BUILDING INFORMATION MODELLING FOR CONSTRUCTABILITY ASSESSMENT OF BUILDINGS DESIGN

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مُسْـتَخْـلَـص

إن تطبيق مبدأ قابلية الإنشاء في صناعة البناء له عائد محتمل على القطاع فيما يتعلق بالوقت والمال. تُظهر الأبحاث السابقة أن مراجعة قابلية الإنشاء في مرحلة التصميم المبكرة توفر فوائد للمالكين والمقاولين والمصممين. وبالنظر إلى مدى تعقيد عمليات تصميم المباني فى الوقت الراهن، فإن هنالك حاجة ماسة إلى توفير أداة لدعم القرار تمكن المصممين من مراجعة قابلية الإنشاء على أساس المعلومات المضمنة في نموذج التصميم. ستكون هذه الأداة أكثر فاعلية في مرحلة التصميم بلوألا بحيث يتم أخذ المبدأ في الاعتبار في التصميم منذ الأفكار الاولية. لذلك ، تبحث هذه الدراسة كيفية استخدام الأدوات الحديثة و النماذج المعاصرة لتقييم قابلية التصميم للبناء في مرحلة مبكرة تمكن من تحسين التصميم.

ABSTRACT

Implementation of constructability principles in the AEC industry offers improved construction performance with smooth project delivery and savings in time and money. Previous studies suggest that appraising design constructability at the concept design phases provides great benefits to clients, contractors and designers. Considering the complexity of current practice in buildings design, there is a need to provide a decision support tool that assists the design team to assess their design constructability, utilizing embedded information in the design model. Such targeted tool is most valuable at the early stage of buildings design that constructability is considered in the design solution starting from its inception. Therefore, this research investigates how contemporary process- and object-oriented models can be employed assesse the design constructability, informing decision making at an early stage that supports design optimization.

Keywords: *Constructability Assessment, Buildings Design, Building Information Modelling (BIM), Appraisal Framework*

1 Introduction

The constructability concept aims to integrate engineering, construction and operation knowledge and experience to better accomplish project objectives (1). The term is defined by the Construction Industry Institute (2) as "The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives". Similarly, the Construction Industry Research and Information Association (CIRIA) defines the buildability as "The extent to which the design of a building facilitates ease of construction, subject to overall requirements for the completed building" (3).

In recognition of the importance of designing for constructability, many studies were conducted to investigate how to implement the concept. They took various approaches to benchmark the constructability of design solutions and to enable the objective evaluation of abstract concepts. One key approach to improve and enhance constructability is through a quantified assessment of designs (4).

The importance of deploying the constructability concept at the early design stage stems from the criticality of this phase in any architectural, engineering and construction (AEC) industry project. The building design is a fundamentally complex process, with most influential design decisions being made in the early design stage (5). This includes the consideration of design constructability, which is often ignored by designers and building clients until the commencement of the construction phase, when they are confronted by potential adverse and costly realities (6).

Based on the current practice in appraising design constructability and its associated challenges, the paper defines a set of implementation requirements that should characterize any decision-support tool for assessing design constructability, deploying advanced technologies. Then, a model-based approach is proposed to enable employing current information technologies to assess design constructability. Such a model can contribute significantly to address the identified gaps in the evaluation process. The proposed model and its components are described and its potentiality in improving design constructability is explained.

2 Current Limitations in Designing for Constructability and Emerging Challenges

Figure 1 below reveals that average construction projects have 80% overruns in their capital costs and experience 20 months of delays. This is mainly due to wrong decisions taken at the early design stage regarding the design shape, layout, section sizes, dimensions, materials selection etc. (5). So, it is really critical to use our construction knowledge and experience to avoid any expected problems while achieving the design objectives, which is known by designing for constructability. However, it is not easy task to implement such concept. In fact, more than 30% of designers and practitioners who realise the importance of the concept, they think it is hard to implement it (5).

