Developing a Framework for the Budgeting of BIM and Its Integration into Estimation

A Case Study on the Practices of an Electrical Subcontractor

by

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ABSTRACT

The applications of Building Information Modelling (BIM) technology extend beyond performing clash detection and avoiding installation issues among subcontractors. When properly budgeted and fully integrated into the pre-construction work-flow, BIM technology can improve the accuracy of estimates and reduce material as well as labor costs. The purpose of this paper is to analyze BIM-related budgeting practices and explore options for optimizing BIM budgeting strategy as well as integrating BIM technology into an estimating strategy. The methodology chosen was a case study. A study of an electrical contractor was conducted using BIM budgeting data based on actual and estimated figures for 245 jobs completed in the years 2015-2019. A review of literature was conducted for the purpose of researching current options with regard to the implementation of BIM as part of estimation, its associated financial cost, and the challenges faced in adapting existing frameworks to meet new demands. It was observed that the current resources allocated for BIM are under-utilized on an aggregate basis. It was also observed that the budget for these resources is sometimes exceeded for larger projects and frequently, grossly under-utilized for smaller projects. There is a strong correlation between contract value and project type, suggesting that contract value is a primary predictor of BIM requirements. The review of literature suggests what employee skills are most necessary for integrating BIM with estimating: the ability to perform accurate takeoffs from BIM models, evaluate the cost of materials that are typically not modeled or appear poorly in the model, the ability to work with a variety of BIM software, the ability to know if a model is accurate, and an understanding of how the model interacts with other aspects of the construction process. It also discusses the challenges faced when adopting BIM in estimation. This paper contributes to the field of construction management by expanding the body of research for the BIM budgeting strategy in electrical contracting; an area of research which is not well developed. The data analyzed from this single electrical contractor provides the basis for an exploratory case study that contributes to the development of a conceptual framework for accurate BIM budgeting, where no such framework had previously existed.

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INTRODUCTION

Construction is an extremely competitive industry with often slim profit margins. It is vitally important to identify as many efficiencies as possible throughout the project life cycle in order to consistently generate profit. Accurately estimating and controlling costs at the outset of a project is extremely important in consistently avoiding cost overruns (Ali and Kamaruzzaman, 2010). Therefore, the pre-construction phase - including BIM coordination - is an area in which great cost savings can be found if the work-flow is optimal and efficient. It is already well-established that the use of computer simulation techniques such as BIM can improve the accuracy of estimates (Alashwal and Min, 2017). The use of BIM allows an estimator to account for a wide range of potential variances in project cost (Marzouk et al, 2010), (Azhar et al, 2015), (Cheng and Chen, 2013), (Krygiel and Nies, 2008). A well-estimated and well-coordinated job optimizes everything from materials to labor to scheduling.

Part of putting together effective estimates and coordination is the economization of time spent on those activities. The purpose of this paper is to analyze BIM-related budgeting practices and explore options for optimizing BIM budgeting strategy as well as integrating BIM technology into an estimating strategy. Such analysis will provide a framework for the development of a more cost-effective and streamlined pre-construction work-flow.

The review of literature focuses on the most relevant research regarding the implementation of BIM as part of the overall estimating strategy, its associated financial costs and performance, and the challenges faced in transitioning to a new level of interdepartmental flexibility. The research focuses primarily on implementation at the scale of a medium-sized contractor; the subject of this thesis case study. There is ample research to show that the implementation of BIM in construction demonstrably and consistently improves overall project performance (Cao et al, 2015). Integrating it into the estimation phase specifically also has a number of quantitative well as qualitative benefits (Ying Hong et al, 2019).

The budgeting analysis of BIM data breaks down 245 projects across three categorizations. The amount of money budgeted for and spent on BIM is expressed in hours. These hours can be converted into total dollar values using a defined coefficient corresponding to the dollar value spent per hour of BIM-related activity, given in Table 1. Each categorization focuses on certain statistical measures to best understand the accuracy of current budgeting practices and provide a basis from which recommendations for future action can be developed. Statistical measures are discussed in greater detail in the Methods and Discussion Chapters. There is an overall analysis of the data, focusing on the overall accuracy of budgeting practices and the amount of total budgeted in comparison to the total hours used. The data is then categorized according to project size (broken into quintiles), project manager, and building type. Specific details on the breakdown of project types can be found in Appendix A.

CHAPTER 2

LITERATURE REVIEW

This literature review is broken into three sections: The first discusses the implementation of BIM into the estimating work-flow, the second the associated costs and the third discusses the associated challenges.

Implementation

Ying Hong et al developed a model that identified several key qualitative factors in the implementation of BIM, which are useful in developing a basis for understanding the necessary steps for integration into estimation. It was determined that the most significant qualitative variables in BIM implementation are the desire to be competitive within the industry, an understanding of the potential benefits of implementation, staff capability, and knowledge support. Developing a framework around these considerations represents a valuable step in reshaping an organization to make fuller use of available technology.

