Efficient evaluation of construction submittals using BIM

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Abstract: - Submittal review is a formal process for evaluating all of the material, equipment, and processes submitted by a contractor before they can be used in a project. For projects involving unique architectural components, contractors often submit alternatives that have minor deviations from specifications. Thorough evaluation is therefore necessary to save project time and quantify the best acceptance conditions. This paper discusses the development of a BIM-based decision-support framework to help evaluate key architectural submittals during construction in an efficient and speedy manner. BIM is used for storing design rationale and specification data within its 3D model of a building. The framework uses this data and applies the multi-attribute utility theory (MAUT) and the analytical hierarchy process (AHP) to evaluate the degree of submittal compliance with design rationale and performance criteria. Accordingly, it suggests correct acceptance conditions, based on analysis of the cost and time implications at the short-term and the long-term during operation. Applying the framework to a case study shows its ability to reduce subjectivity in submittal evaluation, determine the best-value decisions, and automatically update as-built data to facilitate correct operation of a building.

Key-Words: - Building Information Model (BIM), Submittals, Architectural windows, Analytical hierarchy process (AHP), Utility functions, Design rationale, Decision support system

1 Introduction
The quality of drawings and specifications generated during the design stage of a project has a large impact on the construction and operation stages of building projects. This effect is clearly indicated in a study by Josephson and Hammarlund [1] which revealed that approximately 30% of all defects that arose during construction and 55% of all defects that appeared during operation are due to design defects. Although both drawings and specifications (which embody all of the design details) are important for construction [2, 3], specifications receive less attention during design and thus become a main cause of construction disputes [4].

Prior to installation, submittal review is a formal process that evaluates all of the material, equipment, and processes submitted by a contractor for compliance with specifications. As part of quality assurance during construction, contractors are required to submit samples of materials or products and follow the formal submittals review/evaluation process. This necessary process is important to “demonstrate the way by which the contractor proposes to conform to the information given and the design concept expressed in the contract” [5, 6]. Although submittals are not included as part of contract documents, they must be scheduled and provided by the contractor during construction for all building systems and components [7]. Submittals can be material samples, shop drawings, schedules, equipment, products, and catalogues. The evaluation of these submittals can be a difficult task [8] due to time constraints (typically 14 days); missing information in the submittal package [9]; problems in interpreting design intent in the case of vague specifications; and lack of defined evaluation criteria [10, 11]. Thus, under mounting deadline pressure, the tendency to accept items that appear to have only trivial deviations from specifications can culminate in a sizable negative impact on project performance during construction and operation stages. Therefore, a structured process for speedy and thorough evaluation of submittals is needed to save project time and bring best value to the project.

Among the various types of submittals, architectural components can be among the most difficult to evaluate. They uniquely involve aesthetic requirements (e.g., colour level, style, texture, material, etc.) that require a high degree of subjectivity and experience in their evaluation. One key challenge to the evaluation process is the fact that the design rationale is never documented and, as...
such, it becomes difficult to decide if a submittal is consistent with the intention of the design especially in cases of submittals with minor changes. Furthermore, architectural components that are part of the building enclosure are the most critical. Leak, a major concern in buildings, is often caused by the architectural windows [12]. Whether the leakage is water or air, the problem remains significant. While water leakage can cause severe damage to building structure, air leakage can cause energy waste and discomfort. The energy consumed to compensate unwanted heat loss or gain through window was reported to cost the United States $20 billion in 1990 alone, which is equal to one-fourth of all the energy used for space heating and cooling [13].

Increasing efforts to control submittals have become apparent in the industry, although more on the commercial level than the research level. Submittal management systems are often part of a construction document management system. Such systems mainly manage the submittal register, track submittals, and save time on data entry and follow-up. Despite their usefulness, however, most systems lack decision support capabilities for submittal evaluation that consider compliance issues and the construction / operational implications of accepting or rejecting submittals.

To facilitate submittal evaluation, several studies in the literature have reported the importance of documenting the design rationale for the purpose of preventing violation of the design’s original intent [14, 15, 16]. Since submittals can lead to changed items during construction, documentation of design rationale is necessary for the evaluation of submittals. However, to the authors’ knowledge, no previous efforts in the literature have proposed or utilized adequate design rationale documentation to facilitate the evaluation of submittals.

