex ones in a faster and more accurate way. The exchange of input and results between design and calculation software formats—not necessarily compatible—occurs on a regular basis. Time and energy consumed on a specific software are saved from other parts of the workflows, since all kinds of information produced are circulated and used as an input. BIM by default enables the reuse of information generated during modeling and calculations, avoiding data duplication and inconsistencies which typically occur when different parts process the same input.

The most common "translator" used widely in infrastructure is the Industry Foundation Classes (IFC) [6]. IFC is an open common data format/structure transferring and decoding information. It works as an open data model schema for the definition of components' geometry, physical, and engineering properties, providing a rigid and authoritative semantic definition of the elements and the produced associated relationships, dependencies, and properties. IFC is documented as an international standard, and due to its extended usage and proved efficiency, it often consists of a major requirement in projects' contracts and standards. In this way, all involved faculties have a common language, which becomes even more valuable in our era, when projects are typically accomplished from people and accompanies of different countries. In this way the design is not reliant on a particular software. Moreover, information could be used and tested from one project to another, in order to compare and verify results. Modeling information exchange is targeted, working on the principle to only share what is relevant and applicable to specific activities and disciplines, using IFC as a parent data schema. In combination with other applications, components could be analyzed and monitored with the goal to improve performance in the entire range from engineering to operation and cost. IFC acts as catalyst, tightly interlinking the processes and forming an iterative loop of communicated information in the flow of investigate-plan-design-calculate-construct-monitor-operate-maintain.

4.4 Monitoring: risk assessment and hazard control

A main task of a project's design which is also continuously present during construction stages and operation is progress and performance associated with *risk and hazard control*. All project decisions come with both short- and long-term implications and risks. The key to success is to understand the impacts and act in a precautionary way taking full advantage of *advanced monitoring*, using high technology equipment combined with scientific experience and correct engineering assessment. In *monitoring*, BIM can work with many digitalized tools and equipment, in order to provide measurements and results of the current condition. Moreover, with the use of the already elaborated models and calculations, we are able to compare results between the designed and the current state and consequently verify our estimations, in order to proceed to probable modifications and even prevent emergency situations. Gathering and evaluation of data are quite critical during temporary states and works. However, this has to be implemented without disturbing and dragging back construction progress. In our days, *drones and 3D laser scanning* resolve the issue of space and access, while they also provide trustworthy results which can be easily handled and exported for further process. Optical fiber sensors can be installed on any place without compromising structure's functions.

Monitoring tasks are not based anymore on single measurements, theoretical assumptions, and hypothetical cases. Upgraded tools have widely extended the fields and potential of monitoring. New devices offer the ability to measure both static and dynamic events and detect and filter fake measurements and temporary obstacles, while ensuring good temperature compensation, which is a must, for facing several environmental conditions. Strain gauge-based sensors have an advantage of high long-term stability, being operational during the whole lifetime, without needing recalibration. Crack detection and crack shapes are realized on a reformed basis, and in combination with calculation software and hardening concrete models, we have the valuable asset to predict cracking. The range of collected data is spread on multiple fields and in all construction phases, such as measured and expected displacements, loading of shotcrete lining, surface settlements and spatial distribution, ground deformation in the area of structures, allowable distortion or curvature in the expected influence area of the underground construction (buildings, railway tracks, gas-water pipes, wastewater sewers), corrosion and fatigue of concrete, reinforcement, and any material. Laser scanning delivers accurate and reliable complex cavities, openings, and as-built plans, allowing performance of exact volume calculations and quantity surveying tasks, monitoring of construction, and detection of narrow areas in advance. The total outcome enables engineers to identify structures' "normal behavior," detect deviations on time, and assess and predict all types of displacement development and ground conditions. A live and continuous comparison of designed, predicted, and measured data is feasible, and any party has easy and transparent access. In special and accidental cases, as earthquakes, smart sensors study the resonance behavior, in order to better predict structural performance. Sensor technology, combined with seismic and time history analysis running on as many ground motions as needed, provides response histories and maximum global seismic demands solely based on sensing results without making any finite element model. The affiliation of records with BIM models can also conclude to suggested design alterations and/or corrective measures.

