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BUILDING INFORMATION MODELING OF A TIMBER BRIDGE – A CASE STUDY

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ABSTRACT: The development of using BIM models as the sole documentation in road projects has come a long way, but in Norway the development has come particularly far. A BIM model gives the user a good overall picture with access to any information needed. One of the biggest advantages of BIM is that the design basis is more elaborated and with higher level of details. The reduction in change orders on site is noticeable.

This case study shows how a BIM model can be used, from calculation and modeling to structural review, productions and procurements, assembly and useability after construction. Tande Bridge is chosen as an example of this process as it one of the first timber bridges to be built based solely on BIM models and was a success. A BIM model of a timber bridge includes large glulam beams, concrete abutments and steel joints with essential detail. We can therefore conclude that we have a well-functioning system for BIM models in a bridge life span that can be used on every kind of construction and material. Even greater success will come with more standardization and development of software.

KEYWORDS: Timber Bridge, Building Information Modeling (BIM), Model-based Design, Drawingless Design, Model Maturity Index (MMI).

1 INTRODUCTION

Norway has a long history of timber bridges. The breakthrough came with the Olympics in Lillehammer in 1994. A new method for connections was developed (slotted steel plates with dowels) and creosote impregnation guaranteed a life span of 100 years. This was the beginning of making larger road bridges in glulam. In recent years, many overpasses have been built in glulam, especially in the eastern part of Norway. Medium-sized timber bridges with a pre-stressed timber deck are competitive with other materials, especially when there is limited construction time and deck hight is needed.

The design basis has historically been 2D drawings. The change from 2D drawings to 3D models was done in a few years' time around 2016 in Norway. At first Building Information Modeling (BIM) models were used as the basis for creating 2D drawings, whereas we now use the same BIM models throughout the whole project. The development has come a long way, and in Norway the development of drawingless projects has come the furthest [1]. This paper shows how BIM can be used as sole documentation for the whole life cycle of a timber bridge. From calculation and modeling to structural review, productions and procurements, assembly and ultimately archiving and maintenance.

BIM models offer a much better visualization than 2D drawings, but it is important to find the right platforms to disseminate the knowledge. One of the biggest advantages of BIM is that the design basis is more elaborated with a higher level of detail. A 3D model can also make clash controls easy in the early stages of the bridge design, which leads to a reduction of the number of changes on site.

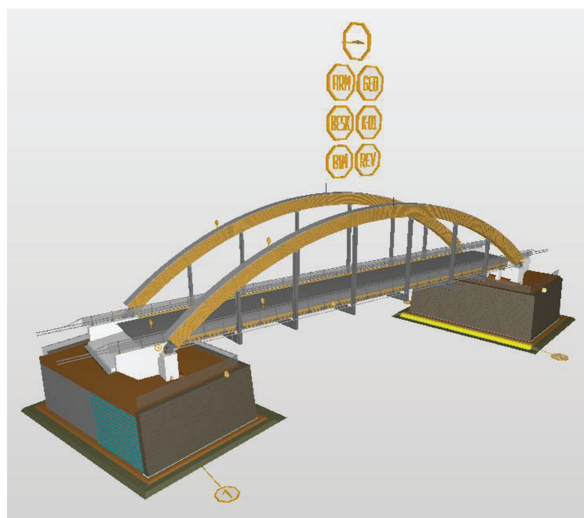

Figure 1: *BIM model of Tande Bridge*

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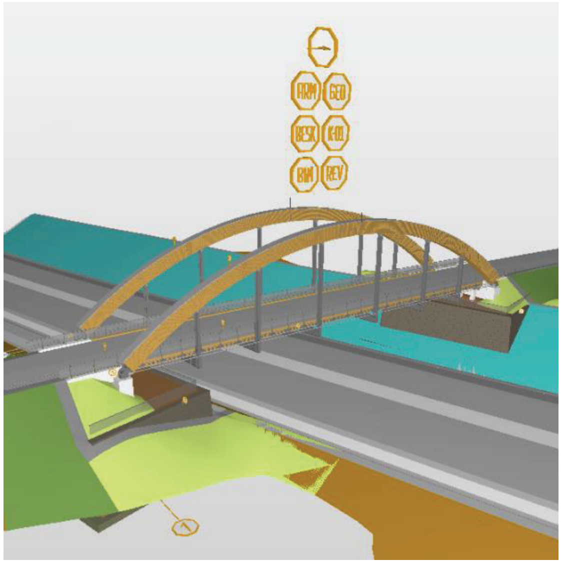

