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Integrated 3D Design for Heavy Movable Structures

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Introduction

Bridge design often involves a combination of model types to analyze the structure, prepare construction documents, develop renderings, and in some cases provide Bridge Information Modeling (BrIM). Movable bridges and other heavy movable structures offer opportunities to capitalize on this integration of models. This paper presents the extensive use of Autodesk Inventor in design and delivery of a new movable bridge in Great Yarmouth, UK. Inventor was used across multiple disciplines and throughout the various tasks of detailing, analysis, drawing development, and fabrication.

What is BrIM? And why did we choose Inventor?

Bridge Information Modeling (BrIM) is a common term used to coin the three-dimensional (3D) modeling of bridge structures in the digital delivery of infrastructure projects in the Architecture Engineering & Construction (AEC) industry. While there have been many advancements in the development of this methodology, certain drawbacks still exist in its adoption, execution, and standardization.

At its core, the BrIM process adapts the Building Information Modeling (BIM) process for bridge infrastructure use. It relies on software, filetypes, and design processes originally developed for vertical building design and adapts them for bridge use.

In March 2021, the Federal Highway Administration (FHWA) released a report titled *Demonstration of Bridge Project Delivery Using BIM*. In the report, the FHWA examined a case study of a new construction highway bridge project that used the implementation of BIM for digital delivery. They examined the lifecycles of digital assets from the design development stage all the way through to owner asset management. They found that the current file “exchange specification...does not fully support bridge geometry,” and furthermore that “fabricators were not able to use models developed in design directly in fabrication because the [design files] were not interoperable with their proprietary software…There was no way to exchange the contract documents into the steel plate girder fabricator’s shop drawing software,” (Brenner 25-30).

In H&H’s practical experience, we have found that this current adaptation of the BIM tools of the building industry is not yet sufficient for full adoption in the fixed bridge industry, let alone the movable bridge industry. The large strength of the BIM process is in its reuse of already authored components such as steel rolled shapes, HVAC ducting, doors, and windows. By and large, components of movable bridges are custom fabricated elements such as main girders, trunnions, supports, and more. We have found that because of the geometric complexity, tolerances, and clash detection required in the design of movable bridges, the current “3D BrIM” tools available lack the precision and customization for the proper 3D digital delivery of a movable bridge.

For the Great Yarmouth Third River Crossing (GYTRC) project, we chose to use Autodesk Inventor for the integrated 3D design and detailing of the full steel superstructure and all mechanical components.

Inventor was developed as a mechanical design tool and was already widely used by our mechanical engineers in 3D design of movable bridge support, drive, and auxiliary system machinery. We adapted its use for design and detailing of the bridge superstructure and found it provided the appropriate tool to accurately model the bridge’s roadway profile, individual steel plates of the built-up bascule girder and structural elements, as well as the properly author the mechanical components.

Project Description

The GYTRC project is located over the River Yare in Norfolk County, England and includes the design of a new double-leaf bascule bridge. With two carriageways and two footways that support cyclists in both directions, this structure is intended to ease traffic congestion, improve the reliability of the surrounding infrastructure, and reduce travel time. The Norfolk County Council prioritized this bridge to support the investment, regeneration, and economic development in the town and surrounding boroughs by creating jobs and improving the quality of life of the community. The project is estimated to cost £121 million with construction underway and scheduled to be completed for use in early 2023. The project is being delivered by a design/build team led by a joint venture of BAM and Farrans. Roughan & O'Donovan (ROD) of Dublin, Ireland is the lead designer and Hardesty & Hanover (H&H) is the movable bridge specialty subconsultant to ROD.

As shown in Figure 1, this steel double-leaf bascule bridge is 25.2 meters wide, 68 meters long (center to center of trunnions) and utilizes a welded orthotropic deck with twin box girders and integrated transverse beams. The roadway geometry created detailing challenges as the cross section was asymmetric due to a cycleway on the bridge's north side. Additionally, to meet roadway elevations off bridge, the vertical crest of the bridge's roadway profile was not centered between the trunnions; therefore, the east trunnion was 600 millimeters lower in elevation to the west trunnion. As a result, each leaf and each bascule girder web had to be individually detailed for drawing production. Building the model in 3D gave us an efficient way to coordinate these details.

