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BIM-Based Decision Support for the Evaluation of Architectural Submittals during Construction

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Abstract: Submittal review is a formal process that evaluates all the material, equipment, and processes submitted by a contractor, for compliance with specifications, before being installed in a project. For projects that involve unique architectural features, contractors often submit alternatives that can involve minor deviations from some specifications. Thorough evaluation is therefore necessary to save project time and avoid accepting faulty items that have costly long-term impact on the project. To improve the evaluation process, this research develops a structured BIM-based decision-support framework. The proposed framework does not reject submittals with minor deviations; rather, it evaluates the value of accepting them if they meet the original design rationale and some thresholds for the technical criteria. The framework then evaluates the cost of accepting these submittals in terms of additional construction cost and/or operational cost. Finally, the contractor is required to absorb the additional item cost as a condition for acceptance. To facilitate automation, the proposed framework uses a BIM platform as an information depository and integrates it with an analysis tool developed using the Multi-Attribute Utility Theory (MAUT) and the Analytical Hierarchy Process (AHP). The research examines the top architectural submittals on building projects and applies the developed framework on the architectural windows. The framework is expected to help project managers make efficient decisions in a speedy and objective manner, considering the best project value and the long-term impact on the project.

1 Introduction

The quality of the 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 is clearly apparent from the study by Josephson and Hammarlund (1999) which revealed that approximately 30% of all defects arose during construction; and approximately 55% of all defects that appeared during operation and maintenance are due to design defects. Although both drawings and specifications are important during construction (CI 2007; Rosen et al. 2010), specifications receive less attention during design and thus become one of the main causes of construction disputes (Jahren and Dammeier 1990).

To accelerate the preparation of specifications, they are often drafted based on previous specifications, generic standards, experience, and/or poor details (Emmitt 2001). This lack of critical information opens doors for changes and modifications and may transfer problems and disputes to the construction phase (Kululanga and Price 2005). As such, the final as-built specifications for many building components and their actual operational characteristics are updated and finalized during the construction phase (Sherbini 2010). Toole and Hallowell (2005), for example, listed 24 building components whose specifications are not determined until construction.

Before contractors can use a specific type of material or product, contractors are required to follow a formal review process called the submittals review process. This deliberate and necessary process (De Lapp 2003) 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”* (AIA 2007). Submittals can be material samples, shop drawings, schedules, equipment, products, and catalogs that must be turned in for all building systems and components (Porter 2008). Throughout the submittals review process, the general contractor is required to submit all proposed submittals according to an approved submittal schedule. The evaluation and approval of these submittals can be a difficult task due to time constraints (typically 14 days), information missing from the submittal package (Atkins 2006; Liescheidt 2003) and problems in retrieving related information from different file formats including graphical and textual (Wood 1996). In addition, the lack of defined criteria for the evaluation can add to these difficulties (Sherbini 2010), especially when minor changes or deviations can affect the overall performance during the construction and operation stages of the project. Also, assigning personnel with low experience to evaluate submittals can affect the quality of decisions (Elovitz 2003; Garrett and Lee 2010).

Among the various types of submittals, Architectural components can be one of the most difficult to evaluate. They uniquely involve aesthetic requirements (e.g., color level, style, texture, etc.) that involve 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. Acoustic panels, as an example of architectural-related submittals, can be a critical element to evaluate. During the evaluation process, compliance issues may arise and need consideration. It is important for reviewers to verify the architectural design intent behind the shape, style, and material of the original panel design. Designers, for example, may have suggested panels to be blue, rectangular, made of fabric material, and have a specific pattern to achieve a desired architectural and aesthetical affect. If this design rationale is documented, it is possible to examine the actual panel being submitted for compliance.

Based on the above discussion, evaluating architectural-related submittals is a difficult process due to the undocumented design rationale, lack of identified criteria, time constraints, and the difficulty in quantifying construction-related and operation-related impacts. A framework that combines a Building Information Model (BIM) and a decision analysis tool has been suggested in this paper to overcome these difficulties.