Having an accurate centralized depository of project documents and specifications is useful to the submittal evaluation process. In recent years, active research has promoted BIM to replace CAD as a more powerful depository of building information [17]. In essence, BIM provides AEC professionals with both a geometrically accurate 3D representation of a building and also the capability to integrate attributes and data for the components inside the model. Being parametric-based (as opposed to geometric-based in traditional CAD) makes BIM more suitable for the implementation of design changes and for its ability to embed analytical features into the model. Due to its powerful data depository features, this paper develops a framework that combines BIM and a decision analysis tool to document design rationale and performance-related criteria in the BIM platform and facilitate the evaluation of building submittals.

The aim of this paper is to develop a BIM-based decision support framework that helps decision makers evaluate architectural submittals in an objective and speedy manner. This research selected windows as a key architectural submittal in buildings and identified the different levels of criteria to use in architectural submittals, including design rationale that capture the subjective aspects of submittal evaluation (e.g., style and colour); and performance-related criteria that relate to construction and operational implications. Thus, a new submittal evaluation framework is proposed which uses BIM to store design rationale, update specification data, and facilitate the evaluation of window submittals. The framework utilizes the MAUT to evaluate the compliance of window submittals with design rationale and performance-related criteria, in addition to computing the overall utility of a submittal and its related life cycle cost. The following sections discuss the development of the framework, and present a hypothetical case study (modified from a real-life case study with some assumptions made regarding the missing information) to validate its computerized prototype which automates the evaluation process.

2 Proposed Submittal Evaluation
The basic premise of the proposed framework is that it is sometimes beneficial to conditionally accept a submittal with trivial deviation from specifications (referred to in this research as borderline item) if it provides good project value and does not impact the life cycle economics of the building. However, these submittals must comply with design rationale criteria and satisfy performance-related criteria as determined through a detailed analysis. A conditional acceptance in this case means that the project should be compensated for any additional costs associated with accepting these items. A borderline item that appears to be acceptable during construction phase may produce undesirable effects during operation and may eventually cost more money over the lifecycle of the building [10]. Therefore, construction-related impact (e.g., extra handling/installation charge) and operation-related impact (e.g., extra energy consumption) need to be estimated for borderline submittals and considered as a basis for compensation (e.g., price reduction) as a condition for acceptance. Developing the proposed submittal evaluation framework involved two main phases: Setup and Evaluation (see Fig. 1). These are explained in the following subsections.
The setup phase is performed before construction starts, consists of two steps: Decision Support Tool (DST) Setup and BIM Setup. The DST Setup includes defining the weights and utility functions of performance-related criteria, calculation of implications, and deciding minimum acceptance threshold. These are defined (and can be modified for each new project) by the project team before the start of construction based on standards/code, project location/zone, and levels of required performance. In this step, MAUT was utilized to generate a utility function for each evaluation criteria. Pair-wise comparison using the Analytical Hierarchy Process (AHP) of Saaty [18, 19] was adopted to define the weights. Both utility functions and weights were then utilized to evaluate overall scores (utilities) for any submittal. Details on the criteria, utility functions, and weights for evaluating window submittals are discussed alongside the description of a case study in the next section of this paper.

The second step (BIM Setup) in this phase includes customizing the BIM platform to enable storing, editing, managing, and visualizing of specification data for building components (as shown in Fig. 2). Customization also enables designers to add all design rationale and performance-related criteria for the critical architectural items into the 3D-model of BIM. These data are recorded as custom attributes associated with the parametric properties of 3D items. In this framework, design rationale is represented by a set of rationale criteria with each having a range of acceptability (e.g., acceptable patterns, colours, etc.) which designers set based on design concept, user preferences, project type, etheric impact, etc. The performance-related criteria are proposed according to the CSA-A440-00 performance standard for windows [20]. Fig. 2 shows the BIM platform used in this paper, which is Revit Architecture 2011 by Autodesk, and the custom data.

The evaluation phase is then performed during construction and consists of three steps: “Compliance Check”, “Impact Assessment”, and “Reporting and Updating”. First, analysis of compliance requires observance of both the design rationale and the performance-related criteria of the submittal under evaluation (right side of Fig. 1). Items not complying with the design rationale criteria are rejected without further analysis. After passing the design rationale, the submittal is evaluated in terms of technical
Fig. 2: BIM setup with design rationale

aspects. To facilitate this step, the overall score (utility) of a submittal is calculated by multiplying the weights and utility scores (determined from the utility curves) and summing all performance-related criteria, which must meet a predefined threshold in order for the item to be conditionally accepted. More explanation is presented in the case study later. Acceptable borderline submittal options are then assessed in terms of their impacts on construction and operational costs. “Construction-Related Implication” is concerned with quantifying all construction costs and delays resulting from accepting borderline submittals. Also, “Operation-Related Implication” is concerned with forecasting all of the additional operation-related costs along the life-cycle of the building. During the “Reporting and Updating” step, all information of the acceptable submittals is presented in a final report for decision making; finally, the approved option with its updated specifications is sent back to update the BIM platform.

