EVALUATING THE IMPACT OF BUILDING INFORMATION MODELING (BIM) ON CONSTRUCTION

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ABSTRACT:

This research assessed perceptions about the impact of the implementation of Building Information Modeling (BIM) on construction projects. Survey questions centered on impact with respect to six primary construction key performance indicators (KPIs) commonly used in the construction industry as accepted metrics for assessing job performance. These include: quality control (rework), on-time completion, cost, safety (lost man-hours), dollars/unit (square feet) performed, and units (square feet) per man hour. Qualitative data was collected through a survey instrument intended to assess practitioners' perceptions about BIM impacts on the six Key Performance Indicators. The survey was targeted at National Institute of Building Sciences (NIBS) Facility Information Council (FIC) National BIM Standard (NBIMS) committee members. The survey, with a response rate of 50 completed surveys, showed preliminary results indicating that the NIBS FIC NBIMS members felt that a BIM-based approach improves construction metrics compared to construction without BIM. Specifically, the highest three ranking KPIs in order of most favorable responses were quality, on time completion, and units per man hour. The second tier of favorable responses included overall cost and cost per unit. Finally, only 46%, or less than half, of the respondents thought that construction safety was improved through BIM.

KEYWORDS: BIM, Construction, NBIMS, Metrics, KPI

1. INTRODUCTION

In 2004, the National Institute of Standards and Technology (NIST) published a report stating that poor interoperability and data management costs the construction industry, approximately $15.8 billion a year, or approximately 3-4% of the total industry. Since this report, many have labeled Building Information Modeling (BIM), an emerging technological information management process and product, as the answer to this problem. From the pending release in July 2007 of the National BIM Standard (NBIMS), a BIM (i.e. a single Building Information Model) is defined as "a digital representation of physical and functional characteristics of a facility." Furthermore, a BIM represents a shared knowledge resource, or process for sharing information about a facility, forming a reliable basis for decisions during a facility's life-cycle from inception onward. In the words of the NBIMS Executive Committee Leader and former Chief Architect of the Department of Defense, Dana K. "Deke" Smith, R.A., "A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (NBIMS 2007).

2. METHODOLOGY

2.1 Overview

This paper focuses on only the first phase of our research, which proposes to accomplish data collection and analysis in four phases. These four phases will be aligned with a process originally created by United States Air Force Colonel John Boyd (1927-1997) and shown in Figure 1. Information Management (IM) professionals have often used Boyd's model, which is widely known as the "OODA Loop" (Observe, Orient, Decide, and Act), to demonstrate the continual improvement process of strategic decision making. The OODA Loop will be used here to structure the research to ensure that each phase builds on the one before it and in this way the conclusions will be logically valid. Boyd developed the theory based on his earlier experience as a fighter pilot and he initially used it to explain victory in air-to-air combat. But in the later years of his career; he expanded his OODA Loop theory into a grand strategy with benefits to anyone who needs to pragmatically and quickly process information.

Colonel Boyd's philosophy dictated that individually, people will observe unfolding circumstances and gather outside information in order to orient their decision making system to "perceived threats." Boyd states that the *orientation* phase of the loop is the most important step, because if decision makers perceive the wrong threats, or misunderstand what is happening in the environment, then the decision makers will orient their thinking in erroneous directions and eventually make incorrect decisions. Boyd said that this cycle of decision-making could operate at different speeds for different organizations but the goal is to complete the OODA Loop process at the fastest tempo possible. However, in this research, it will be used to make the best, not necessarily the fastest, choices about the proper items to collect and investigate. Through Boyd's OODA Loop; this research will be structured in four phases aligned with the ideas of *observation*, *orientation*, *decision*, and *action* (Boyd 2007).