2 Identifying Critical Architectural Submittals

The process of identifying the critical architectural submittals involved two steps: analysis of collected submittal logs; and soliciting feedback from experienced practitioners. In the first step, complete sets of submittal logs for 2 projects with total of 358 registered submittals were analyzed to identify the critical architectural submittals. The initial analysis indicated that architectural submittals reserved the largest number of submitted items with 233 records (65%). Mechanical submittals hold the second rank of all submittals with 20% followed by structural and electrical submittals with 8% and 7%, respectively. Figure 1 (part a) shows the initial analysis of all recorded submittals.

Unlike other disciplines, architectural works and products are described in several divisions in the specifications. On the collected logs, they are described in 11 divisions, as shown in part b of Figure 1. Each division includes several sub-divisions that cover all works and products submitted for evaluation. An analysis to the architectural submittals of all divisions and sub-divisions was conducted and revealed that “Division 04 Masonry” involved the largest number of registered submittals, with 51 records (22%), followed by “Division 08 Openings” with 47 registered submittals (20%). Figure 1 (part c) illustrates the result of the analysis performed to rank the retrieved architectural submittals.

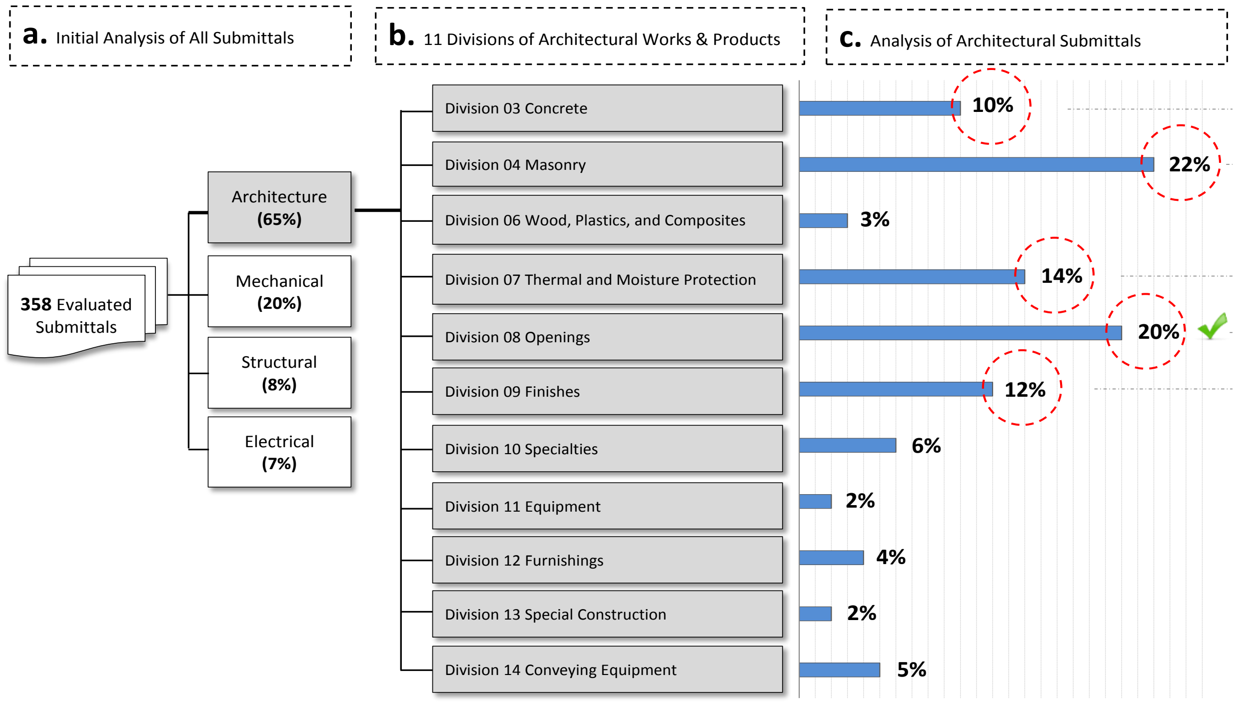

Figure 1: Analysis of Submittal Logs

In the next step, the list of top 5 submittal items were examined by the participated practitioners based on a number of criticality measures. During several rounds of interviews and discussion, it was decided that for a submittal item to be most critical, it must be: (1) an essential part of building envelop that affects the overall performance of the building (i.e., energy consumption, cost of operation, levels of satisfaction, etc.); (2) consists of different material to achieve specific functions; (3) involves a process of procurement, testing, and commissioning; (4) requires special process to customize, fabricate, install, and maintain; (5) holds aesthetical and architectural (non-measurable) features; and (6) requires more time and high level of experience to be evaluated and approved. Although the "Division 08 Openings" was the second top on the initial analysis (in terms of number of submittals), participated practitioners ranked it to be the most critical architectural submittal and "**architectural windows**" were selected to be the top item that requires decision support for submittal evaluation.

