Randselva bridge and Drawingless projects – Planning and building bridges solely based on BIM models

Ponte Randselva na Noruega – O projeto e a construção de pontes recorrendo unicamente a modelos BIM (sem desenhos)

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Abstract

This paper describes the methods behind drawing less design and how a 634 m long free cantilever bridge is being built without the use of a single drawing, solely based on BIM-models.

Drawings have been part of the construction industry for thousands of years. So, why would one want to stop using drawings? The answer is complex, but the main reasons are:

- Understanding scope of work: A 3D-model greatly enhances understanding of the scope of work about what will be planned or built.
- Clash control: Finding, anticipating and solving clashes in a BIM-model is a lot easier and cheaper then solving clashes at site.
- Parametric design: BIM-models can be made with the help of parametric design.
- Preparing for the future: If one wants to improve automation in the construction industry, BIM is the alternative to 2D drawings when transferring information from design to site.

Keywords: Bridge / Construction innovation / BIM / Parametric design / Model based design

Resumo

Neste artigo descrevem-se os métodos de projetar sem recurso a desenhos e como uma ponte de avanços sucessivos em consola com 634 m está a ser construída unicamente com base em modelos BIM, sem se utilizar um único desenho em obra.

Os desenhos fazem parte da indústria da construção há milhares de anos. Então, qual o motivo para não se usarem desenhos? A resposta é complexa, mas as principais razões são:

- Compreensão do âmbito: um modelo 3D melhora consideravelmente a compreensão do âmbito do que será projetado ou construído.
- Controlo de conflitos: encontrar, antecipar e resolver conflitos num modelo BIM é muito mais fácil e económico do que resolvê-los em obra.
- Parametrização: os modelos BIM podem ser produzidos recorrendo a parametrização.
- Preparação do futuro: o BIM é uma alternativa aos desenhos 2D melhorando a automatização na construção e a transferência de informação do projeto para a obra.

Palavras-chave: Ponte / Inovação na construção / BIM / Parametrização / / Modelação 3D

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VIEIRA, T. [*et al.*] – Randselva bridge and Drawingless – Projects Planning and building bridges solely based on BIM models . **Revista Portuguesa de Engenharia de Estruturas**. Ed. LNEC. Série III. n.º 18. ISSN 2183-8488. (março 2022) 115-122.

1 Bridge concept

Bridges link previously separated geographic areas unavoidably transforming the landscape. Each bridge concept depends on the local factors that may influence and determine the final solution chosen for a valley or river crossing. So, every single bridge has its own history and should, therefore, be seen as unique.

On Randselva bridge those factors are strongly related with the asymmetric river valley geometry and a major geotechnical constraint of a steep slope located on the west side of the valley, composed by sands with 80 m height. These key requirements together with other functional crossing needs related to an existing railway line, the Kistefoss road, a future parking place and a local access road have determined the bridge solution which harmonizes all these requirements.

As result, a bridge consisting of a continuous concrete superstructure over the full length with 7 spans: 75 + 194 + 137 + 3 x 60 + 48 = 634 m (between abutments axes) was designed, as shown in Figure 1. The deck cross section, with a total width of 14.6 m (including edge beams), comprises a single cell concrete box girder with variable heights on the 3 major spans (axes 1 to 4) and a 4 m constant height concrete deck on the smaller east side spans (axes 4 to 8). Due to the different geotechnical scenarios crossed, four different types of foundations were designed: concrete bored piles with ∅1500 mm (axes 1, 2 and 3), steel core piles with ∅ 270 mm (axes 4, 5, 7 and 8) and a shallow footing (axis 6).

2 BIM

A drawingless project, or the so-called model-based project has the following advantages:

- Understanding scope of work: A 3D-model greatly enhances understanding of the scope of work when both planning and building. While a drawing gives a limited amount of information, like levels and measurements, a BIM-model gives the user the ability to access any information needed. Compared to a 2D-drawing, a BIM-model also gives the ability to sequence information.
- Clash control: Finding, anticipating, and solving clashes in a BIM-model is a lot easier than on a 2D-drawing and cheaper than solving clashes at site.
- Parametric design: BIM-models can be made with the help of parametric design. This way of working gives a lot of flexibility to design changes and saves a lot of time when working on repetitive tasks.
- Cross border cooperation: A BIM-model looks the same in any country, while drawings usually are very country-specific. Thus, cross country collaboration becomes easier.
- Procurement: As all objects that need to be built or bought are represented in the model, updated accurate data for volumes and quantities are always present in the BIM-model. Also, reinforcement can be ordered directly from the BIM-model, eliminating the need for manually made bar bending schedules.