Using those records, a series of cases can be detected, and workflow efforts can be managed to mitigate risks. Benefits of reliable risk and hazard control apply to construction workforce, as well as to project operators and maintainers and of course to users and general public. Dangerous activities in use and operation are recorded and handled. Critical equipment during work execution is protected properly, and the planning for emergency and alarm situations is realistic. Specific feasible plans and schedules for managing construction and functional hazards are conducted and timely implemented. We are able to define substances and components hazardous to safety and health. The goal for monitoring project structural health is to form a database for tracking the behavior of structure and avoid any potential deterioration in safety and performance (bearing capacity, stiffness, serviceability, durability). This whole sector is quite critical, not only because it is required by legislation, yet it applies on the essence of engineering that sets as a first and central priority the assurance of safety and integrity.

4.5 Maintenance and operation aspects: productivity growth

Maintenance and operation are features systematically neglected in infrastructure sector during the design and construction stages. We end up consuming great amount of money and energy on those through the life cycle of projects, and at cases those costs even exceed the cost of design and manufacture! BIM provides a series of procedures to manage those issues. The accurate costs, demands, and activities can be planned and calculated in advance, interacting precisely with projects' development, qualifying optimization design against future demands. As-built models and centralized data systems remain at the disposal of projects' operators, subject to revisions. Renovation of existing structures is released from inconsistencies, becoming a feasible and functional solution. BIM can be leveraged in the entire construction network management. By using the information in external data sources, the optimal distribution of capital, time, and resources is plausible to meet defined objectives [4].

It consists of an undeniable fact that the application of BIM philosophy integrated with advanced tools affects *productivity* in a positive way. Each one of the mentioned aspects and benefits has a direct or ancillary impact in job performance and productivity. The more easy way to modify and revise the design, while ensuring that alterations are communicated and shown at all respective deliverables and disciplines, becomes clear to every BIM user from the very start of application. This is enhanced considering the new ways of dealing with repetitive and tedious tasks. In general, the ability to communicate design intent and ongoing work progress, associated with the continuous access on actionable records of project's current and foreseen status, promotes the boost of job performance. Time schedules are visualized, and suggestions for improvement are easily communicated in order to optimize sequence of activities. The meaning and value of collaboration and teamwork are apparent more than ever before and in a broader extent. Transparency is finally present in all procedures, enforcing hazard identification and engineering judgment and responsibility.

A common practice in engineering is using references and already realized projects as a source for already resolved cases and evidence of fixed issues. The truth is that engineering faculty has not been quite committed and diligent on saving and organizing the bulk of information generated up to the structures' accomplishment. Regarding maintenance and operation time, lack of data is even more evident, and even at cases, where records are available, they appear to be inconsistent with previous phases of design-construction. This issue is partially justified from the fact that before BIM implementation, retaining and updating the entire information of a structure in a secure and useful manner required time and resources, ending to unaffordable costs. Thus, a vicious circle has been created, since we are actually constructing the same type of projects with a vision to be more advanced, without using past experience and acquired knowledge. In this major wound of successful infrastructure, BIM provides solution not just by offering a database yet by giving the option of *parametrization*, since no project could be identical to an existing one. BIM enables the easy, accurate, and functional creation of databases and libraries to include all models, input, output, and deliverables all through the life cycle. This is an innovative way to accelerate the design, without jeopardizing safety and quality, since the performance of existing structures is recorded. Moreover, databases are used as tools of further examination and checking and not as an automatism or magic solution used without judgment and evaluation. Each new project has the opportunity to be raised on upper rates of quality and performance. Civil projects appear to be standard; however, differences occur each time, even more when considering that we have to deal continuously with new demands, materials, etc. Advanced software formats enable the creation of parametric elements in all attributes, geometrical, nongeometrical, physical, computational, material, classification, and so on. Models can be built with certain constants and limitations, while enabling parametrization in other parts that could act in a dynamic and variable way. In practice, it is easier to use the right points and nodes to start the design, than creating something new from scratch [10]. In tunnels this applies from the generation of geometry, to load cases and combinations, excavation categories, implemented support measures, reinforcement, niches, utilities, and practically the entire range. We end up creating *pilot projects* by means of "intelligent" constraints and interdependencies between model elements. In combination with BIM's ability to speed up the completion of repetitive design, projects' accomplishment settles in new standards.

