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Comparing Between BIM and CAD Technologies Regarding Project Man Hours

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Abstract:
BIM is defined as the process of design, construction and use of the building or facility infrastructure using information about virtual objects[1].
Previous studies concluded that BIM implementation resulted in increasing the design cost by 6.5%,11% and 17% for Schematic Design phase, Design Development phase, and Construction Documentation phase, respectively. However, there is still a need to compare between BIM and CAD technologies relative to budgeted and actual man-hours.
The objective of this paper is to compare between BIM and CAD technologies in different kinds of projects, relative to budgeted and actual man-hours.
Another objective of this paper is to estimate man-hours for BIM based projects. The significance of this paper is the value of the comparison and its reflection in estimating man-hours with an acceptable accuracy based on data collected from BIM projects, which affects the bidding process.
Key Word*:BIM, CAD, design man-hours****.***

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I. Introduction

BIM became very popular in the construction industry during the last ten years. Its roots, however, goes back to the late twentieth century. While the idea of BIM existed, there were severe constraints and limitations to develop the idea into a mature concept. By this time, the development of the construction industry was focused on these limitations. With the computer's computational power, as well as graphical abilities, several breakthroughs in the last quarter of the twentieth century enhanced the CAD market.

In the 1950's, Hanratty developed the first Computer-Aided Design (CAD) program, a numerical software developed in Pronto, Hanratty is considered to be the father of CAD technology [2]. The first CAD software is introduced in 1963 by Ivan Sutherland called Sketchpad.

First generation CAD software systems were 2D drafting applications intended to automate repetitive drafting tasks. During the 1970's the transformation from 2D to 3D began, then one of the first books marketing CAD for architects appeared by William J. Mitchell. A French Aerospace company developed a program called CATIA® which was one of the leading CAD software programs [3].

In the 1990's, Autodesk released more refined versions of AutoCAD® that were initially developed in the 1980's, the new versions of AutoCAD® allowed 3D solid modeling functions which made AutoCAD® widely spread with competition from packages like Bentley's MicroStation® [4].

In the early 2000's, the term Building Information Modeling (BIM) became popular as described by Autodesk in a paper titled "Building Information Modeling" [5]. Over the course of BIM history, BIM has been closely linked to the evolution and enhancement of CAD technology. The truly significant breakthrough happened when CAD technology was developed into the BIM concept, having the same capabilities of 3D CAD, but also have features that allow modeling of complex shapes and surfaces.

4D modeling was introduced later, which allowed simulating the construction process to avoid conflicts during construction and incorporating time as a dimension. Afterwards, 5D and 6D were introduced to extract accurate cost information in 5D BIM to support facilities management and operation in 6D BIM [6].
BIM also created the idea of Level Of Development (LOD), throughout the project cycle, classified according to the American Institute of Architects (AIA) into LOD 100, 200, 300, 400 and 500 as indicated in Figure (1).

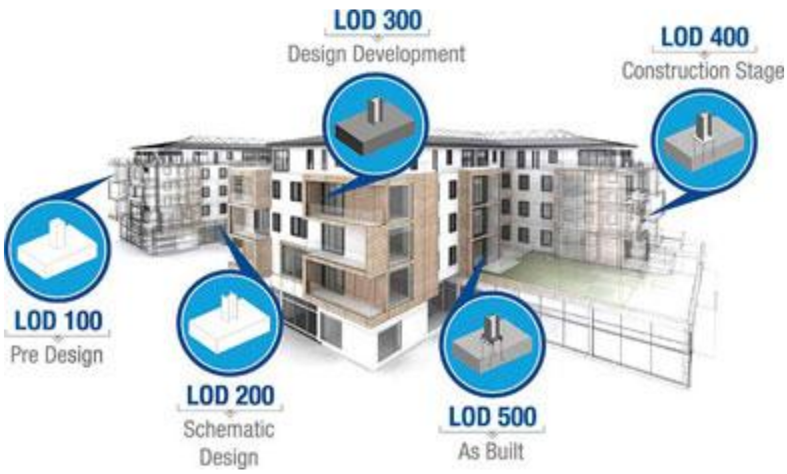

Figure (1): Level of Development during project lifecycle

Utilizing BIM results in better collaboration and communication. Improved information consistency resulted in fewer errors, an improved coordination process, geometrical precision, fewer claims and litigations and less time of documentation needed. Quality can be controlled much better by using BIM processes, one of the most important quality controlling benefits of BIM is the use of clash, conflict, and collision detection [7]. However, as mentioned before, BIM implementation costs more than traditional methods like CAD.