The benefits and applications of BIM are extremely well documented (Cao et al, 2015). The most significant of these with regard to estimating is the ability of BIM to automate take-offs (Cheng and Chen, 2013). Software packages such as AutoCAD, Revit and Vectorworks can be set up such that as a model is created, running tallies of necessary material are stored and can be used for either the estimate or for purchasing (Saldaña, 2015). Research into the procedural generation of BIM models is ongoing and could yield even greater efficiency when combined with an automated take-off (Janssen, 2015). Because of the continuous advances in construction technology, it is vital that office staff are capable of making use of the latest technology. Providing access to training resources is an important cog in this machine. Estimators with little BIM modeling experience and BIM coordinators with little estimating experience must each be fully educated in the required tasks of the other party in order to form a unified and streamlined operation (Hosseini et al, 2016). The top skills identified are the ability to perform accurate takeoffs from BIM models, evaluate the cost of materials that are typically not modeled or appear poorly in the model, the ability to work with a variety of BIM software, the ability to know if a model is accurate, and an understanding of how the model interacts with other aspects of the construction process such as project management (Ying Hong et al, 2019).

Important to note is the overall knowledge of the construction project process required for full utilization of BIM functionality. Business executives must be aware that the employees within their BIM/estimating department(s) cannot just know the software, they must be well versed in the entire project life cycle.

Associated Costs

As a company with an already established BIM department, the associated costs of should be more manageable than starting from scratch (Poirier et al, 2015). It is likely, however, that more users will need to be licensed to use the software packages available. These packages can cost thousands of dollars, and can represent a barrier to implementation if the volume or scope of work performed requiring BIM services is insufficient (Hardie and Newell, 2011). There are also significant hardware requirements associated with simultaneously running multiple heavy-duty modelling packages. Additionally, consideration should be given to the salary requirements of employees who have the skills of both an experienced estimator and BIM coordinator. Finally, it is important that the costs of the estimating/BIM work be incorporated into the overall price of work at time of bid (Shin Min et al, 2018).

Associated Challenges

The challenges frequently associated with the implementation of BIM include the costs discussed above, proper management of information flow, and a lack of readily interoperable data (Haynes, 2009). In terms of information management, the issue lies in the communication between relevant parties (owner, architect, engineer, and relevant contractors) as well as within the subcontractor providing the estimate. There is a much greater volume of information to be processed in building a model from which an estimate can be generated when compared to completing an estimate based on a set drawings. The time-frame for the generation of this model is also compressed when compared to the time that would normally be allotted for coordination (Allen Consulting Group, 2010). Readily interoperable data refers in this case to the ability for data from one software package to be used on another platform. Complications to this work-flow impede the swift delivery of an estimation model (Yan and Damian, 2008).

Literature Review Conclusion

This literature review was conducted for the purpose of expanding upon the central issues discussed in the thesis. It reviewed relevant literature with regard to the implementation of BIM, its associated costs and, and the other challenges that may inhibit swift implementation of a new pre-construction work-flow. The reviewed literature presents an outline for how the subject company can further engage with BIM and presents a backdrop for further discussion about the performance of the company in question with respect to the presented topics.

CHAPTER 3

METHODS

The data for this paper were obtained from, and with the permission of, a medium-sized electrical contractor operating in a major metropolitan area within the United States. The data were collected from company accounting records for jobs between the beginning of 2015 and the end of 2019. 245 projects had sufficient BIM budgeting and overall contract value data for the desired analysis. Organization and statistical analysis of data was conducted using Microsoft Excel and Minitab. The categorization of project data by contract value, project manager, and project type was carried out according to the following logic.

The categorization of data by contract value was conducted by splitting the data into quintiles of 49. Using quintiles allows for an accurate understanding of the distribution of contract value across the data set. Additionally, the dataset is such that using quintiles, instead of quartiles, provides a more specific detailing of how project values are distributed and are evenly divisible into equal groups. This allows for more specificity in identifying trends within the data and allows for a more substantive discussion of results.

The categorization of data by project manager allows for an examination of the human element of budgeting by seeking to understand what level of responsibility can be borne by project managers when determining budgeting accuracy (or inaccuracy). The limitation of this categorization is that project sample sizes for individual project managers are in some cases very small, meaning that judging the individual performances of those project managers is not feasible.

The categorization of data by project type is much more subjective. Projects were organized by the similarity of their requirements: a description of project types can be found in Appendix A. The primary limitation of this categorization is that not every project necessarily falls neatly into a specific category. This is especially the case with large projects, which may be constituted of multiple buildings. A large shopping mall, for example, may include a movie theater, retail space, and a parking garage. In these cases it is not viable to breakdown these projects into their constituent types because those types are not individually budgeted for coordination.

With regard to the methodology of the case study itself, there are a number of strengths and weaknesses, and it is important to understand what those are in order to set bounds on the scope of the research presented. One of the advantages of the case study methodology is that it allows for examination of data within the context of the practical. A case study takes into the account the specific factors by which an individual entity is affected. Therefore, the results of data analysis can be concretely applied to the organization or entity being studied. Data for a case study may also be more easily retrievable as it relies only on a single source, rather than relying on dozens or hundreds of sources.

Primary weaknesses of the case study methodology include difficulty in replicating results and an inability to make generalized conclusions. These issues occur for similar reasons. Because the data examined are based on the organizational methods of businesses within a subset of an industry, replicating results using the data analysis of one case study for another business outside that subset may be difficult because a different subset of an industry likely has a different methodology for how they are organized structurally. Similarly, because data analysis occurs in a localized context, it is not possible to make generalizations about the entire construction industry based on the data and practices of an electrical contractor.