The constantly increased demands of modern world have raised the levels of project delivery. The large number of ongoing constructions on a worldwide basis and the high standards they are expected to achieve impose the improvement of all available applied methods. The factor of time tends to be one of the most important priorities and an indicator of success. Therefore, *prefabrication* has turned into a main asset. Computer-aided manufacturing is becoming a common practice. Using software simulating tools, engineers are able to create machines' setup and procedures and analyze the whole chain of fabrication. BIM models can be converted and used for the manufacturing process, for example, milling and laser cutting. A quite representative case is the reinforcement of tunnels, where the design data can be fed directly to machine tools and link design with manufacture without needing any intermediaries.

To sum up, BIM works as a binging agent and ensures a constant and smooth alignment between those who design and construct a structure and eventually those who manage and use it. Enumeration and evidence of the acquired value could be further developed and specialized at cases. However, working and interacting even once in BIM environment can provide the best proof in a concise and practical way. Importance and revolutionary changes of BIM are self-justified and overriding. Value of science, knowledge, and experience find the best means and paths to be expressed, quantified, and implemented in infrastructure. Technology, automation, and digitalization act as conductors of this evolution, incentivizing all forces to reach successfully the final achievements.

5. Case studies: metro projects and underground structures

An increasing request for the use of underground space has been fostering the tunneling industry during the years. In combination with renovation and repair necessities, there is an immediate demand for the progress and use of advanced numerical simulation tools. Those urgencies are even more fed by an increasingly intensive interaction with ground structures, which necessitates not only a common and functional operation; however, it also reveals hazards and risks from the construction stage up to the whole life cycle.

Civil engineering is particularly risk-averse. Conservative nature has been deeply established in the entire industry, in order to balance uncertain factors and unpredicted conditions. BIM involvement in advanced tools of *structural and monitoring analysis* has already caused great difference in tunneling and implemented methods. Great underground projects all over the world have been successfully delivered in those terms [7]. Design and construction have been fully developed in 5D rules. This level has been conquered and consists of a prerequisite. The distinguished difference, which has been achieved in tunneling, is modeling linear structures joined with complicated sections (enlargements, shafts, junctions, etc.) in a background of ambiguous behavior regarding strength and deformation. *Representative cases of built projects and potential of 5D up to 7D development are mentioned in the following*. Some of them are in initial stages; however, the field is favorable and promising for quick progress [12].

Starting from *ground investigation*, an initial model is generated using the advanced monitoring tools—preferably 3D laser scanning—and locations for exploratory holes are identified. Real-time data gathered from the field are communicated to geotechnical laboratories, and after tests and process, the results are consistently introduced back to the *geotechnical model*. Tools are used to visualize this information, interpret data, and conduct reports. Besides verified and interpreted data, the digital model must also represent and use the state of uncertain knowledge. This is a crucial ability, which BIM offers comparing to traditional methods. Produced results assist to further refine the geotechnical model, and material properties are added to physical zones including also the time-dependent behavior within the model. In continuation, all geometry-engineering attributes are inserted as input into analytical software. Special purpose models related to specific requirements can also be assembled to a coordination model. As the design is built and altered, the analytical results are automatically updated. Although complete digitalization is not yet feasible, data can be easily exported and transferred to the analytical software minimizing the need to retype. Laborious interpolation and extrapolation of the determined ground evidence and connection of individual boreholes to form strata boundaries are executed in a more advanced and secure way.

