Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani & Celestino (Eds)

Interoperability between BIM models and 4.0 approach: Theoretical models and practical cases

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ABSTRACT: Building Information Modeling (BIM) and 4.0 represent the hottest topics in construction and Industry. BIM is a process to create and manage all of the information on a project across the infrastructure lifecycle. The output of this process is a digital model that contains all the information of the infrastructure. 4.0 is a term used to refer to the developmental project in the management of manufacturing and chain production. It includes cyber-physical systems, the Internet of Things, cloud computing and cognitive computing. But how can the explosive mixture of these two approaches generate a revolution and a successful result in the construction field? Our paper wants to focus on how the 4.0 interoperability and information transparency can support and provide information to the BIM process during construction and moreover during maintenance phase of the infrastructures. Furthermore, we illustrate some of the best practises on machines carrying out aspects of production on digitalized model where BIM represents a repository for machine output information. We show the related benefit for an intelligent supply chain in real time. The result will demonstrate how the fourth industrial revolution affects the construction world and why the BIM-4.0 strategy represents a time and cost efficiency, a unique opportunity.

1 INTRODUCTION

BIM and Industry 4.0 represent the hottest topics in construction and industry. Building Information Modeling is a process for creating and managing all of the information on a project across the infrastructure lifecycle (see Figure 1). The output is a digital model that contains all the information of the infrastructure.

Industry 4.0 is a term used to refer to the developmental project in the management of manufacturing and chain production. It includes cyber-physical systems, the Internet of Things, cloud computing and cognitive computing.

Figure 1. Continuum Construction Cycle.

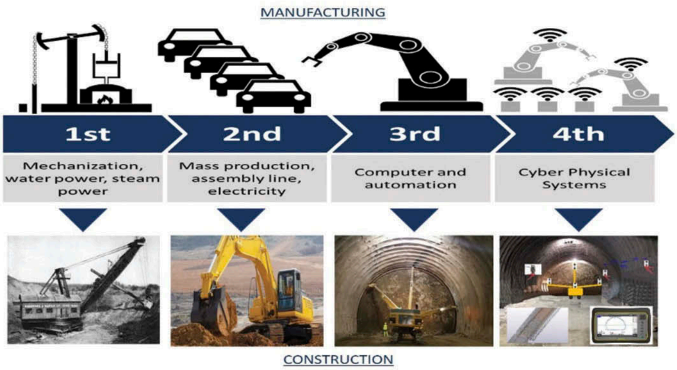


Figure 2. Industrial revolution vs. Construction revolution.

But how can the explosive mixture of these two approaches generate a revolution and a successful result in the construction field? The presentation wants to focus on how the 4.0 interoperability and information transparency can support and provide information to the BIM Model during construction and moreover during the maintenance phase of the infrastructure.

Along the present article, we report some successful case histories on machinery which help to automatically export information functional to data collection. Therefore, we illustrate benefits related to an intelligent production chain that can be queried in real time. The result confirmed how the fourth industrial Revolution influences the world of construction and why a BIM - 4.0 strategy represents an efficiency in terms of cost and time of realization.

2 DEVELOPMENT

Here we illustrate, how interoperability BIM INDUSTRY - 4.0 positively affects all construction and maintenance processes:

- Carousel (Fabrication)
- Steel Rib Erector (Construction, Construction Logistics)
- IoT Sensors, Maintenance System (Construction Logistics)
- Maintenance Software G-Safe (Operation)
- Predictive Program (Maintenance)

The correlation between BIM and Industry 4.0 offers operational advantages in terms of information retrieval and improvement of production cycles during all phases of infrastructure implementation. A methodical approach, therefore, will not only offer a scalable digital platform at the end of construction of the infrastructure, but improve the management process in the pipeline.

Follow up reports of case studies for each of the phases of the construction continuum are shown. Some of them are completed processes, others are projects that are being developed. Another fundamental aspect for the success of any interoperability project is the correct management of organizational aspects, since the introduction of this new working methodology must be accompanied by a correct preparation of the company structure and from correct tracking of the processes inside the company, especially regarding the aspects concerning reading of the data and the operating procedures to be carried out.