2.2 Phase I: Observation

Because BIM is so new in the US Architecture, Engineering, Construction, and Operations (AECO) industry, there is little empirical data regarding its application and use. Therefore, in addition to the typical review of literature in the field, a qualitative survey was administered to garner initial data about practitioners' perceptions about the effects of BIM on construction key performance indicators (KPIs). This survey data was used to determine current BIM practices and perceptions to formulate additional research hypotheses for use in Phase II. Phase I included publishing a web-based survey with the sole purpose of garnering industry stakeholders' impressions of BIM's effect on construction through specific construction metrics based on six (6) primary, quantitative construction KPIs: Quality Control, On time Completion, Cost, Safety, $/Unit, Units/Manhour as determined in a 2003 study by Cox et al. (2003). In this way, qualitative industry perceptions were quantified. The survey was hosted on http://www.zoomerang.com through an account login funded by the National Institute of Building Sciences, Facility Information Council (NIBS-FIC). In concert with the National BIM Standard (NBIMS) Committee testing team, a subset of the NIBS-FIC, this data was shared for their own empirical research.

2.2.1 Survey

After receiving University of Florida Institutional Review Board (UFIRB) authority, the first iteration of the survey was available from March 5, 2007 until April 5, 2007 and was advertised to a select group in two different ways: direct email through a distribution list and a website advertisement. First, an email was sent to the FIC listserv distribution list. This listserv had 104 members from across the AECO industry at the time of the survey's launch. Halfway through the month-long survey availability, a reminder email was sent to the listserv asking for more people to complete the survey or for those who had started the survey to complete the survey. The second method of garnering qualified respondents was to advertise the survey on the NIBS FIC website, http://www.facilityinformationcouncil.org/bim, under their "NEWS" portion. Since most people only happen upon this website when signing up to join the NIBS-FIC NBIMS committee, and this website is only "advertised" in the AECO community, the possibility of tainting the data was considered negligible.

2.2.2 Survey Specifics

The survey was divided into four sections:

- Part I: Basic Demographic Information
- Part II: BIM Effects on KPIs
- Part III: Ranking KPIs
- Part IV: Free Answer

Part I was intended to find descriptive information about the respondents, to ensure that they were qualified to answer the questions, and to group answers from similar respondents together across the data pool. Most questions were standard for surveys such as gender, age, and the state where the respondent resided. Questions especially germane to the research were the following which were targeted at collecting the respondent's educational level, annual company revenue, and people's organizational role. Regarding organizational role, respondents were asked to make a selection from a list based on the organizational roles listed in Table 32 of the Construction Specifications Institute (CSI 2007). First, respondents were asked to select their overarching organizational role, and then the survey skipped to the question that addressed the proper organizational role with a follow-up question formulated to find out the specific role the respondent filled on a daily basis. These choices also came from the CSI's (2007) Omniclass Table 32 for organizational roles.

Part II of the survey served as the beginning of the primary data collection instrument. This part asked questions on each of the six construction KPIs in various formats with varying scales of favorable to unfavorable perceptions regarding the impact of BIM on construction. In this way, the possibility of errant responses from people just putting the maximum answer down for every question was avoided. At the beginning of Part II, respondents were asked to rate their perception of BIM's impact on the list of six construction key performance indicators. Specifically, question #14 of the survey addressed BIM's impact on units per man hour. Units per man hour were defined for respondents as "measure of completed units (typically square footage) put in place per individual man hour of work." The respondents' choices of answers ranged on a 5-point Likert scale from least favorable to most favorable with the following possible choices:

Severely Inhibits	Lessens	No Effect	Improves	Maximizes
1	2	3	4	5

The next question, #15, asked for the same perception about BIM's impact on "dollars per unit" or cost per square foot ($/SF) with the same choices on the 5-point Likert scale. Question #16, asked about safety. Regarding safety, respondents were asked to "read the following statements and choose the one that most closely matches your view of BIM's effect on safety." The answers, with regard to lost man-hours, were again arranged on a 5-point Likert scale:

Eliminates	Lessens	No Effect	Increases	Greatly Increases
1	2	3	4	5

The next question, #17, had to do with cost. Cost was defined as "cost variance in actual costs to budgeted costs." Here there were five sub-questions under this one question that centered on different types of costs including: General Conditions, Structural, Mechanical, Electrical, and Plumbing (MEP), Finishes, and Overall. Here, respondents could choose from a 5-point Likert scale, as well as the additional choice of Not Applicable or "N/A." The 5-point Likert scale had the following choices:

Max Variance: ($ Lost)	Worsens	No Effect	Improves	Max Variance ($ Saved)
1	2	3	4	5

Question #18 focused on "on time completion." The response options were similar to those for question #17 with the exception of variance equating to a "late" project on the unfavorable side of the scale to "max variance – early" on the favorable side of the scale.

