HEAVY MOVABLE STRUCTURES, INC.
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DESIGN OF HEAVY MOVABLE STRUCTURES USING ADVANCED MODELING AND VISUALIZATIONS

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Summary

The Heavy Movable Structures (HMS) industry, which includes movable bridges, kinetic architecture, and stadium roofs, in general, has not implemented building information modeling (BIM) to the same extent as other sectors of the Architecture/Engineering/Construction industry. The use of the solid modeling and visualization concepts inherent in BIM can be beneficial to the design and construction of HMS. HMS are typically complex, dynamic mechanisms that require coordination of multiple disciplines of design professionals, such as structural engineers, architects, mechanical engineers, and electrical engineers. The development and advancement of computer aided design and three-dimensional modeling tools permit close coordination amongst these groups and overall project quality to be increased.

Keywords: movable, bridge, visualization, rendering, animation, electrical, mechanical, solid, modeling

Introduction

Design professionals have historically used three-dimensional views to convey their design conceptions beyond what could be achieved through the use of standard two-dimensional views. The three-dimensional views, often shaded and referred to as renderings, were typically used to communicate the design concept to non-professionals or others who are not as familiar with the language of technical drawings. The renderings were typically supplemental to and exclusive of the technical drawings used as construction documents.

With the advent of computer-aided drafting and solid modeling software, the use of visualizations and renderings has become more integrated with the design process. These tools have simplified the process of creating the visualizations and also given them purpose beyond their original supplementary role. This paper will discuss the multiple roles visualizations can fulfil for a design professional and how they can be used as part of the design process for complex structures.

Visualization and the Design Process

In order to understand the role visualizations can perform it is beneficial to define the term in the context of a design professional. The dictionary [1] defines visualization as the “formation of mental visual images.” The pencil and paper have been the common means to translate this mental image into visual data that others can utilize. However, in the context of the current design marketplace, the definition of visualization has evolved. The term is now used to represent the physical, in lieu of mental, three-dimensional image of a design concept. The visualization (meaning the produced image, not the process) has been removed from the mind of the designer and moved onto various forms of physical media (paper, computer images, etc.). This change in definition is indicative of a dramatic shift in the design process.

In order to fully understand the implications of this evolution in the definition of the term *visualization,* it is prudent to evaluate the typical design process and compare it to the newly emerging process. In the typical design development process, the conception initiates with the designer as a mental image (a *visualization* in the original sense of the word). This mental image is then translated into sketches on paper (two-dimensional views). These views (plans, elevations and sections) are then used to generate two-dimensional contract drawings. The contract drawings are then interpreted by a constructor in order to physically manufacture components and assemble them into a three-dimensional structure. This process, with its condensation and expansion of dimension (three to two to three-dimensions) is inherently inefficient and prone to misinterpretation of information through the various steps. These misinterpretations lead to interferences during construction which must be addressed.

Through the use of technology the newly emerging process does not compress the dimension of the conception throughout the steps of the design. The use of technologies such as Building Information Modeling (BIM) and three-dimensional computer-aided drafting allows the designers to both think (design) and communicate in three dimensions. This permits a greater level and more effective means of communication for the design partners. Technology has allowed design professionals to develop their conceptions in a more natural manner. As a result, the line between the mental image and the working conception has been eliminated and we now use the term *visualization* to represent both the initial mental image as well as the consumable product of the design process.

Comparison of Design for Vertical Construction and Infrastructure

The efficiencies and benefits of BIM have been well-documented. The use of BIM is becoming more commonplace in the vertical construction (buildings and similar structures) sector. The infrastructure (roadways, bridges, tunnels) sector has not seen the same widespread use of BIM. Civil works (roadways and tunnels) have used geographical information systems and mapping to improve the layout and design of these facilities but the bridge design sector has not utilized these types of technology to the same degree. This is especially true of a niche of the sector such as movable bridges.

BIM for building design and construction assists in the coordination of the multiple systems present. These systems include the building structure and architectural features as well as the mechanical, electrical and plumbing (MEP) systems. One advantage of building design and construction is the repetition of floor layout. This permits a few templates for the systems throughout the building to be developed. BIM assists in verifying that the template can be applied throughout, and that special features not conforming to the template, can be identified and addressed. The prevalence of repetition in a building is a function of the design conception. With more signature structures being designed, the repetition of the interior space is reduced but the efficiency of BIM still exists.

