Virtual Mock-up Simulation of Building Skins for Design to Fabrication Integration

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ABSTRACT
With the growing demand for mock-up integration into late design and pre-construction phases, there is an increasing gap between the virtual design model of the building and the construction model. The gap is reinforced by lack of strong iterative exchanges between design and fabrication and consequently the construction of the building skin systems. This paper will discuss the research being conducted using virtual mock-ups as an earlier insertion of fabrication parameters into design process and presents a solution to bridge this gap. Studies of model integration will be introduced using component-based 3D-CAD modeling to link front and end user scenarios.

KEYWORDS: virtual mock-up; fabrication; integration; building skin ; simulation

Introduction

Building skin design, as a multi-disciplinary effort, is mostly a disjointed process from the preliminary concept, to its detailing, testing, and construction. With heavy demand of packaging the design, through renderings and the emphasis on the visual representation of the building design, a gap exists between what is actually built and what is drawn in the architectural set in terms of the mechanics of how the building skin is constructed. Architectural set details, becoming notoriously unreliable and often a result of designers re-using material systems and details, have led to contractors mainly relying on separately drawn shop drawings. Shop drawings, which are construction drawings supplied by the fabricator that reference architectural plans, are critical documents for construction, and in some cases also function as fabrication drawings. The approval of shop drawings is a turning point in the building skin design to fabrication transition and once approved, become primary documents for information exchange between the builders and designers. At this point, physical mock-ups are also used to test the feasibility of the systems represented in the shop drawings. This traditional project workflow is still common, however with the advent of integrated project management through model integration, earlier and faster information sharing there is a need to understand how to integrate the design and fabrication process of building skins. The research found that projects that utilized customized skin systems, to some level, had begun addressing this issue however with a high-cost precondition. The paper describes the workflow of customized building skin systems based on project case studies and new automated workflow activities triggered by an integrated virtual exchange environment – virtual mock-up.

Use of Mock-ups

The use of mock-ups - representative sample replicas of proposed systems - on building projects is heavily relied on, in particular for the building skin design. In some instances, guidelines highly recommend its use and on high budget projects they are always implemented at several points throughout the project. The critical mock-ups are visual, performance and field mock-ups, which happen at early design, pre-construction and construction phases respectively. The performance and field mock-ups are most important since they test the skin design for compliance to prescribed performance measures of infiltration, thermal resistance, structural integrity and constructability. However these mock-ups occur at the early construction phase and are based off of shop drawings that have typically been re-drawn by the fabricator. Although after the design phase, results from these mock-ups percolate to the design, fabrication and construction platforms of exchange. This leads to mainly "bandage" modifications since there is limited design flexibility at that point. The research focused around the premise that a mock-up within the virtual environment (virtual mock-up) introduced earlier in the design phase would allow for more design flexibility and earlier consideration of fabrication and construction parameters.

The Issues

There are two main issues that the idea of the virtual mock-up addresses: 1) Decrease disparity of project integration based on budgets and; 2) create bridge between the design and construction of the building skin system and increase integration of BIM processes. To explain the issues, there needs to be an understanding of the bipolar practices emerging out of the fundamental process of design being front-end and fabrication/construction being back-end. The intensity of work is bipolar with architects heavily collaborating with engineers through simulation at the front end, and the fabricators heavily collaborating with general contractors and related subcontractors for constructability, coordination, cost control and scheduling at the back-end (Fig. 1). With higher budget projects, there is some attempts to jump between the design side and construction side, however for more budget-conscious projects, the process is more linear and fabrication and design have a small overlap and little opportunity for effective design exchange.

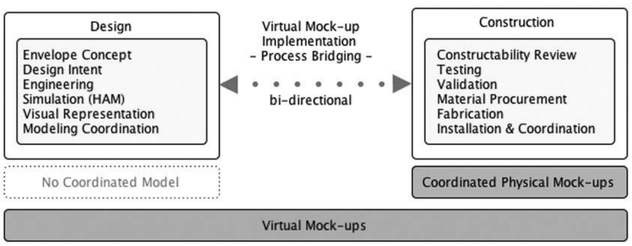

Fig. 1. Bipolar workflow of design and construction of building skin. Virtual mock-up addresses the gap between front-end and back-end of the building skin process, forming a bi-directional relationship.