The main objective of this research is to develop a model to estimate the man-hours required for a BIM project. One benefit of this comparison is to determine the accuracy level of different types of projects when estimating the budgeted man-hours.

Research data belong to 40 construction projects ranging from 500 m^2 up to 200,000 m^2 in built-up area. Collected data are used to estimate man-hours for BIM projects based on the average floor built-up area.

Research Methodology

1- Review the past literature regarding BIM projects and man-hours estimates for projects.
2- Collect data regarding projects man-hours.
3- Compare between CAD and BIM with regard to man-hours.
4- Develop a model for estimating man-hours for BIM projects.
5- Validation of the model.

II. Research Background

Even though BIM was introduced since long ago, the construction industry lacks a framework to accurately estimate the cost of BIM services implementation during the design stage.

Barlish and Sullivan[8], studied the effect of BIM implementation through a case study, and by developing a model to analyze the outcome from implementing BIM in projects, the research compared BIM approach to traditional or non-BIM approaches. It was concluded in this study that there was a saving of 42% of standard costs, 50% decreased RFI's compared to the standard approach.

Fanning[9], conducted a comparative study of the impacts and benefits associated with using building information modeling (BIM) on accelerated bridge construction in the Denver metropolitan area. The results of the study suggested that the first implementation of BIM resulted in significant costs. The study showed that BIM may have provided approximately 5% cost savings during construction by contributing to reduced change orders and rework.

Koo, Shin, and Lee [10], introduced a framework that estimate the additional costs incurred for providing BIM related services in the design phases of a project. The framework also estimates man-hours for non-standard work items as a proportion to the standard work item.

Jin, et al[11], studied BIM application and risk in China using a questionnaire survey. The findings from this empirical study provided an overview of BIM investment, return, and implementation-related risks for Architecture, Engineering and Construction (AEC) professionals.

The study recommended that future BIM related studies consider different AEC fields as BIM, by its nature, aims to enhance cross-disciplinary collaboration and communication.

III. Data Collection and Analysis

The available data was collected from a reputable consultancy firm, having more than 50 years of experience in the field of architecture and landscape, structure and civil, electromechanical and environmental engineering. The collected date is the structural department data for 40 projects in the last 10 years as listed in Table (1), the frequency of building types is listed in Table (2).
The data listed in Table (1) consists of 40 projects, 20 of the projects were done using CAD, the other 20 used BIM. Numbering of the projects is done according to the letter "C" which is used for CAD projects, and the letter "B" which is used for BIM projects. It is worth mentioning that LOD for BIM projects is LOD 300, as shown in Figure (1).

The area used is the average floor built-up area for each building, the varies from 200 m2 up to 180,000 m2, the table also indicates the usage of the buildings, duration, actual and budgeted man-hours.