The repetition and full advantages of BIM are not readily achievable in heavy movable structure design. Similar to building construction, heavy movable structures have multiple systems that must be accommodated. These systems include the structure itself, as well as, the drive machinery and the electrical and control systems. In the operator occupied space, plumbing systems and systems more common to building construction are also present. With heavy movable structure design, the systems are integrated into one space and no templates exist. Each movable structure has its own characteristics and the system layout is a function of the structure type (bascule, swing, or vertical lift bridge, for example).

Use of Visualizations in Heavy Movable Structure Design

While the advantages of BIM cannot be fully realized when used for heavy movable structures, the use of three-dimensional modeling and visualizations as part of the design process has advantages. Modeling and visualizations can be used in three main ways:

Communication with Client (Owner) and Public Outreach

Marketing and Business Development

Design Development

The use of visualizations for the first two ways noted above has been documented extensively and is not the focus of this paper [2]. These uses will be discussed briefly below in order to provide context to the primary use in Design Development.

CLIENT COMMUNICATION AND PUBLIC OUTREACH

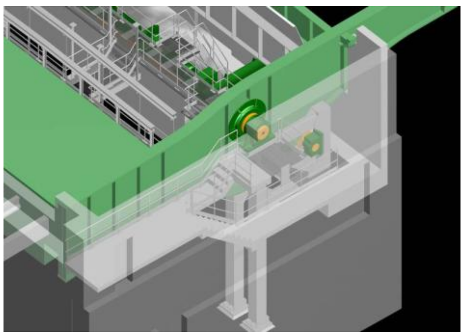

Fig. 1: Bascule Span Pier and Machinery Room

In the heavy movable structures sector, as well as other public works projects, the role of the owner (client) and the community are an important part of the design process. With respect to the owner, a number of owners are less familiar with movable structures than with the more typical structures in their inventories. This unfamiliarity can lead to communication issues and unrealistic expectations if not addressed. In this regard, visualizations assist the designer in depicting the various components of a movable structure and animations can inform the owner on the operational characteristics. Visualizations serve as a teaching tool for the designer. A typical visualization used for this purpose is shown in Figure 1 and depicts the operating machinery room for a bascule bridge. This image was used to demonstrate to the owner the components that require maintenance and the access points for the maintenance staff.

Fig. 2: Movable Bridge Control House Option 1

In addition, the communities in which projects are constructed are having a greater voice in the design development process. This involvement spans from project conception through design and construction. Structures are being conceived and designed with what the industry commonly refers to as context-sensitivity. While the foundation of good design lies in understanding the needs of a particular project site from all aspects (social, environmental, technical), context-sensitive design does have additional benefits. The major benefit is that the needs of the users and affected persons are determined through direct communication of the design team. In most instances, the community becomes part of the design process. This has successfully been accomplished through design competitions, design forums and the development of project task forces of owner, designers and community members. Visualizations aid in this interaction significantly since project decisions are not the sole domain of technical persons. The laypersons of the community must be informed, and educated in order to participate. Basic visualizations, such as those of Figures 2 and

Fig. 3: Movable Bridge Control House Option 2

3, can be used to depict options. These images assist in the comparison of options and foster decisions by concerned parties.

Animations are particularly useful for community and public outreach for heavy movable structures. The dynamic nature of the structures is presented directly to the public and the movement operation can be clearly shown. Also, various vantage points, for example from travellers in vehicles on the structure, pedestrians on and around the structure as well as marine traffic near a bridge, can be presented. These types of images immerse the viewer into the project and make them understand the nature of the structure.

As such, visualizations assist in bridging the gap between the technical matters and the general public. The images serve as means of conveying the design concept in a manner which is easily interpreted by the layperson so decisions can be made.

MARKETING AND BUSINESS DEVELOPMENT

Where the use of visualizations described above is for the benefit of the owner and the communities in which they operate, the use of visualizations for marketing and business development purposes primarily benefits the design firm.

