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Measuring the Constructability of a Project using BIM as Data Collecting Tool

Sarah Barakat[a], Ibrahim Abdel Rasheed[b], Mohamed A. El-Mikawi[c]

a. MSc. Researcher and Demonstrator - Department of Structural Engineering – Faculty of Engineering – Ain Shams University
b. Emeritus Professor – Department of Structural Engineering – Faculty of Engineering – Ain Shams University
c. Emeritus Professor – Department of Structural Engineering – Faculty of Engineering – Ain Shams University

الملخص:

يمكن أن يؤدي النظر في مشكلات قابلية البناء في وقت مبكر من مرحلة التصميم إلى تحسين عملية البناء بشكل كبير مما يؤدي إلى تنفيذ سلس للمشروع وتوفير في الوقت والتكلفة. عادة ما تكون مشاكل البناء التي تتم مواجهتها أثناء عملية البناء نتيجة للتصميم غير المناسب. خاصة أن عملية التصميم عادة ما تكون منفصلة عن عملية البناء. يجب النظر في مبادئ قابلية البناء في وقت مبكر لتحسين قابلية البناء. في هذه الدراسة ، الهدف هو تطوير نموذج تقييم يمكن استخدامه لتقييم قابلية التصميم للبناءً على أكثر مبادئ البناء شيوعًا. يتطلب نموذج التقييم استخدام تكنولوجيا نمذجة معلومات البناء كأداة لجمع جميع بيانات المشروع. تظهر النتائج سهولة استخدام نموذج التقييم وأنه يمكن أن ينتج تقييمًا جيدًا لإمكانية بناء المشروع.

Abstract:

The consideration of constructability issues early in the design phase can significantly improve the construction process leading to smooth project delivery and savings time and cost. Constructability problems that are encountered during the construction process are usually a result of inappropriate design. Especially that the design process is usually separated from the construction process. Principles of constructability must be considered early to improve the design constructability. In this study, the aim is to develop an assessment model that can be used to evaluate the constructability of a design based on the most common constructability principles. The assessment model requires the use of BIM technology as an automated tool for collecting all the project data. Results show the ease of use of the assessment model and its ability to produce a sufficiently proper evaluation of the constructability of the project.

Keywords:

Constructability Assessment, Design Impact, BIM, Construction Management, Project Management

1. Introduction:

The Construction industry has always and still to date suffers from the lack of connection between the design phase of a project and its construction phase. More innovative designs open new challenges. Improving the Constructability concept of projects is a complex subject but worth undertaking due to the expected benefits.

Many factors impact constructability within this field. Problems regarding the constructability of a project often never receive sufficient observation until it is too late to make design changes. (Fadoul et al., 2018). The three most common approaches to improve constructability were: quantified assessment of constructability of a design, constructability review, and using a constructability program. Barriers to implementation of constructability must be identified to find strategies to overcome those barriers. Constructability barriers can be categorized as: owner barriers, designer barriers, contractor barriers, and waste management barriers (Ahmed & Othman, 2011).

The use of 3D and 4D modeling during the constructability review stage has great added value in the form of visual aspect and can be applied to a wide scope of projects (O'Brien et al., 2012). Building Information Modeling (BIM) can have a huge role in facilitating the process of early implementation of constructability process through early input into the design options which leads to improved quality of buildings and lower cost and time (Eastman et al., 2008).The American Society of Civil Engineering (ASCE) stated that BIM technology can be used to validate a new constructability tool (Gambatese et al., 2007).

This research aims to develop a user-friendly tool that can analyze extracted data that has been input in a 5D BIM model, and factors that have been incorporated to give a rating score for both constructability and cost of the project which can be used to minimize the gap between design and construction phases. The aim is to find an easy method to quantify the constructability of any project based on predefined set of criteria.

2. Benefits of measuring Constructability:

(Eldin, 1988) defined constructability as the integration of construction knowledge into all project phases as a way of reducing the project duration and costs. Assessing the constructability of a project means that experienced construction personnel should be involved from the earliest stage of the project so he can make early decisions that affect the project. This involvement improves project schedule, quality, and operability. It is much more effective that the design accommodates the constructability requirements from its preliminary stages than to try to force this concept at a later stage (Mendelsohn, 1997).

Many considerations may affect the ease of construction of a project including technical, managerial, and environmental considerations. However, the major influence is in the control of the design team. Although using a program for constructability measuring can add extra cost to the design firm, it also introduces benefits like developing better relationships between clients and contractors which improves the reputation (Arditi et al., 2002).

3. BIM and Construction:

Building Information Modeling (BIM) is defined as the application of combined information known to be well-coordinated, consistent, and computable, related to a specific project. These various forms of information have a parametric nature where they can be used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning (Krygiel & Nies, 2008).

The Virtual building gives the possibility to experiment with construction sequences and make adjustments to the project prior to the actual construction. All the aspects of the project and its mistakes can be considered and worked out before the instructions for construction are finalized.

4. Proposed Analysis:

4.1 Factors Identification:

Multiple institutes and personnel have done extensive research about the constructability and its relation to the design phase and the different factors that could be considered as a measurement for the constructability. It was established from the literature review that there are many factors that can affect the constructability of a certain construction project. These factors differ according to the assessment method whether it is quantitative or qualitative. The objective of this research is a quantitative analysis of the constructability using “BIM” as a data collection tool. And so, the factors chosen are the ones that are suitable for this data collection tool. The following are the factors to be considered:

- Prefabricated Elements
- Standard Dimension
- Resources Availability
- Construction Sequence
- Weather Effect
- Safety Measurements
- Material Accessibility
- Equipment Accessibility
- Elements Formwork
- Repetition (HZ and VL)

4.2 Data Collection:

Each factor that is to be considered has a different level of impact on constructability. This difference can be identified as relative and not an absolute fact. It can differ from one country to another depending on the construction method and personnel. In order to obtain a relative importance for each factor, a questionnaire was used to collect opinions of personnel and experts in the construction field in Egypt. The response from this questionnaire was used to calculate a relative importance value for each of the factors to be used for the purpose of this research.

The Questionnaire was designed to collect information about the opinions of different construction experienced personnel of how significant is the impact of the chosen factors on the constructability of the projects. The Questionnaire was distributed randomly among Site engineers, Construction supervisors, and Construction managers selected from Egyptian Construction Sites.

Respondents' opinions can be collected as rankings using the “Likert-type scale”. This adopted scaling method is an ordered, one-dimensional scale by which respondents choose one option that best represents their view. It gives the respondents a group of multiple-choice questions in which the answers are a scale of negative to positive views. Each Question rates the effect of one of the factors that were determined previously in this research on constructability. The scale used ranges from ‘1=lowest level of effect on constructability’ to ‘5=highest level of effect on Constructability’

Rating Scale	Very low Impact	Low Impact	Moderate Level of impact	High Impact	Very High Impact
Rating value	1	2	3	4	5

4.3 Relative Weight of Factors:

The method of RII was used in this study to calculate the Relative Importance for each of the factors that affect the constructability and to be able to compare between different ones. Relative Importance Index is a method of obtaining priority rankings of different attributes. This method is commonly used in the construction industry along with a structured questionnaire that is used to collect rankings of different respondents in the field. It is reliable and has been used in multiple researches in several topics. The formula used to obtain the RII for each attribute is as follows:

$$Rii = \frac{\sum_{i=1}^{i=5} W_i . X_i}{AN}$$

Equation 1

Where:
Wi is the weighing which respondents give to each attribute ranging from 1 to 5.
Xi is the number of respondents who gave rating Wi.
N is the total number of respondents.
A is the total number of respondents.
The RII value ranges from 0 to 1. Higher the value, more important is the factor.

The Relative Importance Index (RII) was calculated for each of the factors that were included in the questionnaire done for this research. The RII presents the most and least significant factors in construction projects. However, the RII factors cannot be used as the weights of the factors because the sum of the RIIs of the factors does not equal to one. Therefore, to calculate the weight for each factor, it's RII was divided by the total sum of the RIIs for all the factors. The total sum of the final weights will then be equal to one and so it effectively represents the importance of the factor compared to the other factors. Table 1show the calculated RII for each factor using the respondent's scoring that ranges from (1=very low impact to 5=very high impact), their ranks, and their calculated weights.

Table 1: Relative Importance Index (RII) of factors

ID	Constructability Factor	RII	Rank	Weight
F1	Prefabricated Elements	0.71489	9	0.09344
F2	Standard Dimensions	0.74894	6	0.09789
F3	Resources Availability	0.90638	1	0.11846
F4	Construction Sequence	0.87234	2	0.11402
F5	Weather Effect	0.52766	10	0.06897
F6	Safety Procedures	0.74043	7	0.09677
F7	Materials Accessibility	0.80851	4	0.10567
F8	Equipment Accessibility	0.83404	3	0.10901
F9	Formwork	0.7617	5	0.09956
F10	Repetition	0.73617	8	0.09622
			SUM OF WEIGHTS	1

5. Assessment Model Framework:

5.1 BIM Model Development:

Several approaches and techniques will be used to collect data for the different constructability factors considered in this research. One of the approaches is using the shared parameter property that is available in the Revit software which allows you to collect the data you need for each element according to what you input as a parameter.

The Shared Parameters option will be used for the data collection of factors F1, F2, F3. The data imported to the elements of the project can be exported in the form of Revit schedules. A schedule will be created for each of the categories to be included in the evaluation of this project. For factor F9, the collected data required is the area of formwork needed to cast the beams and slabs. For Factor F10, the data required will be collected through visual analysis using the full 3D model of the project. The personnel assigned to assess the constructability will have to check visually to how extent is the repetition of the elements of the project. Using the data from the tables, each of the factors can be evaluated or measured using the criteria presented in Table 2.

Table 2: Rating Criteria for data extracted from the 3D model

Factor		How to be measured	Effect
F1= Prefabricated		% of Prefabricated Components	The higher the better
F2= Standard Dimension or custom made		% of standard dimensioned Components used in the project	The higher the better
F3= Resources Availability		% of Resources Available	The higher the better
F9= Elements Formwork		Beam to Total Floor Area Ratio	The lower the better
F10= Repetition	VL	Floor to Floor repeated Columns and Walls	The more modular the better
	HZ	repeated Slabs and Beams Dimensions	The more modular the better

Traditionally, the quantitative assessment of some factors that depend on time is exceptionally difficult, given the qualitative nature of these factors. Studies have been done on introducing the idea of using visual analysis for assessing those qualitative factors (Hijazi et al. 2009). The 4D modeling using Navisworks program makes it possible to use such visual analysis techniques. Linking activity time durations to each element in the model makes it possible to virtually see the complete construction sequence of the whole project before the construction has even begun. And therefore, the visual analysis will be used to evaluate the construction sequence of the project, however, it might need an expert point of view for this step.

5.2 Constructability Assessment Tool development:

The concept of developing the assessment model is the automation of the calculation process. Since all calculation methods for the factors scores have been established, and so was the calculation of overall constructability rating score, the automation of the calculations will decrease the time required for the process. Furthermore, any engineer that is aware of the project data will be able to use this assessment platform without having to be aware of the calculation method of any of the factors. The platform contains all the calculations required to be executed in order to reach the final overall constructability score. Microsoft Access program was used to generate this assessment platform because it has customizable database applications and required visual aid that can be easy to apply and create the platform interface. In addition, Microsoft access is widely used and can be easily found on any computer.

SMART will be used in this research to be able to quantify the evaluation of the factors by transforming them into utility values. The utility factor is an indication of whether the result of the used equation or checklists is either good or bad and to what extent. shows proposed Scale #1 and Scale #2 that will be used to calculate the utility value of each factor.

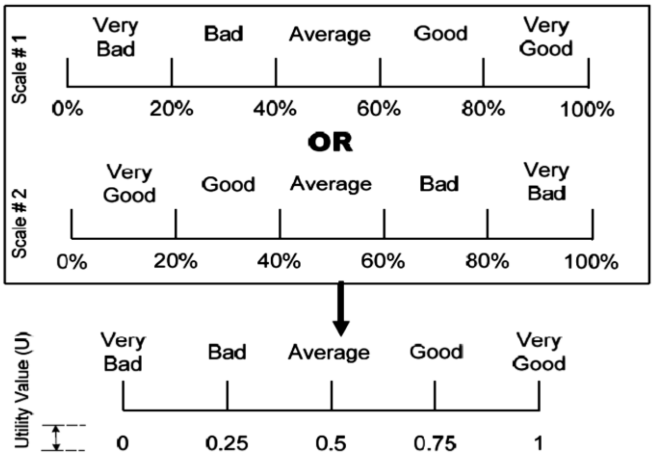

Figure 1: Proposed Scale #1 and Scale #2 (Hijazi, 2009)

All factors now can be given an evaluation in the form of percentage number which can be transformed into a rating and a utility value. With the utility values of the factors and the RII and relative weight of each factor available, the Constructability index for each factor can be calculated. A constructability index is a number that reflects the impact value of a specific factor on the overall constructability assessment score. The Constructability index for each factor can be calculated using Equation 2.

$$C_i = W * U$$

Equation 2

Where:

Ci = the Constructability index for each factor.

W = The Relative Weight of the factor.

U = The Utility value of the factor

While the total constructability score of the whole project can be calculated by summing up the constructability index of all the factors as shown inEquation 3.

$$C_t = \sum_{f=1}^{f=10} W_f * U_f$$

Equation 3

Where:
Ct = The total Constructability score
F = constructability factor
Wf = the Relative Weight of each factor
Uf = The Utility value of each factor

6. Case Study and Results:

As proof of concept, the developed platform previously discussed was tested using a case study. The construction of a commercial building located in the 6th of October City; Egypt was used for the case study. It is fully constructed and considered one of the best commercial projects in the Giza city. The provided plans were in the form of 2D AutoCAD drawings which were used to develop the BIM model. The Revit model contains all structural elements except for the foundation which will not be included in the study due to the situation that the foundation is common between this building and another one. It also contains architectural elements but not the interior design of the building. MEP components will not be included in this study due to its complexity. Components that are included in the model and study can be classified as Structural Columns and Walls, Structural Beams, Structural Slabs, Curtain Walls, Architectural interior walls, Parapets, Doors, and Windows. Navisworks program was used to link the time schedule duration to the BIM model elements. Each element was attached to its respective activity in the time schedule in the Microsoft Excel file. The software can then automatically generate the 4D simulation of the construction of the project.

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Based on Scale #1 for factors F1,F2,F3,F4,F6,F7,F8,F10

Evaluation Value	Rating	Utility Value (U)
0% < Value < 20%	Very Bad	0
20% < Value < 40%	Bad	0.25
40% < Value < 60%	Moderate	0.5
60% < Value < 80%	Good	0.75
80% < Value < 100%	Very Good	1

Based on Scale #2 for factors F5,F9

Evaluation Value	Rating	Utility Value (U)
0% < Value < 20%	Very Good	1
20% < Value < 40%	Good	0.75
40% < Value < 60%	Moderate	0.5
60% < Value < 80%	Bad	0.25
80% < Value < 100%	Very Bad	0

Factors Utility Value

Factor	Rating			Utility Value (U)
F1= Prefabricated	20.40	%	Bad	0.25
F2= Standard Dimension or custom made	61.71	%	Good	0.75
F3= Resources Availability	100.00	%	Very Good	1
F4= Construction Sequence	90	%	Very Good	1
F5= Weather Effect	22.93	%	Good	0.75
F6= Safety Procedures	60.00	%	Moderate	0.5
F7= Material Accessibility	100	%	Very Good	1
F8= Equipment Accessibility	30	%	Bad	0.25
F9= Elements Formwork	7.94945	%	Very Good	1
F10= Vertical Repetition	90	%	Very Good	1
F10= Horizontal Repetition	90	%	Very Good	1

Figure 2: Assessment model Result (1): Factors Utility Values

The final results obtained from the model consists of 2 tables. Figure 2 shows the first results table. This table presents the evaluation percentage for each factor along with its corresponding rating and Utility value. The determination of the rating and utility value is performed according to the two scales previously discussed. Each rating is given a color for better visual perception. The results from the case study show that the factor F1 (prefabricated) evaluation was calculated to be 20.40% which falls in the rating category (Bad) and utility value of (0.25) because as the prefabrication percentage increases in the project, the more positive impact it has on constructability. Therefore, this percentage is very low and that's why it is given a rating (Bad) according to Scale #1. An example of the factors that were evaluated using Scale #2 is factor F9 (Elements Formwork) which is due to the fact that the lesser area of formwork required for beams the better impact it has on constructability. Results indicate the majority of the factors fall into the category (very good) which will drastically improve the overall constructability evaluation of the project.

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Factor	Utility Value (U)	Relative Weight	Constructability Index
F1= Prefabricated	0.25	0.09344	0.023360
F2= Standard Dimension or custom made	0.75	0.09789	0.073418
F3= Resources Availability	1	0.11846	0.118460
F4= Construction Sequence	1	0.11402	0.114020
F5= Weather Effect	0.75	0.06897	0.051728
F6= Safety Procedures	0.5	0.09677	0.048385
F7= Material Accessibility	1	0.10567	0.105670
F8= Equipment Accessibility	0.25	0.10901	0.027253
F9= Elements Formwork	1	0.09956	0.099560
F10= Vertical Repetition	1	0.04811	0.048110
F10= Horizontal Repetition	1	0.04811	0.048110
Constructability Score =			**0.758073**

Constructability Assessment By: Eng. Sarah Waleed

Figure 3: Assessment model Result (2): Evaluation for Constructability

Figure 3 displays another result table that can be obtained from the assessment model. This table shows the utility value of each factor along with its relative weight. For example, Factor F2 (Standard dimension) was calculated to have a utility value of 0.75 which is good but it might not have a very high relative weight throughout the whole factors. Therefore, it might not affect the project constructability as drastically as another factor with similar utility value but higher relative weight. The last data that can be obtained from this table is the summation of the constructability index which corresponds to the final (Constructability Score). The final Constructability Score is the most important data because it is the actual objective of this research which is to obtain a number that reflects how good is the constructability of the project. For this case study, the final constructability score was calculated to be (0.758) which falls into the category (Good) based on the SMART Scale. This number means that the constructability of the project currently is good but it can be further enhanced. The final score can be enhanced through investigation and modification of the factors that were found to have a low constructability index and high relative weight.

7. Conclusion:

The main contribution of this research is in using BIM technology as a data collecting platform to be used to assess the constructability aspects of projects. This research also proposed an assessment model to quantify the constructability of a project during the design phase. A user interface created by Microsoft Access to analyze all the data collected in the BIM model using queries and checklists to obtain a Constructability score for the project. This user interface was created specifically for the purpose of this research to act as a tool that will facilitate the quantifying process for the constructability of any project. The model was verified through testing a reinforced concrete commercial construction project in Egypt. The results show that it is user friendly and useful as a tool for measuring and evaluating the constructability of a project. The process can be repeated several times by reviewing and modifying the factors that negatively affected the final score to reach the targeted constructability score base on the situation of each individual project.

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