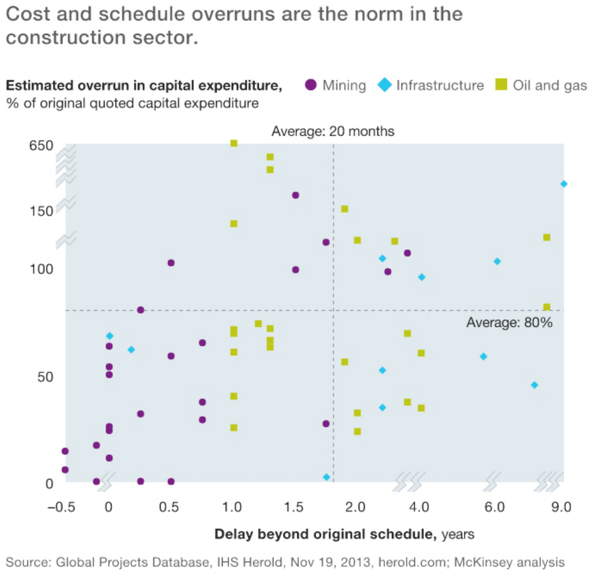

Figure 1: Cost And Schedule Overruns in the Construction Sector (7)

The current building design practice is lacking a decision-support tool that could help designers to make critical decisions related to constructability. Previous studies that tried to address the issue, came up with models that are based on collected experts' opinion using questionnaires and surveys, which is very subjective and might not truly reflect each one's situation. In such developed assessment models, actual users have no input in designing the model and assigning the importance of different constructability aspects. Moreover, advanced technologies such as BIM are not utlised in these assessment models to facilitate the implementation process and ensure the accuracy of its outcomes. Thus, this research investigates how process and data modelling techniques can be utlised to provide a mechanism that assesses the design constructability to inform decision making at an early stage.

3 Information Technology for Improving Design Constructability

BIM technologies can play a vital role in improving design constructability through a collaborative process with early construction input. It facilitates the integration between the design and construction processes that consequently leads to improved quality of building with savings in the project cost and time (8). Object-oriented models have a real potential in quantifying constructability application where designers can observe its factors using a fast, simple and precise tool to assess their designs (9). In addition, BIM has the ability to electronically model and manage the vast amount of information encapsulated into the building design, from its conception to end-of-life. Such information can be employed to estimate, schedule, detail, automate shop drawing, and construction planning for all of the relevant trades.

4 Requirements for Modelling Constructability in Building

A comprehensive review of related literature was undertaken to identify the shortcomings of current assessment tools and challenges to be addressed in this area, particularly with regard to potential and actual deployments of recent advanced technologies. Subsequently, this study defines seven requirements that need to be available in each appraisal system to facilitate the constructability assessment process and deliver it in an effective, fast and accurate way (Figure 2).

5 A Proposed Framework for Constructability Assessment of Buildings Design

This section presents the constructability modelling framework and its implementation. It discusses the components of the framework and how the various constituent objects relate to the operation of the model.

5.1 Modelling Framework

Figure 3 illustrates the proposed methodology to assess design constructability using the embedded information within a BIM. It demonstrates the modelling framework in four parts: the conceptual design model, the constructability assessment model, the assessment process model and the decision-making phase.

5.1.1 The conceptual design model

The conceptual design model refers to the digitized building model that needs to be assessed for its constructability. At this stage, designers build their conceptual model using a BIM software and provide the necessary information that the model should contain according to the agreed level of details (LoD).

5.1.2 The constructability assessment model

Figure 4 below illustrates the proposed constructability assessment model, it assesses the constructability of four components in the conceptual design model, they are AEC systems, rules of thumb, complexity and location. These components are balanced with weighting factors assigned based on their importance in achieving a constructible design.