Fig. 4: Movable Bridge Concept Study Alternative

Fig. 5: Pont Bacalan-Bastide [3]

Visualizations in this regard are typically used in promotional materials and other marketing collateral to demonstrate the capabilities of the firm. Visualizations allow a firm to market projects in development (Figure 4) and construction (Figure 5) to a new owner. For business development, visualizations are used in proposals, project interviews and similar settings to demonstrate capability as well as technical approach to the client's problem. Similarly, the use of visualizations serves as an educational tool to increase the potential client's level of comfort with the firm and the solution. Animations are often used in this setting and are particularly beneficial, especially in the field of heavy movable structures. The use of animations and visualizations permit the design firm to demonstrate potential solutions prior to being awarded the project. This initial investment of technical resources as well as the talents of the visualization staff demonstrates to the client the dedication of the design firm and their desire to work with the client.

DESIGN DEVELOPMENT

For heavy movable structures, modeling and visualization has been used in two manners. Modeling and visualization can be used as a quality assurance measure or it can be used as an integrated part of the design. The first method has been used on a number of projects and has yielded benefits in the overall incidence of field conflicts. The second manner has been used for critical detail areas and has shown promise. To date, a full heavy movable structure design has not been created utilizing this design approach. These two functions are discussed in greater detail below.

Quality Assurance

Modeling and visualization for Quality Assurance checking has been used on a number of projects successfully. For this use, modeling is a post-design process and is used to verify both the technical accuracy of the design as well as the content of the contract documents. In this instance, modeling of the structure occurs as an independent task in the design process. The modeling effort initiates once the design documents have been advanced to a pre-final (90 to 95% complete) stage (Figure 6). At this time, the contract documents are provided to the modeling and visualization staff. The staff consists of engineers and technicians with the requisite skills in modeling software. The staff then utilizes the contract documents in much the same manner as a constructor would to virtually fabricate and assemble the structure. Once the model is complete, areas of potential conflict or other areas noted as questionable by the modeling staff are reviewed in depth by the design engineers to verify accuracy.

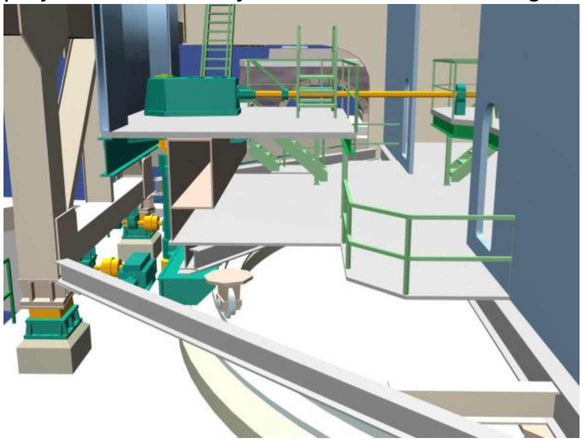

Fig. 6: Swing Span Bridge Pivot Pier Coordination

This type of quality assurance checking provides multiple benefits. First, the development of the model serves as an independent check on the contract documents. The modeling staff does not directly interact with the design staff to obtain information on the design. The modeling staff utilizes the contract documents as their only resource for the development of the model. In this manner, the content of the information in the contract documents is evaluated to determine if sufficient and accurate information is presented. This information is typically limited to principal controlling dimensions and primary parameters of the designed elements. However, in many instances, specific detailed dimensions are required to ensure the detailed fabrication drawings (shop drawings) are consistent with the design intent. Deficiencies in these details can be readily apparent to the modeling staff since they cannot model the members of the structure without this key information. The modeling staff are typically technicians that do not have sufficient skill to interpret the drawings in order to work around the omitted information ("fill in the blanks").

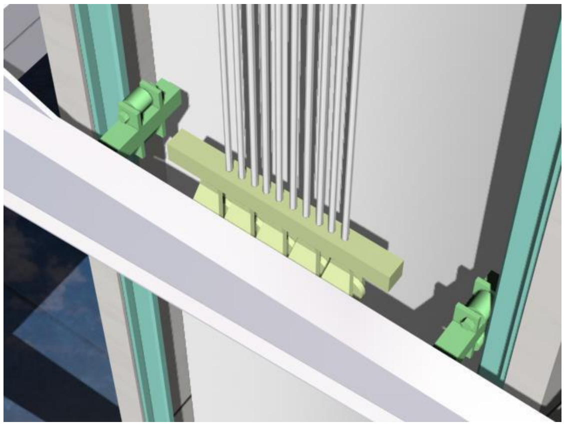

Fig. 7- Lift Bridge Guides

In addition to this check on the dimensional data and other member geometry information indicated on the contract plans, the quality assurance check permits verification of critical clearance points on the movable structure (Figure 7). For this task, the design engineers utilize the model developed to navigate to critical areas. The model is configured in such a manner that the movement of the structure can be simulated to assess clearance between the moving and fixed portions. This task requires the design engineer to have a rudimentary knowledge of the modeling software as well as experience with areas of potential conflict. This aspect of visualization use is particularly important with structure of complex geometry and signature structures that are in vogue today.