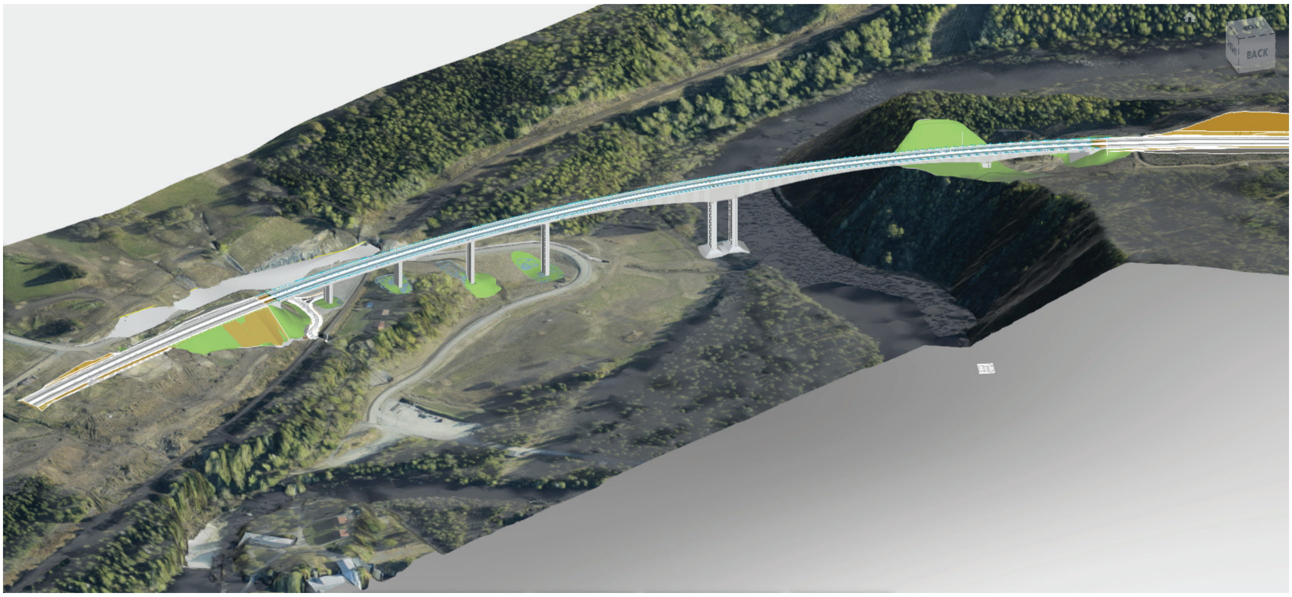

Figure 1 Randselva bridge, Norway – General overview from North (BIM model shown in SMaRT, Sweco AS)

- Preparing for the future: If we want to improve automation in the construction industry, it's essential to find alternatives to 2D-drawings when transferring information from design to site. Feeding 2D-drawings to a robot will not be optimal.

2.1 What is BIM and why use it?

When mentioning BIM (Building Information Model) most people normally refer to digital BIM-models, but the abbreviation BIM can also be used to describe the workflow that ensures information-flow in the process of planning, building, and maintaining structures.

Norwegian Public Roads Administration (NPRA) is the project owner of the Randselva bridge project. Over time they have been gradually extending their demand for how BIM is used in their projects. The first step in this development has been to use BIM-models as the basis for project drawings. Parallel to this development, they have seen a significant reduction in change orders. The main reason for significant reduction in change orders in BIM-projects are better opportunities for clash control and the improved understanding of scope of work.