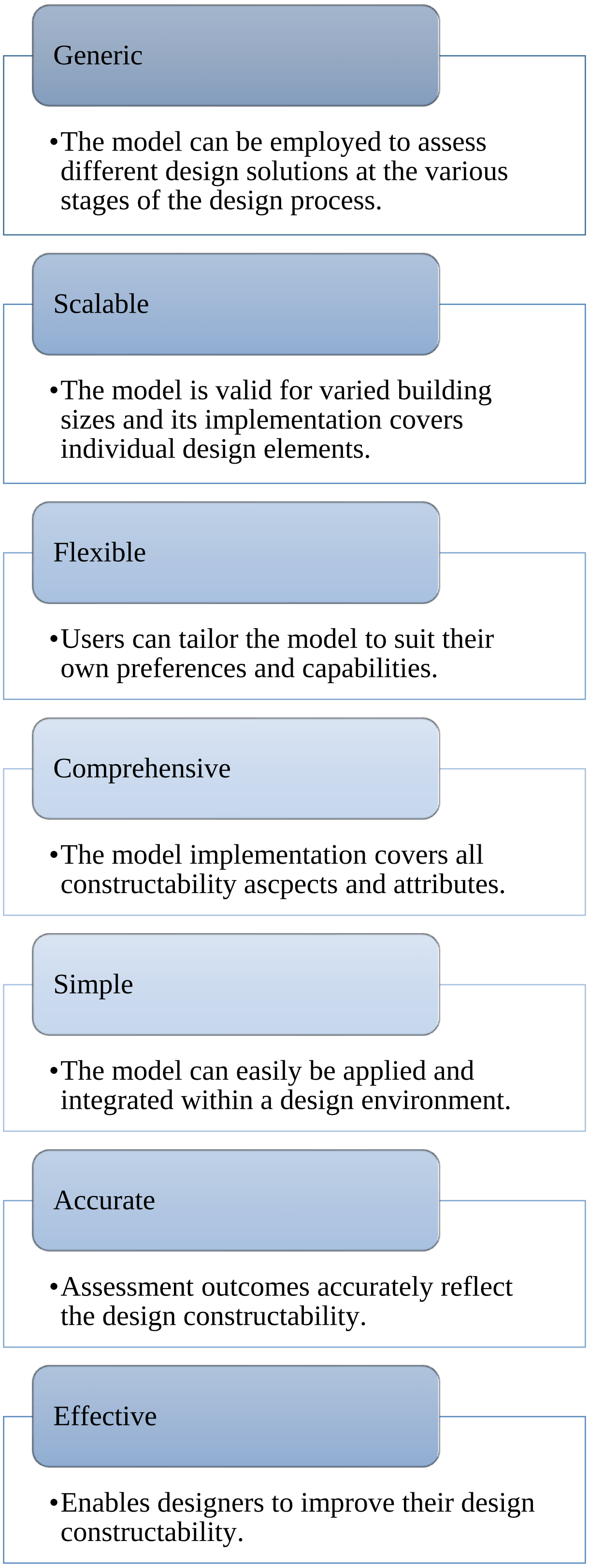

Figure 2: Requirements of Constructability Appraisal System (10)