Another benefit use in this regard is as a safety check for maintenance areas. Heavy movable structures have many parts that require regular maintenance. Visualizations are utilized to assess the access to these areas and can assist in determining the safe clear zones around moving parts in order to provide additional protection to workers on the structures.

The use of modeling and visualization as Quality Assurance checking has substantial benefits to the design process. One major drawback, however, is the lack of integration with the entire design process. The results from this check usually require revisions to the design. The magnitude of the issues may result in significant or only minor revisions. These types of revisions are commonly referred to as rework and may impact not only the project delivery schedule but also the project's profitability. The use of modeling and visualization as a post-process check, therefore, is valuable but other uses of this technology may yield more value to the design process.

Integrated Design

As discussed above the use of modeling and visualization as a post-design process may not be the ideal solution when considering the schedule and budget for a design project. One means of reducing both the design time and the potential for rework is to integrate modeling into the design process. This type of design has been utilized in the past for manufactured parts and components in a number of industries such as the automotive and aviation fields. In an integrated design, the model is developed as the design conception evolves and the model serves multiple purposes.

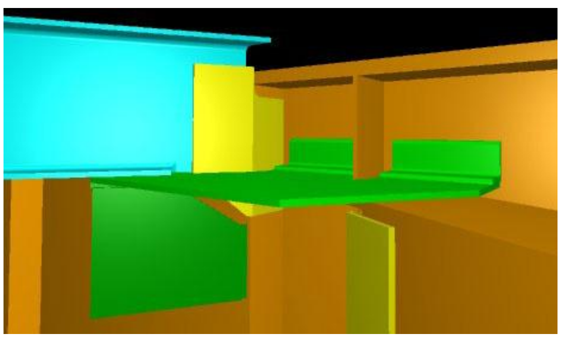

Fig. 8: Design Model-Connection interference checks

First, the use of a detailed model eliminates the dimensional reduction (three dimensions to two) necessary in the typical design process and discussed above. The designers can function and develop the structure in three-dimensions and the coordination amongst the components occurs as a function of the shared model rather than overlaying two-dimensional views (Figure 8). In this manner, the coordination becomes a quality control process and is pervasive to the process rather than an event that occurs at (or near) the end of the design process. This is especially advantageous for heavy movable structures due to the dynamic nature of the structure.

The coordination amongst the structural, machinery and electrical system designers is critical to the execution of the design. The structural and machinery designers must work in close coordination to ensure the tolerances of the machinery are achieved while the structural clearances are maintained (Figure 9). One of the critical locations on a structure such as a movable bridge is the joints between the fixed and moving parts. Depending on the type of movable bridge, these clearances are a function of rotational or combined rotational and linear movements between the parts. With the ever increasing complexity of these structures due to the ingenuity of designers and the desire for one-of-a-kind, signature structures, the potential interferences may not be readily seen considering two-dimensional data. The spatial thinking capabilities of an experienced movable structure engineer combined with the development of a structurally accurate model provide the engineer with exceptional tools to assess and design unique structures. The result is both an increase in the overall quality of the design as well as the freedom to pursue more advanced design concepts and mechanisms. One additional benefit that has been witnessed is the blurring of discipline lines. The more integrated the design approach becomes, the more integrated the designers (structural and machinery, in specific) have become. The project team designers have moved from being exclusively machinery or structural designers to movable structure engineers. This, again, yields benefits in terms of quality and efficiency.