Figure 2 shows a drawing detail (left) and the equivalent area in a BIM-model shown in perspective (right). They both carry information about the top reinforcement of a concrete pile and how it will pass through the bottom reinforcement of the above foundation. The 3d-view does however offer a lot more information on potential clashes and a greatly improved understanding of scope of work even before one start rotating the view.

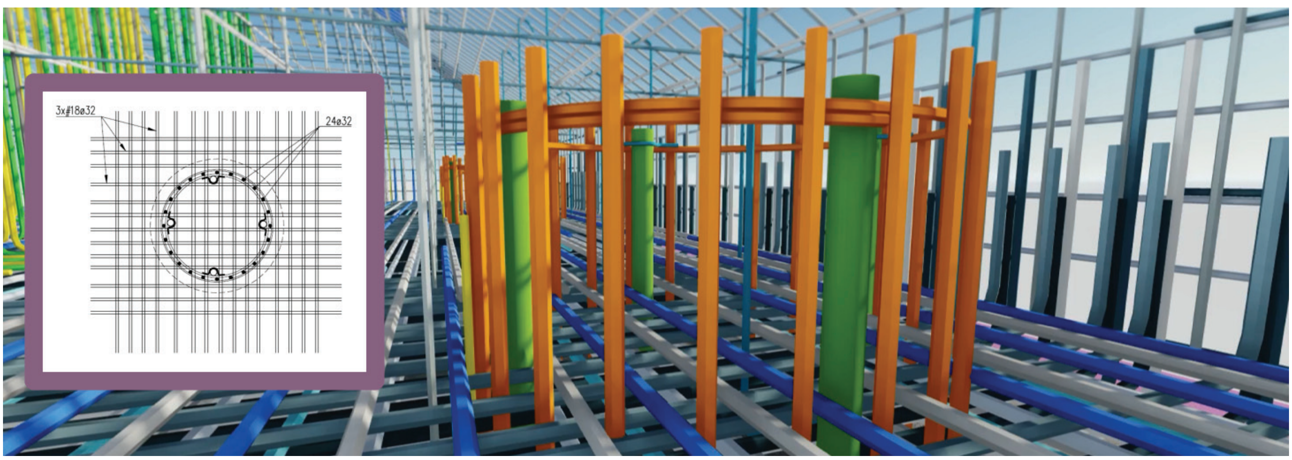

Figure 2 The drawing detail (left) and the 3d-perspective (right) representing the same area in construction

To ensure a successful use of BIM in the Randselva project, BIM-workflows were defined very early on in the project. They included defining:

- Which software would be used;
- Which file formats would be used;
- How quality control was to be done;
- Which UDAs (user defined attributes) was to be used.

2.2 Who will use the model?

A key to successful use of BIM is understanding who will use the BIM-model and understanding what kind of information the users will need to withdraw from the model. The Randselva bridge BIM-models are being used for multiple purposes along its way from design to operational state, as illustrated in the BIM workflow in Figure 3. Users of the multiple stages will normally have different information requirements and use different software to extract the data.

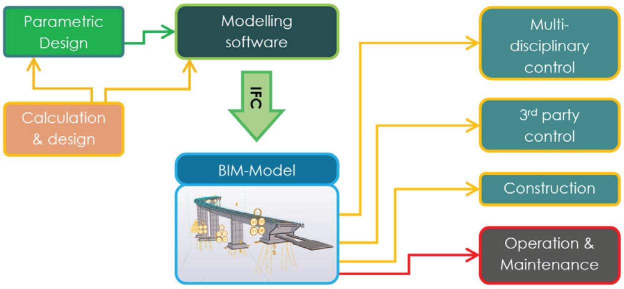

Figure 3 BIM-workflow and model users

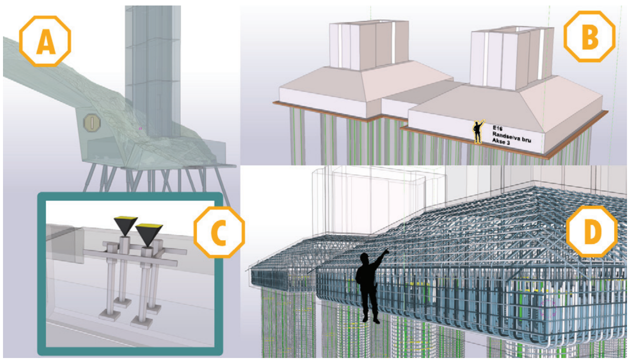

Figure 4 Four main purposes for use of BIM-models at construction site

On the Randselva bridge project, multi-disciplinary control and 3rd party control are mainly done by using Solibri™ in combination with BCF-files. At the construction stage, the model is being used for the following four main purposes schematically shown in Figure 4:

A Earthworks and backfilling;

B Constructing scaffolding / Surveying;

C Producing and placement of third-party products;

D Installing reinforcement (and post tensioning).

These four different purposes all need specialized software and work methods.

Counted in hours, the construction stage is by far the stage where the BIM-models are being used the most. In contrast, it is at this stage where available software is the least developed. Especially methodology for installing reinforcement can greatly be improved.

Even though this is currently not used extensively, the BIM-model will hopefully be used for more than planning and construction and live on to serve as a digital twin with very detailed as-built documentation. This is assumed to be very valuable for the operational period of the bridge and in maintenance purposes.

2.3 Level of detail

Choosing an optimal level of details in a BIM-model is very important. Objects need to be modelled with enough details to be useful in clash control and understanding scope of work. At the same time, too many details will make model very large and software will start lagging and be difficult to control.

Post tensioning tendons and anchorages are important components in the Randselva bridge as they are the "arteries" of the bridge. Due to the bridge curvature in plan view and the combination of two different structural systems, the post tensioning geometry is very complex, and the position of the components is not flexible. However, only the outer shape of the tendons geometry and anchorages is important to model correctly, as it will form the basis for clash control.

The steel strands and the inner geometry of the anchorages are taken care of by the company delivering the product and does not need to be modelled. An excerpt of the 200 tendons modelled at Randselvabru is shown in Figure 5.

All structural reinforcement needed for the Randselva bridge project has been modelled – see Figure 6. This gives a very good understanding of which clashes must specially be designed and fitted due to clashes and potential installation problems. All rebars in the BIM-model are however not clash free. A pragmatic approach is chosen where some clashes between rebars in the model are accepted as long as it is obvious that clashes can easily be adjusted at construction site.

Another advantage of modelling all rebars is that reinforcement can be ordered directly from the BIM-model, eliminating the need for manually made bar bending schedules. In areas with heavy reinforcement and limited space like blisters for post tensioning anchorages, many projects traditionally produce 1:1 mock-ups at worksite to test constructability. For the Randselva bridge project, these mock-ups have been produced digitally and have proven to be a very efficient and cost-effective way of engineering.

In particular, due to the bridge curvature each blister position and corresponding reinforcement are almost unique. In the BIM-model, local adjustments on the general and blisters reinforcement were made for every blister. This would traditionally require a great amount of specific drawings to avoid extra work at site. A comparison between a mock-up assembled at worksite and a digital mock-up developed for Randselva bridge is presented in Figure 7.

