The Effect of Building Information Modeling on the Accuracy of Estimates

Khaled Nassar, Ph.D., AIA
Associate Professor, American University in Cairo

Building Information Modeling (BIM) is motivating an extraordinary shift in the way the construction industry functions. This fundamental change involves using digital modeling software to more effectively design, build and manage projects. One of the implications of using BIM is that project cost and time estimates can become more accurate and precise, by encouraging the sharing of project information throughout the project lifecycle as well as deeper collaboration between contractor and the design team to integrate valuable fabrication, construction and operations expertise into the estimate. This paper examines the effect that BIM can have on the accuracy of project estimates in terms of time and cost. An analytical approach is taken to quantify the potential increase in accuracy. The paper discusses the effect that an increase in accuracy may have on the bidding practices as well and provides numerical examples of the proposed analysis from a classroom experiment where estimated were prepared manually and with the assistance of a commercial available BIM tool.

Keywords: Building Information Modeling, Estimating, Accuracy, Precision, Construction, Bidding

Introduction

In this paper we investigate the effect of Building Information Modeling has had on the accuracy of estimates of construction cost and duration. Building Information Modeling (BIM) is not a new invention (although the term BIM was introduced fairly recently) as the same idea was pioneered by Professor Charles Eastman (currently at Georgia Tech), who actually developed the first true non-commercial BIM tool almost 3 decades ago and dubbed it the Engineering Data Model (EDM), which went through a number of iterations. BIM has been advocated by a number of academicians for almost 4 decades now since the early days of the design of Nicolas Negroponte's "Design Machine" at the MIT in the sixties. Commercially, BIM tools have been around since the late eighties and early nineties. The first two commercially available BIM tools were Nemetschek's Allplan, and Graphisoft's ArchiCAD. Only in the last decade however, have we seen the wide spread of BIM commercially as well as in academia. With the ubiquitous use of BIM, the accuracy and precision of the estimates can be potential influenced. The impact will have far reaching consequences on the practice of construction management, bidding procedures and competitiveness of the construction companies (AGC 2005, CRC 2007, Kunz & Gilligan 2007).

This paper discusses how the estimate of construction time and cost are affected by the introduction of BIM in the industry and puts forth a rigorous analysis method to set upper and lower limits on the precision estimated of quantities and production rates. In the next section, we discuss two fundamentals concepts; one is the precision versus the accuracy of the estimate and the second is the relation between the estimate and the bid. This is followed by a section which provides an introduction to measures of precision of construction estimates and then another section that provides a model on quantitative analysis of the estimate precision using BIM. Examples are provided next and then conclusions and recommendations are presented.

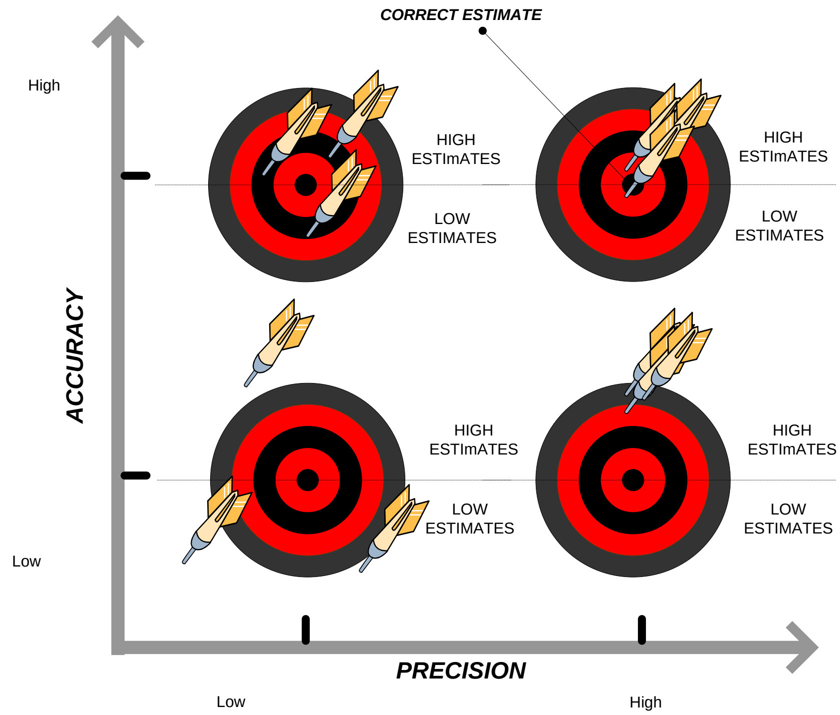

Figure 1: The four quadrants model for precision versus accuracy of construction estimates