Project Code	Usage	Duration (months)	Bgt man.hr (hours)	Act man.hr (hours)	Area (m^2)	Type
B1	Commercial	16	3715	4183	36000	BIM
B2	Residential	21	2280	4950	5000	BIM
B3	Residential	12	1640	5100	4350	BIM
B4	Residential	10	457	396	500	BIM
B5	Commercial	7	2100	2550	22000	BIM
B6	Commercial	8	1570	2940	15000	BIM
B7	Residential	10	7830	7660	8500	BIM
B8	Residential	8	230	620	450	BIM
B9	Residential	5	2500	2780	2650	BIM
B10	Residential	6	1500	1350	1200	BIM
B11	Commercial	12	5400	6000	60000	BIM
B12	Commercial	12	5000	4850	55000	BIM
B13	Commercial	14	6500	7650	75000	BIM
B14	Residential	5	3250	2500	2400	BIM
B15	Commercial	6	2000	2050	15000	BIM
B16	Residential	6	2800	3950	3250	BIM
B17	Residential	8	3000	3150	25000	BIM
B18	Commercial	10	4800	5000	40000	BIM
B19	Commercial	12	5500	4550	35000	BIM
B20	Residential	10	6550	8500	7500	BIM
C1	Administrative	5	990	2890	3000	CAD
C2	Educational	20	31840	16000	180000	CAD
C3	Industrial	8	400	100	1500	CAD
C4	Residential	16	2790	4050	6000	CAD
C5	Administrative	3	412	438	1500	CAD
C6	Residential	7	430	825	1200	CAD
C7	Educational	5	1800	360	1400	CAD
C8	Residential	3	150	40	200	CAD
C9	Industrial	11	1600	1420	4000	CAD
C10	Commercial	3	195	135	700	CAD
C11	Medical	3	260	45	400	CAD
C12	Industrial	2	390	377	2200	CAD
C13	Administrative	10	1650	2170	8000	CAD
C14	Administrative	16	5680	6100	30000	CAD
C15	Commercial	3	2160	5100	25000	CAD
C16	Medical	6	1720	1610	5000	CAD
C17	Commercial	7	11400	7500	35000	CAD
C18	Administrative	6	9900	10650	38000	CAD
C19	Commercial	9	7200	5711	30000	CAD
C20	Commercial	3	2750	3500	20000	CAD

Table (1):List of projects

The budgeted man hours (Bgt man.hr) is defined as the number of hours required to finish the project calculated by the estimating engineer at the proposal stage, while the actual man hours (Act man.hr) is defined as the hours that the project consumed through the duration of the project.

Table (2): Frequency of Project types

Type	No	Percentage	Gross Floor Area	Actual Man Hours	Actual Man Hr/m2	Budget Man Hours	Budget Man Hr/m2
Commercial	14	35.0	463700	61719	0.1331	60290	0.1300
Administrative	5	12.5	80500	22248	0.2764	18632	0.2314
Educational	2	5.0	181400	16360	0.0902	33640	0.1854
Residential	14	35.0	68200	45871	0.6726	35407	0.5191
Industrial	3	7.5	7700	1897	0.2463	2390	0.3104
Medical	2	5.0	5400	1655	0.3065	1980	0.3667

As listed in Table (2), the data consists of several types of building; commercial, administrative, educational, residential, industrial and medical, and then the actual man-hours are divided by the gross floor area to obtain Act Man Hr/m2, similarly, the budgeted man-hours are divided by the gross floor area to obtain Bgt Man Hr/m2.

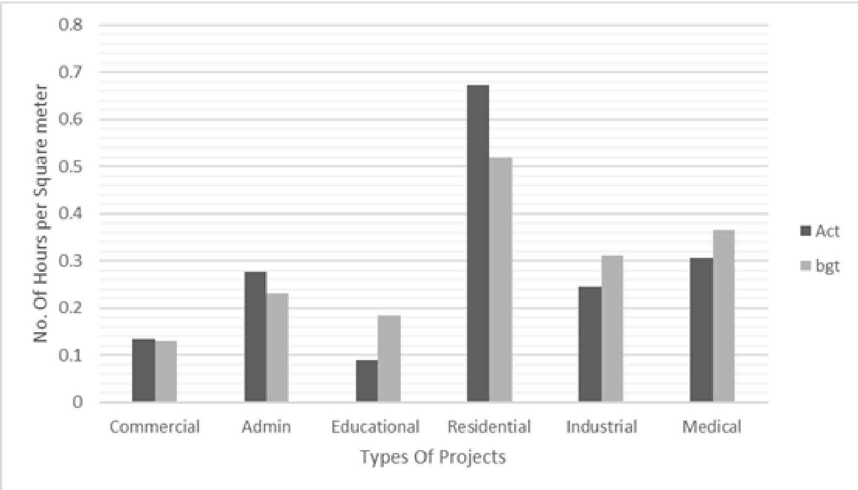

Figure (2): No. of hours per square meter for different types of projects

Actual man-hours with respect to Budgeted man-hours

This study requires the Bgt Man Hr and the Act Man Hr to compare between them in both CAD and BIM projects, so figure (3) shows the difference between budgeted and actual man-hours in different types of projects using CAD technology while figure (4) shows the difference between budgeted and actual man-hours in different types of projects using BIM technology.