2.1 *Carousel TBM segments prefabrication system*

2.1.1 *Context*

The realization of infrastructure with mechanized excavation in tunnels requires the installation of prefabricated segments. Pre-fabrication systems, whether carousel or stationary, already provide for the traceability of information related both to materials and production processes (i.e. certificates of steel related to re-bar cages, et cetera), but at present, such information is not automatically associated with a specific digital model. As a matter of fact, once the infrastructure is completed, the contractor will not have a digital model populated with automatically generated as-Built information at his disposal.

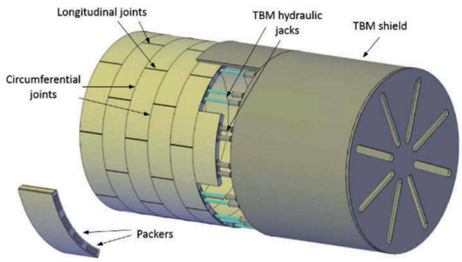


Figure 3. Tunnel Boring Machine Method.

2.1.2 *Objectives*

The objectives of the project are:

- Implementation of an Industry 4.0 model related to the production processes of prefab elements;
- Systematic and transparent data collection related to each individual prefab element as well as of the associated production process and subsequent insertion of said data into a digital model (i.e. certificates of steel related to re-bar cages, certificates of the related concrete batch, etc.);
- Systematic and transparent data collection related to the quality compliance of the prefab elements along the whole manufacturing process and the subsequent insertion of said data into a digital model (i.e. curing curve of the specific segment);
- Generation of a production dashboard able to synthesize the data related to the production performances.

In the specific case of the Segment Prefabrication Plant, for the realization of the Fast Rail Link Tunnel between Genoa and Milan, the main purpose of the implementation of such a system is the creation of a 3D Tunnel Model containing all the construction process information. Once the infrastructure is completed, the Contractor will have a digital model generated according to BIM; this model will include all the as-built information suitable to be provided to the Project Owner, for his record and retrieval for monitoring and maintenance purposes.

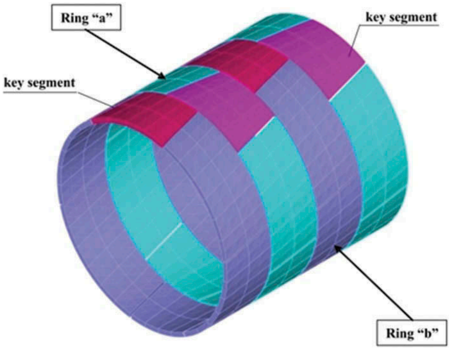
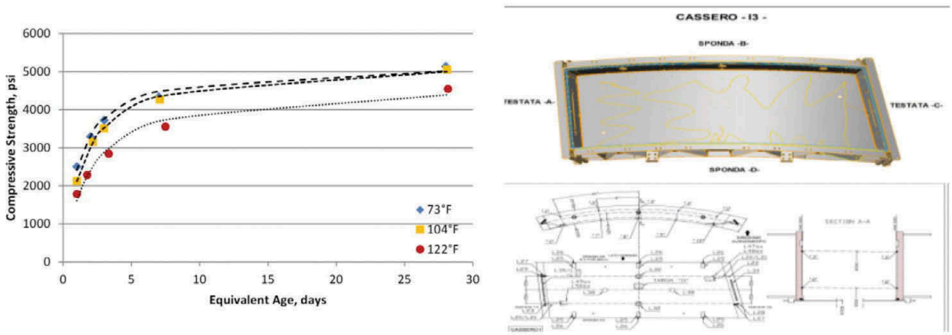


Figure 4. Configuration of segmental tunnel lining.

For the completeness of the model, the system involves the transmission of the model populated to the TBM driving system which will complete the model by adding the exact position of each prefab element along the Lined Tunnel.

2.1.3 *Advantages*

The main advantage of the implementation of such a system is the immediate retrieval of the as-built information (production process data, maturation curve data, data on the materials used, Dimensional controls, etc.). The benefit compared to conventional systems is represented by the ability to retrieve the required information in real time, thus carrying out preliminary analysis and forecasts of ordinary and extraordinary maintenance of the infrastructure.



