ANALES de Edificación

Anales de Edificación
Vol. 5, Nº3, 100-106 (2019)
ISSN: 2444-1309
Doi: 10.20868/ade.2019.4376

Received: 05-10-2019
Accepted:18-10-2019

Uso de la metodología BIM en la remodelación de un puente existente
Use of BIM methodology in the re-modelling of an existing bridge

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***Resumen*— La incorporación de la metodología BIM (Building Information Modeling) al sistema de construcción es una consecuencia de las nuevas posibilidades y ventajas que ofrece la aparición de nuevas tecnologías. BIM permite la reducción de errores de diseño, incompatibilidades, desbordamientos y aumenta el valor del proyecto. Su uso en proyectos de construcción de edificios ya es muy común y también se espera que sea obligatorio en todos los proyectos promovidos por las administraciones públicas en España para 2019. Sin embargo, la situación en el campo de la ingeniería civil aún conlleva importantes incertidumbres. Por lo tanto, el nivel de implementación de esta tecnología en proyectos de infraestructura es limitado. Sin embargo, BIM también será obligatorio en España en este tipo de proyectos para julio de 2019. El objetivo de este estudio fue abordar la implementación de BIM en el diseño de carreteras y puentes para resaltar los problemas que deben enfrentarse con la tecnología existente. En particular, abarcó el modelado de un proyecto de puente de arco existente en Logroño, incluido el modelado de la topografía y las carreteras de acceso, el puente de arco, un puente de vigas, así como la creación de un modelo general que permitió realizar detecciones de choque y cuantificaciones. Además, el software que se ha utilizado comprende Google Drive®, Autodesk Revit®, Autodesk Civil 3D®, Autodesk Navisworks® y Autodesk Infraworks®. La importancia de esta investigación radica en la evaluación de las posibilidades de BIM en proyectos de ingeniería civil. Este estudio encontró que el estado actual de la técnica presenta dificultades ya que el software aún no está adaptado a este campo. Por ejemplo, uno de los software BIM más utilizados, Autodesk Revit®, aún carece de utilidades específicas relacionadas con la ingeniería civil. Es decir, las herramientas o kits de herramientas para el diseño de puentes, la posibilidad de introducir niveles inclinados o las dificultades para modelar formas complejas ampliarían notablemente la aplicabilidad del software BIM existente a proyectos de ingeniería civil.**

Palabras Clave— BIM; infraestructura; proyectos; software; diseño de puente de arco.

***Abstract*— The incorporation of Building Information Modelling (BIM) methodology to the construction system is a consequence of the new possibilities and advantages that the emergence of new technologies offers. BIM allows the reduction of design errors, incompatibilities, overruns, and increases the value of the project. Its use in building construction projects is already very common and it is also expected to be mandatory in all the projects promoted by the public administrations in Spain by 2019. However, the situation in the field of civil engineering still entails significant uncertainties. Thus, the level of implementation of this technology in infrastructure projects is limited. Nevertheless, BIM will also be compulsory in Spain on this type of projects by July 2019. The aim of this study was to address the implementation of BIM in road and bridge design in order to highlight the problems that need to be faced with the existing technology. In particular, it encompassed the modelling of an existing arch bridge project in Logroño, including the modelling of the topography and the access roads, the arch bridge, a beam bridge, as well as the creation of an overall model which allowed to perform clash detections and quantifications. Moreover, the software that has been used comprises Google Drive ®, Autodesk Revit ®, Autodesk**

Civil 3D ®, Autodesk Navisworks ®, and Autodesk Infraworks ®. The significance of this research lies in the assessment of BIM possibilities in civil engineering projects. This study found that the state of the art nowadays presents difficulties as the software is not adapted yet to this field. For instance, one of the most used BIM software, Autodesk Revit ®, still lacks specific utilities related to civil engineering. That is to say, tools or toolkits for bridge design, the possibility of introducing inclined levels or the difficulties in modelling complex shapes would remarkably expand the applicability of the existing BIM software to civil engineering projects.