3 Example Application

Revit Architecture 2011 has been used as the BIM tool in this research due to its popularity, ease of use, and programmability. The Application Programming Interface (API) of Revit was used to customize and integrate Revit with MS Excel in order to retrieve and save project data in BIM. The add-in feature of Revit API plays a significant role in facilitating the framework of this study. The system has been implemented for evaluating window submittals with the utility functions, design rationale, and performance-related criteria discussed alongside the description of a hypothetical case study. In the case study, a contractor examines three window options that are readily available in the market. Each option slightly violates the required U-value of 1.4. Because obtaining the exact item could delay the project, the contractor is interested in evaluating the condition for accepting these options. To start the process, the contractor selects a window object in Revit and activates the evaluation process. For the submittal, the window-to-wall ratio (WWR) for the building is obtained automatically from BIM and is 0.60. The framework automatically calculated the total surface areas of walls (including windows) as 3,750m2. The roof area is 1,200m2.

Upon entering this general information, the evaluation process can be initiated by the user (contractor). The first step of the evaluation process checks the compliance with design rationale. Fig. 3 shows the evaluation form where the stored rationale criteria in Revit (Fig. 2) are listed on the left. Each of the three submittal options is checked for compliance simply through a Yes/No answer. The design rationale criteria of windows include: material, style, colour, glazing, tinting, CSA compliance, and energy star certification. These criteria capture the
subjective aspects of submittal evaluation (e.g., style and colour) that are not captured even in well-documented building designs. For instance, the design rationale for colour has been specified as grey in the exterior to match the cladding material of the building with the acceptable range (according to the European standards) of RAL 7037 to 7045, as shown at the bottom right of Fig. 3. This simple approach of storing and checking design rationale suitably documents the design intent.

In this example, all three submittals are assumed to be compliant with the design rationale criteria. Therefore, the process continues to the next step of checking the performance-related criteria. In this step, the user is required to enter the technical specifications of the proposed submittals. Fig. 4a shows the five technical properties of three window options and their automatically calculated performance scores. The score values (0 to 1.0) are first calculated for each criterion separately based on its utility curve. Fig. 4b shows the utility curve for the “U-value” criterion (generated according to U-values suggested for the province of Ontario, Canada). Such a curve is drawn by plotting at least two points: best and worst. A window with a U-value of 1.4 W/m²K receives best utility score of 1.0 (best performance), while a window with a U-value of 2.0 W/m²K receives a score of 0.08 (worst performance). Thus, a window with any U-value ranging between 1.4 W/m²K and 2.0 W/m²K receives a score between 1.0 and 0.08. In this example, other utility curves were generated for the other four criteria: air infiltration, water penetration, visible transmittance, and solar heat gain coefficient.

The example in Fig. 4b applies to Option 1 window (for which the contractor entered a U-value of 1.5 W/m²K), and therefore receives a score of 0.87 (from the curve) for this criterion. Following this process for all five criteria, the total score for Option 1 is computed as the weighted sum of criteria scores by their weights (automated background calculation hidden from the user), as shown in Fig. 4c. The criteria weights were determined using AHP in the Setup phase. Using an acceptance overall performance threshold of 76%, Option 1 and Option 2 were determined to be conditionally accepted (borderline submittals) while Option 3 was rejected. The two borderline submittals then proceeded to the “Impact Assessment” step. The construction implications were estimated based on the contractor’s input. Operational implication of changing the U-value can be computed as the additional cost of heating associated with a lower quality window. Energy calculation thus depends on factors such as...