The produced comprehensive *3D finite element simulation* model reflects the relevant specifications and auxiliary construction measures, both temporarily and permanently. BIM cases incorporate soil improvement methods, ground freezing, saturated soil, grouting, retaining measures, special formworks, temporary props, etc. All techniques could be either designed initially from engineers or advanced tools could be used to simulate suggested alterations based on the results. 5D importance is more amplified due to the fact that support measures extend through several rounds. Models are built as in real construction, including portal areas, cross passages, launching structures, emergency exits, etc. Differences of excavation from the designed to the actual stage is clear. For the relevant tunnel types, temporary and final lining, deformable shield, and segments are simulated accordingly. Complex numerical analyses are overpassed via a unified, IFC-based product model, directly linked to the numerical simulation software, contributing to decipher and integrating the initially unrelated data. Instead of converting data and jeopardizing misinterpretation or loss of information, data models coexist and provide coherence and continuousness (**Figure 7**).

A special challenge in metro cases is the fact that critical decisions are made on a quite early stage, having a significant and ultimate impact on the direction of the

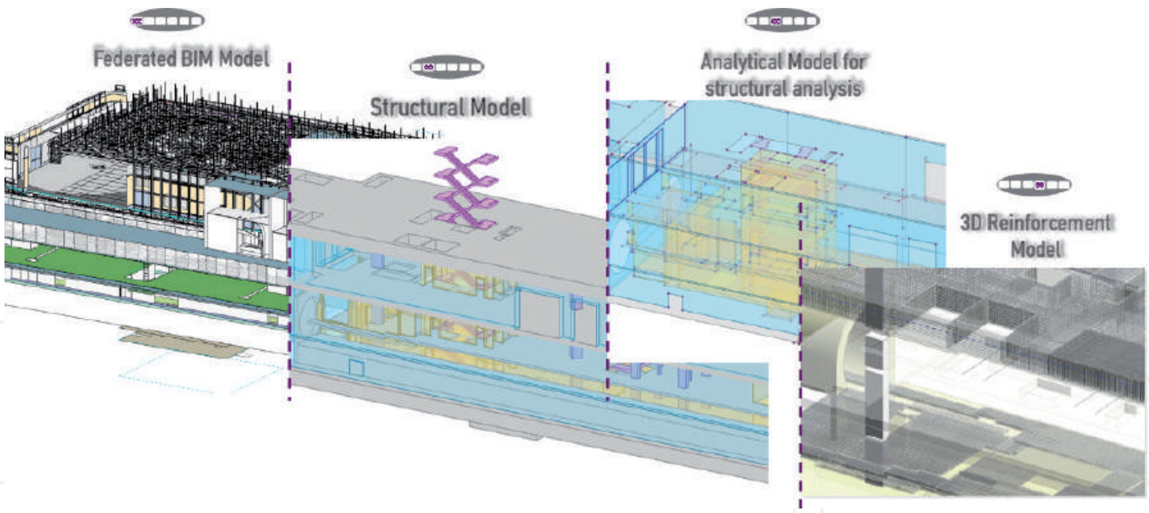


Figure 7.
Interdisciplinary model linking in metro cases and underground structures [8].

final design. This is why the execution of *intelligent analyses* demands accurate existing condition data integrated to thorough semantic modeling. Tunnels must resist to the least favorable combination of parameters, so the produced interfaces must be capable of taking into account lower and upper limits of input ground parameters (E modulus, cohesion, lateral pressure ratio, friction angle, etc.). Calculated and forecast deformation and convergences are derived for the main as well as for ground and surrounding structures. On an early stage, this settlement effect can lead to alignment variants. Collision detection is performed, to detect clashes with existing and planned structures or fault zones in the ground. *A series of engineering calculations can be performed in a reliable way through the advanced tools, without simplifications used in the past*. Groundwater treatment and forced alterations from excavation works can be measured and reflected in results. The same applies for flood, traffic, sonic effect, noise protection, ventilation, smoke extraction, and evacuation simulations. Modeling the interaction of all those challenges offers to engineers and stakeholders various design scenarios, influencing the project in a definite way: extension of tunnel, shortening a trough structure, option of cut and cover, mechanized tunnel, etc.