Figure 2: *BIM model of Tande Bridge with road geometry and landscape*

A BIM model consists of several files. Typically, there will be separate files for each discipline, which provides the user with a clear overview and easy access to relevant information. Figure 1 shows the BIM model of Tande Bridge. In Figure 2 road geometry and landscape design have also been added. To ensure that the BIM model file will not be too big, the road geometry and landscape are customized and only showing what's relevant to the specific bridge. The «coins» (shown over the bridge in Figure 1 and Figure 2) have been developed by Sweco as a practical way of gathering links to useful documents such as the "overview drawing", the design report, the geotechnical report etc. Typically, the documents you will need throughout the life span of the bridge.

To make a good BIM model it is necessary to know who will use it and what they will use it for, for example structural review, procurement, or assembly etc. It is also of great importance what kind of information is needed in the various phases. There is a lot of information inside a model and without good filters in the software, it is difficult to sort and utilize the information. Material, dimension, object name and construction part are examples of topics the BIM model should filter on. An accurate and structured BIM model is necessary to avoid that the user will not experience an overflow of information.

As a tool to ensure good information flow, the BIM manual was introduced. This is a document that always follow the BIM model. The BIM manual describes how the model's structured, the level of detailing used in this particular model, how object information is sorted, how to filter in the model, a review of how model maturity index (MMI) is used, and other relevant information are important topics that are reviewed in the BIM manual. The MMI number describes the level of maturity through number codes. It is not possible to determine whether a construction part has been subject to structural review by simply looking at the object in the model. The MMI level is therefore utilized to link the maturity with the object to explain which phase it is in and if you could use the information for preliminary design, clash controls or procurement. The use of MMI is primarily for the design, structural review and construction phases.

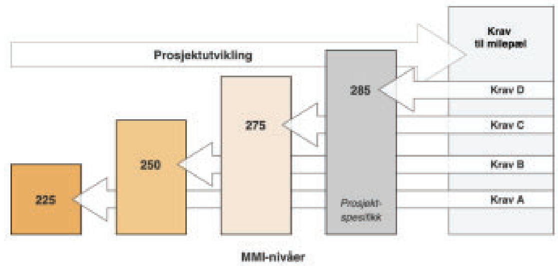

Figure 3: *Conceptual sketch showing the MMI level increasing during the project development and linked to requirements [2].*

Figure 3 shows how the level of MMI increases through the project development and how it is linked to requirements that constitute a milestone. It is possible to have different levels of MMI on different objects in the same model. The total level of MMI for a model always refers to the lowest MMI level. To get a good overview it is possible to sort on the different levels of MMI in every BIM model.

A timber bridge consists of glulam beams, concrete abutments and steel details and generally has a lot of different components from small steel connections to large glulam beams. It is important to choose the right level of detailing on each component. If you can manage the life cycle of a timber bridge solely based on BIM models, you can manage every type of construction and material. Tande Bridge is chosen as an example of this process. Tande Bridge is one of the first timber bridges built solely based on BIM models. Tande Bridge was designed in 2018 and built in 2020. The bridge is a two-way 80km/h road south of Lillehammer, crossing the E6 highway. It has an arch span of 48,5 meters connected with tension bars. The glulam arch is connected at the top with a steel joint.

2 TANDE BRIDGE – FROM DESIGN TO MAINTENANCE

2.1 STRUCTURAL DESIGN

The development of BIM models has come furthest in the planning phase. The priority in this phase is to optimize the structural design and make it even more efficient. In Norway, many of the large road projects are Engineering, Procurement and Construction (EPC) contracts. This has resulted in a reduction of time to complete the structural design, and the need for streamlining and optimizing the design period is noticeable. The introduction of parametric design into modelling is particularly favourable when working with preliminary design. The need for detailing is superior, and the focus is finding a buildable solution for the right price. The use of

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parametric design enables quick changes and gives a good overview over the geometry with a detail level sufficient for the design phase. Pre-made script for all the typical bridge solutions makes it easy to choose the right bridge solution fast. As it is easy to add road geometry, landscape, traction pipes etc., showstoppers are quickly discovered, and a solid bridge solution can be established.