The Accuracy and Precision of Estimates and Their Effect on Bidding

The concept of precision versus accuracy is introduced to construction students in their early surveying and estimating courses where accuracy is defined as the relationship between the value of the estimate and the "true" value of what is being estimated. An accuracy of an estimate is how far the estimated cost is from the actual cost. Precision, on the other hand, describes the degree of refinement with which the estimate is made.

We propose a 4 quadrant model to represent the effect of accuracy versus precision in construction estimates. The model is presented in figure 1 and it shows that construction estimates can vary in accuracy and precision depending on many variables including the tools used in preparing the estimate (such as BIM). Obviously the lower left quadrant is the one to be avoided while the top right is to be desired. For example, an estimate of the cost of a concrete foundation based on a historic database of productivity values can be very precise if the estimate is checked multiple times and the measurements from the drawings are also verified. However the estimate may not be accurate due to errors in the database used to compile the estimate or due to erroneous drawings in the first place. In this case BIM can increase the precision of the estimate but may not have the same impact on accuracy (Thompson 2001, Thompson &Miner 2003). As such, BIM can help in reducing *random errors* but may not be able to reduce *systematic errors.* Random errors are associated with the skill and vigilance of the estimator. Systematic errors on the other hand, are those errors where the magnitude and the algebraic sign can be determined and they are related to the quality of information entered into BIM tools such as the accuracy of the cost databases used in BIM.

Another related idea is that of bid accuracy. This is presented in figure 2. Obviously, the main aspiration in estimating is increasing the accuracy and precision of the estimate. Contractors always expect that making an estimate more precise will also render it more accurate. Although not universally true, estimates also tend to get more precise the more time and effort is put into them, i.e. where preliminary estimates are with 15% of actual cost and final estimates are at 5%. On the other hand the range of bids may be wider or narrower than the estimate accuracy and although the accuracy of bids may only be known after opening a bid, a client may get reassurance if a contractor is consistently with a certain percentage of the lowest bid. One may ask then: what is should be the target of an estimate - the low bid or the average of the bids submitted? The answer to this question will define the acceptable range of error.

The cost of preparing a bid must therefore be weighed against the expected increase in bid precision and therefore hopefully its accuracy. From the designers (architect/engineer) perspective, who has to develop a design within a certain budget, the benefits of a more accurate estimate are often not worth the cost of spending time to actually do it (even with the risk of having to redesign if the estimates are outside the budget). For the contractor on the other hand the accuracy of the estimate is crucial. Thus, the limitation has always been that the methods available at early planning stages could not distinguish accurately (or even precisely) between the alternative design schemes since only overall square footage cost is known. For the architect/engineer, and in turn the contractor, BIM has helped in three main ways; it provided an increased level of precision early on in the design stage especially with the introduction of design-build delivery methods. Secondly, it has reduced the time and cost required for estimates, thirdly, by linking cost bases it provided quick what-if alternatives to the design. This means that contractors now will become more heavily involved in the design stages (and therefore our curricula must reflect such expected changes with less focus on takeoff and more on value engineering and productivity analysis).

Thirdly, BIM has made estimating in general more sensitive to design variations in the building or project form as opposed to the traditional form-insensitive area cost estimating methods. This can be done by introducing more accurate estimating methods such as enclosure estimating methods (which is based on the breakdown of a building into its geometric envelope components, i.e. roof, exterior walls, foundation or the contract area). This increase in accuracy has to be therefore analyzed in detail, not only to assess the benefits of introducing BIM into an organization but also to be able to make better bidding and management decisions (Khemlani 2007, Rosenburg 2007). In the next section we present a rigorous analysis of the potential increase in accuracy that can be achieved by the use BIM tools.