The final question in Part II, #19, asked respondents what they thought about BIM's impact on quality control/rework. This question prepared the respondent for answering by saying, "quality control can be defined as percent (%) of rework in ($) compared to overall cost in ($)." The choices were:

Increases Rework	Worsens	No Effect	Improves	Nearly Eliminates Rework
1	2	3	4	5

Part III of the survey was structured to determine whether there was any one construction KPI which BIM impacted more than any other in a logical ranking fashion, so that it could be investigated more thoroughly in Phase II of the research while collecting case study data. Respondents were asked to rank the KPIs on a Likert scale from 1-10. This means that 1 would be a score showing that BIM inhibited construction to 5 equalling no effect to 10 showing the most improvement.

Part IV of the survey was intended to gather open ended responses from respondents that could help identify problems with the current survey, necessary points to investigate in future surveys, receive contact information if people wanted specific follow-up information, and give respondents a chance to express themselves if they felt the survey stifled their responses in any way.

The Summary portion of the survey was intended to determine respondents' personal definition of Building Information Modeling. There were four choices, including one response; "Don't Know" which was a response intended to eliminate unqualified respondents from tainting the data pool. The other choices included:

- BIM is 3D CAD
- BIM is a tool for visualizing and coordinating A/E/C work and avoiding errors and omissions
- BIM is an open standards based info repository for facilities lifecycles

2.3 Future Research: Phases II-IV, Orientation, Decision, and Action

Phase II will include building on the survey data garnered in Phase I and will test the primary research hypothesis and possible follow on hypotheses by conducting embedded research on federal construction projects. The rationale behind this research is that federal entities have provided testbeds for implementing new ideas and new technologies in the past in the field of construction. While federal work has not always led the way on implementing new technological initiatives, recent strides in the General Services Administration (GSA), Army Corps of Engineers (USACE), and United States Coast Guard (USCG) demonstrate that they are exceeding typical industry rate of BIM adoption. However, despite recent promulgation of BIM procedures in documents like the GSA BIM Guide and USACE BIM Roadmap, there is little documented evidence on BIM's impact on the construction phase of the facility lifecycle. Therefore, future research proposes to evaluate BIM effects on federal construction projects according to the KPI metrics listed in the survey. The specific locations where the embedded research will be conducted due to their considerable experience at managing projects through BIM methodologies are:

- U.S. Army Corps of Engineers (USACE), Seattle District
- U.S. Army Corps of Engineers (USACE), Louisville District
- U.S. Coast Guard Naval Engineering Support Unit (NESU), Charleston, South Carolina
- General Services Administration (GSA)

After assessing and analyzing the data and comparing it to longitudinal data from construction projects similar in size and scope to those studied in Phase II, Phase III will include revisions and changes to the data collection model. In addition, a wider cross section of construction projects will be studied including commercial and industrial projects. Phase III entails comparing the data collected in Phases I and II to longitudinal data. This would be accomplished by using data collected and maintained by research bodies such as the USACE Civil Engineering Research Laboratory (CERL) or the Construction Industry Institute (CII) and comparing their baseline construction data to BIM case study data from Phase II. Lastly, the data will be analyzed to determine if trends exist that demonstrate significant differences in productivity or performance according to the construction KPI metrics.

In Phase IV, after the bulk of the data is collected, the lessons learned from conducting the embedded research will be applied to a further revised methodology recommended for future case study data collection. Additionally, noted trends will be discussed in the research analysis portion of this document and recommended for consumption and implementation by federal entities and construction firms for recommended best business practices that yield the most productivity improvements. In this way, the research will *act* on the lessons learned, fulfilling the OODA Loop. Possible additional case study data will include trend analysis on commercial and industrial projects and comparison to the federal construction projects case study data

3. RESULTS

The first iteration of the survey was sent out to the NBIMS committee of the NIBS-FIC and was available from March 5, 2007 until April 5, 2007. Of the 105 people on the committee when the survey was closed out, 50 respondents fully completed the survey for a highly successful 48% response rate. The information below represents a summary of the results from the survey.