(a) (b)

Figure 5. (a) Correlation compressive strength – maturity age – temperature. (b) Precasting mould and mould tolerances.

In addition, the programming of specific software allows the data collection and recording, including reporting of the production parameters. The risk of data loss is then eliminated.

2.1.4 *Development issues*

Obviously, to collect data in a transparent and efficient manner, the software shall receive the information directly from the Prefabrication Plant, thus in order to avoid use of human resources for the repetitive data collection activities. These resources will be used in more profitable ways for the data analysis thus in order to reveal any criticalities and to improve the quality of the processes.

The specific case showed that the interoperability between the production plant and the BIM – Industry 4.0 oriented, data collection software is fundamental. During the project's development the following criticalities have been revealed:

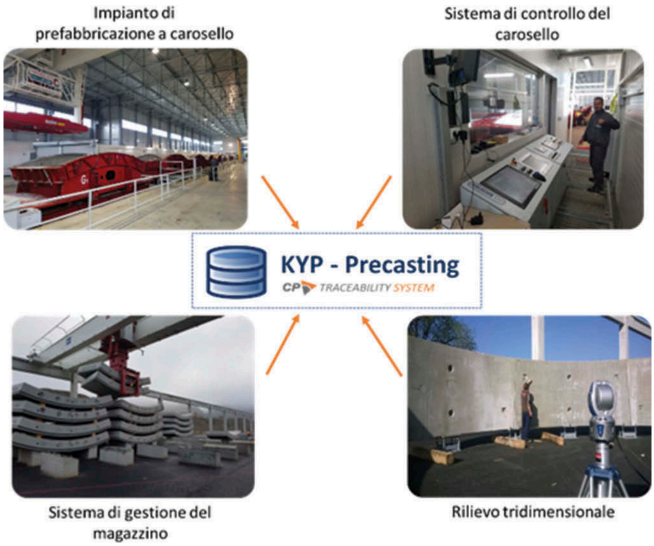


Figure 6. KYP – CP Traceability system flow chart.

- Dialogue between sensors applied to machineries and related software;
- Dialogue between data collection systems of different machineries (TBM – Prefabrication Plant – Accounting management systems, . . .);
- Selection of essential and useful data during the construction processes of the infrastructure (not all data collected are essential, a selection of these data is required in order to let the system be simpler and durable).

2.2 *Tubular steel RIB erector*

2.2.1 *Context*

Conventional Tunnelling can be defined as the construction of underground openings of any shape with a cyclic construction process composed of the following steps:

- excavation, by using the drill and blast methods (explosives) or very basic mechanical excavators
- mucking
- placement of the primary support elements such as:
- steel ribs or lattice girders
- soil or rock bolts
- sprayed or cast in situ concrete

Ground-lining interaction control is one of the most critical processes during a tunneling project implementation. Some of the design and construction decisions during a tunnel project are very critical to reduce the ground movement around the excavated tunnel. These movements have a direct effect on the tunnel stability and the design load of the primary lining. Tunnel linings are structural systems installed during and/or after excavation to provide ground support, maintain the tunnel opening, limit the groundwater inflow, support appurtenances, and provide a base for the final finished exposed surface of the tunnel. Tunnel linings can be used for initial stabilization of the excavation, permanent ground support, or a combination of both.

During the past few years considerable advances have been taking place worldwide in the design and construction of tunnel primary linings. The trend set is a tendency to move away from traditional support, including heavy open profiles made of cold rolled steel arches, to a lighter solution with the use of optimized profiles such as the tubular steel rib, and shotcrete reinforced with wire mesh and/or steel fibers, providing a continuous and durable support. The development of tubular ribs by MACCAFERRI Tunneling, and the development of a Robotized Erector for the semi-automatization Steel Rib installation, designed and manufactured by CP-Technology, has provided engineers and contractors greater design options; increased flexibility; and brought efficient, safer, and cost-effective construction methods. As a matter of fact, the system is designed to:

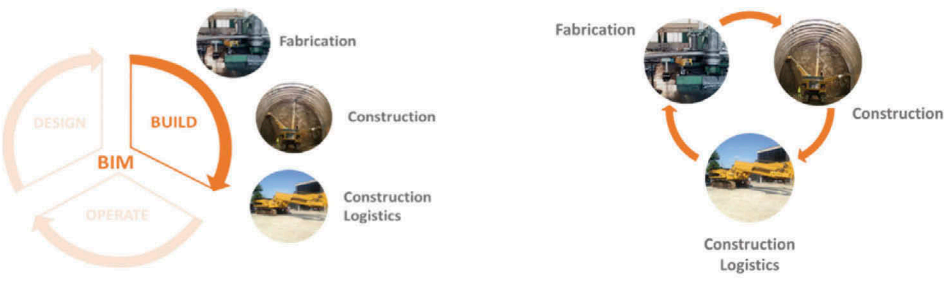
- enable the automation of the steel arch installation;
- tackle and reduce the risk of exposure of the workers to hazardous conditions;
- limit the number of workers deployed to install the supports;
- reduce the installation time;
- implement effective and actual work coordination.

(a) (b)

Figure 7. (a) Traditional steel rib installation method. (b) Semi-automated steel rib installation method.

2.2.2 *Objectives*

Once the design phase of the first tubular steel rib erector prototype, currently used for the construction of the Boscaccio Tunnel by Pavimental, has been completed, a decision has been made to produce a second prototype that combines current safety ideas with the concepts of BIM modeling and Industry 4.0. So as to provide during the construction phase an advantage in terms of quality and to support management activities.



(a) (b)

Figure 8. (a) Continuum construction – building phase. (b) Transforming the continuum construction to a 4.0 lean supply chain.

Referring to the concept of continuum construction, we wanted to link the manufacturing, construction and management phases of the jobsite logistics working on a single digital model. The first step was the generation of a 3D model locating the ribs in the theoretical position using Tekla Structures Software.

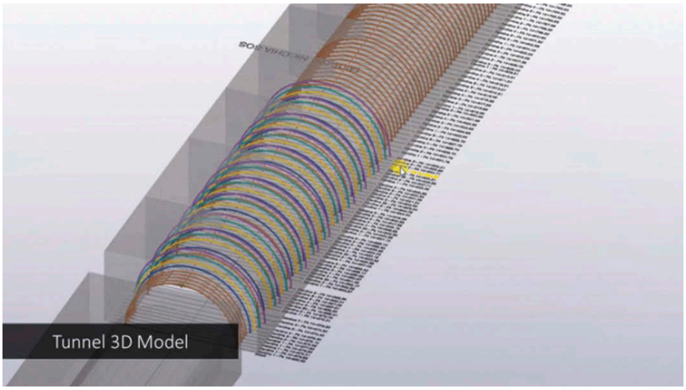


Figure 9. Tunnel 3D model.

Then, the digital model is transferred to the machine, thanks to a tool developed by Harpaceas, in order to display the correct positioning of the rib in the space, in accordance to the mathematical model, providing an effective support to the operator during the installation phase. Thanks to this solution, the correct positioning of the rib in the space is ensured, avoiding the risk connected to the lining under-thickness and therefore the corresponding risk associated with non-conformity of the primary tunnel lining works.

Figure 10. (a) Ekip steel rib placer topographic assistant. (b) Ekip steel rib placer topographic hardware.

The semiautomatic driving system has provided a dialogue between drawing software, machine guidance protocol and the machine positioning systems. In order to guarantee the maximum performance and safety conditions, typical automotive features have been adopted (command response times less than 500 milliseconds, complete driving system redundancy, . . .). Once the positioning phase is completed, the machine returns an as-built report with the correct position of the rib in the space in accordance to the digital model.