3 Proposed Submittal Evaluation Methodology

To save project time and increase the project's value, it is sometimes beneficial to conditionally accept submittals with minor deviation from specifications (referred to in this paper as borderline items) for further consideration. However, these submittals must comply with the original design rationale and satisfy the technical specifications through a detailed analysis. However, 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 if it costs more money over the lifecycle of a building (Sherbini 2010). Therefore, construction-related issues, such as extra installation fee, and operation-related issues, such as extra maintenance fee, should be accurately estimated for the borderline submittals and used as a basis for compensation (e.g., price reduction), as a condition for accepting them in the project.

Developing a submittal evaluation framework that follows this conceptual approach involves two main aspects. The first aspect utilizes 3D BIM models to store design rationale and all information related to the suitable evaluation criteria of submittals. The second aspect utilizes structured decision analysis tools to facilitate accurate and speedy evaluation of submittals, while considering the impact on construction and operational costs. Thus, this research aims to develop a BIM-based Decision Support Framework to help project managers evaluate architectural-related submittals during construction in speedy and efficient manner. The framework components and its working flow are shown in Figure 2. The framework evaluates the borderline submittals in terms of compliance with the design rationale and technical-related criteria (both are stored in the building's BIM model). Acceptable borderline submittals are then evaluated in terms of their impact on construction and operational costs. All information of the acceptable submittals is then presented in a final report for decision-making. Finally, the approved submittal with its construction and operational specifications is exported back to the BIM platform. At the "Analysis & Evaluation" phase of the framework, Multi-Attribute Utility Theory (MAUT) and Analytical Hierarchy Process (AHP) are utilized to evaluate the alternative options of architectural-related submittals.