3.1 Part I: Basic Demographic Information

Figures 2-5 show the data gathered through the Zoomerang online survey or data analysis derived from the data in the survey. Regarding gender, 86% (43/50) of the respondents were male and 14% (7/50) female. The age data of the respondents shows that the mode response was also the median age group, the 45-54 year olds with an overall normal distribution of respondents. There was only one respondent under 25 years old. As far as education level, 86% (43/50) of the respondents had college degrees, with 56% (28/50) of them holding graduate or professional degrees. There was no definite trend indicated on the organizational revenue question, although the most frequent response was $1-$9.9 Million with 24% (12/50) of the respondents choosing this answer. Respondents' geographic locations were varied with 47/50 respondents living in the U.S. and three from outside the U.S. (Note: despite being the U.S. NBIMS committee, several members live and work outside the U.S., but are either American citizens or are liaisons for wider interests such as the North American BIM buildingSmart Initiative (sic), etc. so it is possible for respondents on the U.S. NBIMS listserv to live outside the U.S.) The most frequent response by state was from Maryland, with 18% or nine of the 50 respondents living there.

The organizational role data results showed that the two most frequent responses were from those with a Design Role with 44% (22/50) respondents and from those with a Management role, which accounted for 30% (15/50) respondents. Of the first most frequent response, Design Role, 73% (16/22) of the respondents were architects and 27% (6/22) respondents were engineers. For the second most frequent response, Management, 47% (7/15) were Vice Presidents in their organization and 40% (6/15) respondents were the Chief Executives of their organization.

3.2 Part II: BIM Effects on Construction KPIs

Respondents were asked to rate their perception of BIM's impact on six KPIs. The following list is organized in order of the highest rated to the lowest rated of the six KPIs: Quality Control/Rework (90%), On-time Completion (90%), Cost-Overall (84%), Units/Man hour (76%), Dollars/Unit (70%), and Safety (46%). This was calculated by evaluating responses that exceeded the neutral Likert value of 3 and comparing that to the total number of responses. For example, 34/50 respondents opined that BIM "Improved" the Quality Control/Rework KPI, as well as 11/50 respondents opined that BIM, "Nearly Eliminates Rework" for a total rating of 90% (45/50). Full data on the responses can be seen in Figures 2 and 3.

Cost was similarly broken down and the following list organized in the order of highest to lowest rated favorable opinion (i.e. assigned a value greater than 3 on the Likert scale) by the respondents: Overall (84%), Mechanical, Electrical, and Plumbing (78%), Structural (76%), General Conditions (70%), and Finishes (58%.)

It is important to note that 46% or 23/50 respondents also felt that BIM has "No Effect" on safety or lost man-hours in construction projects, making it the KPI that in their perception is the least impacted by BIM.

3.3 Part III: Ranking Construction KPIs

Respondents were asked to rank the construction KPIs according to their perceptions of how well BIM improved the given KPIs on a scale of 1-10, with 10 showing the most improvement, 5 showing no effect, and 1 showing that BIM inhibits the given KPIs. Organizing the construction KPIs according to merely adding positive response frequency percentages (anything over a score of 5), the KPIs score the following in order from most to least favorable: Quality (94%), On-time Completion (88%), Units/Man-hour (86%), Dollars/Unit (80%), Cost (80%), and Safety (54%.) When weighting the answers for the degree of favorability (Σ(%*100*Score)), the KPIs score the same: Quality (564), On-time Completion (528), Units/Man-hour (516), Dollars/Unit (480), Cost (480), and Safety (324.) This information is graphically illustrated in Figures 4 and 5.

3.4 Part IV: Comments

A few of the most representative comments made by the respondents were:

- Respondent # 3: A BIM will likely affect KPIs rather than the other way around. A good, comprehensive, structured source of accurate data that all the stakeholders can access will reduce stove pipes, redundant data and inaccurate information. It will make it easier to keep the data current and to verify it.
- Respondent #7: The questions that are being asked are of the type that an A/E would ask. You may want to look at asking that questions that a builder, vendor, or trade contractor would ask.
- Respondent #8: The way you ask your questions, it seems as if you assume that BIM should save time and money. In reality, I believe that the BIM makes your planning, scheduling, estimating, etc. more accurate. I have quite often seen that BIM corrects errors, misconceptions and the net effect may be additive (but save the contractor the time, money and the embarrassment of a mistake). If there was inadequate time or more planned for a given scope, than it may it may be just as likely to add time or money as save (sic).