2.2.3 *Advantages*

The digital model is updated every time required with the following advantages:

- Progress Control
- Data availability for financial report
- Docs availability associated with constructed elements
- Work progress Data Availability for managin the logistics of the construction site (construction logistic)

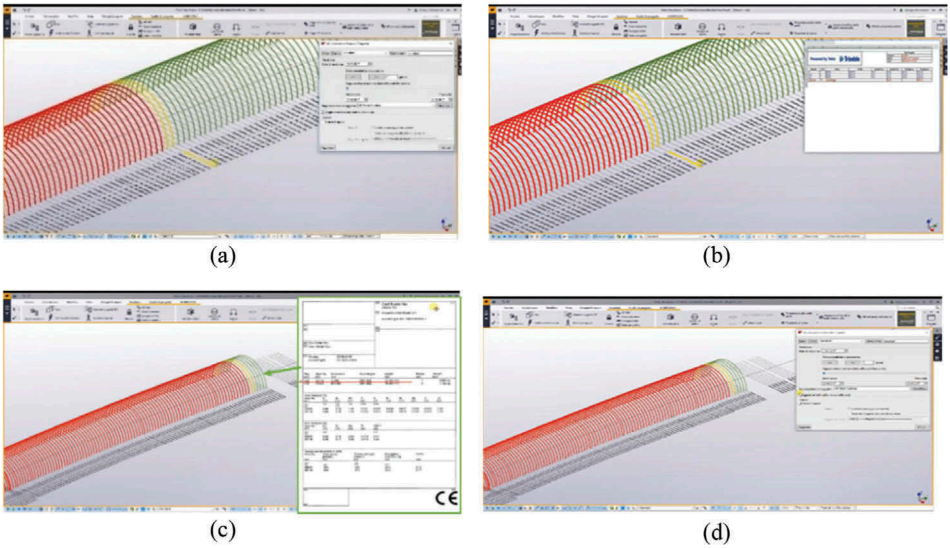


Figure 11. (a) 4D Tunnel model – Progress report. (b) 4D Tunnel model – Construction accounting support. (c) 4D Tunnel – Certification report. (d) 4D Tunnel model – Stock Report.

With reference made to the management of the construction site logistics the system allows to automatically raise an alert to the Steel Rib supplier/manufacture when the job site stock reaches the minimum threshold. The case represents a unique case in the management of the supply chain compliant to the Industry 4.0 Standards, now applicable for the underground infrastructure industry.

2.3 *Maintenance and operation – G-Safe*

2.3.1 *Context*

We may start highlighting some critical issues recurring with very high frequency when managing infrastructure maintenance, in detail:

- Difficulties for operators in collecting all of the data in a single archive for the works managed
- Difficulties in archiving and retrieving information and documentation related to the infrastructure works being managed (new and old)
- Difficulties in implementing well-structured and efficient inspection and maintenance plans
- Difficulties in verifying and certifying that inspections and maintenance activities are carried out as required
- Difficulties in forecasting budgets for routine maintenance
- Difficulties in having a real time picture of the maintenance activities for the managed infrastructure works.

On top of this the Italian Ministry of Infrastructures and Transport have enacted the ministerial decree no. 560 on 1 December 2017, which defines how to gradually integrate, by the contracting authority and operators, compulsory methods and related instruments, such as infrastructure modelling both during the design (BIM), the construction and management phases as well as the related maintenance activities. The obligation for the contracting authority will start from January 2019 for infrastructure works above 100 million euros and shall be progressively extended to contracts with a lower amount to be introduced throughout the public works system in 2025. In this context, G-Safe would be defined as: the digital system to manage the inspection and maintenance of the road infrastructures BIM-4.0 oriented.

2.3.2 *Objectives and advantages*
Which are the distinctive features of this platform?

- is able to integrate as built data in a BIM environment (Building information Modeling);
- is able to associate as built data within a unique inspection and maintenance software application;
- is able to schedule activities and draft budget;
- is able to instantly verify ongoing maintenance activities;
- is able to legally certify that inspections and maintenance activities have been carried out;

Furthermore, a GIS (Information georeferenced system) is integrated into the system with the aim of supporting the work of inspectors and maintainers. G-Safe allows for the collection oh monitoring data for road infrastructures 24/7 by means of IoTs (Internet of Things). The platform is designed to be used by infrastructure managers who can grant access to operators (surveyors, inspectors, builders, maintainers, etc.) in order to ease the sharing of information related to ongoing activities in a transparent manner.