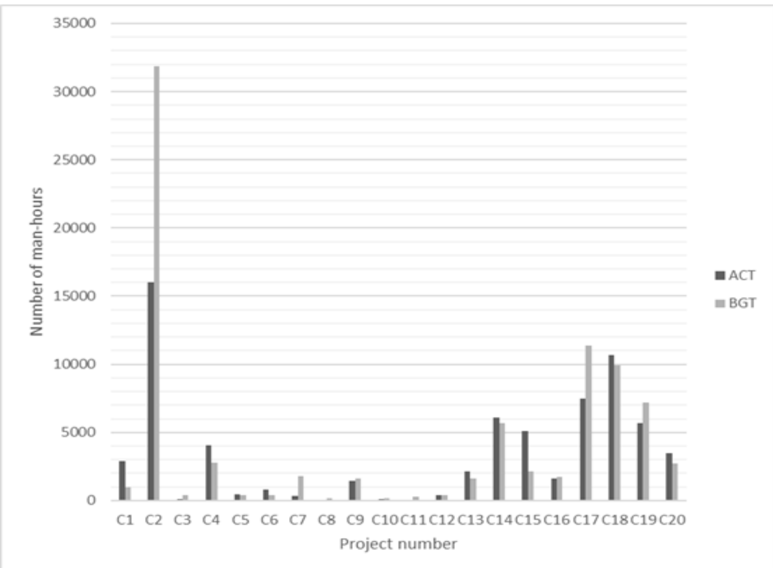

Figure (3): Number of actual man-hours with respect to budgeted man-hours in CAD projects

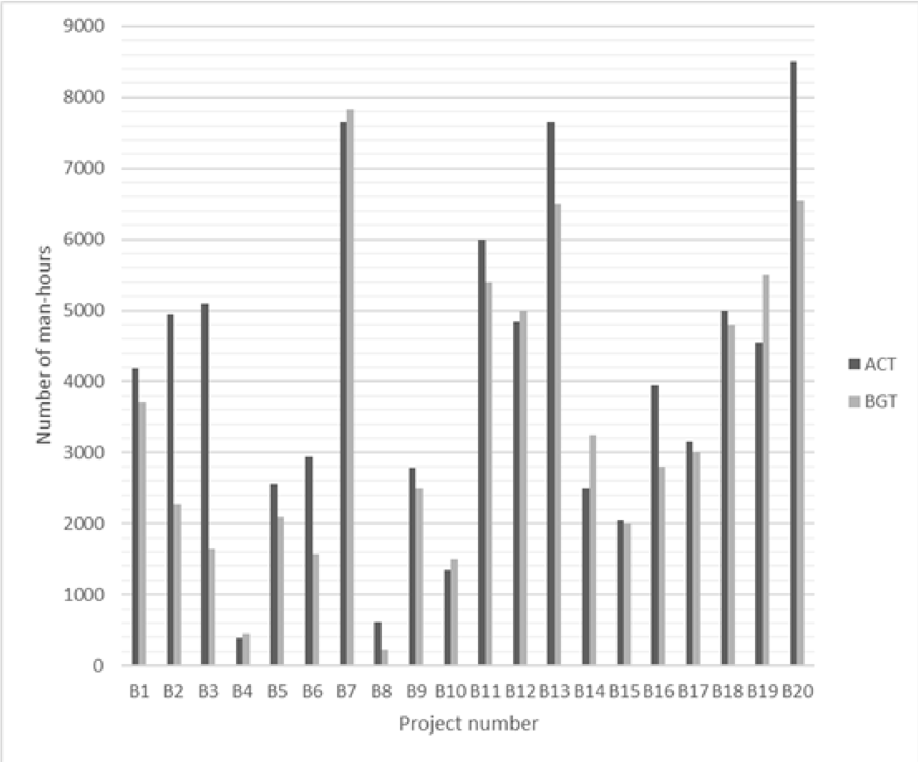

Figure (4): Number of actual man-hours with respect to budgeted man-hours in BIM projects

Model Development

Regression analysis is used in developing the model. Regression is a statistical method that allows the examination of a relationship between two or more variables of interest and is used to predict the outcome based on collected data[12] . In this study's case, the variables are man-hours and floor Area.