- Respondent #13: More KPIs: Reduction in Claims, Improved public outreach/agency coordination, More sustainable structures
- Respondent #16: BIM will minimize change orders, and will also reduce the initial project cost. Contractors will sharpen their pencils and will provide pricing per known factors, the number of unknowns and field coordination efforts are reduced.
- Respondent #17: While BIM a goal to strive for and is relevant to certain projects - the fractured nature of the A/E/C (sic) industry means that it will be a long time before BIM has a significant overall effect on the industry

4. SUMMARY

The summary question in this survey asked respondents which definition of BIM most closely matched their own. No respondents chose the answers “Don’t Know” or “BIM is 3D CAD.” As shown in Figure 6, the definition of BIM according to the NIBS-FIC NBIMS Committee received the most responses, “BIM is an open standards based information repository for facilities’ lifecycles,” with 70% or 35/50 respondents making this selection. The other response was, “BIM is a tool for visualizing and coordinating AEC work and avoiding errors and omissions,” received 30% or 15/50 responses. While this response is not necessarily incorrect, it does not align with the NBIMS’ view of the definition, which means that 15% of the respondents from the NBIMS committee have a personal definition of BIM that is different than the committee’s formal definition. Thus, there is still some work to be done for the NBIMS Committee to educate and inform the AECO community, even within its own organization.

5. CONCLUSION

As the results suggest, the respondents felt that BIM is most likely to positively impact the construction KPIs of quality and on time completion. More research needs to be conducted in order to corroborate the “BIM-favorable” results here. While the respondents are certainly knowledgeable about BIM because of the demographics shown herein and membership on the NBIMS listerv, their affiliation could have also biased their results. Additionally, quantifying the impact of a BIM approach through real world construction case studies will offer a more compelling argument for BIM adoption by AEC firms.

6. ACKNOWLEDGEMENT

This study was partially supported by the National Institute of Building Sciences, Facility Information Council (NIBS-FIC.)