Index Terms— BIM; infrastructure; projects; software; arch bridge design.

I. Introduction. Context

We are facing a time of significant changes. The third industrial revolution has brought a new world of possibilities, in terms of electronics, IT (Information and Technology), or telecommunications. Some authors have concluded that the so-called fourth industrial revolution is taking place nowadays (K. Schwab, 2017) (A. Moreno Bazán , M. García Alberti, A. Enfedaque, . J. Gálvez Ruíz and A. A. Arcos Álvarez, 2018) which advances in connectivity, communication, and the fusion of different technologies.

The implementation of these possibilities results in higher productivity and competitiveness (H. Puma Lupo, G. J. Goyzueta Balarezo 2016). This can be applied not only to brand new hi-tech fields as the ones mentioned before but also to the traditional ones such, as the construction industry. However, this field encompasses some special characteristics which make it more difficult to apply industrialization procedures.

At this point, Building Information Modelling (BIM) methodology stands out being the best example of the application of the previous concepts for construction projects.

According to Adam Strafaci (A. Strafaci 2008), "BIM is not a product or proprietary software program. It is an integrated process built on coordinated, reliable information about a project from design through construction and into operations." It allows the reduction of design errors, incompatibilities, overruns, and increases the value of the project.

In order to do this, BIM poses a transformation in the decision-making process. This is based on the paradigm shown in MacLeamycurve (F. C. Gámez, M. J. S. Severino and R. J. G. Márquez, 2014): the sooner that a change is introduced, the cheaper it will be, and our capacity of introducing it will be greater as well.

Moreover, at the time of writing, the applicability of BIM in the civil engineering field is still under discussion and one of the most important possibilities are based on exploitation and maintenance of the existing infrastructure (Á. Moreno Bazán, M. García Alberti, A. Enfedaque, M. Núñez Fernández and R. Molina Sánchez, 2019). In such a sense, some projects will need to face the problem of modelling reality. This study aimed to assess the difficulties in performing a model from an existing infrastructure. Therefore, the project of an existing bridge has been re-modelled.

II. Origin and present of building information modeling

The concept of BIM appeared in the 1970s when Professor Charles M. Eastman described the concept "Building Description System" referring to the following concepts (C. M. Eastman, 1975):

> "interactively defining elements", "to derive sections, plans, isometrics or perspectives from the same description of an element", "Any change of arrangement would have to be made only once for all future drawing to be updated. All drawings derived from the same arrangement of elements would automatically be consistent.", "any type of quantitative analysis could be easily generated", "providing a single integrated database for visual and quantitative analyses".

In addition, Eastman described a parametric model where contractors could find profitable information for the programming of the project.

One of the first problems that these concepts found was the lack of interoperability between different design computer programs. Therefore, the need for some international standards arose, and the International Standards Organisation (ISO) started the development of a set of standards in 1984: the ISO10303-Industrial Automation Systems, which became informally known as STEP (Standard for the Exchange of Product model data) (R. Drogemuller, 2009).

In 1994, given that the development of STEP was still in process, Autodesk ® announced the formation of the International Alliance of Interoperability (IAI) as an initiative to create a consortium of companies to develop a class of C++ which would be able to support an integrated development of applications. As a result, they set up the Industry Foundation Classes (IFC) (F. C. Gámez, M. J. S. Severino and R. J. G. Márquez, 2014). According to R. Drogemuller, "the IFCs used the same underlying technology as STEP (Express data definition language) but developed a different product model that was customized for the building construction industry rather than using the STEP approach of attempting to cover the entire manufacturing sector" (R. Drogemuller, 2009).

At the beginning of this century, the use of BIM gradually started becoming more common, and by 2007, the General

Services Administration (GSA) began requiring the presentation of a spatial BIM model for the final approval of every major project in the USA [5]. Similar criteria appeared in other European countries. For instance, in 2018 the use of BIM became compulsory in all the building projects promoted by the public administrations in Spain, and in July 2019 its use will also be a requisite for all civil engineering projects.