CHAPTER 4

RESULTS AND DISCUSSION

General Discussion

The discussion of the data will be examined in accordance with the manner in which it was analyzed. Statistics related to the overall sample will be examined first, followed by discussion of statistics according to contract value, project type, and project manager.

At the most general level – an overall analysis of all 245 projects – several interesting figures were noted. The first is the Total Hours Spent (THS) when compared to Total Hours Budgeted (THB). 80.51% of the THB are used; the acceptability of this figure in terms of company best practices is down to the preferences of the individual contractor. Company leaders may elect to adjust individual project budgets to raise this figure, or they may prefer to keep a buffer between THS and THB. Figures related to overall analysis are shown in Table 1.

Interestingly, the average percentage use of hours is 57.27. It is important to note how this figure is calculated. It is not the average Hours Spent divided by average Hours Budgeted multiplied by 100. Instead this figure is an average of already calculated percentages. Each individual job has its percent usage calculated and it is an averaging of these percentages that produce the 57.27 figure; meaning that this figure represents the average percent usage for an individual project within a given category, rather than the percent usage of the category in its entirety. This figure can be conceptualized as a way to measure the accuracy of estimation for a given category: the closer to 100 the figure is, the more accurate the job estimates for that category are. In this context a value of 100 would mean that on average, the jobs within the given category use 100% of their allotted budget. Figures that are well above or well below this value indicate that the category in question should have its estimation methods reevaluated. Alternatively, a different target could be defined as a successful estimate. For example, company executives may prefer that the percent usage for each job reflect the aggregate total use figure of 80.51%.

The discrepancy between the total usage of hours and average percent usage is likely due to the high volume of jobs with a low budget for coordination hours and an even lower usage rate. The converse statement i.e. that there are a low number of jobs with a much higher budget for coordination hours and high rate of usage is also valid and would also account for the observed discrepancy between total usage and percent usage. Using each of these figures as benchmarks, stratifications within the data can be clearly observed, allowing for the identification of specific project sizes (according to contract value) which may need to have their estimation criteria examined in an effort to attain greater accuracy at bid time. The distribution of jobs by contract value can be seen in Figure 1.

Project Size

The first categorization of data focused on examining trends based on contract value, which can be used as an approximation of job size (Drew, 2001). The data were divided into quintiles: each quintile containing 49 jobs of decreasing value. The same figures that were calculated at the general level were calculated for each quintile. This allowed for an analysis of the data based on contract value and job size. Interestingly, the largest jobs appear to be the most accurately estimated. On average, jobs in this subset (>3.2 million dollars) use 102% of the coordination budget and 89.8% of THB. There is a precipitous decline in both of these figures for all other quintiles, which account for contracts of 3.2 million dollars and below. The is most readily apparent by looking at the numbers presented in Table 1, but can be seen to a lesser extent in Figure 2. The next quintile (value range $1.1-3.2 million) shows an average percent usage of 71.1, with subsequent quintiles showing 33.6 (450k-1.1million), 44.0 (450k-260k), and 35.51 (260k-60k) average percent usages. The percent of total budgeted hours spent declines in similarly stark fashion. Just 52.2% of all budgeted hours for jobs in the second quintile are used. From there, the figures for subsequent quintiles are 28.4, 41.4, and 31.1 respectively. These quintiles combined account for 20% of the total budgeted hours, yet less than half of those total hours get used. These figures are shown again in Table 1. The primary conclusion made based on these figures is that smaller jobs require a much smaller coordination budget than they are currently being provided. Whether it is appropriate to change the current estimating strategy is a different question. The excess hours clearly present within the budgets of smaller jobs can be thought of in multiple ways. They can act as a buffer if a larger job uses more coordination hours than are within its budget, because on balance the total BIM coordination budget could absorb the overage. Excess hours could also be thought of as a profit buffer within a project if there are some cost overruns in other areas of the job. They can also be thought of negatively - as an impediment to competitive bidding. If these excess hours were cut from an initial bid, it could lead to the awarding of more contracts, and greater overall growth and profitability for the company. These are ultimately questions of risk, and depending on company leaders' appetite for risk, different approaches to strategy modification may be taken.

Project Type

The second categorization of data focused on trends based on project type. Project types were assigned based on the similarity of services performed in the construction of buildings within each type (Drew, 2001). For example, the construction demands (e.g. a ground floor lobby and several floors of similarly laid out spaces) of hotels and apartments are very similar, so they were grouped together. A breakdown of project types is given in Appendix A. Important to note is that 'Service' type projects refer to recurrent electrical maintenance and upgrades requested by the contracting party. Overall, an immediate trend can be observed reflective of the same trends observed in the categorization based on contract value; figures are shown in Table 1. In general, building types with a higher average contract value had higher average percentage use of hour rates, as shown in Figure 3 and again in a ranking of these measures given in Table 3. Several building types were also found to have exceeded their overall allotment of coordination hours. In these cases, the average contract value of the building type was higher than other building types that did not exceed their allotment of coordination hours. Taken in tandem, these figures suggest the idea that the primary indicator of a project's BIM coordination requirements is size. An ANOVA test (Appendix B) strongly suggests a correlation ($p = .013$) between project type and project size. For example, service type projects had the smallest average budget at $458,891, a percent usage rate of 32.28, and total usage of 19.15%. The latter figures rank second to last and last respectively when compared to all other project types. This breakdown can be seen in greater detail in Table 3.