It is important to consider what level of detailing a BIM model needs. Objects must have enough details to be useful for a good understanding of the model and in a clash control. At the same time, unnecessary details can make the model hard to use, as the files become too large. An example is screws. Screws come predefined in every modelling program, with everything from head to thread modelled visually. However, you still need to describe the object with information such as material, surface treatment etc. in the model before the object can be used for procurement and construction. This means that a better-looking screw will make the file heavier without providing much benefit. For design purposes you would achieve equal result with a cylinder of the same diameter and description as the screw which would not make the file heavier. Considering the number of screws in a bridge construction, it can be favourable to make a simplified screw duplicate as shown in Figure 4.

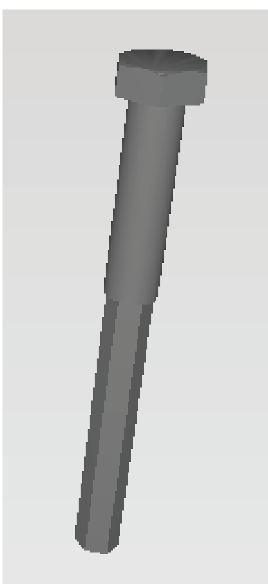

Figure 4: *Simplified screw duplicate used at Tande Bridge*

All price-bearing elements must be modelled. The focus on Tande Bridge were the glulam beams with steel details, necessary detailing of the steel details, the abutments and to sort every component into phases. The holes in the steel are especially important and can be difficult to model. It is important to ensure that the hole stays a hole for the whole process from modelling and to procurement.

Object information is added in the design software before the IFC export (a PDF file for BIM models). Object information is called user-defined attribute (UDA). The UDAs are important information that should be easily accessed, such as material quality, placement priority, links to drawings etc. The information should be short and descriptive. A high-quality BIM model includes useful attributes to objects in the model. The key is understanding what information is needed in the different phases.

The detail level needed for the UDA differs from phase to phase. For a preliminary design, there is less need for detailed attributes compared to a building project where the attributes should be adjusted to procurement. The input in the UDA enables the possibility to classification. Figure 5 shows the UDA for the glulam beams on Tande bridge. Everything from dimension to surface treatment and MMI level are described.

INFO

(B) Object.1.196

Identification | Location | Quantities | Material

Egenskaper | Pset_BuildingElementProxyCommon

Property	Value
A.01 Objektnavn	Limtrebue
A.02 Objektkode-tekst	D8
A.03 Objektkode-nummer	86100000
A.04 Beskrivelse	Limtrebue, tverrsnitt 980x1400, limes opp av 3x140, 2x165 og 2
B.01 Parsell	P2
B.02 Område	S18
B.03 Konstruksjon	04-1752_K660_Tande bru
C.01 MMI	400
E.01 Material	GL30c
F.01 Merknad	Bueender ansees som tilstrekkelig klatresikret med rekkverk.
F.02 Merknad	Buer overflatebehandles med ett strøk Jotun Visir pigmentert c
G.01 Vertikalniva	2
H.01 Status	Teknisk godkjent iht. notat 17/9536-36
H.02 Revisjon	B
H.03 Revisjonsdato	10.03.2019
I.01 PNS	P2210

Figure 5: *Extract from the UDA for a glulam beam*

The setup for UDA shown in Figure 5 follows guidelines given by the Norwegian Public Road Administration in addition to the needs of the glulam subcontractor and the contractor. Every set of attributes is linked to an element to ensure that the necessary amount of information for every phase is provided in the model.

Figure 6 and Figure 7 show how it is possible to filter and sort in the BIM model. In Figure 6 all glulam arcs are shown, and in Figure 7 all element with the material “GL30C” are shown.

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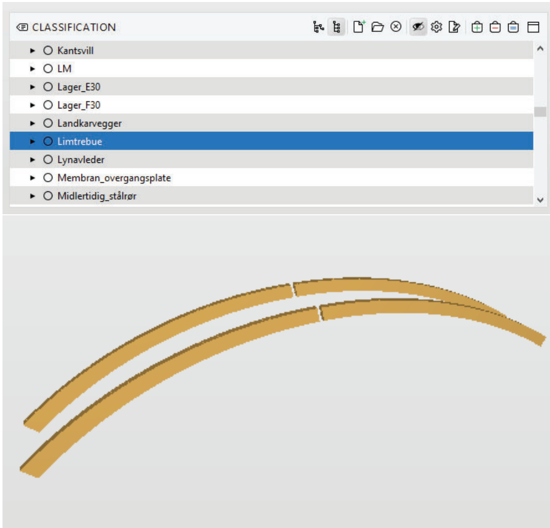