Method and Findings

The research looked at mapping workflows and capturing model and information exchanges through examination of case studies. The selection of case study projects was based on their intention or commitment to implement building information modeling (BIM) and some level of customized envelope system, meaning that there were steps taken by the project design team to ensure the performance compliance of the designed skin. In addition, the case studies were selected to represent a range of different levels of automation within the building process. The project team exchange was studied across all the various disciplines throughout the design to construction of the envelope system. Concurrent to the workflow study, the research looked at specific examples of physical mock-ups and replicated it into the virtual environment to study workflow modifications and methods to integrate design with fabrication.

Further analysis of workflows showed that within fabrication, the fabricators that had integrated practices within its business structure of engineering, fabrication and installation were implementing integrative exchanges at the end phase of building design. Fig. 2 shows a multi-disciplinary integrated workflow of the fabrication integration with performance, fabrication and construction.

One of the case study buildings selected was a building in California that adopted BIM practices in integrating mechanical design, planning, structural detailing however had preliminary attempts at integrating the custom curtain wall design and fabrication process. Fig. 3 shows how even though the project utilized BIM platforms for modeling the building skin, each step of whole building model, solar study and fabrication did not have an iterative model exchange and ultimately led to the physical mock-up which still claimed the traditional function of being a problem finder prior to construction.

This reinforces the point that although there is a surge to integrate disciplines, the focus on performance and construction remains on the fabrication end of the process which tends to have diverse levels of technology adoption. Even within fabrication and construction there is higher technology adoption when operations are integrated than when they exist as distinct entities (Beede 1995). Fabricators who have responded to market demands, are providing manufacturer-specific model libraries (e.g., REVIT families, AutoCAD blocks) for designers. However with limited integration with designers during design phases, the use of these model libraries become generic and in some cases cause more problems due to large dataset complications. The more specific the modeling the more responsive each participant needs to be in filtering out information and include what is necessary for the intended function. So with the main BIM model as a nucleus linking the disciplines there needs to be another portal where designers and fabricators can come to the table and discuss the mechanics of the design – as is done typically when reviewing shop drawings. The virtual mock-up modeling provides this scenario by bringing issues of fabrication earlier into the design process and allowing for localized studies to discuss at the detailed