7. FIGURES

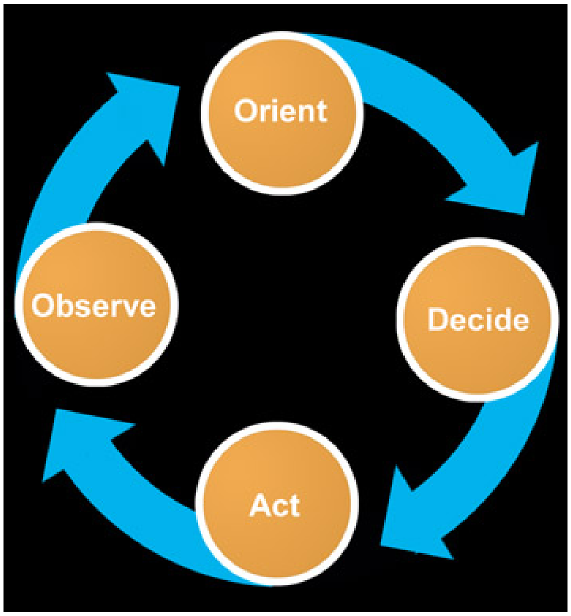
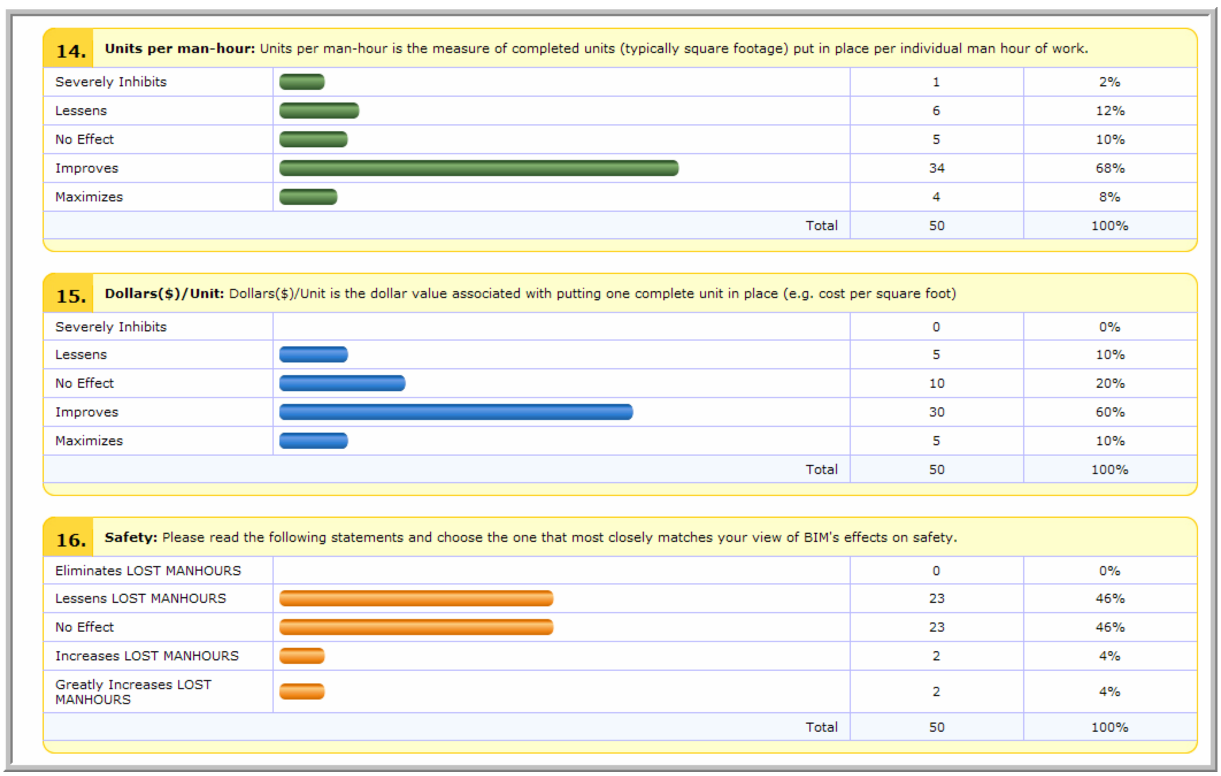


FIG. 1: "OODA Loop" (Observation, Orientation, Decision, Action) (Col John Boyd, USAF (Ret.))



14.	**Units per man-hour:** Units per man-hour is the measure of completed units (typically square footage) put in place per individual man hour of work.		
Severely Inhibits		1	2%
Lessens		6	12%
No Effect		5	10%
Improves		34	68%
Maximizes		4	8%
	Total	50	100%

15.	**Dollars($)/Unit:** Dollars($)/Unit is the dollar value associated with putting one complete unit in place (e.g. cost per square foot)		
Severely Inhibits		0	0%
Lessens		5	10%
No Effect		10	20%
Improves		30	60%
Maximizes		5	10%
	Total	50	100%

16.	**Safety:** Please read the following statements and choose the one that most closely matches your view of BIM's effects on safety.		
Eliminates LOST MANHOURS		0	0%
Lessens LOST MANHOURS		23	46%
No Effect		23	46%
Increases LOST MANHOURS		2	4%
Greatly Increases LOST MANHOURS		2	4%
	Total	50	100%

FIG. 2: Part II Responses about BIM's impact on construction KPIs (raw data from zoomerang)

17. Cost: Cost variance in actual costs to budgeted costs

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	Max Variance ($ Lost)	Worsens	No Effect	Improves	Max Variance ($ Saved)	N/A
General Conditions	0 0%	3 6%	8 16%	31 62%	4 8%	4 8%
Structural	1 2%	2 4%	3 6%	29 58%	9 18%	6 12%
Mechanical, Electrical, Plumbing	0 0%	3 6%	3 6%	27 54%	12 24%	5 10%
Finishes	0 0%	3 6%	12 24%	25 50%	4 8%	6 12%
Overall	0 0%	2 4%	2 4%	32 64%	10 20%	4 8%

18. On-Time Completion: On-Time Completion can be defined as construction duration variance from proposed schedule duration.