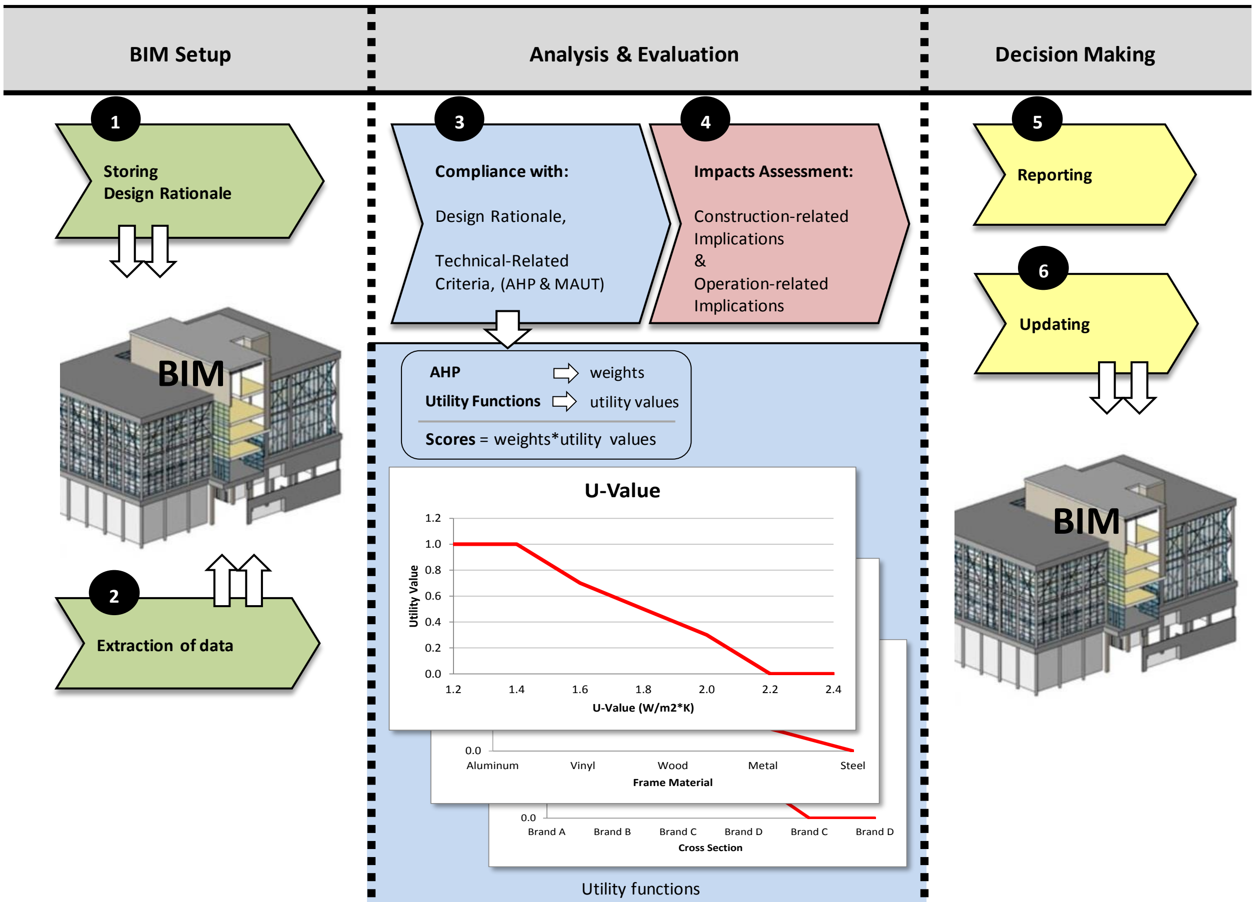

Figure 2: Framework Components and Its Working Flow

The work flow in the proposed framework involves three phases: (1) BIM Setup; (2) Analysis and Evaluation; and (3) Decision Making. There are six steps in total, as illustrated in Figure 2. Steps 1, 2, and 6 are performed in the BIM environment, while steps 3, 4, and 5 are facilitated through a proposed decision analysis application. Details of the work flow phases and their six steps are described in the following subsections.

3.1 BIM Setup

A BIM platform was adopted in this study to store, edit, manage, and visualize all building components. In order to exploit the full capabilities of the BIM platform, the 3D model of the project needs to be generated and fed with all required information. At this step, designers should add all design rationale for the predefined critical architectural items into the 3D-model of BIM. In this study, the design rationale for any 3D element (e.g., window) is defined in terms of a number of designer introduced criteria and their upper and lower bounds that the designer cannot tolerate any deviation from. These are stored as custom attributes associated with the 3D element.