Fig. 3: Compliance check with design rationale
surface areas, heating degree-days (HDD), cooling degree-days (CDD), and the price of natural gas/electricity. Accordingly, the cost of energy consumption used for heating and cooling can be estimated based on Sherman [21]. Table 1 illustrates sample energy calculations for the borderline submittals and also shows the amount of money that could be imposed to building operation over a specific period of time and interest: present worth. As shown in Table 1, the present value for changing the U-value from 1.4 W/m²K to 1.5 W/m²K is $6,250, assuming 10 years of operation and a 3% interest rate. Construction impact (assumed negligible in this example) involves extra installation/handling cost and will be absorbed by the contractor, while operational impact is mainly the cost of energy.

Based on the assessment results in Fig. 5, Option 2 appears to cost more than Option 1 over the long term with costs of $12,501 and $6,250 respectively. Submitting an item with a U-value of 1.6 (Option 2), which is only a difference of 0.2, leads to approximately 10% extra energy consumption cost per year ($12,501 in 10 years). In this example, the proposed framework suggests that these two options could be acceptable but the project will need to be compensated with an amount equal to the extra energy cost: $6,250 for Option 1 or $12,501 for Option 2.

Table 1: Ten-year energy cost calculations

<table>
<thead>
<tr>
<th></th>
<th>As Specified</th>
<th>Borderline submittals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Option 1</td>
</tr>
<tr>
<td>U-value ($W/m²·K)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
<td>1.50</td>
</tr>
<tr>
<td>Cost of Heating ($)</td>
<td>$7,028</td>
<td>$7,429</td>
</tr>
<tr>
<td>(eq. [1])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of Cooling ($)</td>
<td>$5,820</td>
<td>$6,152</td>
</tr>
<tr>
<td>(eq. [2])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Cost of Energy Consumption ($)</td>
<td>$12,848</td>
<td>$13,581</td>
</tr>
<tr>
<td></td>
<td>5.4% difference</td>
<td>10.4% difference</td>
</tr>
<tr>
<td>Operational Cost ($) ($6,250)</td>
<td>N/A</td>
<td>$6,250</td>
</tr>
</tbody>
</table>

After viewing and considering all implications of the submittals, a final report is produced to help assess the analysed information from previous steps. The final report of Fig. 5 summarizes the information needed for negotiation and decision making, including general information, compliance results,
and implications. As shown, Option 1 scores better in performance (i.e., 90%) than Option 2. Option 2 imposes more implications in total but requires less maintenance work in the long run. Best value for the project should be selected by considering the output of the framework. In this case study, Option 1 was selected, as the project performance is critical and of priority. The framework is not intended to provide solid or exact decisions for specific scenarios. It rather reports all acceptable options and allows the decision maker, contractor, and project manager to choose and negotiate the preferred option. Finally, upon the selection of an appropriate option, the approved submittal is updated in Revit to complete the “Reporting and Updating” step.

4 Comments and Future Extensions

Upon development, the decision support system (DSS) prototype was tested on various submittal scenarios. The test scenarios were taken from the collected submittal logs with several assumptions made to compensate for missing design rationale information. The following comments and suggested improvements are made by the authors based on the results of experimenting with the framework on the case study and the feedback from the participating practitioners:

- Typically, mechanical and electrical systems are focused upon during design and submittal evaluation. However, certain architectural components (for example windows, as demonstrated in this study) can cause a significant effect on energy consumption and the overall performance of the building. Thus, these components require greater attention during design and submittal evaluation.

- Integration between the BIM platform (Revit Architecture) and the decision analysis tool required an extensive effort for programming and customization. Part of the challenge exists because the customization features are still basic and may not function properly for some versions of the BIM platform.

- While the proposed system is designed for the purpose of evaluating window submittals, its methodology is flexible, and thus has the potential to be easily adapted to include more architectural aspects or other items for further evaluation.

- In this study, the calculation method of energy consumption can consider the complex details of floors, partitions, ceiling, equipment, occupants, or air infiltration. These latter systems are needed to refine energy consumption calculation.

- Currently, an effort is being made to validate the system on a real-life case study.
5 Conclusion

This paper is part of ongoing research that aims at developing a BIM-based DSS to help project managers make efficient decisions regarding the evaluation of critical architectural submittals. The proposed mechanism evaluates submittals considering design rationale, predefined performance criteria, and construction /operational implications. The framework is designed to offer an on-the-spot decision mechanism for contractors and consultants by integrating BIM platform with a decision analysis application. The proposed system has shown potential in improving the capabilities of BIM to store rationale-related and performance-related criteria, update approved submittals, and facilitate better operation of buildings. Such a mechanism contributes to speedy evaluation, less disputes among all parties, and achieving best value for the project.

References: