MECHANICAL DESIGN APPROACH FOR THE VIRTUAL MOCK-UP STUDY OF BUILDING ENVELOPE DESIGN AND FABRICATION

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ABSTRACT: Building envelope systems with growing complexity in geometry and performance criteria demand adapted workflow processes toward the efficient integration of their design and fabrication. To facilitate integration of the workflow process, this study analyzes relationships among teams who share digital models and exchange information that help project participants identify areas of improvement in task allocation and exchanges among various actors, systems, and activities. In addition, major gaps identified in knowledge transfer, project tracking, and design integration during the performance evaluation stages, emphasize the need for a more comprehensive approach to integrating the design, the fabrication, and the construction parameters of building envelope systems. To evaluate the effectiveness of streamlining interactions of design parameters with fabrication constraints and constructability assessments, this paper examines a mechanical design approach as it applies to various project scenarios to develop a mechanical solution for streamlining building envelope design and construction workflow.

Keywords: Mechanical design; Mechanical CAD; Building envelope performance; Virtual mockup.

1. INTRODUCTION

Critically important to the creation of an attractive building exterior and to savings in energy is a building envelope system, which adopts an efficient building information modeling (BIM) process. Current modeling tools are insufficient in providing a holistic approach to the design of building facades, in particular linking design to fabrication, for several reasons ranging from inconsistent modeling accuracy to non-exchangeable model parameters. There is currently a diverse array of architectural modeling software to model the building design with the ability to represent geometries of building envelope however within the drawing of a facility and its structure. Architectural CAD (computer-aided design) modeling, even with its need to integrate modeling information from several disciplines, is not able to efficiently sustain high levels of detail of the building envelope needed for such processes as fabrication. This is further challenged as the buildings and their façades undertake non-rectilinear forms and matrices demanding more automated exchanges and alternate modeling platforms, such as non-uniform rational basis spline (NURBS). A common underlying principle, however is the inability of the architectural CAD platform to link with the fabrication and construction of the designed façade.

A case study was performed to test a different approach using a modeling platform mainly targeted for production and used in mechanical engineering and design. The aim of the mechanical CAD modeling was to address the inadequacy of architectural CAD modeling and bridge the gap within design and fabrication processes. The case study is based on an built project where there was a virtual mock-up modeled in Autodesk Navisworks mainly for better coordination between the trades. The MCAD model is compared with this coordination model as a baseline. The study investigated additional steps to integrate performance indicators of environmental impact, thermal gain, associated energy use, constructability and safety were considered to validate the envelope design. Typically energy analysis is coupled with design during the design phases leaving issues of constructability, efficient fabrication and performance compliance to later phases such as pre-construction. This method of workflow unfortunately forces the design to go through another iteration and modification at this later phase. This paper discusses the methodology used and the effectiveness of mechanical CAD modeling: in automation through a fabrication-level digital model; and integration of design decision parameters within a fabrication-level model. The modeling criteria was based on the function of mock-ups which are used to gauge performance compliance and constructability of building envelope systems.

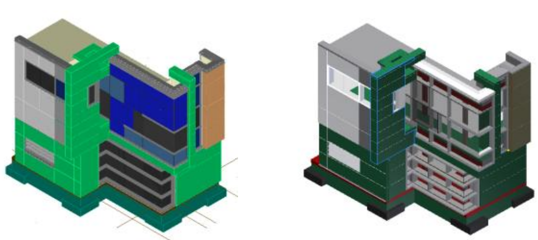
2. MATERIALS AND METHODS

2.1 Current building information modeling and mechanical CAD

For modeling the sample design of a building, the case study used Autodesk Inventor, a mechanical modeling software. The case study consists of three component files: a Revit Architecture file, a Revit MEP file, and an AutoCAD file. These component models of the project were combined by Navisworks for implementing the virtual mock-up test. A comparison between the Autodesk Inventor model and the Navisworks model demonstrates the pros and cons of the MCAD application in a virtual mock-up test. The comparison of these two models includes the following four categories: files and assembly, model information and possible capabilities, a virtual mock-up model for fabrication, and a modeling process and change management.

