BIM Standard: Tensile Structures Data Modeling

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ABSTRACT

To leverage all the benefits that building information modeling (BIM) is bringing to the build environment, the AEC industry recognized the critical need for BIM standardization. The issues of level of details and interoperability as means to communicate and integrate various model-based applications into an efficient workflow have materialized to the forefront of the standardization process. The ultimate goal of BIM standard is in part to enable capturing all relevant data in the BIM model, and to allow for flawless data exchange between the various applications. Current BIM tools that have been developed to model conventional structural steel and concrete construction are not yet satisfactory for modeling tensile structures. This paper reviews the current state of BIM platforms in modeling tensile structures and formulates the functional requirements for cross-platform standardization and interoperability. This study centers on advancing standardization of BIM models for designing and analyzing tensile structures. Specifically, the study addresses the Information Delivery Manual (IDM) and Model View Definitions (MVDs) as they aim to provide the integrated reference for process and data required by identifying the distinct processes undertaken to design tensile structures as well as to create an efficient method for unified, reproducible exchange of consistent information that is customarily acknowledged by the industry.

INTRODUCTION

With the rapid adoption and increasing interest in Building Information Modeling (BIM) in the AEC industry, the issues of specifying and articulating with a high level of transparency and accuracy the content and consistency of BIM models have emerged to the forefront of the professional attention. The eventual success of addressing these issues will in part depend on the ability to include all relevant data in the BIM model, and to certainly exchange data between the various parties and disciplines. The effective means of dealing with these issues is through a standardized data exchange format. Standards are critical when communication between different trades and disciplines. All the different entities utilizing BIM technology in the construction and building industry including architects, engineers, contractors, facility owners and operators, and software developers, have diverse nomenclatures, diverse vocabularies, geometries, computing paradigms, data formats, data schemas, scales and fundamental world-views (Nawari 2012a). They also have different requirements for accuracy, verisimilitude, and rendering performance. These various organizations have different standards and business processes for which they have developed their own paper and digital delivery procedures. To solve these problems and achieve Integrated Project Delivery (IPD) objectives nationally and internationally, advancing standardization is becoming a vital factor.

The problems of interoperability between software systems have existed since the introduction of computer-aided design (CAD) in the 1970s (Pratt 1993). The same issues have become critical in the architecture, engineering, and construction (AEC) industries with the widespread adoption of building information modeling (BIM) in the early 2000s (Eastman et al. 2008). The US National BIM Standard (NBIMS) is established to resolve such problems by providing the digital schema and requirements for efficient BIM application in the AEC industry. It recognizes that BIM requires a disciplined and high level of content clarity and reliability, which supports: a specific business case that includes an exchange of building information; the users' view of data that is necessary to support the business case; and the digital exchange mechanism for the required information interchanges.

This combination of content designated to support user needs and described to support open and neutral digital exchange are the basis of information exchanges in the National BIM Standard. NBIMS is chartered as a partner and an enabler for all organizations engaged in the interchange of information throughout the facility lifecycle.

Tensile structure are special type of structures that differ from conventional building structures such as concrete, masonry, steel, or wood structures in many aspects. Conventional structures possess gravity and stiffness, which make them stable and capable of transmitting and discharging loads safely to the support systems. In contrast to that, tensile structures do not have such characteristics and their weights are almost negligible and possess no rigidity (i.e. highly flexible). Thus, their elements must be configured in a specific geometric form and must be subjected to specific pattern of internal forces (prestressing). These exceptional design conditions can be effectively explored using BIM, making the evaluation of structural functions and composite forms an easier and more productive process. Furthermore, BIM standard for tensile structures should offer a pronounced opportunity for architects and engineers to change their views and drive tensile structures beyond their bounds as they explore innovative and exciting new design ideas.