The situation in the infrastructure projects is still in the beginning, and the level of implementation of this technology is not as deep as it can be found for buildings. Consequently, R. Drogemuller pointed out that the term Building Information Model does not fit well with the civil construction sector (R. Drogemuller, 2009). As evidence of this, some experts' definition of BIM has been only focused on its application on architecture and construction of buildings (E. Coloma, 2010). However, while it has its roots in architecture, the principles of BIM can be applied to everything that is built, including bridges, roads, trains, harbours and others.

Therefore, the term Virtual Design and Construction (VDC) was introduced by the Centre for Integrated Facility Engineering at Stanford University. Moreover, other terms such as Bridge Information Modelling (BrIM) have been proposed for more specific fields among civil engineering such as bridges construction.

III. CASE STUDY

In this academic work a parametric 3D model from an existing bridge has been done, in order to identify the advantages and disadvantages between the traditional methodology, which was used for the design of the original bridge, and BIM. This work is embedded in the new subject of the Civil Engineering School (Escuela Técnica Superior de Ingenieros de Caminos Canales y Puertos) from the Universidad Politécnica de Madrid called "Smart Construction: BIM", which details can be seen in references (Á. Moreno Bazán, M. García Alberti, A. Enfedaque and A. A. Arcos Álvarez, 2019) (A. Enfedaque, J. C. Gálvez Ruíz, A. A. Arcos Álvarez, M. García Alberti and Á. Moreno Bazán, 2018).

Some other objectives of this work are to allow clash detection before the construction and to produce precise quantifications.

A. Other examples

As seen before, the use of BIM is quite extended among building construction but not so usual in the civil engineering field, concretely, in bridges.

Interesting use of VDC was on the San Francisco-Oakland Bay Bridge for the "Bay Bridge Seismic Safety" project in 2007 (R. Drogemuller, 2009). A movie showing the full extent of the project was produced for public information (see in **¡Error! No se encuentra el origen de la referencia.**).

Another similar example is a BrIM case study about a concrete bridge in Colombia comprised of several 20 m span beams (see **¡Error! No se encuentra el origen de la referencia.**) (A. Gómez Cabrera and J. S. Gaitán Cardona, 2014).

Fig. 1. Photogram of the video done for the San Francisco-Oakland Bay Bridge. San Francisco-Oakland Bay Bridge East Span Simulation. [Film]. Metropolitan Transportation Commission, 2007.

The objective was to apply the "BrIM methodology in order to improve the performance and planning development of the construction of this type of structure". A parametric model was also created from an existing design to identify the advantages and disadvantages of the classic and new methodologies.

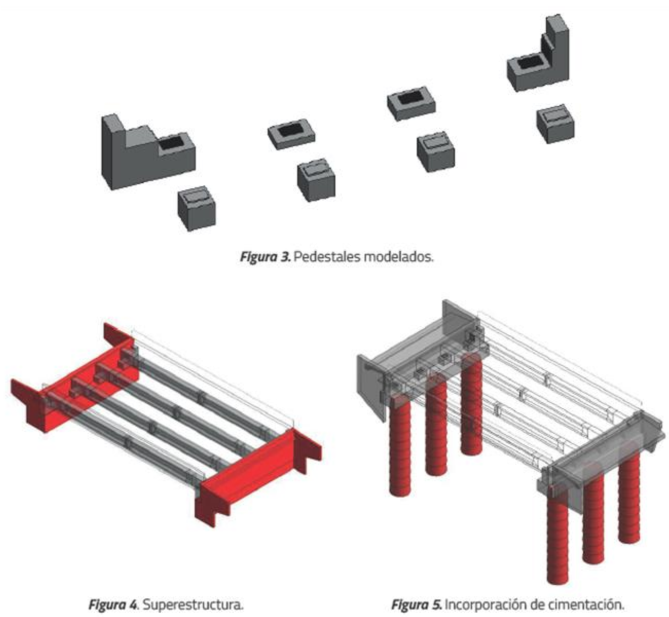

Fig. 2. Concrete bridge 3D model. Available online in Ciencia e Ingeniería Neogranadina, 2014.