Max Variance (Late)		1	2%
Worsens		1	2%
No Effect		3	6%
Improves		41	82%
Max Variance (Early)		4	8%
	Total	50	100%

19. Quality Control/Rework: Quality Control can be defined as percent (%)of rework in ($) compared to overall cost in ($).

Increases Rework		0	0%
Worsens		0	0%
No Effect		5	10%
Improves		34	68%
Nearly Eliminates Rework		11	22%
	Total	50	100%

FIG 3. Part II Responses about BIM's impact on construction KPIs (raw data from zoomerang)

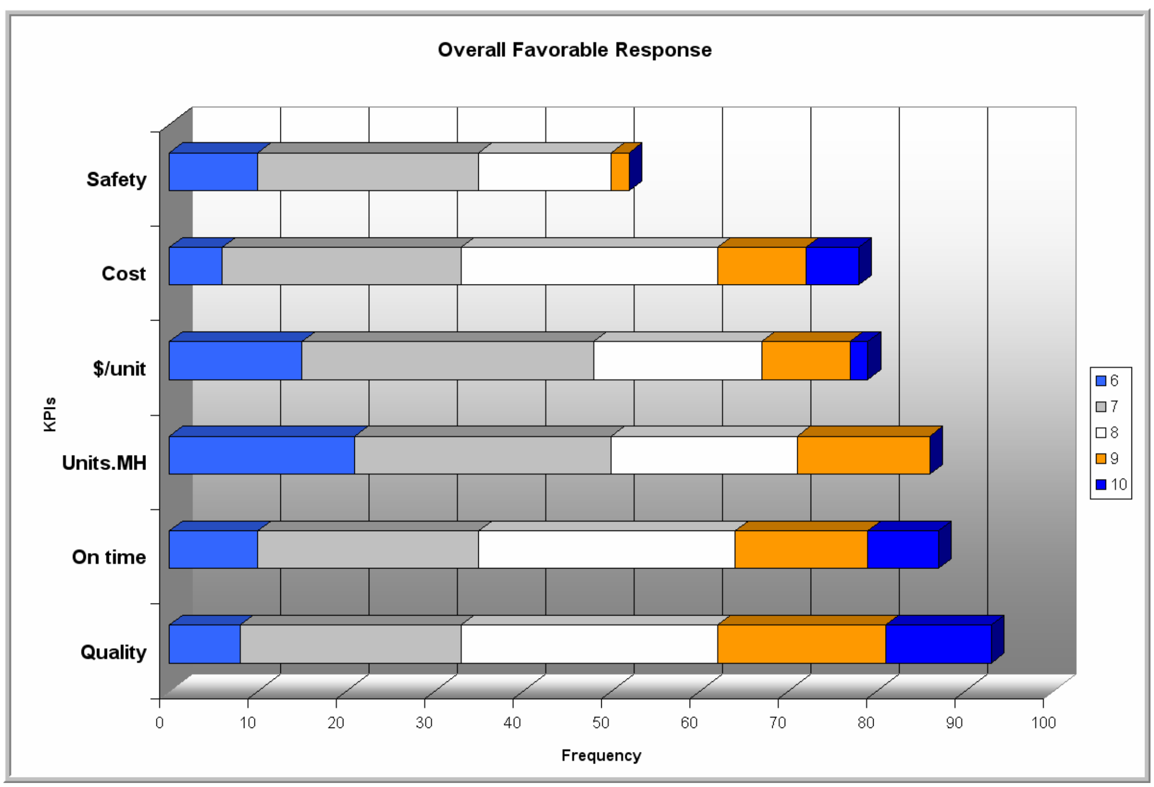


FIG. 4: Overall Favorable Responses when ranking KPIs with respect to impact on BIM (unweighted)