Project Manager

The third categorization of data focused on project manager. There were 26 unique project managers that appeared in the full data set. In some cases this made it impossible to accurately determine the individual performance of some project managers with regard to BIM budget accuracy because there was not a large enough sample size for them as individuals. However, data analysis according to this categorization was still quite useful in determining the overall influence that project managers have on projects with respect to the accuracy of BIM budgets. This was done by performing a t-test between contract value and average percentage use of hours according to the project manager classification. The purpose of this test is to determine the degree to which the project manager influences the relationship between the contract value and average percentage use of hours (e.g. the accuracy of the budget). This same test was also performed on the other categorizations; the results can be seen in Table 2. When determining the most influential factors with regard to the accuracy of budgeting, we see that project type and project manager have a much greater relation than project size. As previously established, project size is most important in determining initial budget, with the project type and project manager being the most important values in predicting budgetary accuracy from then on.

The additional implications of this analysis are significant because they suggest a high degree of inaccuracy within the estimates of many jobs, even though overall the BIM department is staying within its total allotted budget. It is important to note here the limitations of the data and analysis presented. These data represent figures for a single electrical contractor and the conclusions drawn from an analysis thereof may not be applicable to other types of contractors or subcontractors. However, this analysis can provide a general framework for how other electrical contractors may examine their BIM budgeting strategy.

CHAPTER 5

CONCLUSION

A case study was undertaken with the purpose of focusing on the technology and budgeting practices of an electrical contractor and was aimed at establishing a framework within which electrical contractors may better ascertain their budgetary needs with regard to BIM. The proper budgeting of BIM resources along with its integration into the estimation process were the primary areas of research interest. The subject of this case study was a medium-sized electrical contractor in a major metropolitan area. There are several main conclusions that can be drawn from the research effort.

Large projects need a commensurately large budget. Based on the analysis provided, the contractor has a tendency to underestimate the BIM coordination requirements for projects of contract value in excess of $3.2 million. It is recommended that contractors looking to establish a budgeting framework based on this analysis adjust appropriately their budget for jobs that would fall into their top quintile of jobs by contract value. As discussed previously, it was determined that project size is the primary driver of initial BIM budget requirements. Subsequently, electrical contractors should then assess the type of project and then consider the previous success of their specific project managers with regard to BIM budgetary accuracy when determining the BIM budget for a project.

The next conclusion is that small projects need a smaller budget. In contrast to the issue faced by some larger projects, many of the smaller projects use only 30-40% of their budget. The coordination budgets for these jobs could be reduced by 50% and still leave a gap between the amount of hours budgeted and hours spent. In developing a conceptual framework for budgeting, electrical contractors should consider that many small jobs barely need any BIM coordination budget at all.

Beyond making adjustments to coordination estimates, the integration of BIM into the estimation process would allow for a better understanding of modelling requirements at the outset of the pre-construction phase, because those requirements are actively being assessed, rather than having a budget assigned based purely on past projects. This would also allow a company's BIM department to get a jump start on the coordination process, which would in turn allow for more time to be spent on clash detection further along in the coordination process. This could provide for faster, more efficient and cheaper coordination overall. Though it is beyond the focus of this paper, this would also have the bonus and more significant effect of optimizing the materials estimate, if the technologies currently available were appropriately utilized.

It should be acknowledged that there may be an underlying logic to the existing budgeting strategy. It may be that to increase bidding competitiveness for larger contracts, coordination hours are intentionally underestimated. To offset this, coordination hours on smaller jobs would need to be overestimated to make up for what would otherwise be a shortfall in hours.

Currently, the majority of BIM processes at the subject company are done using the latest version of AutoCAD MEP. More sophisticated software packages such as Revit are much more commonly used by general contractors, architects and engineers (The National BIM Report, 2019). However, to fully realize the potential of available technology and optimize pre-construction, it will be necessary to adopt programs such as

Revit, which can fully track every piece of material modeled, produce schedules, and attach dollar values to modeled material. Additionally, modelling a project during bid allows for the ability to save time when coordination and clash detection are undertaken later on in the pre-construction process (Li et al, 2014). Incorporating programming language add-ins like Revit's Dynamo or VBA in Excel provide another opportunity for time and cost savings. The automation of tasks, or even the entire coordination process itself through the use of techniques such as procedural generation, represent a possible next step in pre-construction work-flow optimization (Dore and Murphy, 2014), (Janssen, 2015) (Thomson and Boehm, 2015).

Again it is important to acknowledge the limitations of the chosen research format, and also remember the intent of the research. The results of this case study cannot be generalized and applied across the entire construction industry. The results of this case study are intended to yield findings relevant to the electrical contracting industry and aid in the development of conceptual framework for BIM budgeting among electrical contractors.

Areas for future research include expanding the analysis performed to include metrics such as customer satisfaction or project success. This would require an updated dataset and is not presently possible for the specific case study performed, as these metrics are unavailable for the jobs that were analyzed.