B. Bridge over the Ebro river

The aim of this study was to address the implementation of BIM in the design of the bridge over the Ebro river that continues the motorway LO-20, in Logroño (Spain). This bridge was designed by the company IDEAM and can be seen in **¡Error! No se encuentra el origen de la referencia.**. The works for construction were made by the UTE Acciona Infraestructuras - IC Construcción ingeniería y gestión de obras. These works ended in 2015.

The work can be divided into several parts:

Firstly, the arch bridge. It is formed by a metal bow-string type arch with a span of 120 m and a section of bridge beam with spans 37 + 5 x 39.2 m. The arch is formed by two nerves which are joined at the extremes. The deck of this arch bridge is made of steel and it is suspended by 14 hangers from each nerve.

Secondly, there is a beam bridge, which is formed by two lightened concrete sections (one for each road).Finally, the foundation is deep by piles and the abutments of the bridge have extension wings.

Moreover, there are two access roads, one in each side, consisting of two sections of motorway supported byan embankment. They are made by two three-lane roads of 3.50 m each, separated by a median strip.

Fig. 3. Visual aspect of the bridge over the Ebro river in Logroño (Spain). Available online in http://www.ideam.es/ideam_projects/bridges/ a3aa2project_id331project_category_id8.

IV. WORK METHODOLOGY

To start, a BIM Execution Plan (BEP) was defined. It provides a framework that would let the owner, engineers, and construction manager deploy building information modelling technology and best practices on this project faster and more cost-effectively. This plan has governed the collaborative work of individual team members. It establishes the roles and responsibilities of each party, the detail, and scope of information to be shared, relevant business processes and supporting software. Moreover, the BEP has been continuously updated in parallel with the development of the model, and it is also prepared to be used during the construction project.

To continue, the methodology that has been carried out in the project will be described. In this process, coordination between the different programs and collaborative work among members of the project has been very important. For this purpose, the online cloud has been used to share information from different programs and models. Each group member had the task of monitoring a different part of the project, so all the changes that were made in each part had to be approved by this member to avoid overlaps.

The software that has been used for each part of the work was:

- Preparation of original plans in order to subsequently import them into the BIM programs → AutoCAD ®.
- Platform used for sharing files and allowing collaborative work→ Google Drive ®.
- 3D terrain modelling, performances related with the terrain (such as embankments) and all the access infrastructures → Autodesk Civil 3D ®.
- 3D modelling of the arch and beam bridge, and the definition of all their components, materials, etc. → Autodesk Revit ®.
- Coordination model for synchronizing the terrain models and the bridges→ Autodesk Navisworks ®.
- 3D integration environment for the contextualization of the situation of the bridge → Autodesk Infraworks ®.
- Realization of the budget and the measurements (which were directly made in the model)→Revit ® + Microsoft Excel ®.

A. 3D surface model and terrain corridor

A 3D surface terrain and the access roads have been modelled with the Autodesk Civil 3D ® program. In order to do this, the topographic information available in the original project (contour lines, dimensions, road alignments, etc.) was used and imported into Civil 3D ®. Using this program, we created a three-dimensional surface topography and a road with the alignment and the cross section obtained from the original plans of the project, as shown in **¡Error! No se encuentra el origen de la referencia.**.

Furthermore, to have a wider view of the field surface where the bridge is located, a model of Autodesk Infraworks 360 ® has been created. This allows the observation of the bridge in a wider environment. However, the program does not offer a high-quality topography, so it should be improved to really become a useful application in civil engineering. Nowadays, this program is quite limited and according to what has been observed, its practical use is limited to the contextualization of the project within a geographic area or to get an overview of it. Also, the interoperability with AutodeskCivil 3D ® and Autodesk Revit ® should be improved. Despite these facts, it is a good starting point for conducting basic projects or first drafts, and others, and it gives the feeling that after some technological development could, it can become a very useful program in the near future.