Figure 6: *The BIM model when sorting on glulam arc*

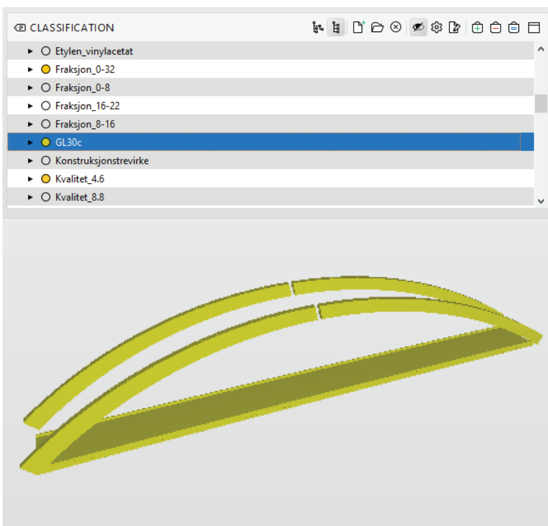

Figure 7: *The BIM model when sorting on "GL30c"*

Even if we have a BIM model, we still make the "overview drawing". The drawing gives an overall view of the construction and should provide the necessary information without having to look up the design report or look at the model. When modelling a bridge, a cost-benefit assessment should be made. How do you show what is needed without doing a needless amount of work that will also make the file unnecessary big? Therefore, drawings showing the principle of backfilling around the bridge and maintenance drawings with tables to be filled out after the bridge opening are still being made.

2.2 STRUCTURAL REVIEW

When working with a 3D model, collisions will immediately be apparent. Discovering collisions at an early stage gives a far more effective opportunity to address the issues than fixing collisions when discovered in the late stage of structural design or on site. This advantage is significant for economic reasons and decreases time delays for the contractor. In the first phase after model completion, the models are used for interdisciplinary control and afterwards for third-party control. With a greater degree of standardization, more checks can also be done automatically and that will help improve quality and save time.

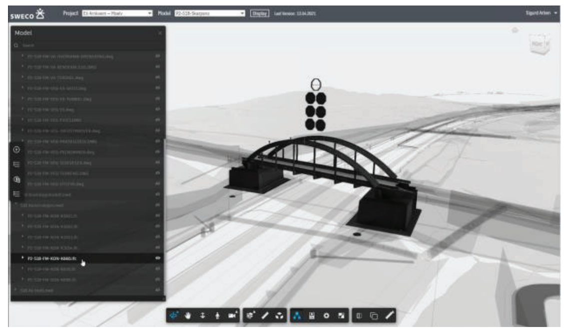

Figure 8: *Tande Bridge in the online model viewer for the road project*

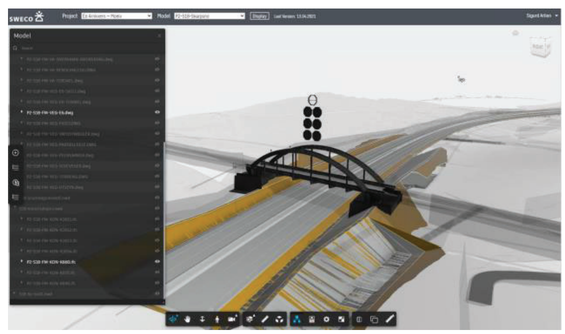

Figure 9: *Tande Bridge with road geometry in the online model viewer for the road project*

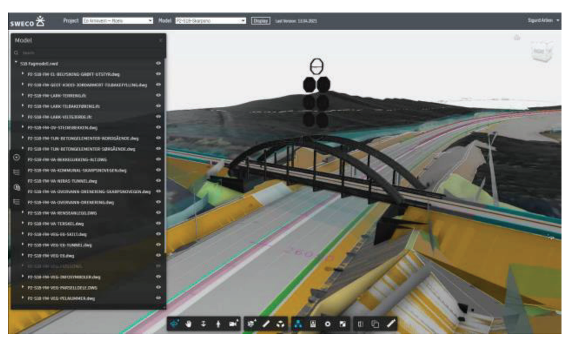

Figure 10: *Tande Bridge with all the different models visible in the online model viewer for the road project*

Having a good solution for showcasing all the different models are important. This is particularly useful when you have several bridges with models not only from the civil engineer, but also from road engineer, landscape architect etc. It should be easy to navigate and to turn on and off

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each model. Figure 8, 9 and 10 show Tande Bridge in the online model viewer used in the road project. Figure 8 highlights the bridge alone, while Figure 9 also includes the road geometry is highlighted. In Figure 10 all the different models are visible.