TABLE 1 – ANALYSIS OF DATA

Project Category	N	Average Contract Value ($)	Average BIM Hours Budgeted	Average BIM Hours Spent	Average Percentage Use of Hours	Total Hours Budgeted	Total Hours Spent	Percentage of Total Hours Used
Overall								
	245	2378722	219.5	177	57.27	53779.9	43300.5	80.51428136
Project Size								
Quintile 1	49	8929836	880	790	102.2	43124	38729	89.80845933
Quintile 2	49	1757833	111.3	58.1	71.1	5455.1	2848	52.20802552
Quintile 3	49	698303	52.68	14.96	33.6	2581.2	733	28.39764451
Quintile 4	49	343095	35.01	14.48	44	1715.6	709.5	41.35579389
Quintile 5	49	169544	18.44	5.73	35.51	903.5	281	31.10127283
Building Type								
Core & Shell	23	4780826	297.4	422	87.6	6839.4	9717	142.0738661
Data Center	13	3112421	212.2	100.8	109.9	2758.7	1311	47.52238373
Educational Facility	19	1589132	96.7	91.4	44.4	1836.7	1737.5	94.59900909
Government	12	2608119	178.5	95.1	50.2	2142.4	1141	53.25802838
Healthcare	19	3932000	608	304	34.4	11544	5779	50.06063756
Hotel/Apartments	13	3007106	281	331	77.4	3658	4298	117.4958994
Parking Garage	4	983644	86.6	36.8	42.64	346.3	147	42.44874386
Retail/Dining	9	1588064	134.8	60.1	19.4	1213	541	44.60016488
Service	47	458891	42.65	8.15	32.28	2004.7	383	19.10510301
Sports & Entertainment	9	4302432	776	922	168.8	6980	8299	118.8968481
Tenant Fit-out	77	2322120	187.7	129.7	53.28	14456.4	9947.5	68.81035389
Project Manager								
PM1	20	1201954	101.7	68.5	27.6	2034.6	1371	67.38425243
PM2	7	1135891	85.7	7.29	5.38	599.8	51	8.502834278
PM3	8	7605642	592	778	99.8	4733	6221	131.4388337
PM4	8	2363440	223	150.5	71.5	1788	1204	67.33780761
PM5	9	1296822	55.4	6.17	17.38	499	55.5	11.12224449
PM6	28	493745	25.33	11.5	42.6	709.2	322	45.40327129
PM7	19	3644053	215.2	208.7	139.1	4089.4	3965	96.95798895
PM8	11	3455161	278.5	30	14.22	2580	330	12.79069767
PM9	5	5879827	841	875	189.3	4207	4376	104.0171143
PM10	9	1320115	124.7	124.9	50.5	1122.4	1124.5	100.1870991
PM11	15	731250	114.2	34.3	16.48	1712.8	514	30.00934143
PM12	3	544102	33.4	1.33	58	100.2	4	3.992015968
PM13	20	4853539	589	314	73.7	11784	6277	53.26714189
PM14	6	5420752	912	1175	107.5	5473	7051	128.8324502
PM15	11	772862	54.8	9.73	18.29	603.3	107	17.73578651
PM16	11	5110261	379	295	69.9	4173	3243	77.71387491
PM17	5	4898887	353	494	77.8	1767	2470	139.7849462
PM18	3	608514	26.33	29.3	145	79	88	111.3924051
PM19	8	431394	21.7	21.38	82.6	173.6	171	98.50230415
PM20	10	645936	33.85	0	0	338.5	0	0
PM21	1	1092533	28.3	0	0	28.3	0	0
PM22	4	1044748	92.9	43.3	32.7	371.7	173	46.54291095
PM23	1	3967000	443.3	804	181.37	443.3	804	181.3670201
PM24	14	245527	57.4	2.07	20	803.6	29	3.608760577
PM25	6	449603	67.9	61.8	88.7	407.4	370.5	90.94256259
PM26	3	12918008	1053	993	134.3	3159	2980	94.33364989
AVG Hourly Rate ($):	61.97							

TABLE 2 – T-TEST RESULTS: CONTRACT VALUE AND AVERAGE PERCENTAGE USE OF HOURS BY PROJECT MANAGER, PROJECT SIZE AND BUILDING TYPE

Average Contract Value and Average Percentage Use of Hours				
	N	T-Value	DF	P-Value
by PM	26	4.77	25	0.000068
by Project Size	5	1.43	4	0.225
by Building Type	11	6.25	10	0.000095

TABLE 3 – RANKED LISTING OF CONTRACT VALUE AND AVERAGE PERCENTAGE USE OF HOURS BY PROJECT MANAGER, PROJECT SIZE AND BUILDING TYPE

Rank by Average Contract Value	Rank by Average Percentage Use of Hours	Project Manager
1	5	PM 26
2	7	PM 3
3	1	PM 9
4	6	PM 14
5	13	PM 16
6	10	PM 17
7	11	PM 13
8	2	PM 23
9	4	PM 7
10	23	PM 8
11	12	PM 4
12	15	PM 10
13	21	PM 5
14	18	PM 1
15	24	PM 2
16	26	PM 21
17	17	PM 22
18	20	PM 15
19	22	PM 11
20	25	PM 20
21	3	PM 18
22	14	PM 12
23	16	PM 6
24	8	PM 25
25	9	PM 19
26	19	PM 24