MODELING TENSILE STRUCTURES

Tensile structures are often broadly organized into cable and membrane structures. These include cable-stayed roofs or bridges, guyed towers, tensile members forming surfaces such as saddle domes, tents or pneumatic structures. Also, three-dimensional surfaces can be generated by interesting cable beams or by multidirectional tensegrity principle, where floating individual non-tension members in contact with each other are fixed in place by the continuous tension cables. These types of structures are generally light in weight besides inherently flexible and form active. Due to the lack of bending and buckling resistance, they commonly adjust their forms to the respective loading conditions. As a result they must be stabilized against form instability specifically under dynamic loads.

Another structural challenge is the anchorage of tensile structure at the boundaries. The tensile forces might be guided either directly to the supporting ground or foundations, or they may be connected to flexible or rigid boundary structures. These supports systems may be of the open skeleton type (e.g. Frames, arches, …etc.) or they might be of the closed type where internal tensile forces balance each other (e.g. cable-stayed, horizontal or spatial ring beams). Figure 1 depicts examples of typical support systems for tensile structures.

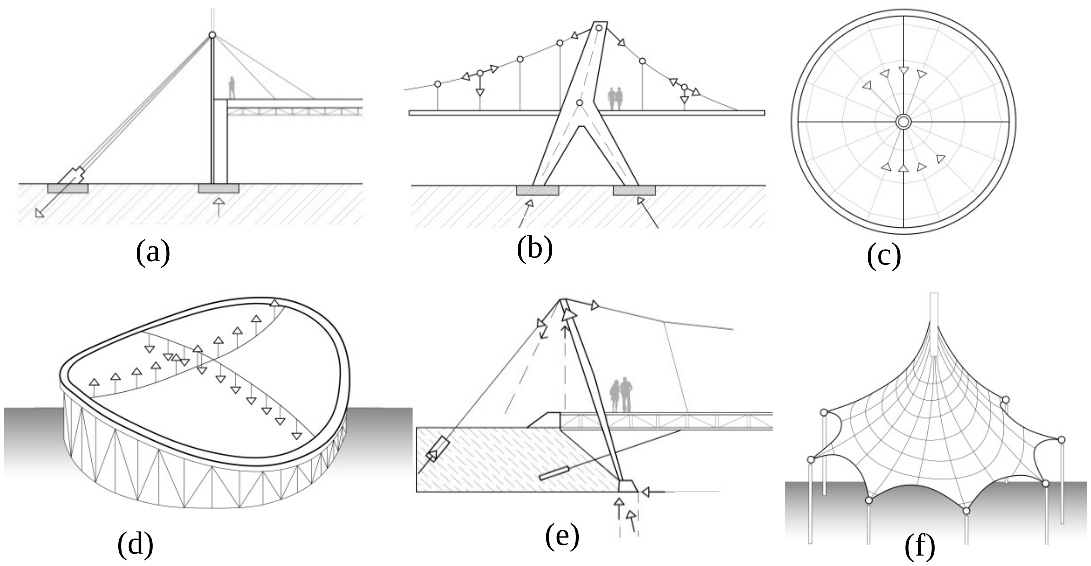

Figure 1. Typical anchorage systems for tensile structures.

Tensile structures seem to be weightless and float in the air contrary to gravity-type of structures, where weight and inherent massiveness of materials transmit a feeling of stability and security. These antigravity structures generally require different architectural and structural qualities where curve rather than linear element is the structural form generator (Figure 2). The form of tensile structures is critical to the overall functions. Their geometric order reflects the structural laws which keep the forces in equilibrium. Thus, their digital modeling in a BIM environment necessitates different requirements.

These design complexities can be effectively explored using BIM, making the evaluation of structural functions, composite forms, and shapes an easier and more productive process. The parametric nature of BIM information will allow changes made to the design to be reflected in all locations in the project in virtual mode that will greatly empower designers to investigate different design options with fewer errors, and omissions, which could become costly and time consuming, possibly delaying construction for months. BIM models can also provide information on material quantities, which gives designers and contractors the ability to obtain more accurate quantity take offs in relation to the space created.