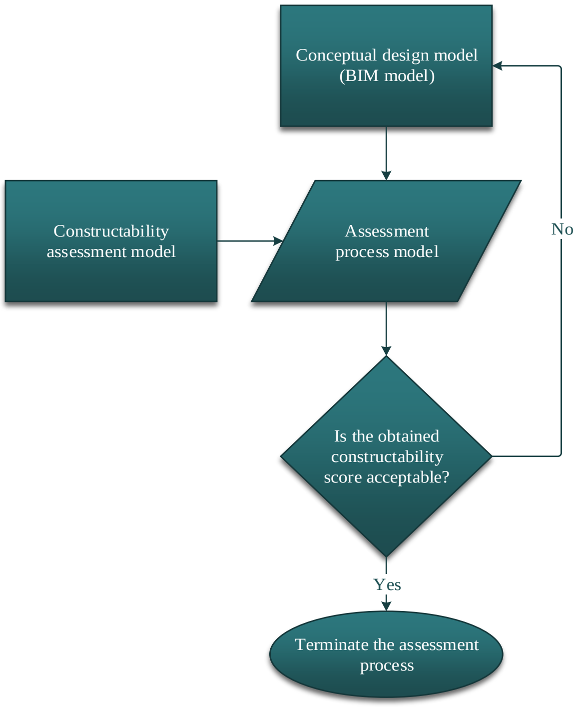

Figure 3: Constructability Assessment Method

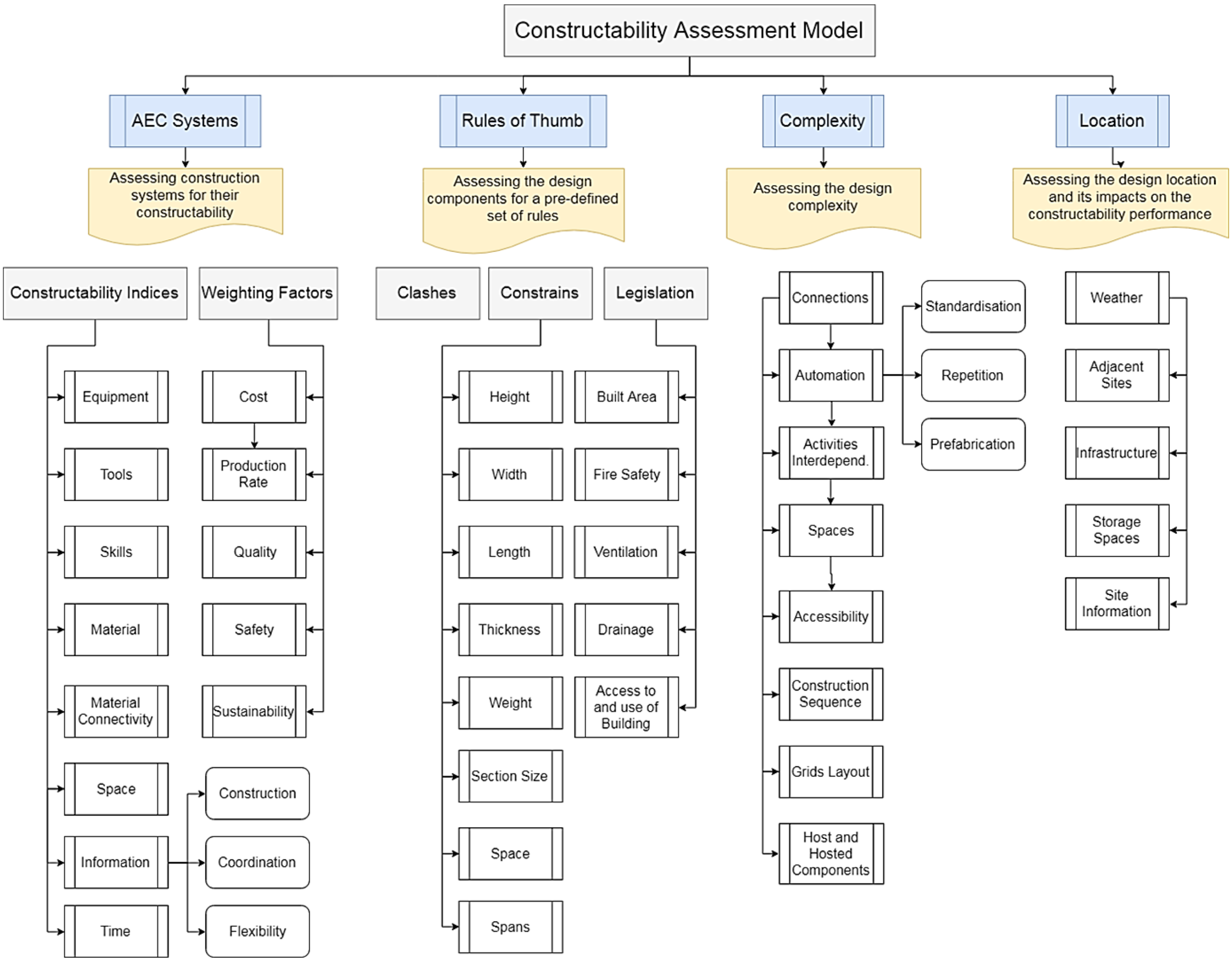

Figure 4: Proposed Constructability Assessment Model

- The AEC systems component assesses the constructability of selected design elements based on the available resources and imposed design constraints. This is achieved by identifying the considered constructability factors and attributes in the assessment process from the users perception, and then calculating constructability indices of different design elements using analytical hierarchy process (AHP) method (11). It ranks the elements based on their constructability from users' perspectives and hence enabling them to decide between alternative designs.