2.2.1 Files and assembly

The case study model of Navisworks is a single project (*. NWC file) with combined multiple model files including AutoCAD, Revit Architecture, and Revit MEP models. The software application is aimed at grouping objects into logical elements and to embodying the environment of a complete project. However, the file configuration of an MCAD system is based on hierarchical file dependencies among files of various types; Inventor has an compiling function in an assembly file (*. IAM file) including part files (*. IPT file). This case study model using Autodesk Inventor is managed separately in the form of an IPT file that allows users to implement efficient design modifications. These entities are correlated with a parametric link so that when individual components are changed, an assembly file can be automatically updated. In addition, the IPT file enables users to reuse each part-file in diverse projects as a library file because they are separate stand-alone objects. Moreover, the assembly capacity of Autodesk Inventor enables a user to define relations of components with constraints, including various functions such as mate, tangent, insert, and concentric. These constraints help improve the accurate assembly of separate parts.



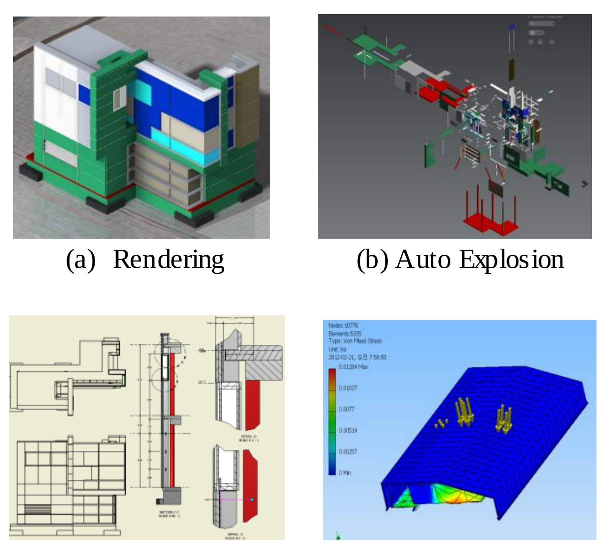
(a) (b)

Fig. 1. The case study model of Navisworks (a) and Autodesk Inventor (b)

2.2.2 Model information and possible capabilities

Navisworks incorporates the integrated information of building models. This essential feature aids the clash detective ability, which allows a user to check clashes among various types of models. With Navisworks, users can reduce human errors and omissions. In addition, this application enables users to visualize large complex assemblies, allowing them to create animation by saving their own viewpoints. Another key feature is four-dimensional sequencing, which enables users to manage a model with a project schedule. In other words, Navisworks supports the visualization of the sequences of projects based on a defined timeline.

The diverse capabilities of Autodesk Inventor include mechanical modeling, dynamic visualization, and physical analysis, and it allows one to use parametric relationships. In particular, this software engine for digital prototyping enables users to create and manage their models efficiently. In addition, because Autodesk Inventor provides a powerful detailed modeling function designed for a complex three-dimensional mechanical model, modelers are able to create an accurate building model representing minute elements. The detailed modeling function helps builders minimize their effort when they redesign the fabrication model. In other words, because Autodesk Inventor requires detailed modeling, builders can use an architectural model to create shop drawings when they need a precise fabrication plan. Furthermore, Autodesk Inventor has a useful analysis function for examining stress, energy, and other physical properties of the model. Moreover, Autodesk Inventor Publisher, which is an extension program of Autodesk Inventor, allows a user to implement the auto-explosion of a model. With the explosion function, a user can simulates the fabrication process of a model and can create a dynamic video content for illustrating manufacturing sequence.



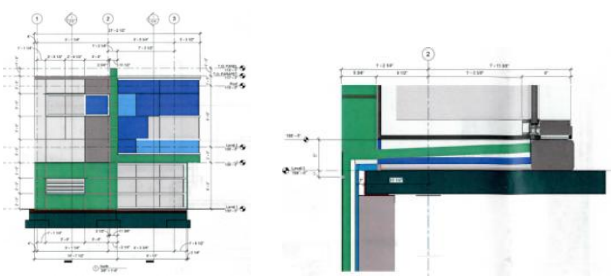
(a) Rendering (b) Auto Explosion

(c) 2D Auto-Drawing (d) Stress Analysis

Fig. 2. Case study model and capabilities of mechanical CAD

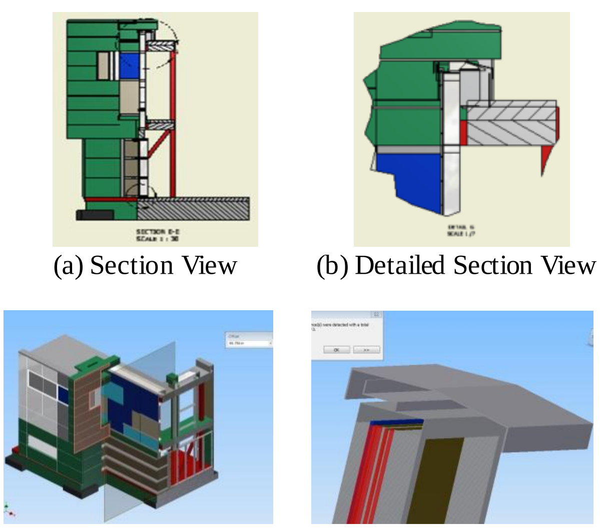
2.2.3 Virtual mock-up model for fabrication

The primary goal of Navisworks is to merge different models into one composition for verifying a coordinated file and checking clashes among models. This capability helps project stakeholders detect interference clashes among project models during the final stage of a design. However, one limitation of Navisworks is that when it combines model files derived from various sources, it could generate an error, an omission, or even a transformation of models. These problems decrease the accuracy of a building model and do not permit models of Navisworks to be used during the fabrication phase. However, a virtual mockup test implemented with Autodesk Inventor allows users to store a model and use it throughout all the design and fabrication phases because it helps users create a detailed 2D drawing function that has diverse capabilities to attach a dimension and an annotation. In other words, when creating a shop drawing for a complex structure with MCAD, builders can avoid doing unnecessary work such as merging various models which can cause serious problems.



(a) (b)

Fig. 3. Shop drawing created from mechanical CAD



(a) Section View (b) Detailed Section View

(c) Cut View (d) Interference Check

Fig. 4. Modeling functions of mechanical CAD

2.2.4 Modeling process and change management

Once several models are combined into one file on Navisworks, the integrated model is presented as a geometry used only for visualization. That is, this shape model cannot be modified intelligently. The difference between a 2D drawing and a Navisworks file is that with the latter, a user can view a product as a 3D model, not as a sketch. Another different feature is that the Navisworks file supports the implementation of clash detection and shows the entire building environment. However, unlike the Navisworks file, the MCAD model is based on components; that is, even though the various files are combined, each object can be activated separately. Thus, in the MCAD environment, users can apply the interference check capacity, which depends on a component and a geometry.

In addition, the component-based MCAD model is able to simplify the design change process with the parametric ability of MCAD. For example, when users find an error through clash detection in Navisworks, the error should be changed in the previous software platform such as Revit Architecture or Revit MEP. After participants in charge of different models update their models, the modified file is sent back to Navisworks. After all of the models are modified, Navisworks combines the models and allows users to implement the clash detective feature. This design change process is similar to the case in which a 2D drawing is used. However, the MCAD application provides a number of benefits in building modeling. For one, as the coordinated model supports a parametric capability, when an error occurs and the assembly model is edited, the MCAD tool automatically updates all parts of the model related to the assembly. Thus, users can skip data exchange work that entails updating errors that occur during modeling based on Navisworks. Furthermore, the MCAD approach facilitates the completion of the integrated project delivery (IPD) approach. Because a design using MCAD requires detailed drawings that can be completed only with the input of all members of a project, they have to become involved in the early stages of a project. Early involvement of the parties not only reduces errors and omissions and thus precludes the need for reworking a design in later stages of a project but also prevents future disputes causing liability issues. Ultimately, such early communication can also enhance the quality of a project.