The second part of the "BIM Setup" phase is "Extraction of Data" (Figure 2, step 2). At this step, the detailed information about a specific submittal is retrieved from the BIM model and exported to the decision analysis application for the purpose of "Analysis and Evaluation". The selected element is exported as a parametric entity with all its properties and design rationale. For example, the properties of a door include dimensions, descriptions, and identifications, as well as the recorded design rationale.

3.2 Analysis and Evaluation

This phase consists of two steps: "Compliance" and "Impacts Assessment". First, the analysis of compliance requires observance of both the design rationale and the technical criteria related to the submittal being evaluated (Figure 2, step 3). Items not complying with design rationale are rejected without further analysis. After passing the design rationale, the submittal is evaluated in terms of technical aspects. To facilitate this step, AHP and MAUT techniques have been used to develop a decision support application. AHP is utilized to obtain the weights of predefined technical criteria through pair-wise comparisons. Also, utility functions of all criteria have been created and stored in the BIM model. The multiplication of weights and utility values for the submittal results in a score, which must meet a predefined threshold in order to be conditionally accepted by the project managers. More explanation is presented in the hypothetical example in section 4.

The "Impacts Assessment" step (Figure 2, step 4) of the framework includes two aspects. "Construction-Related Implications" is concerned with quantifying all construction costs and delays resulting from accepting borderline submittals, while "Operation-Related Implications" is concerned with forecasting all the additional operation-related costs along the life-cycle of the building. Extra installation fees, specific storage space, and more time for delivery are considered as "Construction-Related Implications". Extra maintenance or replacement fees are examples of "Operation-Related Implications".

3.3 Decision Making

The last phase of the proposed framework is the "Decision Making" phase. This phase involves two steps including "Reporting" and "Updating". At the "Reporting" step, all accumulated information from previous steps is presented in a final report, where the final approval is determined. The decision maker is a key player in approving the best option for the project according to the circumstances of the project. If technical issues are the priority for a project, then the best score (resulted from MAUT and AHP) should be selected, while an option of minimum time implications is the best selection for projects with tight schedules. Upon approval, the framework prepares the final submittal to be exported to the BIM platform for "Updating". The approved submittal will be exported to the BIM model where it replaces the existing information, and all related drawings and specifications are updated accordingly.

The final result of the framework is a dynamically updated project that reflects all deviations and modifications occurring during construction. Final as-built drawings and specifications can be extracted from the BIM file and used as a guide for maintenance and operation.

4 Implementation on a Hypothetical Example

Revit Architecture 2011 has been used as a BIM platform in this research due to its popularity, ease of use, and programmability. The Application Programming Interface (API) of Revit allows users to customize and program Revit using any ".NET" compliant language including Visual Basic.NET, C#, and C++. In this research, C# was the programming language used to integrate Revit with MS Excel and export all required information, and vice versa. The add-in feature of Revit API plays a significant role in facilitating the framework of this study.

The "BIM Setup" phase of the framework starts with adding all design rationale to Revit. To evaluate a submittal for windows, for example, the window object is selected and its data extracted from the 3D model in Revit. Accordingly, all properties of the window are exported to the decision analysis application, where the "Analysis & Evaluation" phase is initiated. All predefined utility functions and criteria are then used for selection and evaluation.

The first step of "Analysis & Evaluation" is Compliance with Design Rationale. Figure 3 shows the interface where imported rationale from Revit is listed and checked. The figure shows three rationale criteria of the item "window": Material, Style, and Colour. The criteria of the "window" captures some aspects that are usually ignored during evaluating submittals as they are un-measurable (e.g., Style and Colour) even in well-documented building designs. For instance, the "Style" criteria for this window has been specified to be fixed (not operable) and the rationale behind this criteria as explained by the designer is to provide that part of the building with secure environment, more water tightness and less air infiltration.