- The rules of thumb allow users to define a set of rules that need to be satisfied in their considered design. These rules are applied to impose the design limitations and constraint in terms of spacing, layout or dimensions, which may affect the construction process later. The system verifies the satisfaction of such rules, assigns them weights through a guided scoring process, and then obtains a final score that is combined with scores from other categories.

- The complexity assesses the effects of selected design solutions in facilitating various constructability aspects during the construction process, such as the intricacy of the design, automation of the process and uncertainty associated with its different aspects. The research is currently investigating this feature and how to attain the full potentiality of BIM in capturing such aspects during the assessment process. For example, visualization and interaction with the BIM model within a 3D environment provided by a game engine, which can be enhanced to an augmented or full immersion virtual reality environment, may help the users to better assess their designs interactively. Detailed construction simulations or simpler 4D animations may also support in the decision-making process of the designer to improve constructability.

- The location component assesses the influence of surrounding environment factors on the construction process and how that is factored in the considered design. Such factors include infrastructure, site conditions, and adjacent buildings. Although the scope of implementation in this research does not cover this, the feature was included in the framework description to strate its ability to accommodate such aspects in the assessment process, enabling users to achieve accurate and reflective constructability assessment outcomes.

Usually, the definition of the assessment model is done once and used to assess many similar projects. Adjustments may be necessary for projects of different types.

5.1.3 Assessment process model

The process model extracts semantic information from BIM model and analyses its constructability by applying the constructed assessment model. It incorporates scores obtained from the different components of the assessment model (AEC systems, rules of thumb, complexity and location) as per user choice, as shown in Figure 5.

5.1.4 Decision-making phase

Based on the obtained feedback, designers can decide whether an improvement in their design constructability is needed.

5.2 Framework Implementation

The proposed framework is implemented through a prototype using Application Programming Interface (API) as a BIM extension, as illustrated in Figure 5. The plug-in software for Revit is implemented in the .NET Framework environment using the C# programming language. The assessment process model acts as inference engine that synthesizes extracted features and properties from the conceptual BIM model (e.g. quantities, dimensions and elements' properties etc.). It then applies the rules and indices from the constructability assessment model to such features and properties and determines the constructability scores.

The proposed model is implemented in the .NET Framework environment using C# programming language. The elicitation of a use-case guiding the programming direction is shown in Figure 6

The implemented prototype allows users to explore different design alternatives and decide on a design based on its constructability performance. Such feature enables the design Optimisation by observing the impacts of using different construction systems on the obtained assessment outcomes and hence improve them as Figure 7 shows.

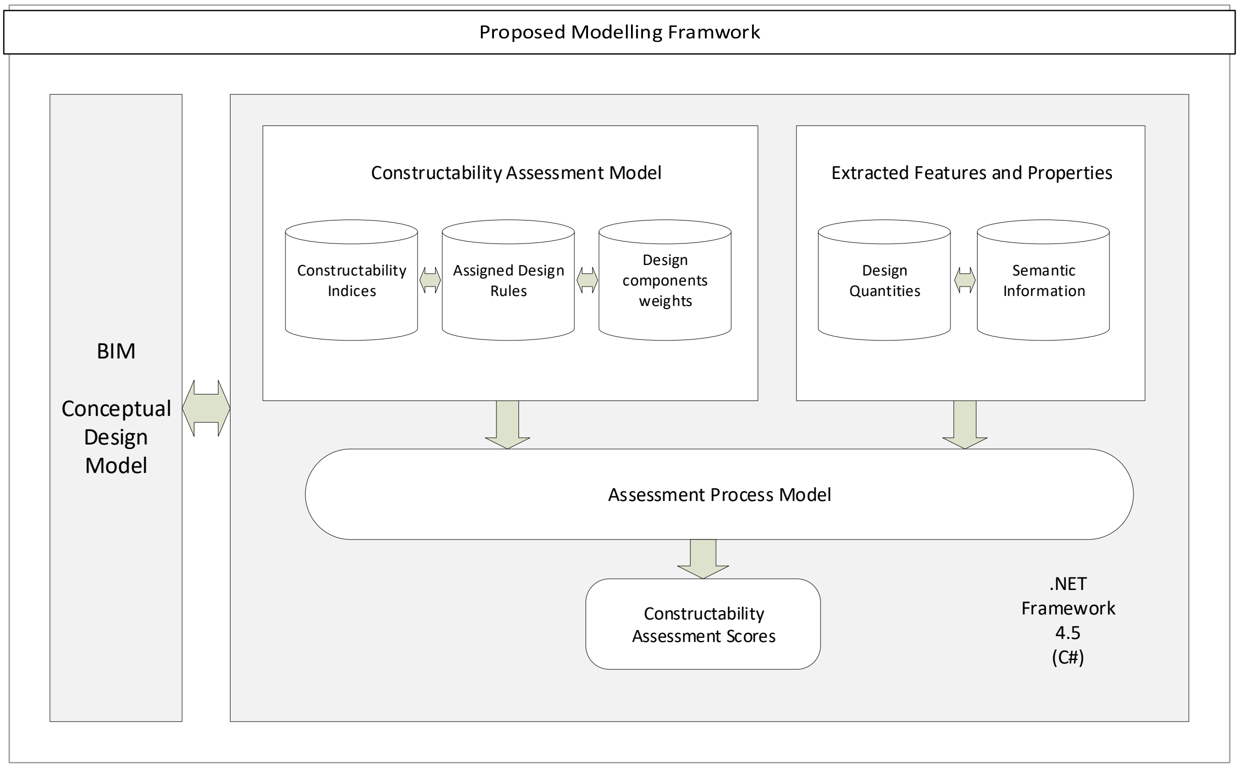

Figure 5: Proposed Modelling Framework

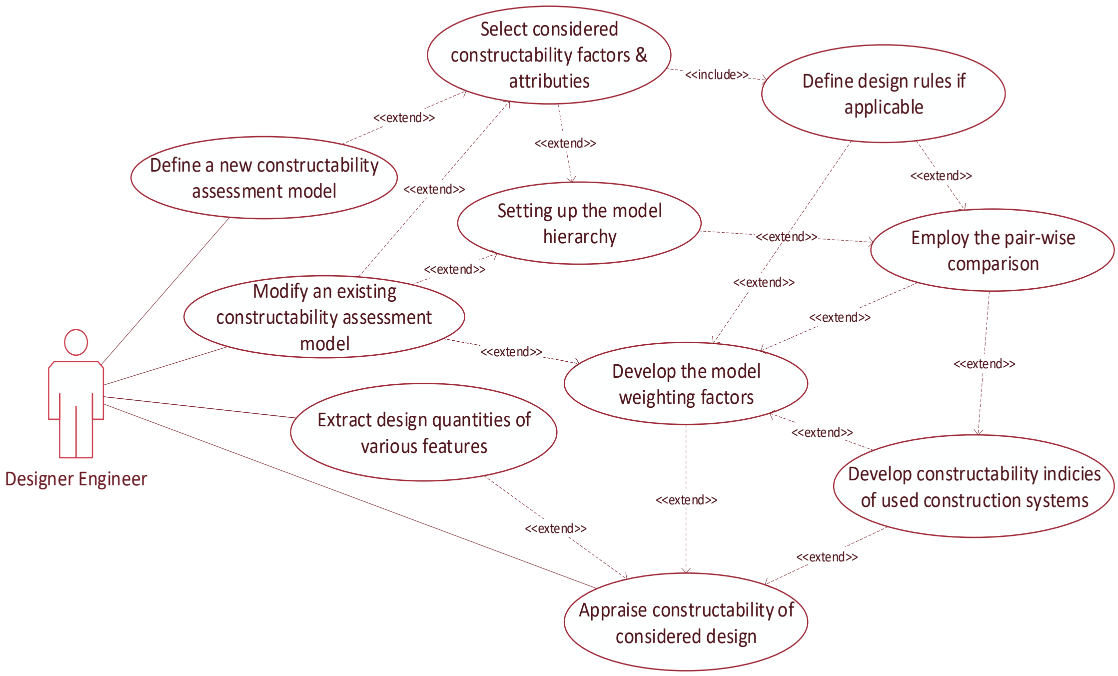

Figure 6: Use Case

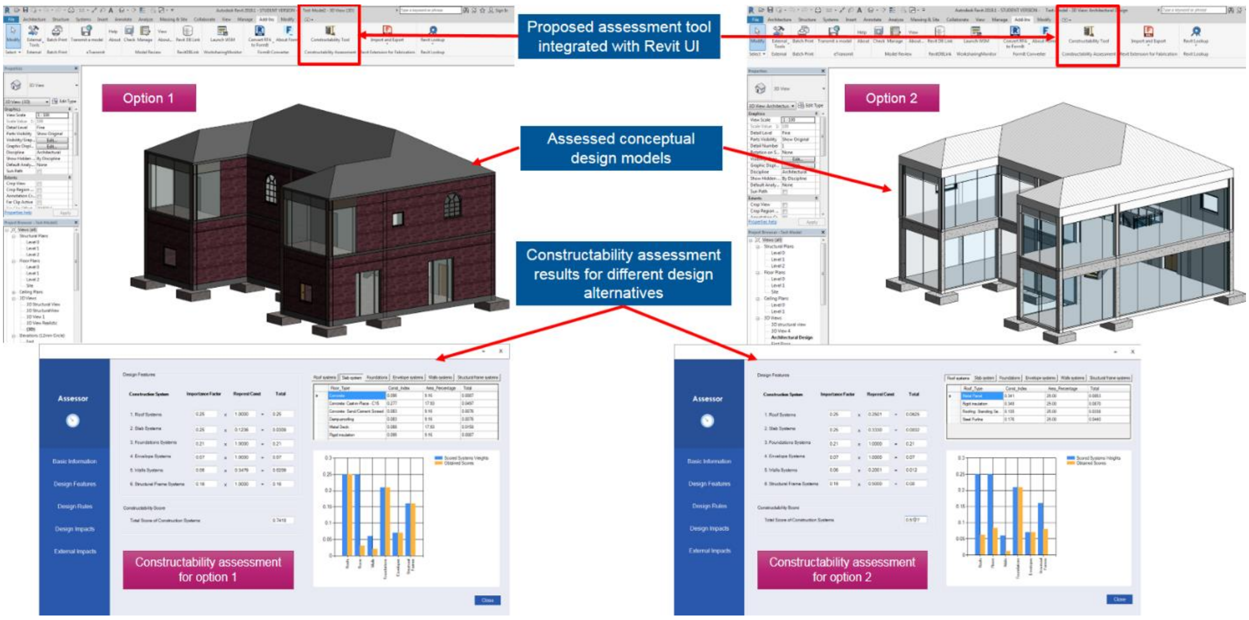

Figure 7: Constructability Assessment Outcomes of Design Alternatives

6 Conclusion

Despite awareness of the potential benefits of designing for constructability, it remains very challenging to devise tools that can implement the concept. The use of new technology-based tools to assess the constructability of designs has not been fully realized. The challenge now is how to build a tool that assesses design constructability and quantifies its abstract nature while making use of current information technologies such as BIM.

Based on the reviewed current conventional methods for assessing design constructability, the paper has identified the shortcomings of current assessment systems and challenges to be addressed in this area. Consequently, it defined a set of modelling requirements that should characterize an ideal constructability tool, characterised by being generic, scalable, flexible, comprehensive, simple, accurate and effective in the assessment process.

It then proposed a model-based approach to quantify the constructability of design. The potential of the model stems from its employment of the latest design techniques and contemporary information modelling technology, which facilitates its integration with current design tools. The proposed modelling framework consists of four parts: the conceptual design model, the constructability assessment model, the assessment process and the decision-making phase. The proposed model and its components are described, and its implementation using the BIM concept is explained. It satisfies the modelling requirements for potential assessment tool defined from evaluating current ones. The proposed system is a major step towards design automation, whereby a design can be automatically examined and the outcome used to improve its constructability.

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