To further establish the above, the *experience of complete metro and underground structures* consists of the best evidence. Modeling, on direction of 7D terms, is even more critical, since the project interacts from the beginning with urban and socio-economic environment and rapid adaptability has been a consistent demand. For example, it is quite common to deal with difficulties in finding convenient places for shafts and stations due to existing infrastructure, expropriation, and intervention in social life but also due to other parameters, such as crooked and intensive settlements during excavation works. Unique challenges could be also encountered, such as archaeological findings (**Figure 8**).

The reduction of time that the use of BIM has brought in workflow processes is even larger due to the size scale. Ground models cover an extended area through the alignment, which means that besides the initial process of data, accountable amount of rework is required for any alteration. Reality capture methods, advanced monitoring, and automatism in construction make all procedures of a project site fast and less painful. As the work progress continues, changes are imported and updating all models, calculations, and consequently results. 5D models are capable of representing the caused variability of scheduled dates and resulting cost consequences. This is very important, since a factor typically derails time and cost schedules are the repetitive variation

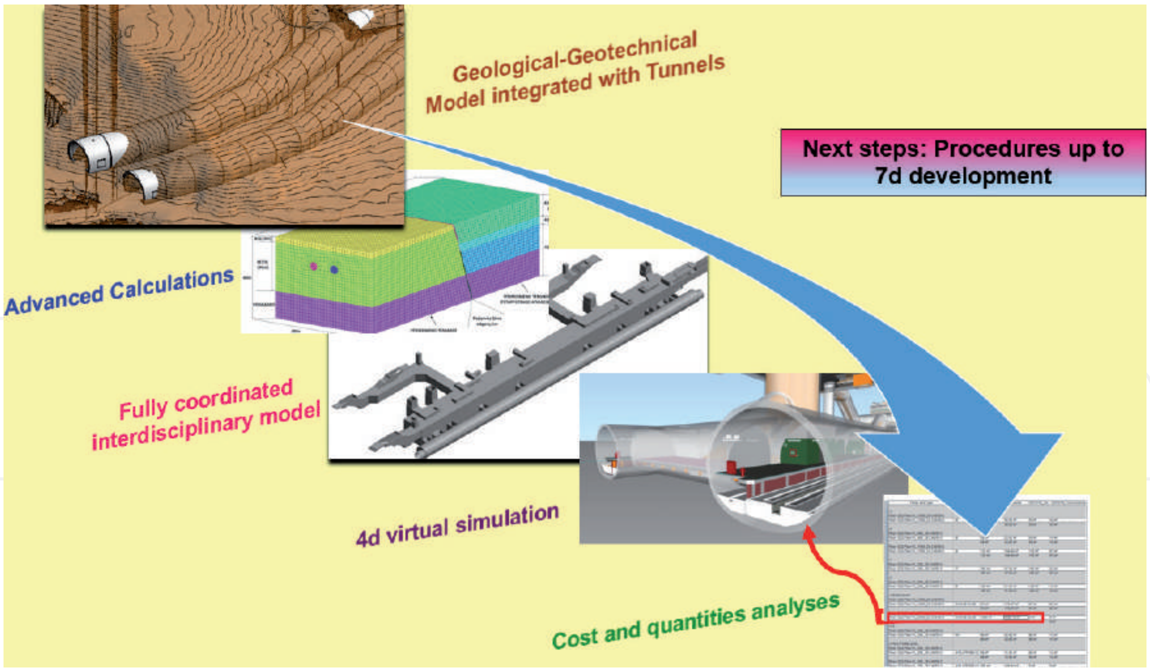


Figure 8.
Metro cases and underground structure models in minimum 5D design [8].

orders, requested for a series of reasons such as clashes on disciplines and constructability (**Figure 8**).

Operation and maintenance in metro projects dominate the life cycle, since a typical period is about 80–100 years. Over the entire use, the nominal costs reach the magnitude of the initial investment. This is why a digital twin of the integrated model must be used to update all systems, components, and landscape. A detailed strategy plan for this purpose can be developed in advance, offering exact knowledge to operators, instructions for optimum facility management, simulations of structures' behavior, and renewal options. Occupational health and safety plans in metro projects are not anymore disregarded; on the contrary we have virtual reproductions of hazard analyses, escape and rescue routes, rescue facilities, visualization of accident risks, and access restrictions.

All mentioned and elaborated benefits of BIM concept apply and provide huge advantages in tunneling design-construction, monitoring, maintenance, and operation. As we are proceeding to a complete incorporation in tunneling, further ways and tools are tested, and we are able to have documented performance, remove impediments, and achieve effective risk assessment. We are not anymore forced to artificially set low benchmark by the inclusion of projects that fail to deliver value. The field of improvement in tunneling remains still wide and requires changes, investment, and encouragement of innovation. The attained gains are the best motivation to remove hesitancy, stop procrastination, and finally move tunneling in the new digitalized and interconnected era.

6. Future, vision, and targets: the new era is here waiting for us to respond

A revolutionary change that BIM concept has brought in infrastructure is that we are no longer imagining future as something distant. Evolution is at our disposal, and it is in our will whether and how we take advantage of it [14]. We are actually experiencing a reverse of the whole concept. In the near future, our needs will dictate tools and procedures. Technology methods used in sectors irrelevant with engineering can work as an inspiration and provide solutions to infrastructure (**Figure 9**).

Since nowadays we are using point clouds, gradually BIM models will be entirely created and built from *reality capture data*. Aerial and object photographs, points from laser scanning, etc. will be converted to 3D models, and from this start all other parts shall be accomplished. Even for underground projects, drones and satellite images are valuable, since structures are always a part of a broader urban or suburban environment.

Virtual construction is closer than ever to be established as a common practice. 3D models will interact with construction schedule, planning, and phasing and are constantly updated with data received from the field, providing a cloud-based project. Regular photogrammetric surveys will track the building progress also detecting physical changes in underground-ground conditions enabling live monitoring of the whole complex, including earthworks and surroundings. Aerial surveying methods can provide safety, especially on hard to access or inaccessible areas, where conventional methods could be dangerous or impractical. Especially in tunneling, where the accuracy and adequacy of geological/geotechnical data are a top level priority, design and construction processes could be reformed at a great level. Construction management and decisions shall be based on real-world environment capture. Drones could also provide point clouds creating 360 degree photos, fly-through animation videos, and many other virtual reality experiences. Consequently, internal and approval procedures will be based on a totally different basis to convey the information. Submissions and documentation will no longer include hard copy deliverables. All means and devices, even tablets and mobile devices will gather, update, and convey information. Jobsite performance will be managed on a daily basis, and site conditions will take into account weather conditions to adjust the schedule and provide specific proactive measures. By scanning existing conditions, we will analyze requirements for future excavations, backfilling, etc., using also the produced accurate surface models.

Job automation is already here, and it will continue to dominate in infrastructure. It will transform older and existing industries and create new ones. Workforce will be adapted, so engineers will be interacting with technology more than ever in a technologically upgraded and sophisticated environment. Gradually, rework and redesign procedures will be part of the past, and the gained time could be used more creatively, to solve real problems. In fabrication, robots on site will be working side by side with construction workers. Workforce will be gradually moved from handling machines and equipment to handle and supervise software and input flow. All those will allow the implementation of unique techniques, since from the labor viewpoint cost and effort will be the same. *Augmented reality and virtual reality* (AR and VR) are an integral part of future evolution, and they are also entering infrastructure industry. We will get at a point, where AR and VR will work together, providing innovative experience and integrating the actual with the virtual aspect, since besides walking through the structure, we could experience pressure, temperature, materials, and so on.

Another technology asset, already in use, is *3D printing*. In the near future, 3D-printed deliverables will be a basic demand during workflows, since they could give with clarity the real perspective, overcoming limitation of visual angles. Combined with virtual reality tools, we could reproduce the actual structure. Besides that, 3D-printed components are already used in construction. With the use of robot machines, we will have the possibility to 3D print elements of various materials, including concrete. Building of more complex geometries; reduced waste of material, time, and cost; and safety on site are only some of the benefits.

Regarding *hardware and software*, infrastructure industry is absorbing and adopting in an increased level the evolution and the generated enhanced possibilities. In addition, the dominance of *cloud services* will affect the whole sector and applied procedures. We will not spend time translating and processing data between different software, future cloud will be software free, enabling to capture, create, and edit information regardless the initial format generator. Another feasible potential is to produce multiple iterations in conceptual tools to reflect different design options or to implement modifications without having to remodel over and over again.

All the above will be integrated and conclude to a *radical reform* of concepts, strategies, and procedures. We could mention some *indicative examples*; however, possibilities and limits seem to be undefinable. For instance, imagine the typical case of a modification in our project. Regardless the extent and importance, it will not be just reflected in the model, yet it will act like a trigger, activating a series of necessary arrangements. All relevant parts will be notified, and with the aid of a proper project strategy, instructions and needful activities will be automatically initiated and communicated. We will deal with automatically generated markups in drawings and automatically updated calculations and even receive photos illustrating issues and already incorporating necessary solutions and actions. Suppliers and construction site will be informed for probable changes in their schedule, for additional required materials, etc.

The traditional 5D coordination will be moved in the initial stage of the design. Engineers will feed, for example, the software with load requirements and basic properties, and the algorithm will autonomously proceed to design and model structural, reinforcement, MEP discipline, and so on. Construction phases will be then created, considering all particular conditions and interaction with the real world. Material lists and quantity takeoff will be conducted in accordance with phases and time, transferred to possible suppliers, allowing price comparison and cost-effective budgets. Machines will use the models to start manufacture and building. Robotic cranes and equipment will receive the construction sequence, the same for prefabrication machines and factory suppliers. 3D laser scanners will monitor works, and the records will be constantly redirected to all parts by cloud services. A deviation from risk assessment will mobilize the needful processes. Imagine the case in a tunnel's site where a possible hazard automatically enables the alarm and evacuation actions. Certainly, possibilities extend to operation time, providing information for required repair actions and improving the plans of accidental cases. Sensor data from a tunnel, for example, will detect the initial forming of cracks and other malfunctions, which will be reported on time and efficiently resolved before the occurrence of failure. Through the whole life cycle, the idea is to *resolve the issue before it ever exists*.

As much revolutionary and innovative, this evolution on infrastructure appears to be the real tectonic shift will be made via *artificial intelligence* (AI) in the industry. Through AI, we will not design projects by machines, yet machine learning could enhance the expertise of engineers, by providing from the start the optimum design and construction solution. In general, structures are of specific types, built in certain environment conditions, and defined and restricted by engineering criteria, standards, and safety performance. What if we feed those rules to hardware and software, in order to obtain an optimal building and structural footprint? We will not analyze to get force and stress results, we will ask from the machine to provide us the structural system for the desired output. It might seem as a science fiction scenario; however, AI is applied in many other sectors and soon will be partially used in infrastructure. Instead of conceiving the alignment of a tunnel and questioning for the best and feasible solution, AI will answer "which is the finest infrastructure complex and how the tunnel will be a part of it." From this point, the options seem limitless. AI will give the alignment of the tunnel affiliating ground properties, connection with road network, traffic volumes, transportation requirements, hazard control, specific codes-standards, and future development. For metro cases, additional parameters would be the connection with other lines and transportation means, land acquisition for construction, required accesses, crowd simulation, surface conditions, etc. AI could provide solutions for all aspects: applied excavation categories based on geotechnical parameters, retaining measures, rationalized tunnel geometry per type, TBM segments, required reinforcement, even machine equipment properties (capacity-pressure), arrangement on site, and generally a whole organized construction sequence. During construction, AI could adjust the design on the encountered conditions. Overall, calculated and complete engineering solutions and decision-making could be realized through artificial intelligence. We moved from drawings to models and in the next step from models to systems, where a computer will provide outcomes based on specific attributes, which engineers can review, revise, and set in function.

We conclude, that in the era of connection, instead of questioning whether the project is designed right, we will ask whether this is *the right project from the first place*. Does the tunnel need to be widened? Will it address the expectations as those have been set? We are moving to the era of *generative design*, using automatism and computation to define, explore, and choose alternatives. New expectations require projects to deliver value, and future challenges are treated like they already exist. Infrastructure should acquire the inherent capability to respond and adjust in conditions and ways beyond the ones intended when they were conceived. Environmental issues, incidence, and effects of natural and human disasters have become a reality, and previously those aspects were even ignored in the elaboration of projects.

It consists of an undeniable truth that engineers have also to operate like problem solvers and innovators. All efforts should focus on accelerating the pace of change and evolution. At last there is no need to invent more innovations if we do not test and practice the existing ones. Knowledge and technology are present everywhere, waiting for our actions and response.

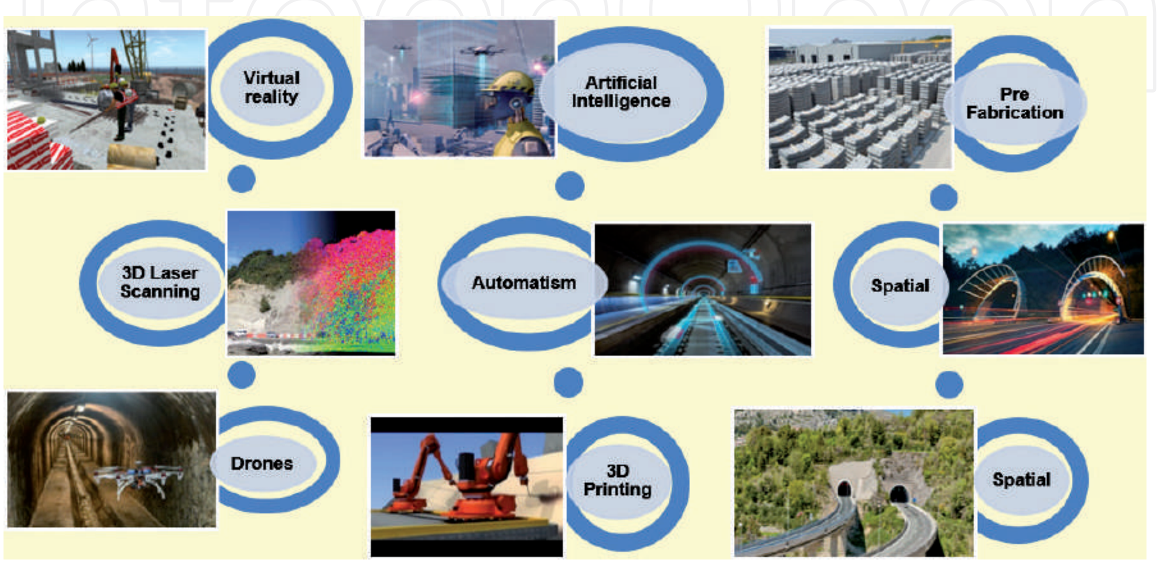


Figure 9.
Future vision and targets.

7. Conclusion

Advanced technology and innovations have really brought radical changes in the way we design and build. Acquired benefits are more than evident, especially in our connection era of overwhelming demands and necessities. We are not justified anymore to treat the parts of design, calculation, construction, monitoring, and operation as individual. BIM concept has created a solid circle to circumscribe all parts. We are moving forward in a velocity requiring continuous alert and flexibility. Instead of being idle, showing unjustified doubt, we should deploy a focused strategy with orientated actions. Engineering faculty shall invest more to research direction and promote faster application of upgraded tools. Engineers shall be active in these procedures, being able to identify and prioritize the emerging technologies and accelerate the integration among diverse sectors. The currently noticed different levels of progress adoption shall be eliminated through investments in skilled workforce, and universities are the point to start fostering the next generations of digital natives.

As much as machines dominate in our lives, the human factor remains the governing leader, pulling the strings. Scientific research and progress have always been the driving forces of engineering, and in the era of digital and accessible information, we could be more confident on setting ambitious and challenging visions and thriving.

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