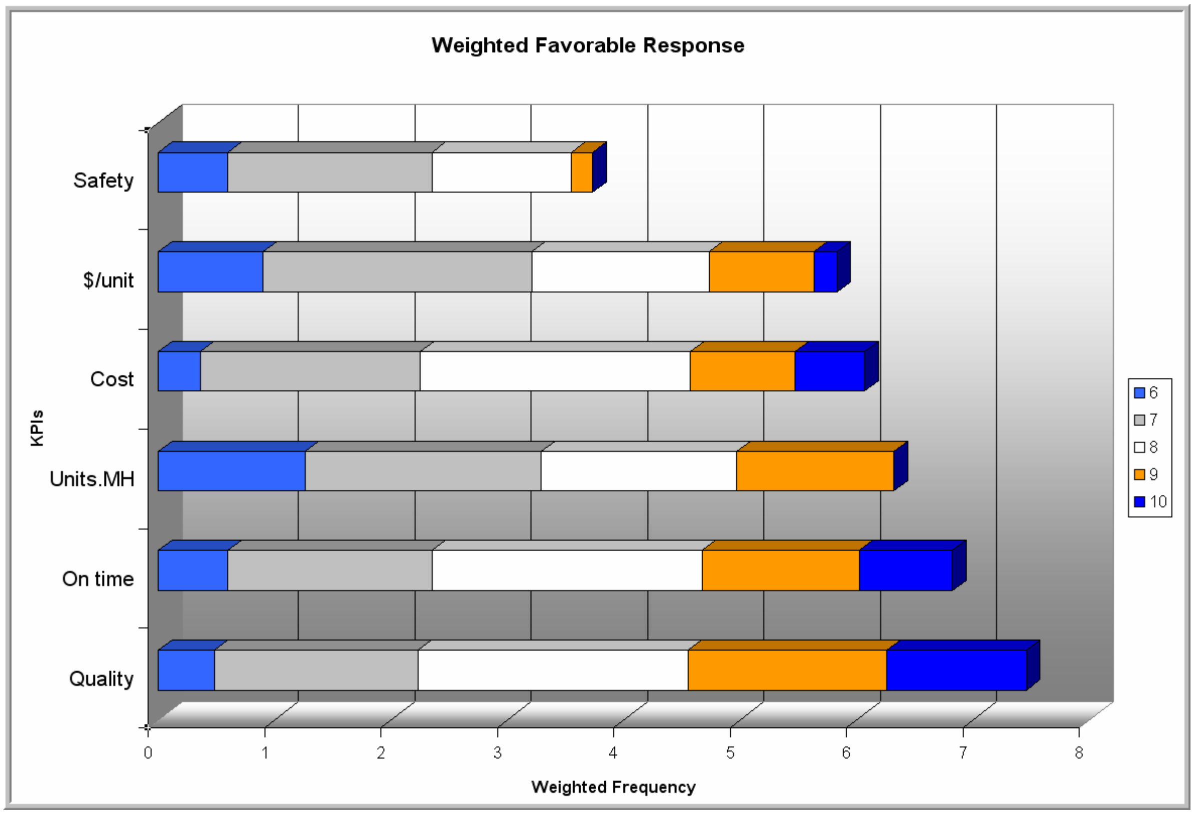


FIG. 5: Overall Favorable Responses when ranking KPIs with respect to impact on BIM (weighted)

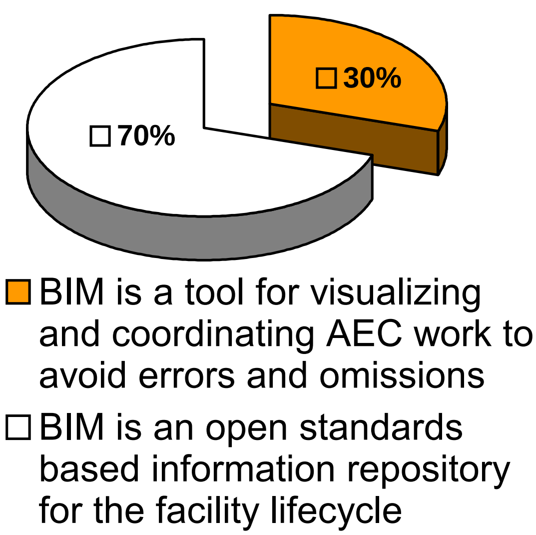


FIG. 6: Answers to definition of BIM Question

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