B. 3D modeling of the bridge

Despite specific BIM software is available specifically for 3D bridges modelling, its current development does not ease the work when it is used on bridges with relatively complex geometries, such as the one done.

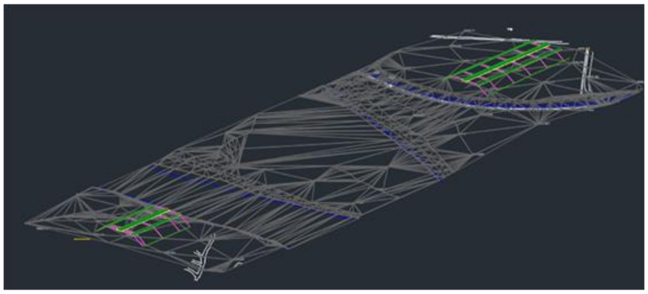

Fig. 4. Terrain model.

Therefore, we have tried to take full advantage from more general software and we have guided its design towards bridge projects. We decided to use Autodesk Revit ® for modelling. This is the reference software as it is the most used one, and the software with the best interoperability with other programs (especially with Autodesk ® ones). This program is primarily oriented to building construction, so it does not have specific tools for bridges modelling. However, the great possibilities that free modelling (working by masses, the components, and creating specific families for bridges, etc.) allow us to virtually model any object or form, no matter how complex they are. Another great advantage is related with the interface, which is much more friendly and recognizable (for instance, due to its resemblance to other Autodesk programs) than other specific programs for modelling bridges.

For modelling the elements, we have sought to use the modelling tools that the program has by default (floors, pillars, foundations, etc.) whenever it was possible. Nevertheless, due to the complex geometry of the bridge, it was necessary to model many components ad hoc, or to create new parametric families. For modelling the components, many different 3D modelling tools program has been used, such as swept blends or extrusions. One of the main problems we have encountered, and which has greatly hindered modelling, has been the slope of the deck. Due to its inclination, working through levels has not been possible and it has been necessary to create many working surfaces for modelling the different elements.

Despite these difficulties, we wanted tof ully implement the BIM methodology, so additional information (e.g., materials, structural characteristics, own weight, or other features) has been added to each modelled element, as seen in **¡Error! No se encuentra el origen de la referencia.**. Thus, all the information is integrated within the model and subsequent materials measurements, as well as a possible structural design, are facilitated. It may also be commented that the option offered by the program to describe the manufacturer of the elements, or to insert images and links is very interesting. This functionality is quite useful for modelling bridges, as there are many standardized components such as imposts, railings, supports, etc.

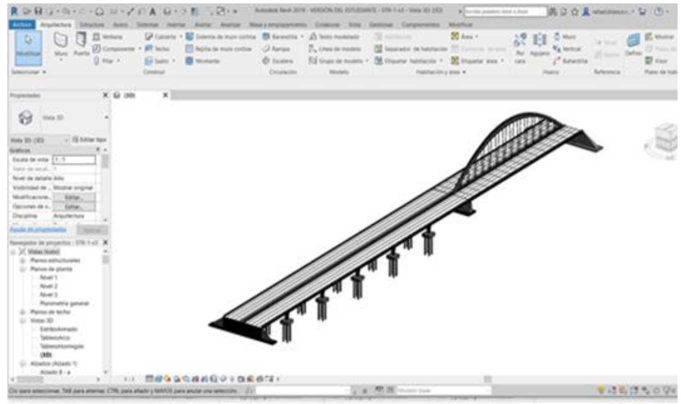

Fig. 5. Navisworks ® model of the arch bridge, and the beam bridge.

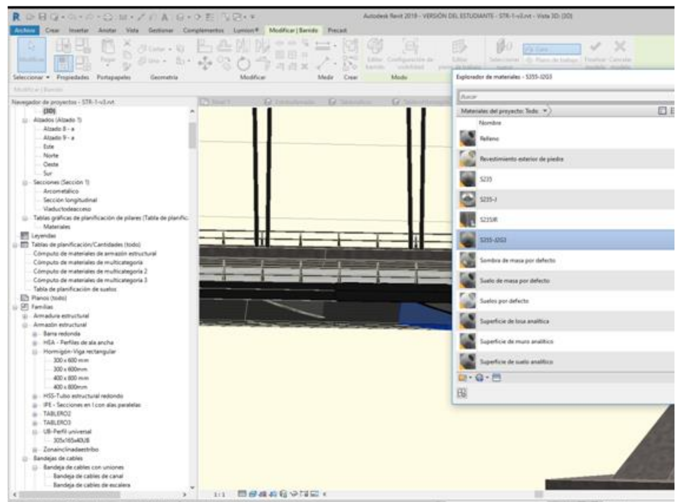

Fig. 6. Elements information included in the model.

Finally, we also have tried to explore all the features of the program. Therefore, we have modelled one of the abutments of the bridge, and its reinforcement, as seen in **¡Error! No se encuentra el origen de la referencia.**. Nevertheless, the reinforcement design tool is primarily oriented to the design of flat elements. Consequently, when it comes to elements with a more complex geometry (like the abutment) it is much more difficult and very time consuming. Hence, our conclusion is that the working time used for this task is too much for the obtained result. However, it may be interesting in order to get a global perspective of the reinforcement of the abutment and to detect interferences between the reinforcement bars.

C. Coordination Model

In order to have a set of elements modelled in Autodesk Revit ® andAutodeskCivil 3D ®, a coordination model in Autodesk Navisworks ® has been created. This coordination model allows interference detection and checks the correct fit of the model.

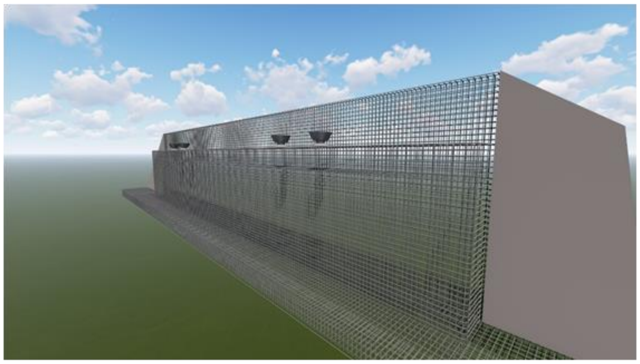

Fig. 7. Reinforcement modeling of the abutment.

In this specific case of bridges modelling, clash detection has limited functionality. If one of the embankments slightly invades an abutment, it is enough to generate an endless list of interferences. Therefore, the coordination model has been used to test in a visual way that all elements fit properly, and that there aren't incompatibilities between models. To sum up, in the coordination model the following statements have proven:

- Level of foundations / Level of foundation land.
- Level of abutment/ Level of the backfill.
- Fitting between access roads and bridge deck.
- Global fitting.

This model of coordination is a key-factor to avoid problems of fitting between the different models. Furthermore, it allows measuring the quantifications, making videos of the global model (see chapter **¡Error! No se encuentra el origen de la referencia.**), or the design and planification of the different construction phases, and its sequence (although this has not been done in this work).

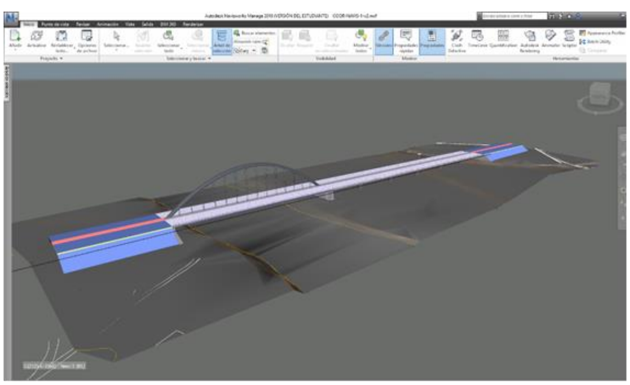

Fig. 8. Navisworks ® model of the whole infrastructure.