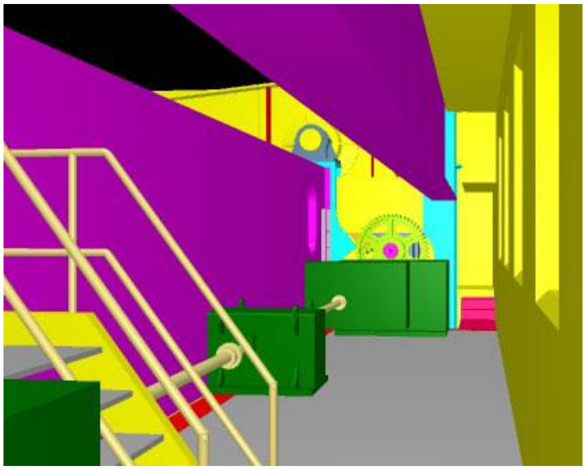

Fig. 9: Design Model-Machinery and Structure Coordination

Second, the model serves as the generator of the two-dimensional contract documents. The functionality of computer-aided drafting and modeling programs is beyond the scope of this paper. These programs have the ability to translate three-dimensional model data into two-dimensional views or sections based on the input of the user. In this manner, interpretation of the components is minimized and the designer can more effectively present the necessary information to represent the design in the two-dimensional contract drawings.

Third, the geometric data from the model can be utilized in various design and analysis software packages, such as finite element analysis software. This again results in efficiency in the design process. The basic design can be completed in advance of the model development. Once the main structure is defined, the model can be developed and advanced analysis performed through the use of analytical software. In this manner, design and detail changes required due to engineering analysis can be incorporated into the model and all parties will become aware of the changes.

Lastly, the model forms the basis of the more common uses of visualizations (i.e. renderings and animation for presentation purposes) discussed previously. One advantage of the integrated design approach is that the model used to develop the materials for presentations is accurate to the design. The artistic interpretation that is commonly used to make a structure more palatable to a particular audience is minimized.

Design-Build Delivery

With the increase in the use of the Design-Build delivery method for both heavy movable structure projects in the U.S. and abroad, the use of integrated design will also see an increase in the near future. In order to meet this demand, firms specializing in heavy movable structure design are utilizing technologies that are well established in other industries. The heavy equipment (cranes, for example) and manufacturing industries have utilized solid modeling software applications for many years. The complexity of the designed systems warranted this high reliance on computer software as a key design tool. As discussed above, the increasing complexity of heavy movable structures makes the use of similar software for HMS design beneficial. The software manufacturers have recognized this potential market for their products and are customizing their products for this application. As a result, these solid modeling programs are becoming more capable in the handling of common bridge and structure components.

The benefit of these solid models to the designer closely resembles the benefits once attributed to the general use of computer aided drafting: increased speed of production, easier modifications to drawings, higher uniformity and quality of deliverable. The added benefit of the solid modeling lies in the parametric nature of the model. The model can be configured such that key dimensions are data entry variables. From these key variables, the entire structure geometry is defined. As a result, a design firm can quickly modify a preexisting model (and the associated two dimensional drawings) for use on a new project. The development of the solid model for this purpose is time consuming and the effort required exceeds that necessary to develop a single set of contract drawings. The ability to modify and re-use the model in part or in whole for numerous similar structures, however, provides a compelling argument for this initial investment in modeling time.

For Design-Build projects, the designer is closely integrated with the fabrication and construction team. The increased use of computer numerically controlled (CNC) fabrication makes the use of a solid model very desirable. The model becomes the core deliverable amongst the project team. The designer develops the basic design model. The detailer then increases the level of detail and complexity of the model as part of the detailing process. The detailed model then becomes part of the CNC fabrication process for the cutting, shaping and drilling of the components. The use of the shared resource (model) is the centerpiece of the project quality program.

Conclusion

Modeling and visualizations have long been used for presentation media in this industry for movable bridges, kinetic architecture, and stadium roofs. With the increased availability and ease of use of the software, the use of modeling as a design tool in the heavy movable structure sector of this industry has increased. Firms specializing in this field have seen the benefits of using modeling as both a quality assurance tool and a design tool. These benefits have impacted the project quality and design efficiency as well as the skill sets of the design engineers. The use of modeling technology in this industry will only increase in the future and the heavy movable structure sector, due to the complexities inherent in the structures, will need to be at the vanguard of this movement in order to meet the demands and needs of the clients for these special structures. An integrated approach to design and modeling appears to offer the most benefit to the designer in terms of efficiency and quality.

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[3] © Lavigne Cheron Architects. Use of image courtesy of Vinci Construction, Jean Muller Int’l Architecture et Ourvrages D’Art, Michel Virlogeux, CIMOLAI, Hardesty & Hanover Int’l. LLC