The Accuracy of Estimates

For the sake of clarity we start by basic concepts of the accuracy of estimates then we introduce the concept of error propagation in construction estimates, where we model errors in construction estimate as an error propagation problem for two variables; the production rate and the quantity. The arithmetic mean of a set of estimate values (for the various line items in the estimate) contains some uncertainty which can be expressed as the standard error of the mean. It a well known fact in probability that the error of a sum of identical measurements is given by the error multiplied by the square root of the number of measurements and that the mean standard error is then given by that sum divided by the number of occurrences. Theoretically, $\sigma = \pm \frac{\sqrt{\sum v^2}}{n}$ in cases where n is very large, $SE = \pm \frac{\sqrt{\sum v^2}}{n-1}$. The laws of probability dictate that the error of a sum of identical measurements be given by the error multiplied by the square root of the number of measurements, $SE_{sum} = SE\sqrt{n}$. The mean is then given by the sum divided by the number of occurrences, $SE_m = \frac{SE\sqrt{n}}{n} = \frac{SE}{\sqrt{n}}$. The terms standard error, standard deviation and mean square error are all used to describe the same concept of precision. This means that the standard error of the mean is inversely proportional to the square root of the number of measurements. This in turn implies that if the measurement is repeated 4 times the standard error of the mean is cut in half. How does this relate to construction estimating using BIM? This tells us that beyond a realistic number, continued repetitions of a measurement do little to reduce the uncertainty. Because as was stated earlier, BIM reduces random errors (recall that the repetition of measurements reduces the random errors) the number of measurement estimate check to decrease the standard error is reduced.

Now, if we know the true shape of the estimate distribution we could quite precisely determine the standard error of measurement for an estimate performed using BIM. There is a disagreement however on the shape of the probability distribution of estimate errors. Some researchers argue that it is normally distributed, while others propose a Beta or a Weibull distribution. In any case, aspects about the precision of the estimate can be identified by considering the underlying distribution. For example, if we consider the error to be normally distributed, then we know certain facts about the error from the shape of the distribution itself, such as shown below.

Practical precision parameters

Error	Certainty
Probable	50%
Standard	68.27%
90% (1.6449 SE)	90%
95% (1.9599 SE)	95%

We will see in the next sections how these values can be used to assess the precision of a construction estimate prepared with a BIM tool.