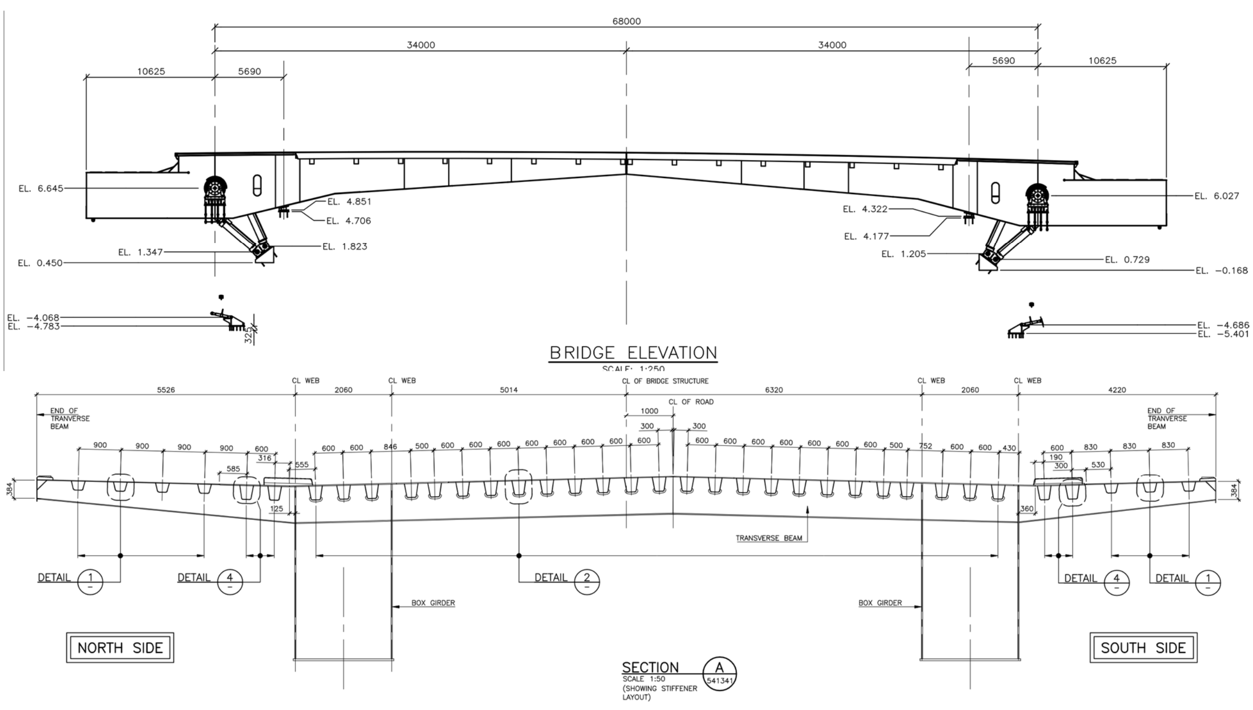

Figure 1: *Bridge Drawings Developed within Inventor*

As shown in Figures 2 & 3, the movable span is hydraulically actuated and operates on two pairs of cylinders in a push-pull arrangement, opening to an angle of 74 degrees. Each pair of cylinders is connected to a longitudinal operating girder and is powered by a closed-loop circuit by way of a pair of fixed displacement pumps.