Rank by Average Contract Value	Rank by Average Percentage Use of Hours	Quintile
1st	1st	1
2nd	2nd	2
3rd	5th	3
4th	3rd	4
5th	4th	5

Rank by Average Contract Value	Rank by Average Percentage Use of Hours	Building Type
1	3	Core & Shell
4	2	Data Center
8	7	Educational Facility
6	6	Government
3	9	Healthcare
5	4	Hotel/Apartments
10	8	Parking Garage
9	11	Retail/Dining
11	10	Service
2	1	Sports & Entertainment
7	5	Tenant Fit-out

FIGURE 1 – DISTRIBUTION OF PROJECTS BY CONTRACT VALUE

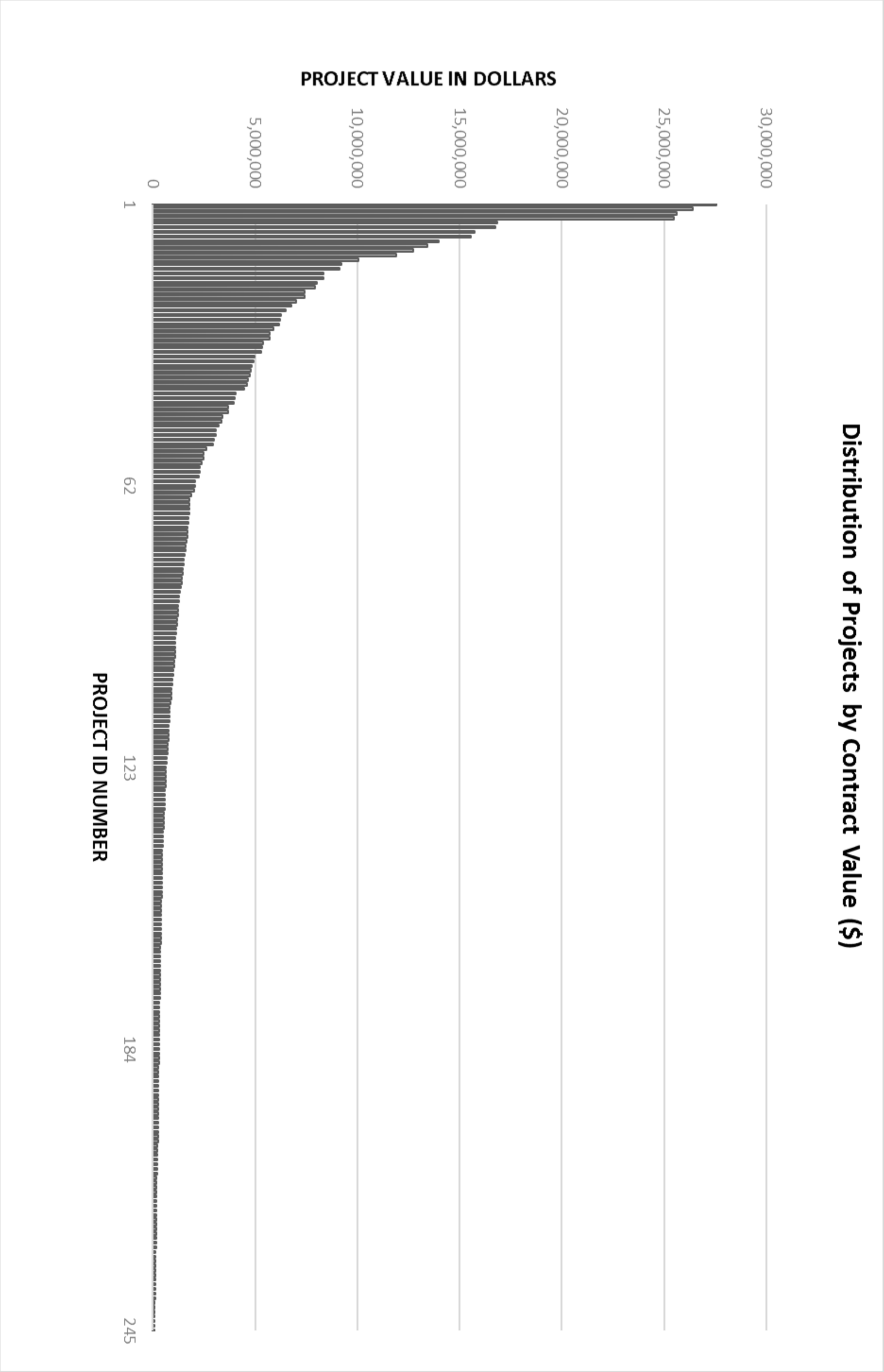


FIGURE 2 – COMPARISON OF CONTRACT VALUE AND AVERAGE PERCENTAGE USE OF HOURS BY QUINTILE

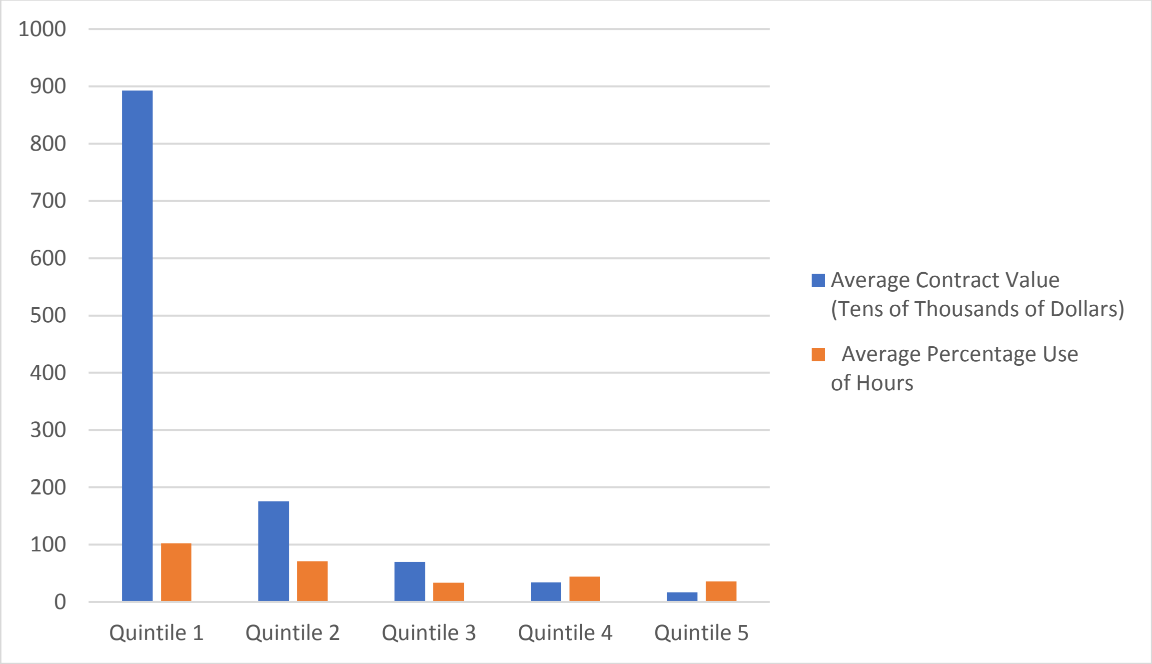


FIGURE 3 - COMPARISON OF CONTRACT VALUE AND AVERAGE PERCENTAGE USE OF HOURS BY BUILDING TYPE

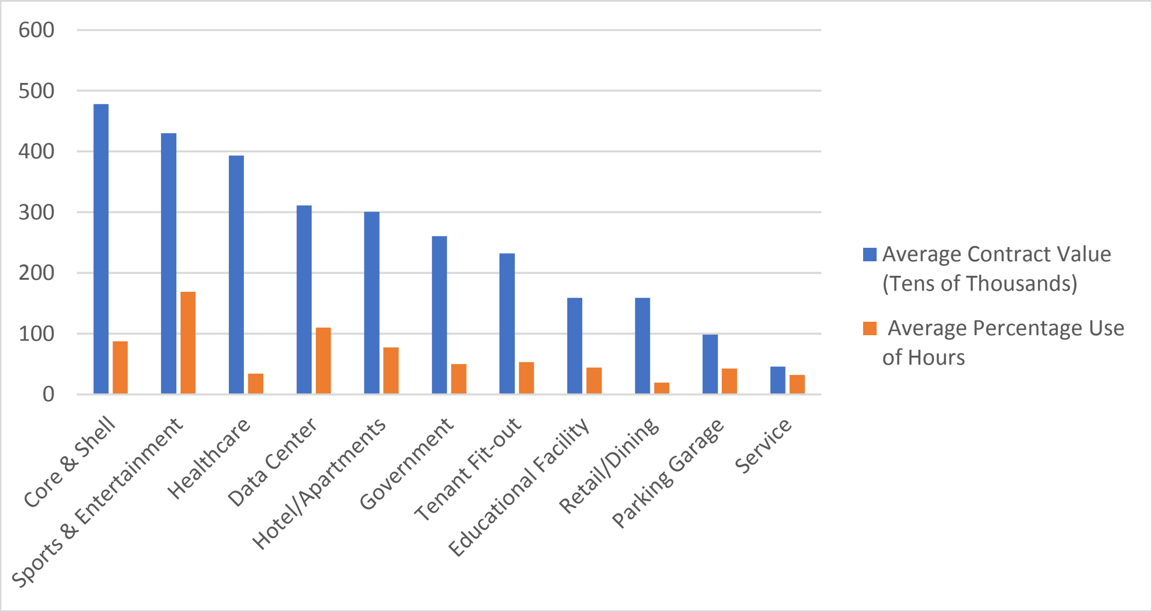
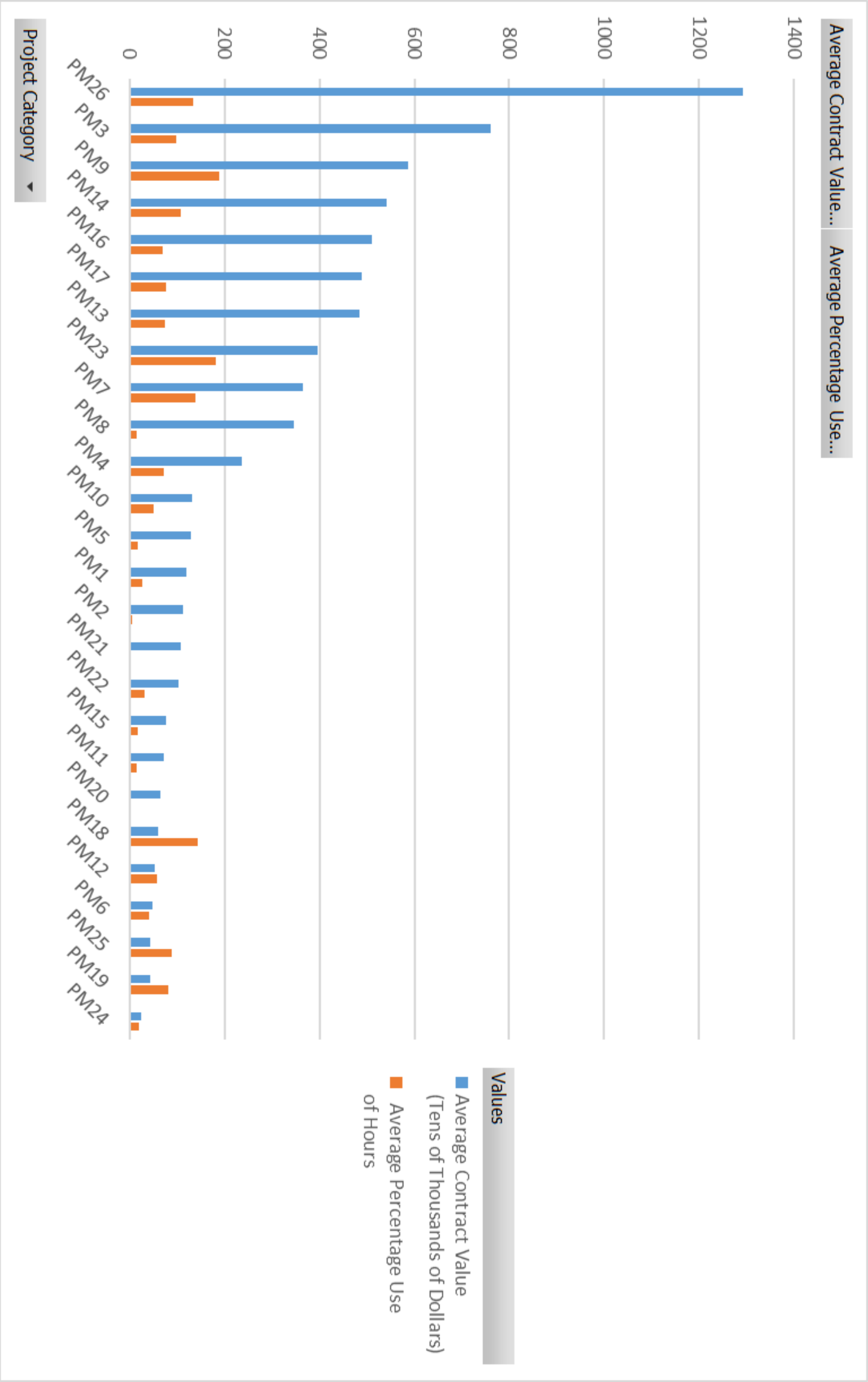


FIGURE 4 - COMPARISON OF CONTRACT VALUE AND AVERAGE PERCENTAGE USE OF HOURS BY QUINTILE



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APPENDIX A

DESCRIPTION OF BUILDING TYPES

