Comparing the Design Alternatives Using Building Information Model (BIM) and Constructability in Iraqi Construction Projects

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Abstract. The Iraqi construction industry suffers from many issues that lead to many design errors, clashes, delays and cost overruns. Therefore, applying constructability will prevent these issues from happening, as it has proven its positive effect in different projects around the world. The goal of this paper is to use building information modelling (BIM) to assess the constructability, provide the opportunities for the project stakeholders to choose the best constructable design alternative and find the affection of applying constructability on project cost. The practical side of this research consists of two parts: in the first part, 37 factors are collected from the literature review as factors that effect on constructability. After that, a survey occurs in two sessions an open and closed questionnaire. The results were analyzed, and their mean, standard deviation, Cronbach's Alpha and developed weight will be found. The second part clears the method of linking these factors with BIM in order to assess the constructability in two different designs' projects and find their cost. The method applies through a case study of an educational building located in Baghdad, Iraq; Rivet and Microsoft Excel programs are used in this paper. the result approves the success of using BIM technology to assess the constructability of a project in Iraq. Also, it shows how project cost will be affected when applying constructability factors.

Keywords: Constructability; constructability factors; design alternative; BIM; Iraq.

1. INTRODUCTION

The Iraqi construction industry like many other construction industries around the world suffers from many issues that lead to different problems to the construction project. The main cause of these issues is lacking connection between the designer and the contractor [1]. The traditional construction system is divided into two main disciplines, design and construction, the little communication between designers and contractors before the start of construction, will make the construction a dynamic, complex, and fragmented process [2]. The project may include a multiple contracts system which means increasing the number of participants, which may cause more management issues and lead to money loss. Therefore, this emanates the need for the introduction of constructability in the construction industry as more management is required to achieve project objectives and maximize its efficiency by including all experience and construction knowledge in the early phases of engineering, planning, procurement, and field operations [3]. Also, the difficulty in controlling project time and budget [3,5], the increment in change orders, clashes between building components and redesign in projects [6]. According to [7,3] there are three main ways to assess, improve and develop constructability which are: constructability program implementation, review of constructability, and quantified assessment of the design. However, because the quantified assessment of design gave comparable results in evaluating the objective of constructability attributes, and because it depended on the completed design product instead of assessing the design practice, therefore it was more sensible, controllable, and practicable [3].

Different researchers started to study the concept of constructability [8] studied constructability the concept in Taiwan, while [9] studied it in South Africa and [10], made a study in Saudi Arabia, etc. There were several benefits of using BIM in the construction industry, BIM could be extended into the management and operation of structures after their construction by using the available data from the model that is accessed to the program by owners; this would help property managers, governments and municipalities make informed decisions; BIM provides many forms of information that help to make design decisions, providing construction documents with high-quality cost estimating, building performance prediction, and construction planning [2,10]. Also, it provided the ability to build the whole structure virtually before the beginning of its physical construction. Therefore, BIM increased the accuracy level and reduced many quality and quantity issues compared with traditional design and documentation methods [3,11, 13]. BIM is a collaborative practice that makes different integration participants (engineers, architects, real estate developers, manufacturers, contractors…etc.) achieve a better plan, design and build a structure through one 3D model [4,14]. The constructability concept in building projects had been an object of research since 1970 in the United States and the United Kingdom, it was used for the first time in the construction industry in the U.S. [15]. In 1986 it was defined for the first time by the Construction Industry Institute CII as utilization of construction expertise throughout all phases of a project, from conception to completion [3,7,9,10,16].

BIM has many applications in the industry and academe sectors. In 2006 a discussion was made on the integration of BIM design and software and engineering information. The American Society of Civil Engineers (ASCE) mentioned that according to [7] in 2009, BIM was presented as a method to assess the application

level of constructability in construction design. It separated widely and became a trend because BIM had the same objectives of constructability (time, cost, and quality) [7]. It was a powerful and effective tool for assessing constructability before project execution, so building errors and reworks were avoided [8]. Constructability aims to improve structure quality, performance, and productivity. BIM would achieve constructability objects through practicing execution and making any adjustments to the design to solve any clashes before it actualized through the virtual nature that BIM model provided and as mentioned previously [7,8,11,17]. It allowed the early involvement of the contractors with the designers [11]. Also, BIM helped to enhance communication between different parties and sharing knowledge and experience in construction to reduce difficulties in the construction phase [7,8]. Finally, BIM offers a comprehensive 3D database that is utilized to estimate, schedule, detail, improve bill production, shop drawing automatically, and plan for all construction trades [2,8]. The research objectives are finding new method to assess constructability by using BIM and show constructability affection on project cost.

2. METHODOLOGY

The main aims of this research were to find a way to assess the constructability of construction projects and choose the best design alternative. In addition, reduce and control many problems that company projects during different stages in its life cycle. The research methodology consists of two parts: filed survey and BIM application to assess the constructability as follows:

2.1 First Part (Felid Survey)

The purpose of this survey was to define the factors that effect on constructability in Iraq. This part was consisted from three sections which were: data collection, open questionaries and close questionaries. After that the selected factors were analyzed. The data was collected from previous studies from deferent resources such as books, articles, journals and website. Thirty-seven collected factors were presented on sixteen experts in variety specialization from five different Iraqis' ministries and institutes. Only, thirty-one factor were chosen from the Thirty-seven defined factors. They were classified into categories, sub-categories and factors, the main categories were: design attributes, construction attributes and external impacts. After that, the closed questionaries occurred, it was created by google form and consisted from five sections and nineteen questions, for rating the data 5-point Likert scale was used, it was sent to variety of experts and specialists through emails and different social media programs. The results of this questionaries were analyzed by using SPSS program and simple mathematical equations [18]. the arithmetic mean, standard deviation, Cronbach's Alpha, relative weight and the decomposed weight for the data were calculated. The total Cronbach's Alpha value for the responses was very good and it equal to (0.963). From the analysis results, it was cleared that the main category design attributes and its factors had the highest effect on constructability. In addition, the factors of this category would be adopted to feed BIM model. Table 1 present data classification and the value of the relative weight and decomposed weight for each factor in the category design attributes.

Table 1: The classification and the value of the relative weight and the decomposed weight for each factor in the category design attributes.

Main categories	Relative Weight	Sub-category	Relative Weight	Factors	Relative Weight	Decomposed weight
Design attributes	0.370	Standardization and repetition	0.317	Prefabrication	0.338	0.040
				Grid layout	0.343	0.040
				Standard dimensions	0.319	0.037
		Economic	0.356	Resources availability	0.203	0.027
				Special skilled labors	0.208	0.027
				Application of Advance Information Technology	0.185	0.024
				Coordination or communication	0.201	0.026
				Simplification of Design	0.203	0.027
		Structure system	0.327	Structural frames types	1	0.120768

2.2 Second Part (BIM Application to Assess the Constructability)

The implementation of BIM in projects have many benefits that could help to prevent many design and other errors which in turn causes different problems to the project. In addition, the nature of functions and features that BIM owns are suitable to assess constructability in quantifiably manner. The softwares that have been used are Rivet (2019) and Microsoft Excel. The steps of the methodology can be summarized as the following:

A- Convert the 2D modelling to 3D modelling.

B- Define the attributes for each factor: The data (9 factors) uploaded to the model as inputs to the program.

To clarify how each factor effect on constructability of the building's components, each factor attributes were clarified (depending on previous studies and expert opinion) as the following:

- Prefabrication: The attributes for this factor will be considered when building component manufactured offsite or preassembly when different prefabricated material or component joined together to formulate a unite.
- Grid layout: The attributes for this factor were horizontal and vertical grid layout.
- Standard dimensions: The attributes for this factor are standard components or custom-made component.
- Resources availability: This factor consists from three attributes which are material availability, equipment availability and personal availability (including skilled and unskilled laborers).
- Special skilled labors: The attribute for this factor is needed special skilled laborers or unneeded special skilled laborers.
- Application of advance information technology: the involvement of the advanced information technology has a major role in clarifying many ambiguous maters like dimensions, quantities, etc... In addition, it agrees with the concept of constructability.
- Coordination or communication: this factor considers as the key to constructability because one of the main objectives of using BIM is increasing the communication between project participants to reduce the errors that formatted from misunderstanding in addition increase the constructability.
- Simplification of Design: whenever the design is clear and simple to the project participants errors will be minimized. The features of BIM help to clear the design and vitalizes all the aspects related to the design. Which lead to enhance constructability.
- Structural frames types: the main using of structural frames types in Iraq are concrete frames and steel frames. From constructability point view, the frames with high percentage of prefabrication have more constructability (depend on expert opinion); and because steel frames sections usually are prefabricated, need less time to installation which mean less time for laborers' hiring, could be recycled. Therefore, it has high constructability, while the concrete frames usually inversely proportional with constructability.

C- Rivet's tools and processes: There are many important tools in Rivet program that will be apllied in this research, more detailed information will be mentioned in the case study.

D- Microsoft Excel: The Microsoft Excel was used in this paper as follows:

- Defining the inputs: The outputs of the 3D Rivet model are used as inputs for the Microsoft Excel program. The inputs are: the factors, the factors' attributes, the building components, the ID of each building component and the usage of the attributes in each building component.
- The usage of factors: simple mathematical calculations are used for example the average, summation and checking are used to find the usage percentage of each factor.
- Calculating the utility value: after finding the usage percentage of each factor, it will be converted to utility value depending on a scale rating as the (very bad, bad, average, good, very good) (0, 0.25, 0.5, 0.75, 1) sequentially.

E- Finding the constructability score: Simple Multi-Attribute Rating Technique (SMART) was used [2] to find the constructability score for each factor and the total constructability score for the model depending on Eq. (1) [11].

$$U = w * u \qquad (1)$$

Where U is the constructability score, w is the affection weight for the factor, and u is the utility value for the factor.

F- The same process was occurred for the second model. More Extensive explanation will be cleared in the case study. Figure 1 presents the flow chart diagram of this methodology.
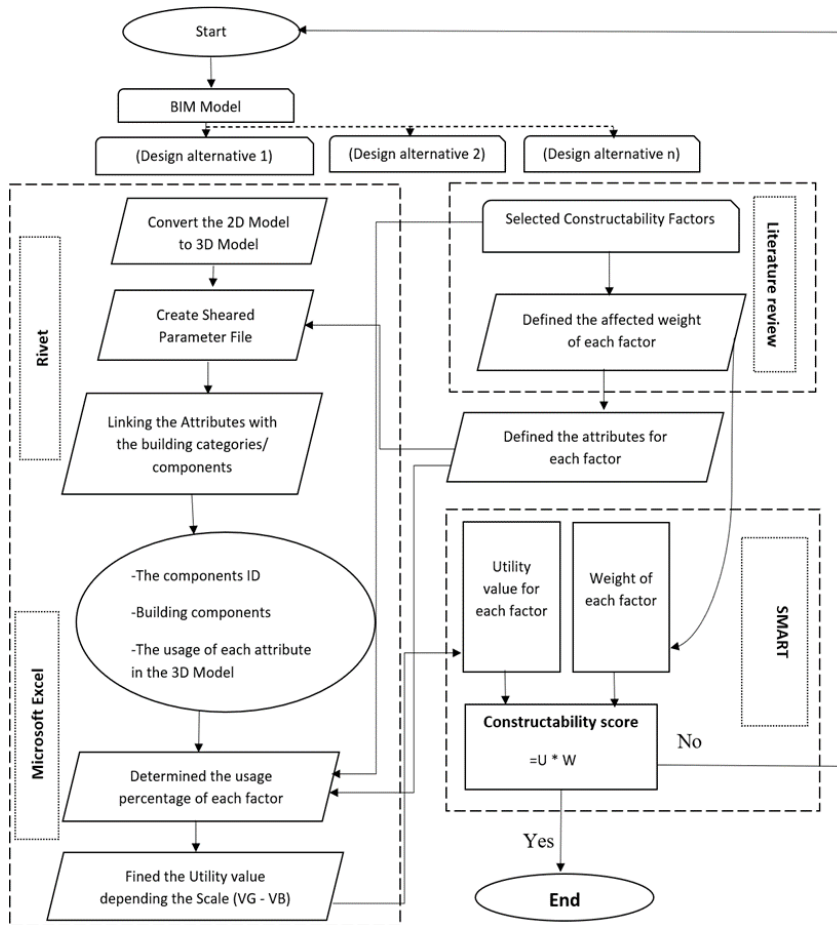
Figure 1: The methodology of the research.

3. CASE STUDY

An educational building project located in Baghdad was chosen as a case study for this research. The selected factors were divided into two groups. The factors of the first group are: advance information technology, coordination or communication and simplification of design. While, the factors of the second group are: Prefabrication, Grid layout, Standard dimensions, Resources availability, Special skilled labors and Structural frames types. This division occurred because the method of applying and relating these factors with the model were different. The factors in both groups applied on this model, however, the factors in the first group considered to be applied on the model as a result of using BIM, because the features and properties that BIM have made from it a tool to ease all designs including the complex designs, it provides a good communication space and finally it considers as a great application of advance information technology.

While, the factors in the second group applied on the model components (floor, walls, roof, columns, stair, railing, windows, doors and solar reflectors) through applying their attributes in Rivet program by using the sheared parameter as shown below:

- Create shared parameter file in Rivet program under the name constructability factors.
- Create parameter groups (each group will represent one of constructability factor) for example the first parameter group name was Resource availability and its attributes were entered to the Rivet as parameters which are (equipment availability, material availability and personal availability). Each one of these parameters had three properties which are: name, discipline and type of parameter. For example, the name of the first parameter was equipment availability, its discipline was common and type of parameter was Yes/No (the discipline and type of the parameters were the same in all attributes in this case study). Figure 2 shows the edit shear parameters window after editing and selecting the attributes. The same process will be occurred for inserting the other factors and attributes.

- After that each parameter was linked with the building component that used in. For example, when selecting the stair in the model, the properties window in Rivet program for this component will be shown in the left of the screen, it includes the division *Other* that contained all the parameters. Then all the attributes (parameter) that use in the stair were chosen which were: custom-made component (as all the stair ramps have the same dimensions), material availability, personal availability, equipment availability, concrete frame and unneeded special skilled laborers, as shown in Figure 3.

- Finally, the IDs of each building component in the model was copied and insert to the Microsoft Excel program, however, for making the calculation easier it was assumed that each family (component) had the same applied parameters would get the same ID number, and the family that its members included different applied parameters they would get more than one ID number such as columns and doors. As a result, the building components were divided to three groups which were: the first group included the following components floor, roof, walls, windows, sun reflectors, stair and railing, the second group included model's doors and the third group included the columns of the model.
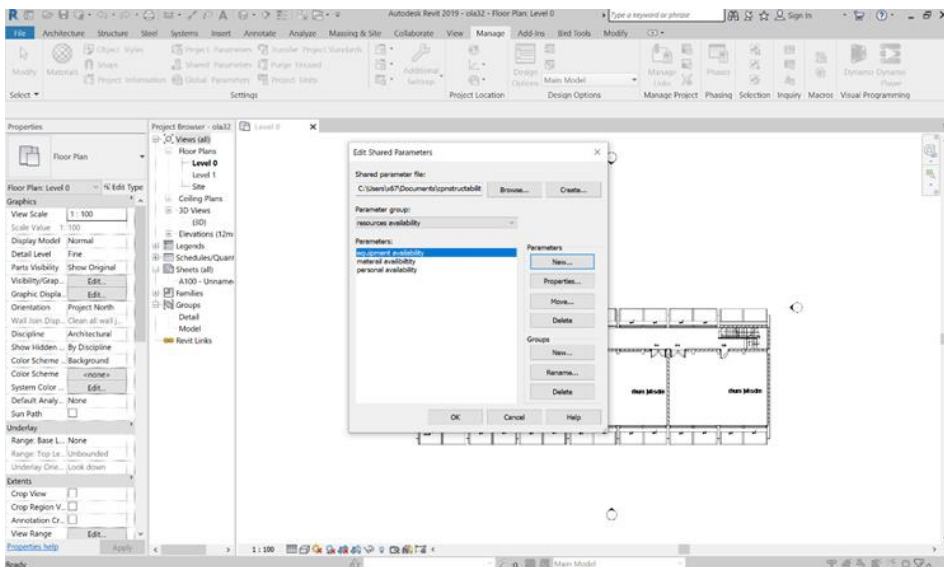
Figure 2: The edit shear parameters window after inserting the attribute.
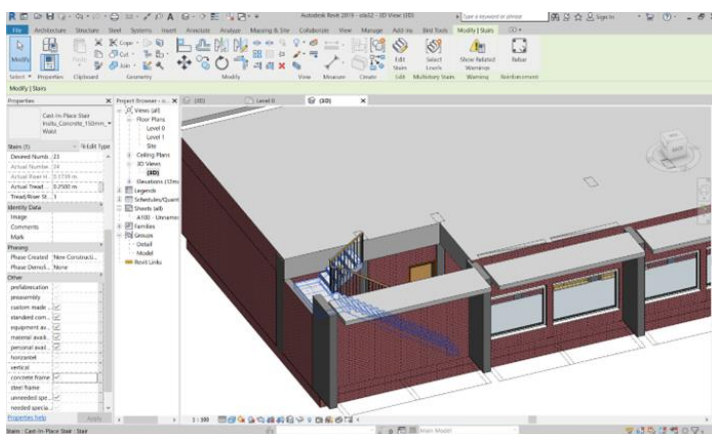
Figure 3: Linking the attributes (parameters) with the stair of the model.

The next step was transferred the outputs of rivet model to Excel program, the usability of the attributes was assumed in the program as (1) if the attribute was used (yes) and (0) if it was not used (No) and it was multiplied by the number of the components that used in. The other previous mentioned inputs were insert to the program for the three groups and the average of the usability for the attributes and the factors were found

and as presented in Figure 4. Therefore, the average factors usability was transformed to the utility value by using the utility scale (VG-VB) and considering the relationships between the factors and constructability as mentioned before. For example, the factor prefabrication got an average usability value of 52.1% which is equalized average (0.5) in the utility scale and the factor standard dimension had an average usability value of 84.1% which transforms to good (0.75) in utility scale. Finally, the total constructability score and the constructability score for each factor was calculated by multiplying its utility value with its developed weight for example the constructability score for the factor prefabrication can be found by multiplied the utility value (0.5) by its developed weight (3.96%) which is equal to (1.978%). Also, the constructability percentage of each factor's contribution to the overall score was calculated as shown in Figure 5. The assessment was applied on the design attributes of the first alternative design and the total constructability score was 21.98% from 37% which evaluated as good.

Figure 4: The Excel calculation to find the factors average usage in the model.

Figure 5: The calculations of constructability score for the first model and the contribution percentage of each factor to overall constructability score.

In order to clarify the working mechanism of constructability the second design alternative will have some design changes which assumed to be occurred on the model stairs, which are changing its type to be assembled stair, material and manufacturing to prefabrication. Then a comparison is made between the two alternative designs including cost comparison. As a result, the model inputs for the second alternative in Rivet program where different in the following aspects:
1) The stair family would be changed to assembled stair.
2) The selected attributes that have been used with this component are: prefabrication, custom-made component, personal availability, material availability, equipment availability and unneeded special skilled laborer.

According to these changes the inputs in the Excel program are updated by adding the usage of prefabrication and deleting the factor concrete frame. In addition, the attributes average usage will be changed as an increment can be noticed in the average usage of the prefabrication attribute by (0.01) and a decrement in average usage of the concrete frame by (0.333). As a result, the factors average usage will be changed too. However, when applying SMART to find the utility value for the second model. There are no changes in the value of the prefabrication, but there is an obvious change in the value of the structural frame type because the utility value is changed from (0.25) to (0.5). Therefore, the constructability score of this factor is changed

and the total constructability score for the model will be changed too. Also, the constructability score of the contribution percentage of each factor to overall constructability score is changed as noticed in Figure 6.

Figure 6: The calculations of constructability score for the second model and the contribution percentage of each factor to overall constructability score.

3.1 Comparison Between the Two Model's Results

A comparison is made between the calculated constructability score of these two models. It is obvious that the second design model gets higher total constructability score with a value equal to (24.999%). While, the first design model has lower constructability score with a value equal to (21.98%). This is due to the change that happens in the factor structure frame type, in the first design model it was concrete that executed in the site which has a negative relationship with constructability because it may involve many errors in the quantities, specifications, quality; also, waste in materials. While, in the second design model the structural frame is changed to prefabricated stair's steps that have positive relationship with constructability; because as mentioned before, the prefabricated components usually manufactured in specialized manufactures according to the specify properties, also, their installations are easier to deal with and less waste. As a result, less errors may occur in the building process in the second model. Moreover, the constructability score of the contribution percentage of each factor to overall constructability score where different too, the structural frame type contribution percentage is increased. While, the other factors are decreased which are prefabrication, standard dimensions, resource availability, special skilled laborer, repeated grid layout, application of advance information technology, coordination or communication, simplification of design. This increment or decrement is due to the increasing in the value of the total constructability score as shown in Figure 7.

Figure 7: Comparison of the constructability score between the two models.

However, the total constructability score for both designs is considered as a good percentage because their score achieved more than half of the specified constructability score for the design attributes which is (37%). Also, this compression is involved the cost calculation for both stairs, for the first model the cost of material,

needed laborer and equipment for one-meter cubic is (430,000 IQD) according to the project's bill of quantities; so, the stair cost is (1,314,427.44 IQD). While, in the second model it is assumed that it adds one unskilled laborer with cost equal to (25,000 IQD) and the cost of stair steps is (665,000 IQD). Therefore, the total cost of the stair is (690,000 IQD). As a result, the second model is more economical than the first model by (47.5%).

4. CONCLUSIONS

The Iraqi construction industry presents an obvious construction movement, therefore, the traditional methods of construction management need to be developed. The objective of this paper was to present a new method to assess constructability concepts in Iraq's projects by using BIM to select the best design alternatives .Rivet (2019) and Microsoft Excel programs were used in this paper. The assessment method was applied in the selected case study. The conclusions for this research were based on the survey and case study analysis results. They are summarized as the following:

- Applying constructability concepts and BIM features will avoid many issues that affect companies a project including design errors, redesign, clashes, frequent changes…etc. Also, constructability must be applied in the earlier stage of the project (design stage) to get the best result and the benefits that this concept provides.
- Constructability is an effective decision taking tool, because it provides the opportunity for the stakeholders to select the best constructible design alternative.
- The compression between the two designs approved that increasing the constructability score will reduce project costs by 47.5%.

In the future the Iraqi government may depend on the current proposed method for assessment in the next projects. For the future study, it may include the integration between the constructability and other management techniques.

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