A simple Excel-based estimating system was implemented to estimate BIM project man-hours, based on the analysis performed on IBM SPSS Statistics 25®, entering the Man-hours as a dependent variable, and floor built-up area as an independent variable to generate customized estimates, specifically users can generate estimates for Man-hours for specific types of building types.

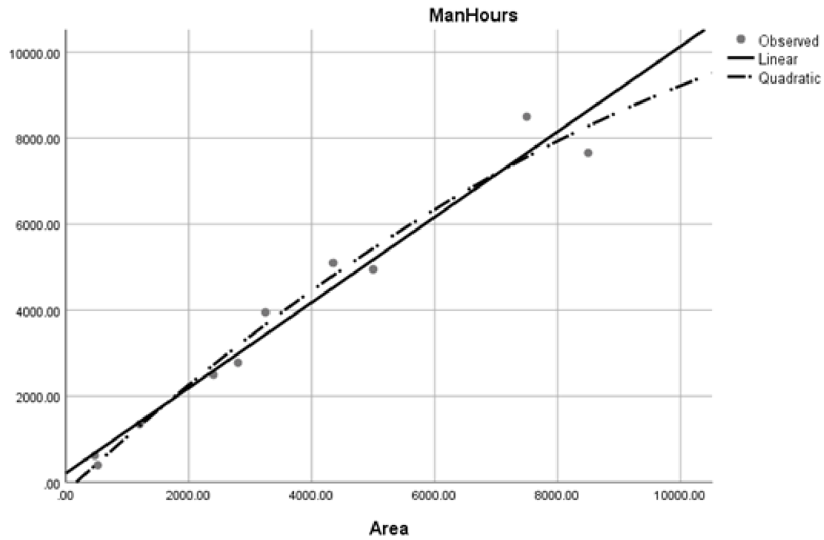

Figure (5): Relationship between project Area (m2) and Man-hours (hr) for Residential buildings type

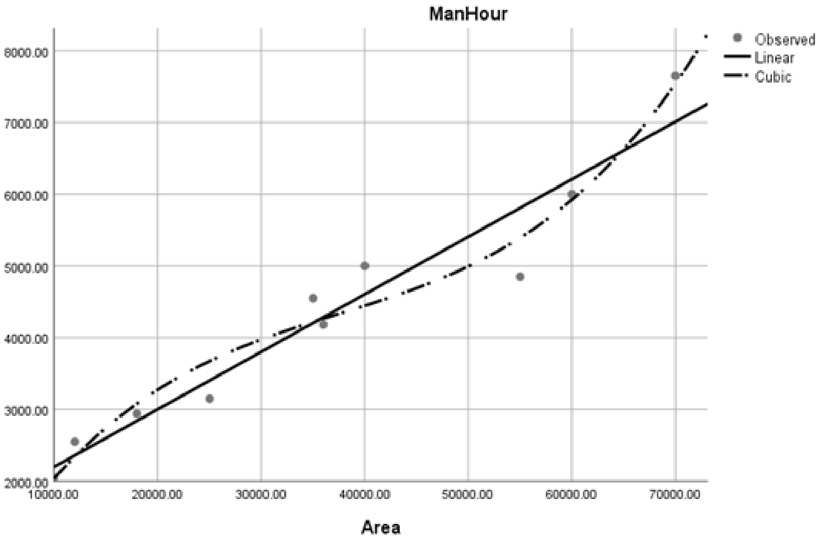

Figure (6): Relationship between project Area (m2) and Man-hours (hr) for Commercial buildings type

Relationship between Area and man-hours

As shown in figure (5) and figure (6) respectively, the analysis was done using Regression analysis, for the Residential buildings type, quadratic regression was the best fitting for the available data, while the best fitting for the Commercial buildings type was cubic regression.