Project Type	Characteristics
Core & Shell	Tenant space left largely empty; only core systems are constructed
Data Center	High volume of electrical equipment and conduit; multiple-redundancy power systems and large load demands
Educational Facility	Typical demands include the construction of classrooms, technology and science labs, libraries and gymnasiums
Government	With regard to the case study subject, these projects often involve sensitive security and emergency systems, with great demand for secrecy surrounding project logistics
Healthcare	Requires multiple-redundancy power systems for critical facility infrastructure (ex. Life-support systems), as well as numerous dedicated circuits and panels for various high-tech systems
Hotel/Apartment	Often characterized by a ground floor lobby with anywhere from a dozen to hundreds of repeating layouts with consistent load demands throughout the structure
Parking Garage	Low power demands, minimal lighting requirements, may require EV charging stations
Retail/Dining	Often a tenant in larger structures (strip malls, shopping centers, etc.) - lighting loads may vary
Service	Involves the installation and/or recurrent maintenance of UPS systems, generators, switchgear and panels
Sports & Entertainment	Necessitates specialty electrical lighting and systems. May require lengthy conduit runs in the case of stadiums
Tenant Fit-out	typically office space projects, with similar lighting requirements and predictable load demands scaling with project size

APPENDIX B

ANOVA ANALYSIS OF CONTRACT VALUE AND BUILDING TYPE

Factor Information

Factor	Levels	Values
Building Type	11	Core & Shell, Data Center, Educational Facility, Government, Healthcare, Hotel/Apartment, Parking Garage, Retail/Dining, Service, Sports & Entertainment, Tenant Fit-Out

Method

Null Hypothesis: All means are equal

Alternative Hypothesis: All means are not equal

Significance level: α = 0.05

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Building Type	10	4.23E+13	4.23E+13	2.33	0.013
Error	234	4.26E+15	1.82E+13		
Total	244	4.68E+15			