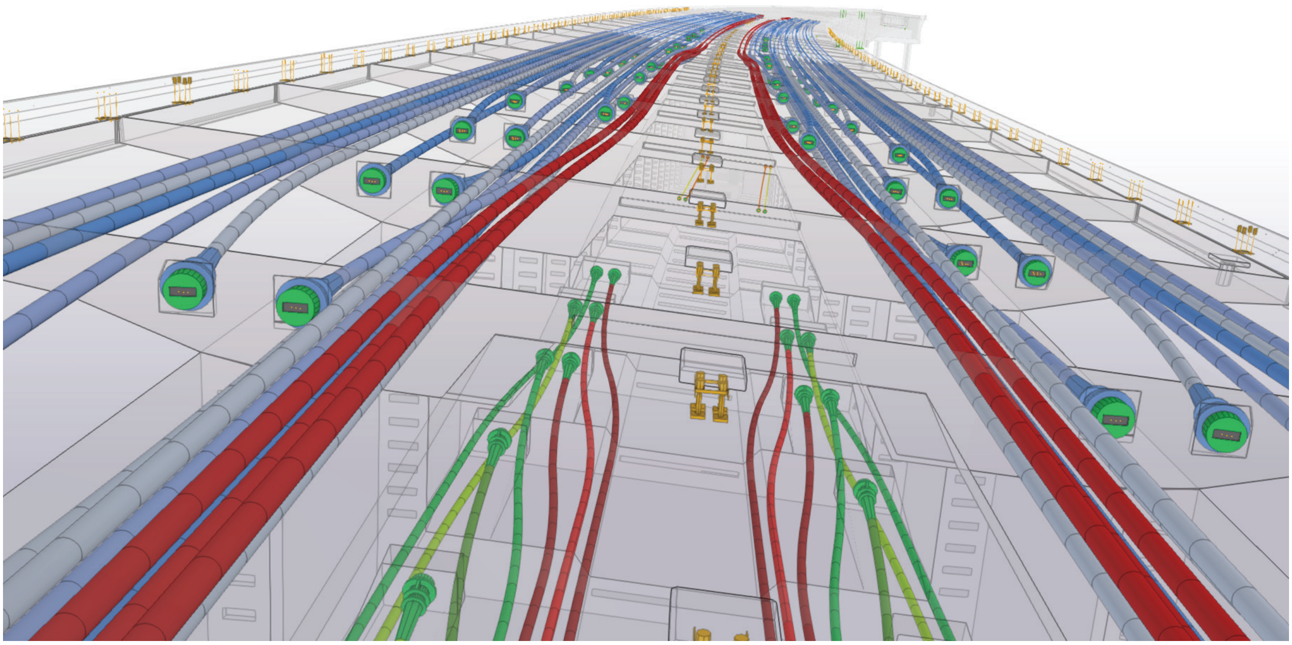

Figure 5 Randselva bridge contains over 200 tendons

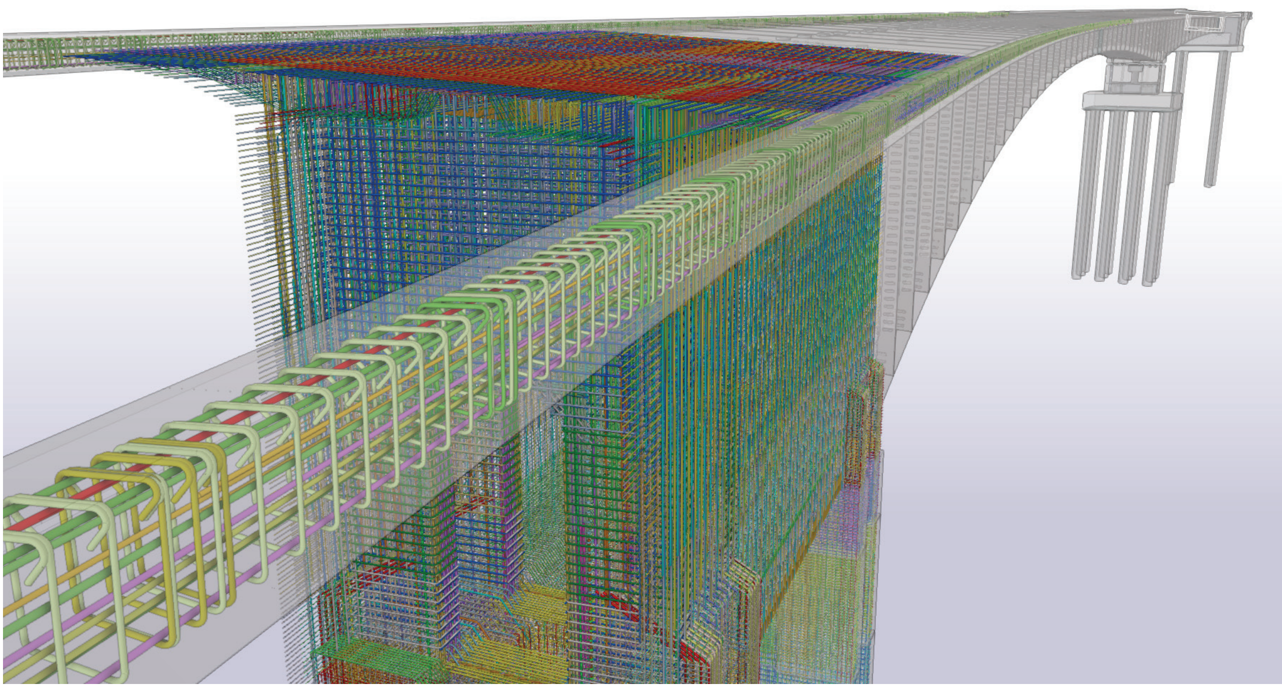