Figure 12. G-Safe – Flow Chart.

The software platform is a subscription service and it can be accessed by means of a mobile device depending on the type of user and level of access. The opportunity of being able to consult easily and in real-time as built documentation related to the selected portion of the infrastructure being reviewed, it helps both to handle inspections and to schedule the maintenance program (considering the ease of retrieving information related to a specific supplier or to the installation date of a specific construction element or retrieving documents).

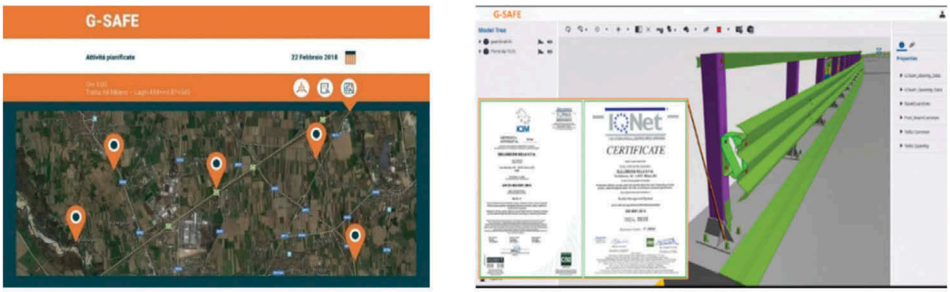


Figure 13. (a) G-Safe Map with GIS position for maintenance plan. (b) 3DModel.

The opportunity to integrate conventional inspection activities with a sensor network able to carry out 24/7 monitoring on the most critical part of the infrastructure, constitutes a great added value.

Figure 14. Iot Sensor.

Furthermore, the activities of field operators will change considerably by using tools which facilitate mobility tasks (tablets and smartphones) and allowing at the same time the generation of more punctual reports.

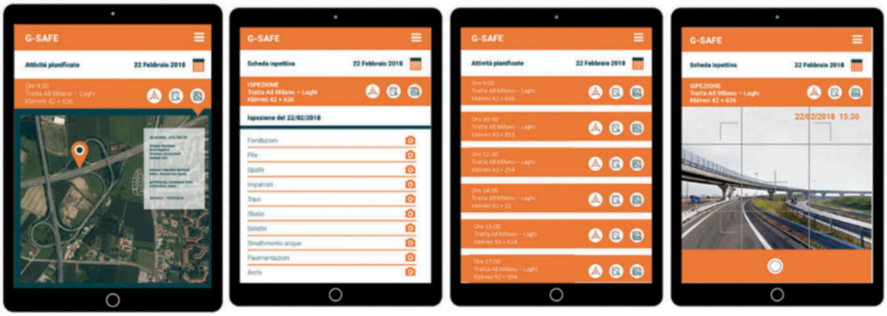


Figure 15. G-Safe: User interface.

2.3.3 *Development issues*

Up to now the main issues faced during the development of this platform were:

- Processes Restructuring. Company processes have to be improved so as to incorporate training and the design and management of new processes.
- Information enhancement. Retrieval of historical information of existing infrastructure and related inspection and maintenance activities is an important matter to be conducted methodologically. In order to take full advantage of the platform's potential the Digitalization of the existing infrastructure will be required, at least of the most sensitive part (i.e. bridges, viaducts . . .)

The development of the platform is continually on going.

3 CONCLUSIONS

Demo application of the Platform reveals that the use of suitably designed sensors built into the equipment may be the only way for a transparent and effective information transmission to digital models according to BIM methodology in a 4.0 oriented way. As a matter of fact, managing the infrastructure according to BIM methodology requires specific skills and extensive deployment of resources, if the digital model data is transferred automatically from the sensors, there is an advantage in terms of information transparency, less data loss and lower cost in collecting data.

The data returned by sensors built into the equipment may be a valuable resource in order to manage procurement, progress control and financial information. By the way, as already mentioned, this also involves a re-design of workflow and all the associated roles.

The first, owners, managers or constructor of infrastructure who will adopt in a functional way such methods and technologies will have a huge competitive advantage both during the construction phase or the maintenance phase.