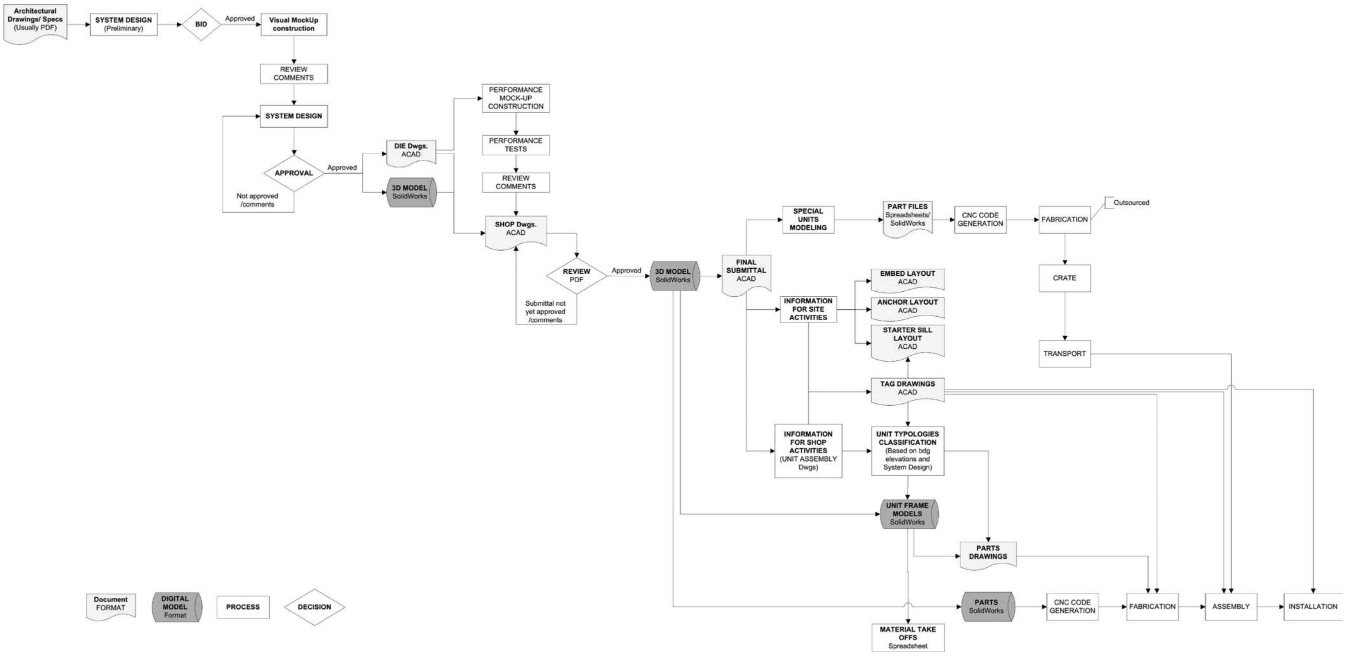

Fig. 2. Curtain Wall Design workflow based on traditional workflow processional design – specify and detail – fabricate – install. Workflow shown is after schematic design completed and concept drawings are handed over to the fabricator.

level using fabrication parameters. The concept of the virtual model is that it will then be carried through to the fabrication workflow eliminating the need to re-draw the designed system.

To test the virtual mock-up concept and assimilate different workflows, a virtual mock-up of a select case study was made given the parameters used for the project physical mock-up built on site. Since the physical mock-up played a critical role and represented a milestone in project sequence, the extent of how much function a virtual mock-up could exhibit would be a key question to its effectiveness. A process of reverse engineering was used to model and embed information that would create a re-enactment of the design process and fabrication process (Fig. 4). The virtual mock-up was first conceptualized then embedded with high levels of detail through solid modeling, using a mechanical product approach through a mechanical CAD platform. The virtual mock-up model would therefore be separate from the BIM model however be extractions from this model. The advantage was the core BIM model would primarily be a surface representation of the building skin and the linked virtual mock-up would be small cut sections of the building skin modeled as a solid geometry to ultimately connect with fabrication processes. Through the solid modeling, analysis of thermal performance, stress distribution, solar radiation, daylighting and energy analysis were performed and utilized in design decisions. For some cases when performing the analysis there were interoperability issues between the different tools used. The findings on virtual mock-up cases performed in the research presents a strong case for this process. As a cost-efficient preview to the physical mock-up, it also creates an opportunity for better dialogue between the design team and fabrication/construction team.

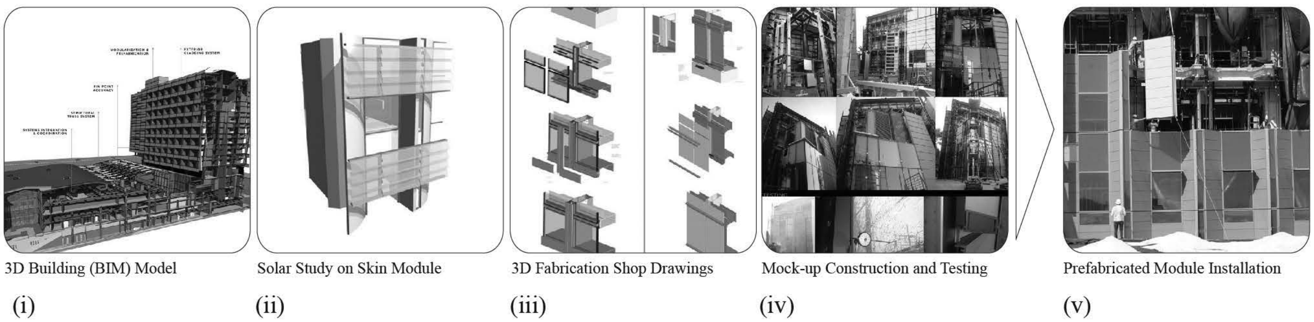

Fig. 3. Case study project which utilized BIM enabled tools(i), however used more traditional workflows when it came to curtain wall design and fabrication. Different models were used for (ii) solar study and (iii) shop drawings. Mock-up was utilized (iv) but after design and prior to fabrication and on-site installation.