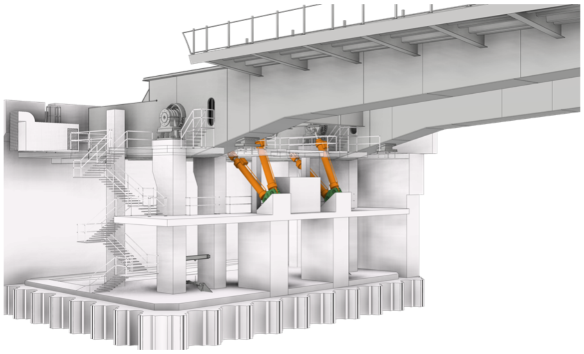

Figure 2: *Bridge Lowered*

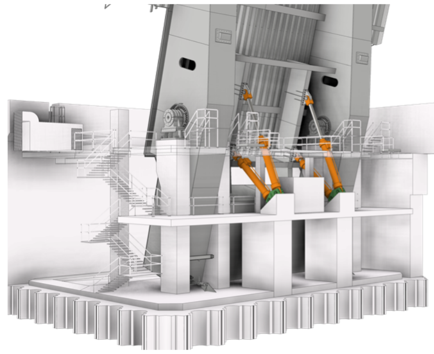

Figure 3: *Bridge Raised*

3D Modeling of the Movable Span

Strategically partnered with ROD, H&H was responsible for the detailed design of the bascule leaves including counterweights, live load shoes, trunnions, hydraulic cylinder operating systems, electrical control systems, and associated structural systems to integrate each of these components. ROD was responsible for design of the bascule leaf deck system and superstructure forward of the live load shoes.

ROD developed the substructure in 2D and 3D AutoCAD while H&H developed the superstructure in Inventor. The deliverables for this project included both 2D construction documents and 3D .step files. The bridge's global and local structural analysis models were developed in MIDAS in parallel.

In producing 3D models, appropriate technical planning is necessary. Inventor is typically used to model machinery with discretized parts which come together to form assemblies. As such, the bridge's mechanical equipment was natively modeled in Inventor by our mechanical engineers. Additional training was required for our structural engineers as the superstructure model required integrating impacts from the bridge's roadway geometry, substructure, mechanical, and electrical systems.

Appropriate levels of details must be determined for each of these systems in order to successfully execute the project. In 3D models, too much detail becomes time consuming and results in large file sizes whereas too little detail can cause inaccuracies and make it difficult to identify potential interferences.

Because these models are shared both internally within the design/build team and externally to owners (clients), organization is imperative. At the start of each project, a designer should consider what the physical boundaries of the model will be and how the individual components will be referenced into the overall assembly.

CADD File Exchange Protocols

As shown in Figure 4, there were several file type protocols used to exchange CADD information within and between the Design and Construction Teams.

For clash detection, 3D AutoCAD files of the bridge substructure were imported into Inventor. Conversely, 3D AutoCAD files of the superstructure were also exported from Inventor for use in the development of the bridge's substructure drawings.

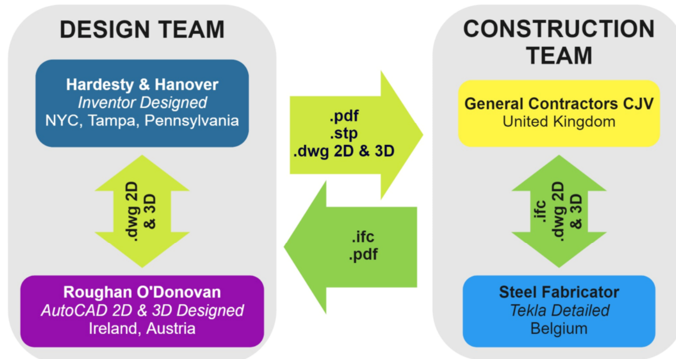

Figure 4: *File Exchange Diagram*

For model coordination between the design team and the steel fabricators, 3D .step files were exchanged for the fabricator's use in Tekla.

A mix of 3D AutoCAD, .step, and .ifc files were used to develop the General Contractor's federated Construction Model.

Benefits of Modeling in 3D

Parametric Modeling

One key benefit of working with 3D models is their utilization of parametric modeling in which the shape of the model geometry can be changed by simply modifying the dimensional values. Inventor has the ability to reference model geometry among parts while maintaining the assembly's integrity automatically, which allows for rapid changes to the part itself and all associated components.