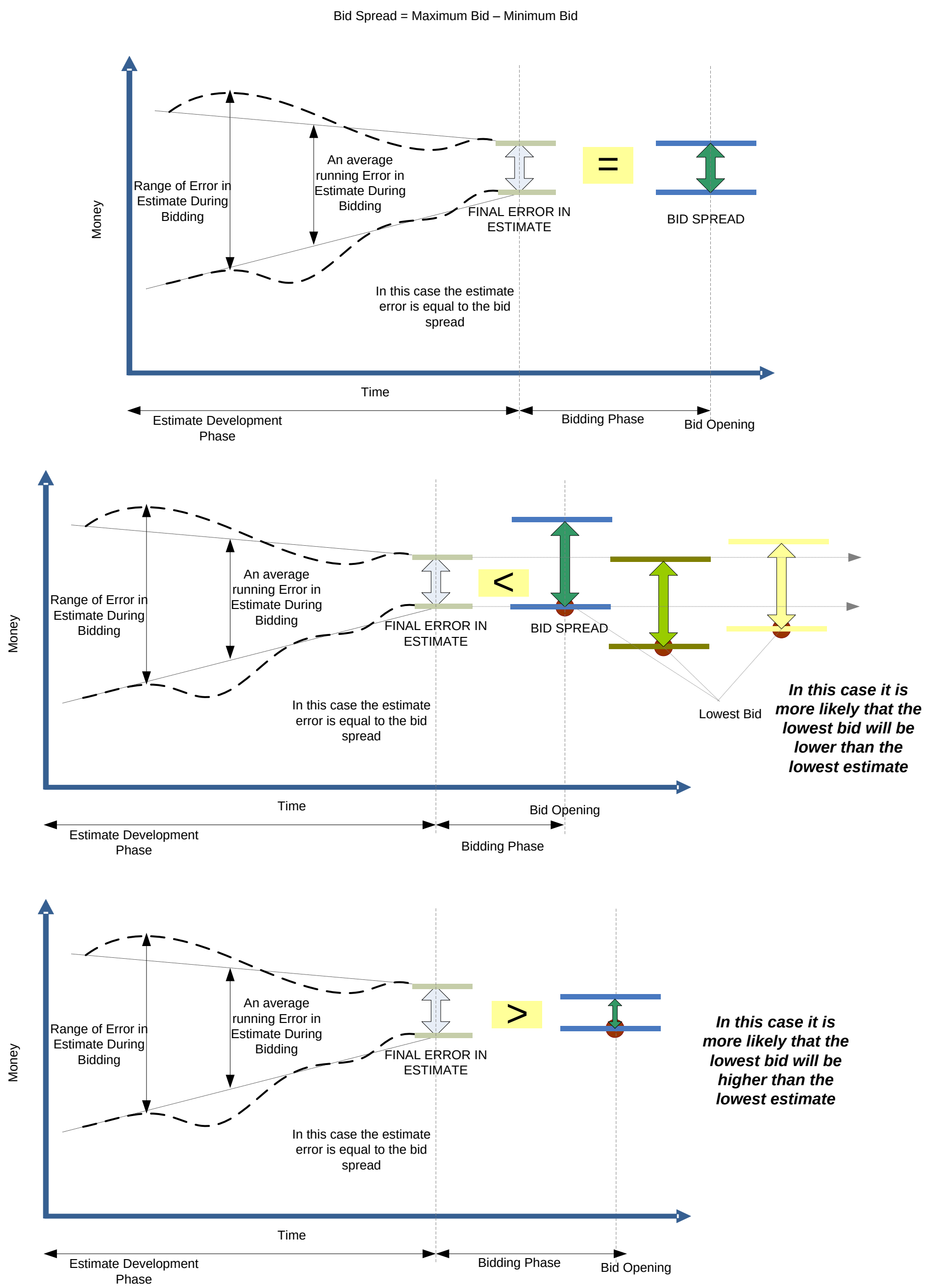

Figure 2: Bidding Accuracy versus Estimate Accuracy

Propagation of errors in Construction Estimates

Consider a case where the contractor over estimates the quantities in a project and simultaneously over estimates the productivity of his/her crew and equipment. The compiled error is not going to be simply the sum of the two error components but will actual propagate faster. Figure 3 shows the propagation of error with increased errors in productivity and quantity.

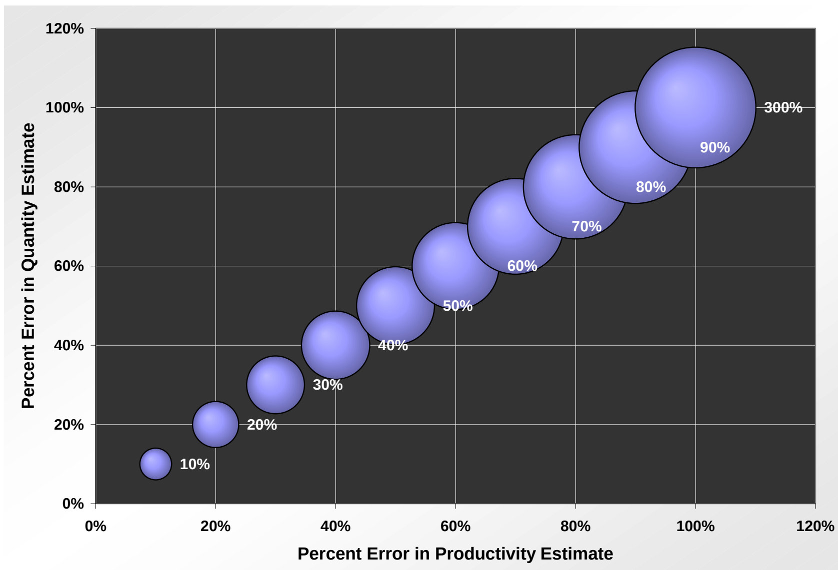

Figure 3: Propagation of error in construction estimates

In the case where the contractor makes random errors for the various line items in the estimate the standard error of a sum of varied measurements is given by,

$$SE_k = \sqrt{SE_A^2 + SE_B^2} \quad (1)$$

On the other hand if the errors are for the same line item which has been measured more than once, then the sum of identical measurements becomes,