The BIM model is also used for structural review. This is an efficient method where it is possible to perform the structural review and add comments directly in the model. The comments are saved in a separate file where it is possible to add answers. The file is then sent back and forth until every comment is sufficiently addresses. Figure 11 shows a screenshot of the structural review of Tande Bridge. The different comments are listed at the bottom with supplementary comments on the left and a visual display top right.

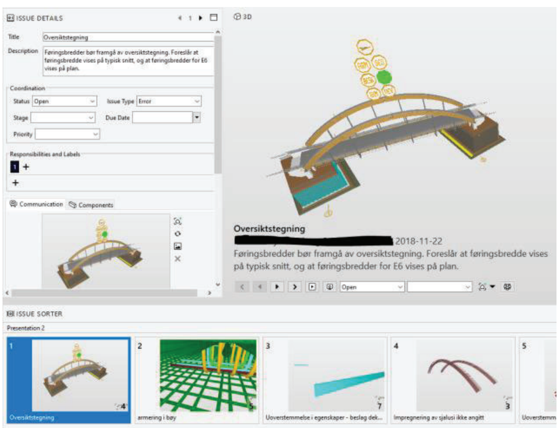
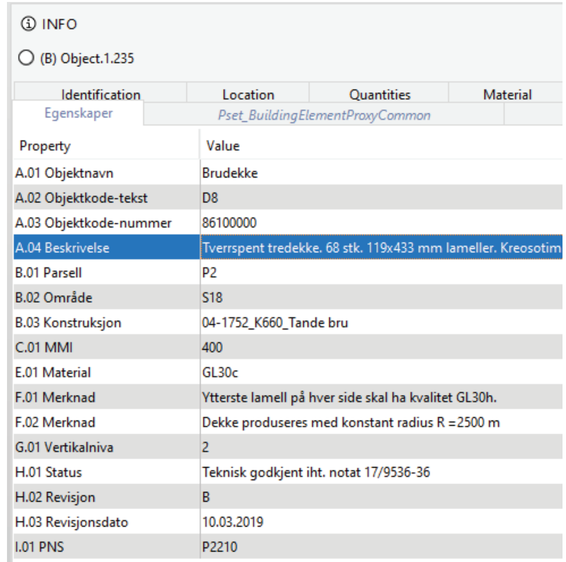


***Figure 11:** Screenshot of the structural review of Tande Bridge*

It is recommended to use the BIM manual to inform the person performing the different reviews. A good, standardized model with a good setup of filters, this will ensure that the structural review can be done in an effective way.

2.3 GLULAM SUBCONTRACTOR

The biggest advantage for the glulam subcontractor is how quickly they get a good overview with a BIM model and how easily the model can be updated when changes occur.



INFO

(B) Object.1.235

Identification | Location | Quantities | Material

Egenskaper | Pset_BuildingElementProxyCommon

Property	Value
A.01 Objektnavn	Brudekke
A.02 Objektkode-tekst	D8
A.03 Objektkode-nummer	86100000
A.04 Beskrivelse	Tverrspent tredekke. 68 stk. 119x433 mm lameller. Kreosotim
B.01 Parsell	P2
B.02 Område	S18
B.03 Konstruksjon	04-1752_K660_Tande bru
C.01 MMI	400
E.01 Material	GL30c
F.01 Merknad	Ytterste lamell på hver side skal ha kvalitet GL30h.
F.02 Merknad	Dekke produseres med konstant radius R =2500 m
G.01 Vertikalniva	2
H.01 Status	Teknisk godkjent iht. notat 17/9536-36
H.02 Revisjon	B
H.03 Revisjonsdato	10.03.2019
I.01 PNS	P2210

***Figure 12:** Extract from the UDAs for the glulam deck*

Figure 12 shows how the glulam deck is described in the attributes, sufficient for procurements. The attributes include surface treatment, radius on the deck, material etc. The attributes also show the status of the model and the corresponding date, as well as the level of MMI for the specific element (here: 400 and ready for procurement).

The import of the BIM model into the supplier's software normally works adequately, but there may be some bugs and the import can be time consuming. The glulam subcontractor produces the glulam with a CNC machine. CNC machines are used to computerize production machines in various types of industry. It is particularly the holes in the glulam that make transfer to the CNC machine challenging. When the model is exported to IFC format, it is important to check that each hole remains a hole and does not transform into splines. Work is continuously being done to address this challenge. A good import depends on an accurate and thorough model, since the IFC format is less accurate than the precision of the CNC machine. A very detailed BIM model is not necessarily sufficient for the supplier. It can make the model too heavy without any benefits. Improved software with good filters and a more standardized setup for models, which considers the needs of the suppliers, are important.