As you can see in Figures 5 and 6, changes within the model will be carried through to the drawings which reduces instances of rework due to geometric changes.

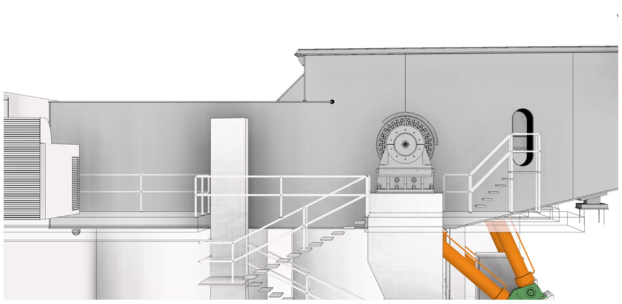

Figure 5: *Bascule Girder as Modeled in Inventor*

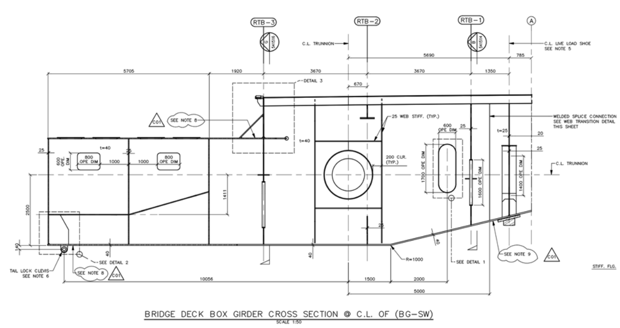

Figure 6: *Bascule Girder as Created in Drawings*

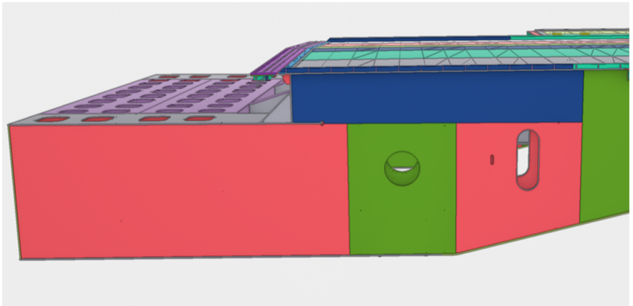

Figure 7: Bascule Girder as Modeled in Tekla

Figure 8: Bascule Girder as Fabricated

Communication

Although the bridge is to be constructed in Great Yarmouth, UK, the bridge design teams are located in New York, Florida, Pennsylvania, Ireland, and Austria.

The mechanical components are manufactured in England, and the steel superstructure is fabricated in Belgium. 3D model exchanges, viewers, and screenshots facilitated project coordination between all the relevant parties and significantly sped up shop drawing approvals. The steel superstructure was modeled in Tekla, as shown in Figure 7, and the shop drawings were created by importing the design model.

Span Balance

One of the most important calculations to be performed for the design of a movable bridge is a span balance. The kinematics of a movable bridge are crucial to ensure that the structure and machinery behave as they were designed. Understanding the location of the center of gravity of the bridge is imperative in maintaining proper operation of the span. Performing a proper span balance ensures the structure is not subject to rotational failure or tipping over when open. To do this, each individual element must be analyzed to determine its weight, volume, local center of gravity, and any additional considerations such as surfacing, machining, or welding. These parameters are then integrated into a weighted average and an overall 3D center of gravity is calculated.

Inventor models are constructed of individual solids rather than simplified shells or line elements in analysis models. As such, it has the ability to assign materials and densities to parts and directly quantify local and global masses and centers for gravity. This gave an accurate accounting of elements on the movable span and an extra level of confirmation while performing quality assurance checks on the span balance calculations.