$$SE_{sum} = \sqrt{n \times SE^2} = SE\sqrt{n} \quad (2)$$

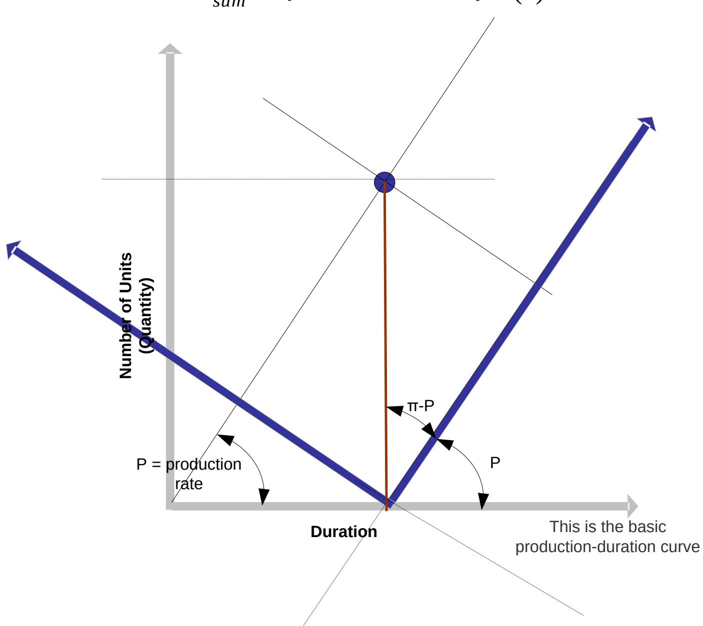

Figure 4: Sources of Error modeled as production rate and Quantity

However what is really of interest here is the standard error for *a product of measurements*, where A represents the quantity and B represents productivity. The standard error in this case is given by,

$$SE_{product} = \pm\sqrt{A^2 SE_A^2 + B^2 SE_B^2} \quad (3)$$

Equation 3 above is fundamental in understanding the accuracy of construction estimates because it shows how to calculate the error of measurement for a production of measurement. This is actually the case we are trying to assess; any construction estimate can be thought of as a product of a number of quantities and the production rate (which is determined from productivity values). Therefore there are two kinds of errors which can happen in any construction estimate; those which are related to estimating quantities and those which are related to estimating production rates (Figure 4). Note that both can have systematic and random errors, however systematic and random errors for quantity estimates can be significantly reduced when using BIM. By utilizing BIM tools we could significantly reduce systematic and random errors in estimating quantities for many reasons. This is well documented in several previous research efforts (Dean 2007, ASC 2005, Woo 2006, Thompson and Miner 2007). However, previous research efforts failed to show quantitatively how this affects the overall accuracy of the estimate, which will be discussed next.

Accuracy of Estimates with BIM

Any construction estimate can be thought of as a two-dimensional estimate; one where the estimator has to decide on the firstly the quantity of work to be carried out and secondly on the productivity of laborers and equipment that will perform the job. Therefore any error in the estimate is essentially a 2-dimensional error with two parameters that need to be analyzed. If we think of the two error components in geometric terms we will be able to define the circle of error. The error in quantity measurement is one dimension and the error in productivity can be modeled as an angular error (or vice versa as it will result in the same analysis). If both errors have equal magnitude then the area of uncertainty is a circle, Figure 5.