2.4 CONSTRUCTION

Looking at hourly consumption, it is on the construction site that the BIM model is used the most. However, this is also where available software is least developed. Software must be optimized to present views and information from BIM models in an easy and efficient way. All information in the BIM model is connected to a component. Thus, a single file can provide all the information needed to build the bridge.

The glulam beams on Tande Bridge were transported to the construction site pre-assembled. Smaller elements

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were prepared at the factory and then transported to the construction site by night. The abutments where already built on each side of the highway. The traffic was redirected, and the assembly could take place during a weekend. Figure 13 shows the assembly of the glulam arcs.

Figure 13: *The glulam arches are assembled on the construction site. Picture taken by Sweco*

Using the BIM models sequenced information for the assembly will be an advantage. The contractor can then go through the construction period to check any time-critical elements and perform space-saving measures.

However, the use of tablets and other digital tools can be difficult on site, especially due to weather conditions. An example is the challenges of using touch screens in rainy weather.

Revisions done in the model must be marked and described carefully, as it is not possible to highlight the revisions as it is for drawings. When updating a model, the change must be described sufficiently including the revision mark and date. That way it is possible to filter the model regarding the updates as shown in figure 14.

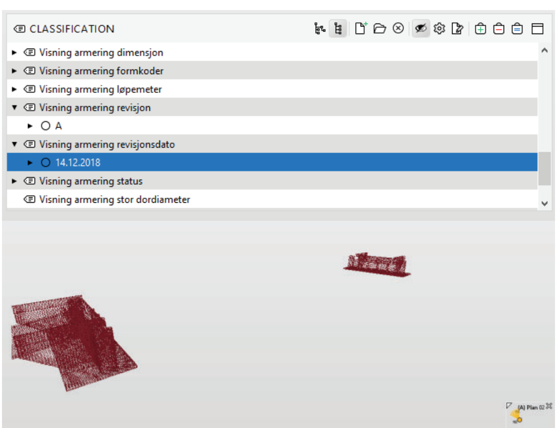

Figure 14: *The BIM model showing a revision made at a certain date*

The history of 3D models on construction sites is not long, so it is important to constantly get feedback from contractors and to incorporate the feedback into the model. A good project includes the contractors' needs from the beginning. Even though there is a requirement that all cost-bearing elements must be included in the model, the needs of the contractors should be given more emphasis.

2.5 USEABILITY OF BIM MODELS AFTER CONSTRUCTION

There is little experience with using BIM models in the operation and maintenance phase. Experience will come with time as main inspections are carried out every five years on bridges in use. As in all other projects, it is important that the BIM model is updated with any changes along the way. The existing national archive system is not adapted for handling BIM models. Currently, everything is just stored together and then it is practical that the BIM model comes in a single file.

On the road project where Tande Bridge is situated, the contractors made a digital display of the entire project which contained all BIM models. All information was connected to a component. It is then possible to extract parts of the database by sorting on object information. This ensures that only the information needed will be provided, thus avoiding information overload.

Figure 15 shows Tande Bridge in the summer of 2022.

Figure 15: *Tande Bridge open and in use. Picture taken by Sweco*

3 CONCLUSION AND FUTURE WORKS

Tande Bridge as a BIM model was a success. This shows that we have a well-functioning system for BIM models that can be used on any type of bridge and any kind of material, and that we can use one BIM model for the whole process. The industry will become more automatized and the need for digital information will increase. The key to even greater success is more standardization in every phase.

As with all projects made with BIM models the collisions are discovered sooner rather than later and often in a phase where it easier and cheaper to correct them. At the moment, the software developed for each phase is not at a stage where we can take full advantage of all opportunities. Since the models are full of information, it must be easy to sort relevant information. We need a

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better structure for information and how to sort it into different phases. If not, it is very easy to get information overload.

The advantages of increased quality and a more efficient workflow will give financial gains and increase the impetus for working solely with BIM models. Hopefully, this will also be an incentive for the development of software. Further collaboration on standardization will be time-consuming and involve some trial and error, but it will be necessary to move the process forward. The collection of best practice from every phase to ensure that the needs of different actors are met, should also be considered in future work on standardization.

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