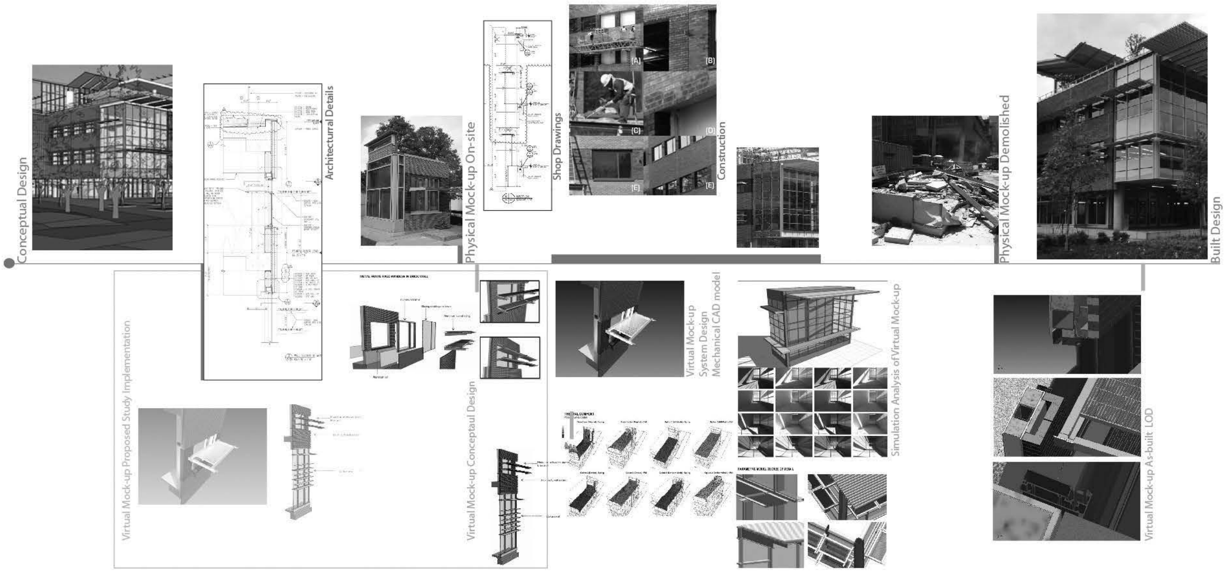

Fig. 4. Project where Virtual Mock-up was tested with Simulation Analysis and fabrication modeling including cost analysis.

Conclusions

Virtual Mock-up simulations were found to be effective in that it allowed for several study areas, less re-drawing, construction and assembly simulations for optimization, performance analysis and a better iterative environment for designers and fabricators than going from a 3D model to 2D shop drawings solely. Our investigation of the fabrication process on the customized skin systems showed that some fabricators were utilizing highly detailed 3D CAD models to represent the skin systems, however these models were typically developed on the fabrication end and did not engage with the architects design process. From our virtual mock-up concept test results, there is strong implication of the potential that, if adopted widely, these mock-ups will make the building skin design workflow more efficient and create market demands on fabricators to comply and utilize the design-fabrication integrated virtual mock-up models.

This research in this paper was conducted through the Digital Building Lab and College of Architecture at Georgia Institute of Technology (USA) and ongoing research at School of Architecture of The Chinese University of Hong Kong. Research is ongoing on testing different ways to integrate the virtual mock-up, to resolve model interoperability and to determine at what point there can be ensured reliability to be more competitive with the physical mock-up. In addition, continued tests for better integration with real-time visualization and variable parameters of tolerance, material changes and interoperability is in progress.

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