BIM for tensile structures would provide a great opportunity for young architects and engineers to gain design experience in augmented approach. Also construction of complex or unusual configurations is naturally challenging and complicated using tensile structures; however, with the assistance of BIM these would be achievable tasks.

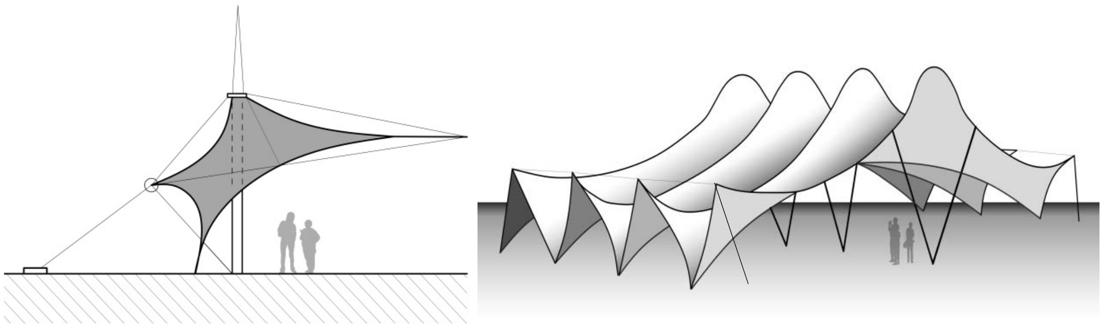

Figure 2. Example of tensile structures.

Current BIM platforms are not mature enough to model tensile structures efficiently to higher levels similar to steel or concrete structures. The central objective of this research is thus to explore the functional requirements for development of an efficient BIM model for designing and analyzing tensile structures.

BIM STANDARD AND INTEROPERABILITY

BIM Standard focuses on the resolution of interoperability issues by standardizing information exchanges between all of the individual actors in all of the phases of a construction project lifecycle. The US National BIM Standard (NBIMS) is thus an industry-wide standard for organizing the actors, work phases, and facility cycles, where exchanges are likely and, for each of these exchange zones, stating the elements that should be included in the exchange between parties. These national and international efforts resulted in the industry foundation classes IFCs (IAI 2007) promoted by BuildingSMART previously called the International Alliance for Interoperability (IAI).

The IFC format is now registered by ISO as ISO/PAS 16739 and is in the process of becoming an official International Standard ISO/IS 16739. The buildingSmart International efforts currently extend beyond the IFC and do include Data Dictionary which is named International Framework for Dictionaries (IFD) Library, and BIM processes, formerly known as the Information Delivery Manual or IDM which captures and integrates business process while at the same time providing detailed specifications of the information that a user would need to provide at a particular point within a project (buildingSMART 2012). IFD Library is a reference library intended to support improved interoperability in the building and construction industry. It provides a flexible and robust method of linking existing databases with construction information to a buildingSMART based building information model. Furthermore, to support the user information exchange requirements specification, Information Delivery Manual (IDM) proposes a set of modular model functions that can be reused in the development of support for further user define requirements. Model View Definitions (MVD) are then defined to translate IDM into software applications. MVD is conceptually the process which integrates exchange requirements coming from many IDM processes to the most logical model views that will be supported by software applications.

In the United States, the National BIM standard (NBIMS) is primarily rooted on the methodologies adopted by buildingSMART International described earlier. However, NBIMS focuses more on the development of information exchanges that define user requirements and localized content supporting the North American approach to the various building lifecycle processes (Nawari 2012b). All major industry stakeholders support these efforts, and the NBIMS represents the neutral environment where all the industry efforts can be coordinated and advanced.

The IFC model provides a range of means to define building objects, processes and other information in a publicly available data schema. The technology for exchanging information using IFC has now been established, but many areas require additional development before comprehensive interoperability solutions are reached. Design and construction of tensile structures are examples of such areas where more efforts are needed to achieve realistic interoperability with other disciplines. Particularly, exchanging information about tensile structures form and material for structural analysis still requires further development.

DATA MODELING REQUIREMENTS

Cross-platform standardization and interoperability remain to be the key factor for the wider adoption of BIM. One of the primary roles of BIM Standard is to set the ontology and associated common language that will allow information to be efficiently exchanged between disciplines (Nawari 2012a). This includes the Information Delivery Manual (IDM), and Model View Definition (MVD). The information delivery manual (IDM**)** is adapted from international practices, to facilitate identification and documentation of information exchange processes and requirements. IDM is the user-facing phase of the BIM standard development with results typically expressed in human-readable form. The Model View Definition **(**MVD**)** is generated based on the exchange requirements specified in IDM. MVD is conceptually the process which integrates Exchange Requirements (ER) coming from many IDM processes to the most logical Model Views that will be supported by software applications. Implementation of these components will specify structure and format for data to be exchanged using a specific version of the industry foundation classes (IFC) standard to create and sustain a BIM application.

TENSILE STRUCTURES IDM

The BIM model for tensile structures must establish, organize, relay, and provide information for both users and computer in conformance with the protocol of IDM and MVD. The IDM protocol specifies a list of data that must appear in the IFC schema while the MVD provides the guideline specifying how the information must be exposed in the IFC schema. The IDM has two main mechanisms: one is the process map detailing the end user processes and information exchange between end users. The other part is the list of exchange requirements. The central classes of exchange requirements for tensile structures IDM can be identified as: data exchanges required between architect and engineer, architect and contractor, engineer and supplier, engineer and contractor, contractor and supplier. The formation of IDM begins with definitions of the data exchange functional requirements and workflow scenarios for exchanges between these parties utilizing the 'use case' concept (Nawari 2012a).

This paper focuses on exchanges between architect and engineer (OminiClass 31-20 10 00 and 31-20-20 00).To establish an IDM for such exchanges, a process map illustrating the details of data exchange requirements has been developed and shown in Figure 3. The exchange model requirement provides a connection between process and data. It applies the related information defined within an information model to satisfy the requirements of a data exchange between two processes at a specific phase of the project. Each exchange model is distinctively recognized across all use cases and besides its name caries abbreviated designation of the use case it belongs to.

The range of the exchange requisite is the exchange of information about structural elements and systems. Each of the exchange models described above contains a wide array of exchange requirements to support the coordination of tensile structural analysis and design needs with architectural form and spatial organization. For instance, the exchange model AS_EM01 represents , data exchange requirement between architect and engineer during the preliminary design and could include the following data: (a) cables, membranes, and geometrical properties of the structural forms: single or double layer cable systems, pretentions cable beams, pre-stressed membranes and cable nets, arch-supported saddle surfaces, edge-supported saddle surfaces, …etc. (b) type of anchorage and stability, masts, connection and membrane joints properties, (c) materials: steel, polyester or vinyl meshes, laminated fabrics, coated fabrics,…etc. (d) temperature, fire and moisture conditions (e) structural usage, (f) exterior and interior finishes.

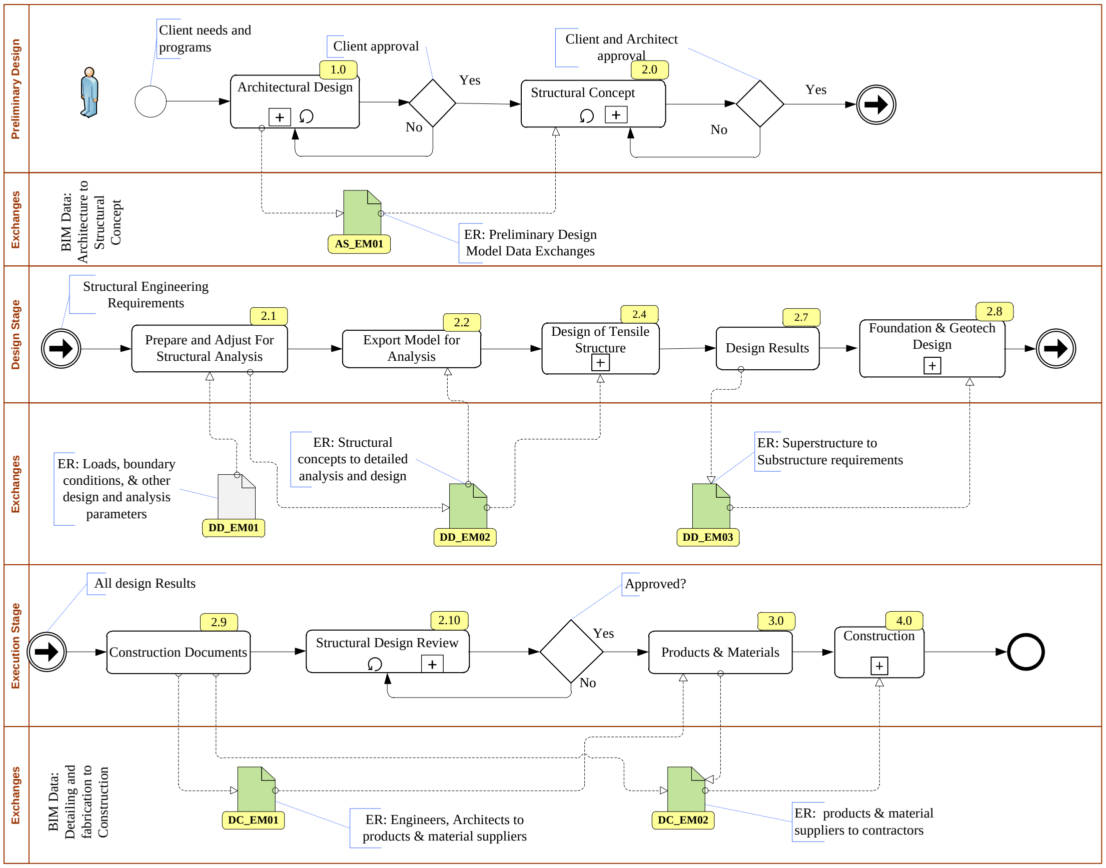

Figure 3. Process map for tensile structures.

Other exchange models shown in Figure 3 are given in table 1.

Table 1. Data Exchange Models.

Designation	Description
AS_EM01	Architectural, Structural Concepts use case exchange models.
DD_EM01	Structural concepts. Loads, boundary conditions, & connections
DD_EM02	Structural concepts, detailed structural analysis use case exchange models.
DD_EM03	Superstructure, substructure Design use case exchange models.

CONCLUSION

BIM for Tensile structure is an interesting area giving opportunity for engineers and architects to utilize BIM technology to improve upon design, analysis, documentation, and coordination between the architectural design and structural engineering teams. In the development of today's lightweight tensile structures, surely BIM offers an additional environment to assist in enhancing interoperability and productivity. To achieve these goals, clear modeling requirements in standardized format to leverage a BIM model to perform tensile structures analysis and design are indispensable. Presently, BIM platforms are deficient in such requirements for analyzing and designing tensile structures. This research focused on advancing BIM standard for tensile structures and its relationship to design and analysis of lightweight tensile structures as well as formulating the functional requirements for development of an interoperable BIM model. The study also addressed the challenges related to implementing the BIM standard and the development of information delivery manual (IDM).

This research provided starting steps in developing IDM and MVD for tensile structures. Despite its initial results on data model exchange requirements, it will provide a clear groundwork for standardized BIM in the tensile structures domain.

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