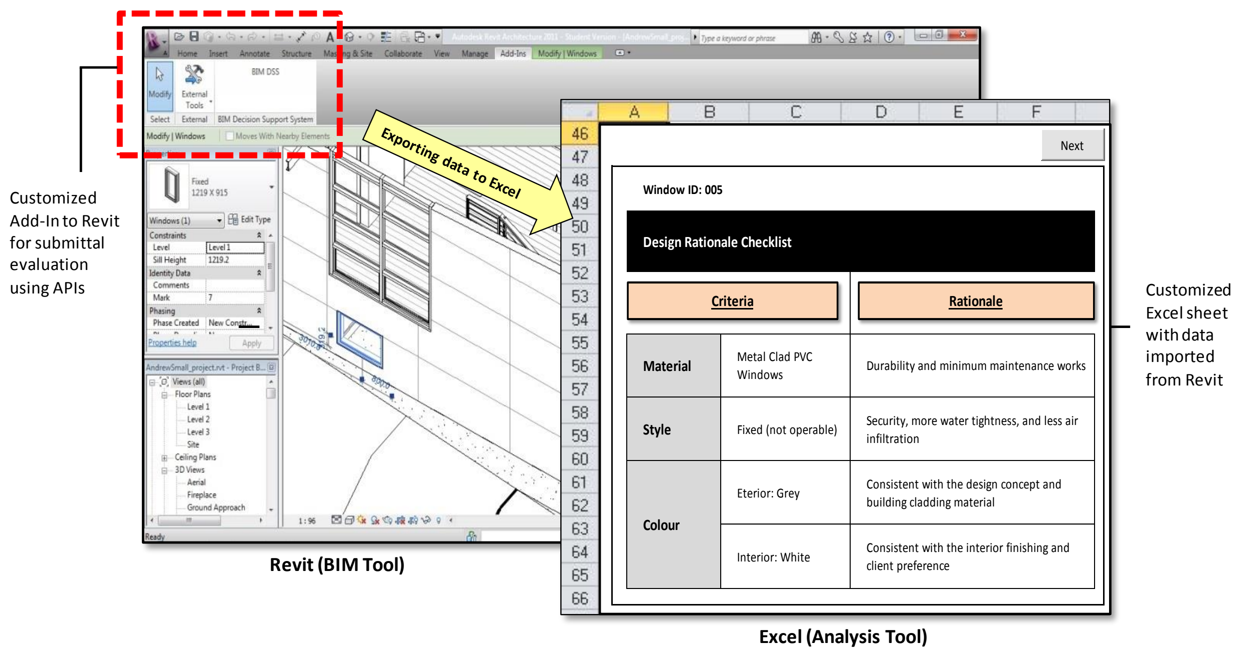

Figure 3: Compliance with Design Rationale

In this example, all three submittals are assumed to be compliant with the design rationale. Therefore, the user is directed to the next step: Compliance with Technical-Related Criteria. At this step, the user is required to specify all the specifications of the proposed submittals. Figure 4a shows the technical properties of 3 window submittals and the automatically calculated scores. Also, the minimum acceptance threshold was specified to be 75%. Option 1 and Option 2 were conditionally accepted while option 3 was rejected, because it scored below the minimum acceptance percentage. The score values are calculated based on the predefined utility functions (MAUT) and weights (AHP), which are set and established in a hidden worksheet. An example of a utility function is shown in Figure 4b for the U-Values of a window generated according to the acceptable U-Values suggested for the province of Ontario, Canada.