As for the Residential buildings, the best R square value, which indicates how close the data are to the fitted regression curve, was found to be 0.973 from quadratic regression compared to 0.965 from linear regression, while best the R square value for Commercial buildings type was found to be 0.959 from cubic regression compared to 0.932 for linear regression.

And after selecting the best fitting curves for Residential and Commercial buildings types, parameters estimates shall be implemented in Excel to estimate the final project hours for the mentioned types of buildings as indicated in figure (7).

INPUT DATA	Type of Building	Residential
	Average Floor Area (m^2)	4000
	Level Of Detail	300

Figure (7): Excel System input data example

The user can select between Residential or Commercial building types, and the user can also choose the required LOD from LOD 100, LOD 200 and LOD 300, and shall input the average floor Area in square meters. After entering the required data, the Excel system calculates the required number of hours based on the parameters estimates obtained from regression analysis.

IV. Discussion

BIM projects

As indicated in figure (3), it's noted that 75% of all BIM projects have exceeded the budgeted man-hours, three of the projects are commercial buildings and five of the projects are residential buildings. All of the commercial projects have exceeded the budgeted man-hours while in the residential projects, about 60% exceeded the budgeted man-hours.

This may be because of the ineffective collaboration between different project participants, disciplines and software and it could be worse if the design teams were located far away from each other, that would make communication difficult and could arise server or IT problems. Also, inexperienced team member or lack of training could have the same effect as calculated man-hours required to finish the project would be consumed elsewhere in training and trails, and last but not least obstacle in BIM implementation is the lack of information about the strict BIM implementation standards and rules for certain project participants, contract obligations in certain countries or unified documentation for regions (such as European Union, Americas, Asia and other).

CAD projects

As for CAD projects, about 45% of the projects have exceeded the budgeted man-hours of which 5 of the projects are administrative buildings, 5 of the projects are commercial buildings, 3 of the projects are residential buildings, 3 of the projects are industrial buildings,2 of the projects are educational buildings and 2 of the projects are medical buildings.

All of the administrative projects have exceeded the budgeted man-hours, 40% of the commercial projects have exceeded the budgeted man-hours, 67% of the residential projects have exceeded the budgeted man-hours, while none of the industrial, educational or medical projects exceeded the budgeted man-hours as indicated in Fig (2).

It's also worth mentioning that the standard deviation of CAD projects is lower than that of the BIM projects. This may be because CAD projects are much more common than BIM projects and it would be safe to say that estimating engineers have far more experience in estimating the number of man-hours for CAD projects rather than BIM projects which are relatively new to the market.

Model Validation

As for the estimating system developed by SPSS Statistical 25 and Excel, the verification of the system was performed using two Residential projects with area of 3600 and 6500 square meters respectively with LOD 300, and actual man-hours of 4200 and 7800 man-hours respectively, the result from Excel system was 4394 and 8351 man-hours respectively, and based on the previous results, the Excel system shows difference of +4.6% and +7.0% respectively.

Similarly, two commercial projects of 24000 and 45000 square meters, having 930 and 1600 in man-hours, and LOD 100, the result from Excel system was 1001 and 1525 respectively showing difference of +7.6% and -4.7% respectively.

V. Conclusion

With the increased need for BIM adoption, AEC firms needed a system though which they can calculate the man-hours for design phases in a BIM project objectively.

This study responds to that need by providing a framework that estimates the man-hours in BIM projects for the structural discipline. The system uses data collected from 20 BIM projects to provide an average man-hour estimate for LOD 300 BIM projects.

This study incorporates average floor area into a system that enables users to generate estimates for a specific building type of which they can choose residential or commercial building types as an option, and a they can choose between different levels of details. Validation of the system showed that there was a 4.6% and +7.0% difference between the estimated and the actual man-hours for Residential buildings type, and a +7.6% and -5.0% difference between the estimated and the actual man-hours for Commercial buildings type, with a reasonable error rate considering the limited number of collected BIM projects.

The discrepancy is in large part due to the average man-hours per gross floor area that were used in the calculation, and their relationship with actual man-hours which could be dealt in follow-up research.

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