D. *Quantifications and budget: Revi ® + Microsoft Excel®*

For this chapter, the ideal working tool would have been Cost-It ®, which is a plug-in of Revit ® made by Presto ®. With this plug-in, both program scan be used at the same time. On the one hand, they can calculate the measurements with the Revit ® model, and on the other hand, they can do the budget using the desired base price of Presto ®. However, due to a problem with the licenses, it has not been possible to follow this methodology. Therefore, a simpler approach has been used, but still, remarkable results have been obtained.

As all the necessary information for each component had been previously added and, we had distinguished between types of steel, steels with or without paint, exposed or unexposed concrete, etc. it has been relatively easy to perform measurement tables with Revit ® to get fairly accurate measurements. After making the measurements, this table has been exported to Microsoft Excel ® where, with the help of reference prices, the project budget has been made. This methodology is very interesting because, by modifying the model, the quantification tables are automatically modified.

E. *Infraworks ® Model and video presentation*

In addition, Infraworks ® program has been used in order to realize a correctly global lace of the bridge in its own environment. This program has a big database with the topography, infrastructure and many of the buildings from most of the developed countries. It should be mentioned that in countries like the USA the development of these databases is significantly higher than in our country of study (i.e., Spain), and therefore the functionality of the program is significantly more interesting there. In Spain, specifically in the study area, the quality of the model is quite limited. Consequently, it has only been used as a general framework to place the model.

Finally, a general video presentation has been made, where the complete model embedded (Infraworks ® model) and animations such as vehicles can be seen as a whole. As it can be seen in **¡Error! No se encuentra el origen de la referencia.**, this video allows people who are not used to interpreting blueprints to get an idea of the complete project. The facilities offered by the BIM methodology to convey the architectural or engineering projects to a wider audience without specific knowledge of the matter is one of greatest advantages over conventional working methods.

V. CONCLUSIONS

As it has been shown before, BIM offers a great variety of new possibilities for the design not only of buildings, but also of civil infrastructures. And these possibilities can increase the value of the total project in different ways.

BIM allows time reduction and better efficiency (as all the elements are parameterized, and a change made in one of them is automatically updated in the whole model and in all the blueprints), doing faster and more precise quantifications, and better telecommuting (because it enables people to work on the project simultaneously without interfering each other). Additionally, attractive videos or presentations can be done and shown to the client, and the construction process can be simulated. This is a useful tool for coordinating the interaction of the various activities carried out by the working groups involved in the work, in order to generate a full and coordinated constructive organization process.

Fig. 9. Photogram of the video.

Furthermore, one of the major advantages of BIM is the creation of a 3D model which integrates all the information of the project. This not only facilitates the design and construction works, but also the maintenance, operation, or the future modifications.

However, from our point of view, there is still a long way until the complete development of a unique model that includes all the aspects of the project: design, calculation, construction, maintenance, etc. At least, this is not yet possible in the field of bridges, where standardization possibilities are not as many as in buildings.

Moreover, there are some more drawbacks. For instance, nowadays there are not so many softwares that offer specific tools for modelling relatively complex bridges, as the one exposed in this work. Consequently, sometimes modelling them is more time-consuming than in the case of buildings (although, as we have seen before, it is still worthy, and faster than the traditional CAD methodology). Nevertheless, we believe that due to the renowned quality of the available software, more specific plug ins will be developed for bridges and civil engineering projects, and this situation will soon be improved.

To sum up, the main conclusion we have obtained from this study is that BIM can already be used for civil engineering purposes, although with some difficulties that need to be cleared up. This fact is very important, as we have seen, its use will be mandatory for all civil engineering project from July 2019 (IDEAM, 3 enero 2019).

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