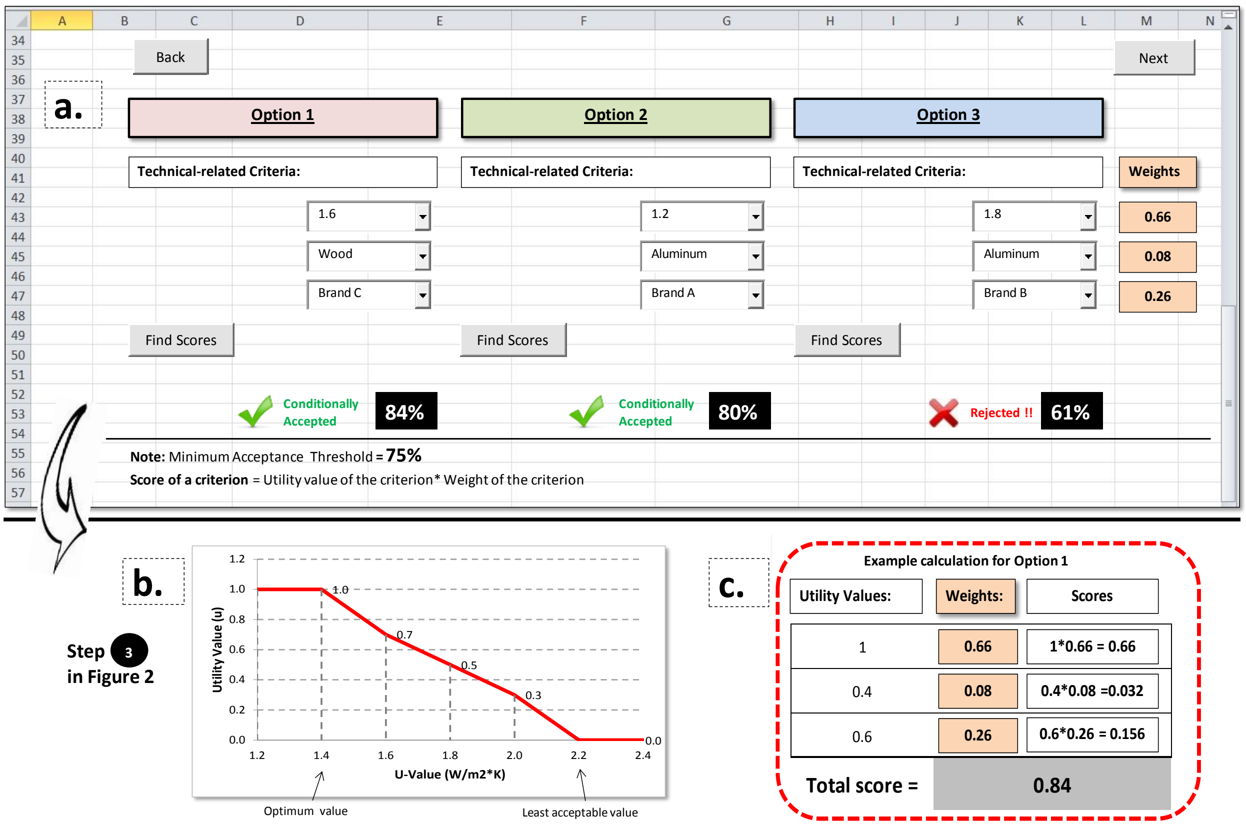

Figure 4: Checking Compliance with Technical-Related Criteria

As shown in Figure 4b, submitting a window with a U-Value of 1.4 offers the best utility value: 1, while the utility value of 0 is given to any window with a U-Value of 2.2 or less. Any value provided within the range will have a related utility between 0 and 1. Other technical-related criteria were considered in this example, including frame material and cross section details. The utility functions for these criteria were generated hypothetically for the purpose of this study. Pair-wise comparison of the AHP technique (Saaty 1980; 1990) is utilized to obtain the weights of criteria as shown in the sample calculation of Figure 4c. The scores calculated, as indicated in Figure 4a, are produced automatically once the user entered the information of the three options.

The two conditionally accepted submittals then proceeded to the “Impact Assessment” step. The values of implications are roughly assumed based on manufacturer feedback and contractors input. Figure 5 shows a summary of construction-related and operation-related implications for this example. These values are to be entered by the contractor as part of the evaluation process and the final decision is negotiated and taken accordingly.