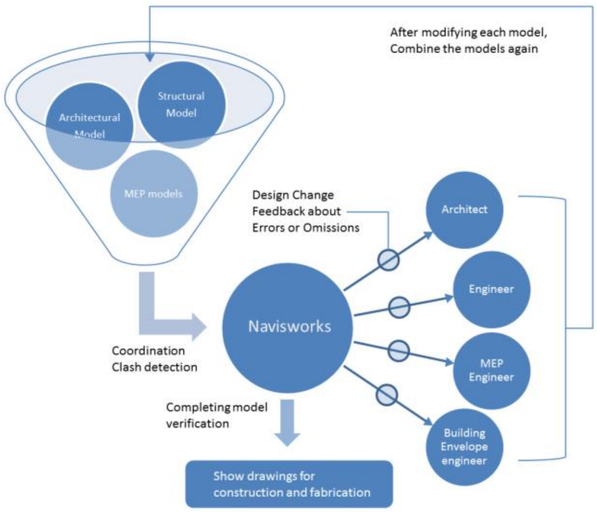


Fig. 5. Modeling and design change process of Navisworks

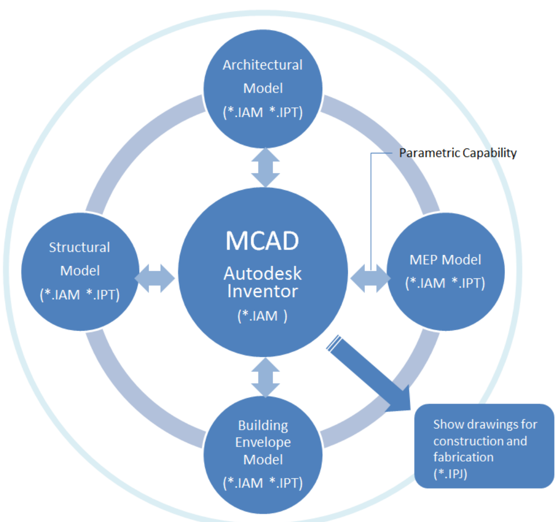


Fig. 6. Modeling and design change process of mechanical CAD

3. RESULTS

This case study shows that for a virtual mock-up test of building envelopes, the MCAD approach promotes intelligent decision making by participants in the architectural, engineering, and construction (AEC) industry by providing enhanced supportive capabilities. One of the benefits is that the method enables virtual mock-up testing, which helps a project team, especially a design team, produce more accurate drawings and create an impeccable model. In addition, because, MCAD virtual mock-up testing typically begins in the early conceptual design stage, after the first review of the virtual mock-up test, users can modify or update the model more than three times during the entire design phase. The purpose of this modification feature is to perfect the model, ensuring that the requirements of the owner, the designer, and the builder are met. In particular, because Autodesk Inventor has a parametric modeling engine, users can easily correct and update the model. For example, when a user edits one small part of an MCAD model, including 2D drawing files correlated with the modified parts, the model automatically incorporates the changes.

In addition to virtual mock-up test capabilities, MCAD, when applied by project participants including the architect, the builder, the owner, and the facility manager, facilitates communication during the early design phase. Early communication of parties reduces the number of design changes, preventing liability issues that may stem from later design problems. Moreover, because of its mechanical drawing capabilities, MCAD can enhance the quality of a virtual mock-up test of a building envelope. For example, it allows a thermal analysis that determines the U-value and thermal flow of a building envelope that engineers can interpret to determine its weak points. Because of such benefits, the use of MCAD could considerably ease the complicated process of designing a building envelope and provide the virtual mock-up industry with a valuable tool that we have confirmed works for the design and construction process.

4. CONCLUSIONS

For improved integration of models and efficient processes of design and fabrication of building facades, a reverse engineering review of the process indicates a need for higher accuracy modeling of the building envelope. The case study identified the benefits of using mechanical CAD in building design as a tool to improve the building envelope design workflow. This paper showed the feasibility of using MCAD to generate a fully coordinated building model during the conceptual design phase and to enable consistent facility management. For this case study we utilized Autodesk Inventor as the MCAD software. From this modeling tool selection we found some limitations in model exchange and issues of data attrition during exchanges with Autodesk BIM software, Revit Architecture. Further research is in progress to address issues of interoperability of information and data exchange, through development of an IFC file of MCAD which can be interoperable with current BIM tools. By defining exchange requirements, information delivery manuals (IDMs), and model view definitions (MVDs), an IFC file in MCAD software solution would be launched so that a MCAD modeling file can be seamlessly exchanged with existing architectural software engines that form the foundation of the efficient adoption of MCAD in the AEC industry.

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