Figure 6 Randselva bridge contains over 200 000 rebars

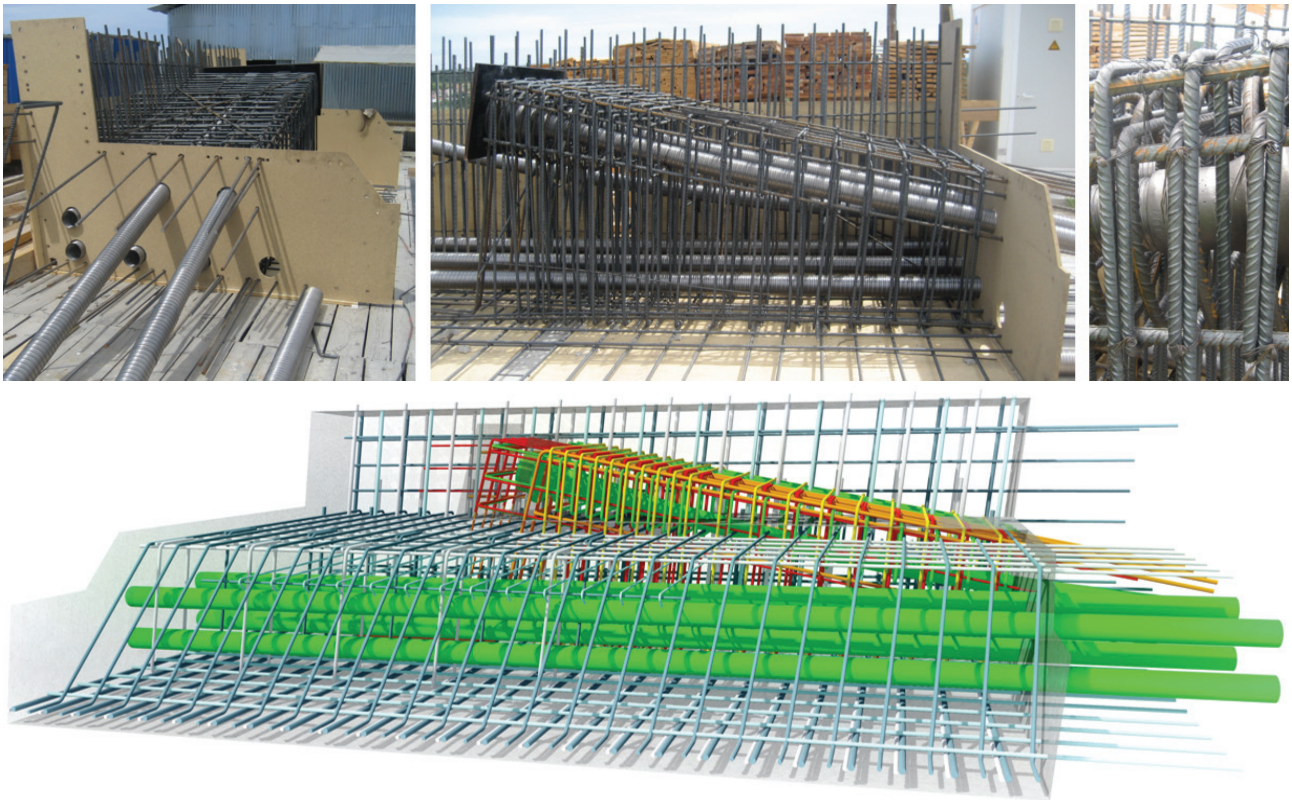

Figure 7 Digital mock-ups have replaced traditional 1:1 construction-site mock-ups