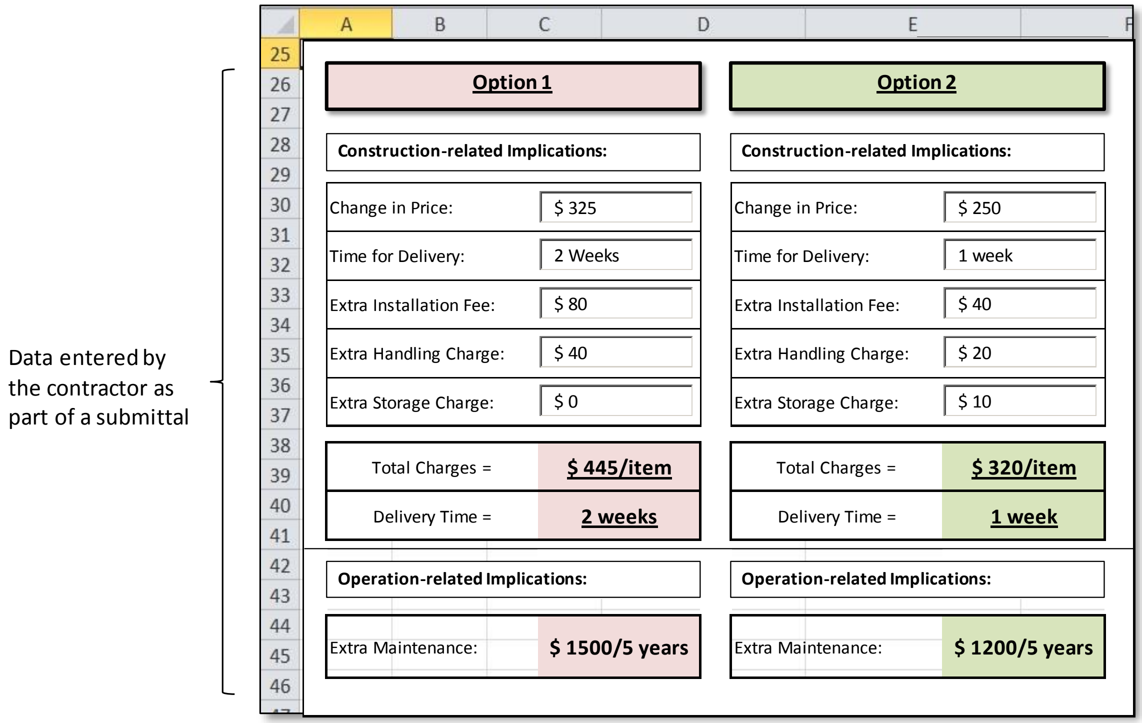

Figure 5: Impact Assessment Analysis

After viewing and considering all implications of the submittals, a final report is produced with the information contained in Figure 5. 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 exported to the Revit to complete the “Updating” step.

5 Summary and Concluded Remarks

This paper is a part of ongoing research that aims at developing a BIM-based decision support system to help project managers make efficient decisions regarding the evaluation of critical architectural submittals. The proposed evaluation mechanism evaluates submittals considering design rationale, predefined technical criteria, and construction/operational implications. The framework is designed to check for compliances and implications; and to offer an on-the-spot decision mechanism for contractors and consultants by integrating BIM platform with a decision analysis application. The data collection task of this this study revealed that *architectural windows* are the most critical architectural submittal and, therefore, are used for further analysis and investigation. Interviews with experienced practitioners have assisted in defining the criteria, weights, and utility functions. The proposed system has shown a potential to improve the capabilities of BIM to store design rationale, update approved submittals, and facilitate better operation of buildings. Such a mechanism contributes to a speedy evaluation, less disputes among all parties, and achieving best value for the project. The system can be enhanced to update all approved submittals with related specifications to achieve a complete as-built 3D model for building operations. The integration with an online specification systems and online submittal logs can be the next step for enhancement and development.

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