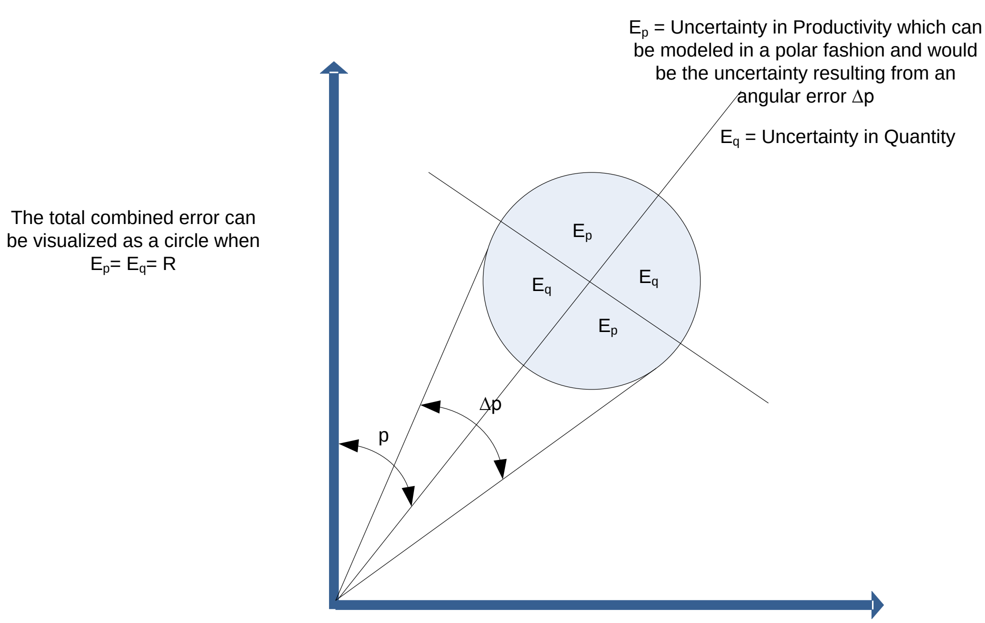

Figure 5: The error circle

When the quantity and the productivity have the same standard errors, the major axis equals the minor axis, resulting in a circle as the area of uncertainty, where $E_q = \sigma X, E_p = \sigma y$ and the equation of this circle can be given as

$$r^2 = \sigma X^2 + \sigma Y^2 \quad (4)$$

In section three above, it was mentioned that in a one-dimensional accuracy analysis, the probability that the true value was within $\pm\ \sigma$ (one standard deviation) was 68%. In the case of the standard ellipse however, the probability that the true value is within the ellipse is 39%. When we want to consider different probability, a constant K has to be introduced and equation 4 becomes,

$$(kr)^2 = \sigma X^2 + \sigma Y^2 \quad (5)$$

This is shown in figure 6. In order to better understand the model presented above a classroom experiment was conducted and will be presented in the next section.

A Classroom Experiment

In order to test the model, an experiment was devised where students in an estimating class were given a comprehensive estimating problem from the textbook for the course. The problem involved a small commercial building. Students were divided individually into two groups; one group was assigned the estimating problem and asked to perform the estimate manually without the use of BIM. The second group was asked to perform the estimate using a commercial BIM tool, namely Revit. As such, we had 15 manual estimates and 16 BIM-assisted estimates. The students were asked report on the quantities as well as the productivities. The project entails a convenience store and did not include any landscape of site elements. The BM modeling therefore was restricted to the structure, the finishes and did not include any mechanical or plumbing. The students were asked to build their own families and components in Revit and populate these families with the appropriate equations to calculate quantities. The required components were derived from the drawings and included wall and roof assemblies as well a foundation system.

The standard error was then calculated for the productivity and quantity values by comparing to the actual values given in the solution manual for the course textbook. As expected and following the model presented above, the standard error for quantities was substantially lower in the BIM-assisted group than the manual group. On the other hand there was no significant difference in the standard error for productivities since most students relied on the same resources for estimating their productivity values.

Conclusions

In this paper we presented a model to assess the increase in accuracy of estimates as result of utilizing BIM. Equation 5 can simply be used to describe this impact numerically and as such can be used for bidding and managerial decisions. Although one of the main premises of this paper is that BIM will increase the precision and accuracy of the quantity aspect of the estimate, it may very well also impact the precision and accuracy of the productivity aspect as well (albeit to a lesser extent). As BIM finds its way to ubiquitous adoption in the construction industry and it use becomes more efficient, one would expect the error ellipse presented in section to "flatten" out to resemble a circle more as the accuracy and precision of the productivity estimate is also affected positively. In any case, the main goal is to have a circle of error whose area is equal to zero!