2.4 Parametric design

Parametric design can be described as a set of rules (a parametric script) that is fed to a computer. The computer then use these rules to produce a digital model. A quite simple example of such a rule can be to place lighting posts every twenty meters along the centreline of the road. The advantages of modelling using parametric design compared to modelling manually are many. If for example the centreline of the road is moved, the computer will automatically move the lighting posts with it, eliminating the human labour needed to update the position of all the lighting posts. If the desired distance between the lighting posts is revised in the script, the computer revises the design in seconds. The same principles can be used for more complex modelling like reinforcement or post tensioning.

When using enough of these rules, most of a structure can be described by parametric design. This leaves a very flexible design that can be revised quickly and without human errors. The parametric scripts can also easily be reused in future projects. For the Randselva bridge project, more than 60% of the structure is modelled using parametric design. All the tendons and over half of the reinforcement and concrete form has been created this way.

2.5 User Defined Attributes (UDA)

All objects in a BIM-model have attributes connected to it. Some of the attributes are predefined by the software used to model the object. Objects can also be enriched with UDA as shown in Table 1.

One of the most important parts of constructing a high-quality BIM-model is adding useful attributes to objects in the model. The more structures data that is added, the easier it is to use the model at later stages. On the downside, a large set of attributes is harder and laboursome to maintain. The key is understanding what kind of information is useful at the different life-stages of the BIM-model.

In an IFC-viewer like Solibri, these attributes are shown when marking an object. For the Randselva bridge project the user defined attributes are shown in the custom-made curtain "A_E16_PART_INFO" seen in Figure 8.

Table 1 User defined attributes used in the E16 Randselva project

UDA-name	Info example	Name of object
01 Object name	Foundation	More thorough description of object if needed
02 Description	Crane foundation	Object code (In Norway: vegvesen.no)
03 Object code	C2	Main process (In Norway: handbook R762)
04 Process	84410000	Level of detailing
05 LOD	350	Object status
06 Status	3rd party control	Object revision
07 Revision	01	Date of revision
08 Revisions date	2019.05.14	If clashing, what object should be prioritized
09 Placement priority	1	Material quality
10 Material	C45	Dimension (only if not clearly given by the object)
11 Dimension	Tube Ø120	Construction sequence / pour phase of object
12 Con. sequence	3C01-01	Drawing name and number
13 Free attribut_01	K01-005 -	Link to drawing (required by NPRA)
14 Free attribut_02	https://a360.co/DSFJDF	…
	…	Name of object

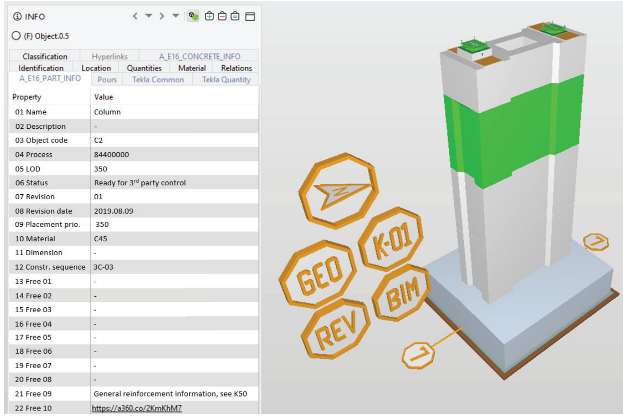

Figure 8 The custom-made curtain "A_E16_PART_INFO" shows the UDAs added for a column part of Randselva bridge

For the Randselva project, one of the most used UDA (user defined attributes) is "construction sequence". This attribute states which cast unit the object belongs to. This enables the contractor to easily plan their orders of concrete, reinforcement and post tensioning better, making logistics at site easier. Figure 9 shows the BIM simulation of the first two deck segments in Axis 3.

As the BIM-model moves through its life stages, the type of user defined attributes needed for an object will most likely change due to revised requirements. Changing user defined attributes for objects in the BIM-model is relatively easy.

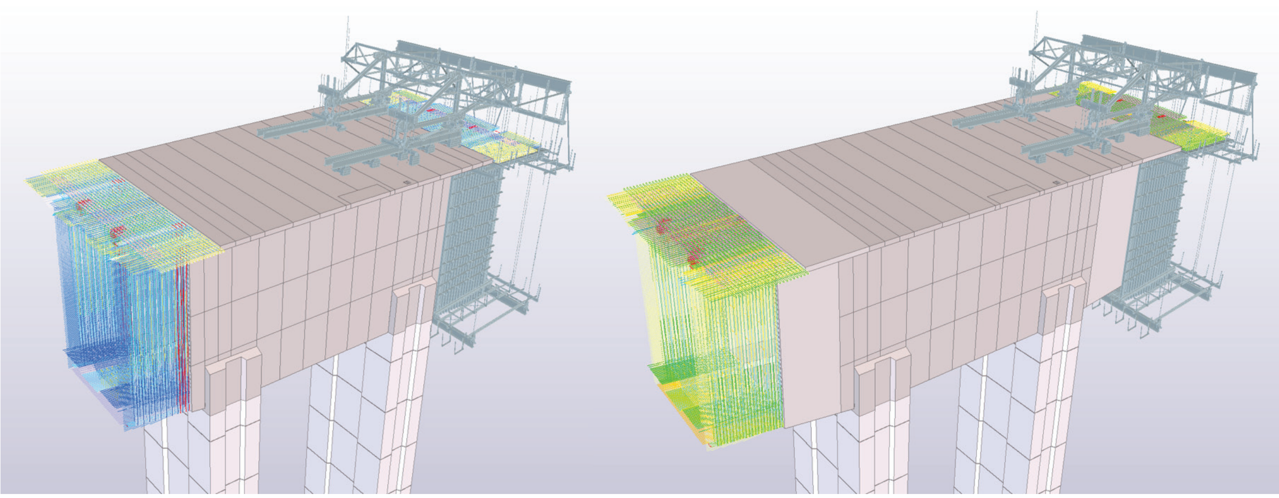

Figure 9 Using UDAs (user defined attributes) to show different construction sequences (Axis 3: segments 01 and segments 02 phases)

2.6 Disadvantages

Drawingless projects improve a lot of traditional workflows and ways of transferring information between involved participants in a project. There are however disadvantages to this method of working. The main disadvantages we have identified are summarized below:

- BIM-models contains a lot of information. Without good software and good ways of filtering data, it is hard to extract the needed data.
- How long will the IFC-format exist? Will future users of the BIM-model be able to read the data and how are digital links to connected documents maintained?
- In a BIM-model, informing the user about revised or added objects are easily done by adding UDA-information to the object. Informing the user about deleted objects are however more difficult, as there is no longer an object to attach the UDA-information to. So far, the mediocre solution to this problem is creating a revision log.
- Presenting tables of information in a BIM-model is hard. So far, this is normally solved by adding links to documents.
- In a drawing, a reinforcement concept valid for multiple similar construction elements (like piers) can be presented and is easily controlled. In a BIM-model, however, all reinforcement for all elements have to be present in the model, making modelling and control more laborious.
- In a drawing, a flexible concept can easily be presented. An example of this are piles (shown with break lines) set on top of bedrock, even though the level of the bedrock is unknown. This type of flexible design concept is hard to communicate in a BIM-model.

3 Conclusions

This paper summarizes the main features of Randselva bridge in Norway, the world's longest bridge designed and currently being built solely based on BIM-models. Along with a brief description of the bridge concept, the main focus is sharing the BIM modelling methodologies and features used for design and construction of this advanced model-based project.

2D drawings usually follow certain CAD rules and specific country defined notes and descriptions. BIM models make cross-country collaboration a lot easier than in 2D drawings, since a BIM-model practically looks the same in any country.

Experience from Randselva bridge also shows that the high level of detailing used in the BIM-model is allowing a more standarized fabrication of reinforcement and is significantly reducing the number of questions and change requests from the site. On the other hand, to achieve this performance there is a need for an important investment from all stakeholders in this new digitalization methodology.

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