Clash Detection

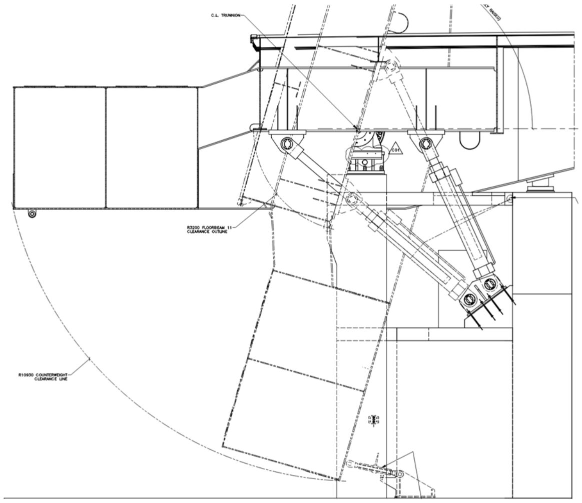

Figure 9: Bascule Pier Clearance Diagram

Of the 3D modeling tools available to the AEC industry, Inventor is one of the few with the capability of defining variable positions to objects within the model. With traditional 3D BIM tools, objects can be moved but their position is considered static.

Since Inventor was developed as a mechanical design tool, the kinetic motion of the bridge can be virtually analyzed and any interferences with static elements can be check at any position within the bridge's rotation.

Finite Element Analysis

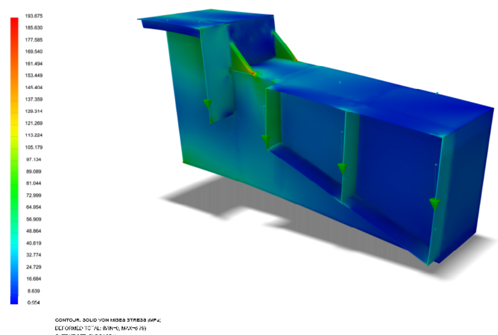

Figure 10: FEA *of Bascule Girder* at the Counterweight

Finite Element Analysis (FEA) is a computerized method for analyzing physical structures that are too complex for hand calculations or beam element models. As shown in Figure 10, FEA analyses were performed for the bascule girder transition to the counterweight section. This area consisted of significantly large out of plane forces. The Inventor FEA model allowed us to evaluate these steel details to confirm the capacity of our weldments. While unsuitable for a large-scale model, Inventor has the ability to perform detailed stress analysis on subassemblies.

Renderings

An additional benefit of Inventor is its ability to create renderings. As shown in Figures 11 and 12, with control over various aspects such as lighting and camera angles, photo and video renderings can be created in order to visually convey complex design concepts of the bridge, how the bridge moves in its operation, and its context within its surroundings to both the project team, clients, and other stakeholders.

***Figure 11:** GYTRC Bridge Rendered in Inventor*

***Figure 12:** GYTRC Bridge Rendered in 3DsMax from the Inventor Model*

Conclusion

As discussed above, there are many benefits to designing and detailing a movable bridge in 3D with an integrated model. This project benefited from the fact that it was not constrained by a client CADD standard. Since the deliverables for the project were 3D models and .pdf drawings, there were no laborious requirements to assign proper levels or layers to drawing linework.

While Inventor provided the ability to perform FEA analyses on local geometry, it lacks the capability to analyze the bridge structure globally. As such, a separate analysis model was created in MIDAS to analyze design loads on the bridge.

Overall, the modeling process can be time consuming and expensive. Geometric changes to the bridge can be performed relatively quickly; however, properly setting up the 3D model for 2D drawing production is much more laborious than creating the drawings in 2D alone. Depending on the length of the project, there may not be enough time available to successfully execute a 3D delivery in this manner.

In terms of the modeled components, H&H modeled the bridge steel superstructure to Level of Development (LOD) 400 which was determined to be appropriate for our use. While LOD 400 is currently the highest level defined in the OmniClass guidelines, it still lacks the camber, plate, and weld preparation information required by steel fabricators. The proper level of detail for each individual elements must be considered before agreeing to provide files for the project. With proper coordination and planning, a 3D model provides an efficient means of delivering a movable bridge project.

References

Brenner, Joseph M, et al. 2021, Demonstration of Bridge Project Delivery Using BIM.

Bedrick, Jim et al. 2021, BIM Forum Level of Development (LOD) Specification for Building Information Models.