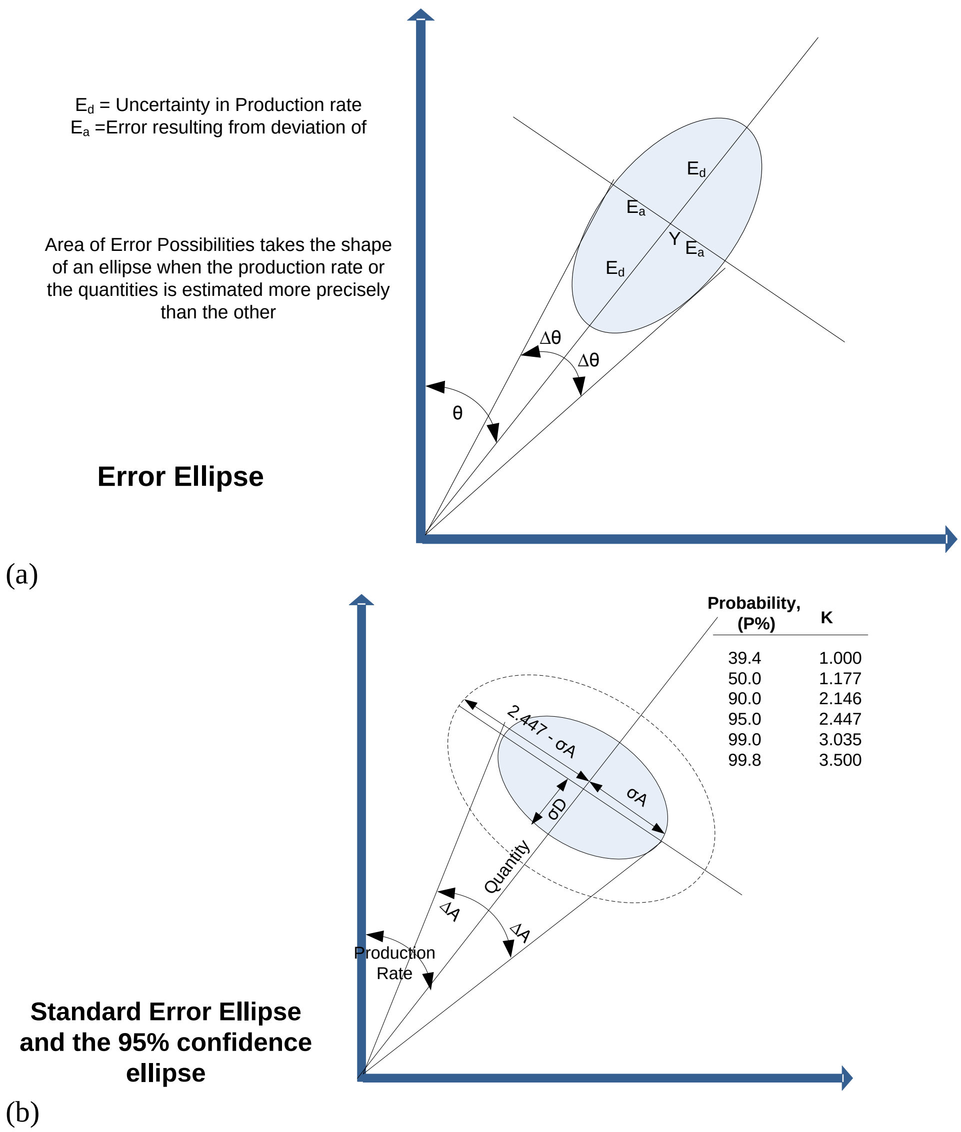

Figure 6: The error Ellipse

References

Associated General Contractors of America. (2005). *The Contractor's Guide to BIM*, 1st ed. AGC Research Foundation, Las Vegas, NV.

CRC Construction Innovation. (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House*, Cooperative Research Center for Construction Innovation, Brisbane, Australia.

Dean, R. (2007). *Building Information Modeling (BIM): Should Auburn University Teach BIM to Building Science Students?* Graduate Capstone, Department of Building Science, Auburn University.

Fischer, M., and Kunz, J. (November 12, 2006). *The Scope and Role of Information Technology in Construction* [WWW document]. URL http://cife.stanford.edu/online.publications/TR156.pdf

Khemlani, L. (November 22, 2007). “Top Criteria for BIM Solutions”, *AECbytes,* October issue [WWW document] URL http://www.aecbytes.com.

Kunz, J., and Gilligan, B. (October 23, 2007). *Values from VDC/BIM Use* [WWW document]. URL http://cife.stanford.edu/VDCsurvey.pdf

Rosenburg, T.L. (2007). “Building Information Modeling.” [WWW document] URL http://www.ralaw.com/resources/documents/Building%20Information%20Modeling%20-%20Rosenberg.pdf

Thompson, D.,B. (2001). “e-Construction: Don’t Get Soaked by the Next wave.” *The Construction Law Briefing Paper* [WWW document] URL http://www.minnlaw.com/Articles/68553.pdf

Thompson, D.B., and Miner, R.G. (2007). “Building Information Modeling - BIM: Contractual Risks are Changing with Technology” [WWW document] URL http://www.aepronet.org/ge/no35.html

Woo, J. H. (2006). “BIM (Building Information Modeling) and Pedagogical Challenges”. *Proceedings of the 43rd ASC National Annual Conference*, Flagstaff, AZ, April 12-14.