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Correlation of Construction Performance Indicators and Project Success in a Portfolio of Building Projects

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Abstract: Construction management is a highly competitive project-based field of complex specialized services, creating or altering the built environment for a client. For construction projects to be successful, and in turn, for construction firms to be successful, understanding the relationship of performance statistics as indicators of project outcomes, such as cost, time, and profitability, is essential. There have been a number of efforts made to identify key performance indicators related to construction project success. However, due to lack of available data, many questions remain. There lies an opportunity to analyze project statistics as indicators of project success, similar to the way analytics have been used to predict success in sports. Construction firm project data for a portfolio of building projects were analyzed, and this study identifies correlated factors for completed building construction projects. A highlight of this correlation analysis identified profit differential as demonstrating a strong relationship with the number of requests for information and architects supplemental instructions on a project.

Keywords: correlation; performance indicators; construction management

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1. Introduction

Construction management is a highly competitive project-based field of complex specialized services, creating or altering the built environment for a client. For construction projects to be successful, and in turn, for construction firms to be successful, understanding the relationship of performance statistics as indicators of project outcomes, such as cost, time, and profitability, is essential. Historically, these evaluations have been performed internally by the firm, and limited literature is available based on actual internal project statistics for commercial construction building projects. There lies an opportunity in the industry to analyze project statistics as indicators of project success in much the same way that analytics have been used to predict success in sports, as popularized by the book and subsequent movie *Moneyball* [1]. An ENR top 400-ranked construction firm requested analysis of project data for a portfolio of commercial building projects, in search of factors that can be closely managed to improve the opportunity for project success. The analysis presented here searches for patterns, related project statistics, or related factors in the project portfolio data. This study identifies correlated factors in the completed construction project data. Then, the correlations are analyzed for contributing factors that may indicate project success and to attain recommendations for further analysis.

2. Background

Project management research generally deals with solving practical problems and identifying the factors that influence projects and that are relevant to managerial implications [2]. The exploration of success in construction projects, along with efforts to better understand what constitutes a successful outcome, and what factors contribute to success, have been ongoing for decades. Pace [3] recognized that project success factors are important to the overall successful outcome of a project, examining a number of studies in an attempt to correlate reported project success with the chosen project management methodology, but recognizing only a weak correlation at best. Determining project success is dependent on the stakeholder's role in the project [4–16]. Pinto and Slevin [10] discussed the criteria for a project consisting of the following characteristics: a specified time for completion (schedule), a limited or defined budget (budget), performance expectations and a series of activities (performance), and issues dealing with the client (client satisfaction). The defined characteristics of a project become the criteria evaluated to determine success, and if the characteristics are incomplete, a determination of project success may be incomplete or inaccurate. Critical success factors (CSFs) can help quantify the success of a project, but which CSFs contribute the most to performance and if they apply equally to all stakeholders continues to be an ongoing debate [12]. Atkinson [5] goes on to state that success must be defined beyond the simplistic "iron triangle" of cost, schedule, and quality, and should include the criteria of the information system, organizational benefits, and stakeholder community benefits. Shenhar et al. [9] identified four project success dimensions: project efficiency, impact on the customer, organizational success, and preparation for the future. Cooke-Davies [6] identified 12 critical success factors in three distinct categories: project management success (time, cost, quality, performance), project success (overall project objectives), and consistently successful projects (repeated performance).

For contractors, overall project success may be out of their hands if the goals of the project do not align with the client's organizational need, investment strategy, or changing market conditions, regardless of project management success or consistently successful organizational operations practices [7,14]. The complexity of construction projects can impact project success from the perspective of the contractor; however, the investigation of those elements and the quantifying of their impacts on project success is limited [16]. Rämö [17] discusses the concept of performing project processes (doing things right) in efficient project time, but notes that the success of the project may require taking the correct action at the key appropriate progression of the project (doing the right thing), and the contractor may not have the knowledge or authority to do so. As a business, construction managers and contractors acting as project delivery organizations invest time and resources to complete a project, with the expectation that the project will recoup the investment and earn a profit. In that case, strategic project selection and allocation of resources at the firm level can play a role in client satisfaction and project success, independent of project management success [2]. Determining when a project is successful requires the appropriate scale for the appropriate stakeholder, such as project management success, project ownership success, and project investment success [8].

Construction managers and contractors, as project delivery organizations, should focus on understanding what project factors, statistics, or attributes contribute to project management success such as profit and are essential in directing project effort to achieve project success from their perspective [8]. The Project Management Institute identifies the knowledge areas essential in meeting construction project requirements as: integration; scope; schedule; cost; quality; resource; communication; risk; procurement; stakeholder; health, safety, security, and environment; and financial management [18]. Self-assessing performance is crucial for a contractor to drive individual performance improvement [13]. Gunasekara et al. [13] found that the key areas of performance included the categories of health and safety, quality, experience, financial, environmental, human resources, and productivity. Although construction managers and contractors may define project success by a number of factors for their organization, including keeping their workforce employed, developing a new client or market, strengthening reputation or capabilities, and growing experience, in the financial category, project success can be quantified in terms of return on investment, realized profit, and debt ratio [8,11,13].

Earned value management (EVM) considers scope, time, and cost to monitor performance over time to drive project success [15]. EVM should motivate project teams to monitor costs and progress to make timely decisions to achieve project success. EVM, however, may not account for the implications of all factors regarding the project. Construction managers and contractors, in determining project success from their perspective, should seek to understand the implications of the documented occurrences on a project, such as project factors, statistics, or attributes, and how they relate or contribute to project success, such as through realized profit or profit margin. If the factors related to project success can be identified, improving the performance of those factors can improve performance on a project or a portfolio of projects. Cooke-Davies [6] found that cost escalation was not strongly correlated to schedule delay for individual projects. In that study, self-reported and inferred project management practices among 23 organizations were ranked by their developed process maturity on a scale of "not at all adequate" (1), to "fully adequate" (4). Analyses of these processes resulted in a correlation between schedule and cost performance against the schedule and budget, respectively. The projects evaluated averaged USD 16 million and 3 years, with a median of USD 2 million and 18 months, and ranging up to USD 300 million and 10 years. Cooke-Davies [6] further found that the presence of a few of the project management processes, rated by maturity and adequacy, correlated to on-time or on-cost performance. However, quantifying factors such as the adequacy of company-wide education on the concepts of risk management or the maturity of an organization's process for assigning ownership of risk to an outcome is very difficult. Whether or not a company participates in these practices and the qualitative maturity or adequacy of a practice does not indicate correlation to an outcome of success on a given project, or any factor of the project. Further, Shahandashti et al. found that considerable research consistently highlights the importance of risk management to success, but found that schedule, cost, cash flow, change management, and safety were the top five areas of key results [11].

Construction performance management involves the monitoring of past performance, improvement of individuals and teams, and evaluation and improvement of processes [19]. Key performance indicators (KPIs) in construction performance management play a critical role in the success of construction projects [20–24]. The benchmarking of KPIs could improve project management performance [11,25]. Suk et al. [26] and Alvarado et al. [27] proposed performance dashboards for benchmarking project performance and the performance of a portfolio of projects. These dashboards proposed the use of performance scores based on KPIs, weighted schedule performance, or budget performance. However, weighted performance scores and several of the KPIs suggested are qualitative and difficult to correlate with quantitative project factors.

According to Habibi et al. [28], " ... success of construction projects can be attributed to the effective time/cost performance of project ... " Many studies have attempted to identify the leading performance indicators (LPIs) of engineering, procurement, and construction (EPC) projects, but inconsistency between indicators identified in the studies and their ability to indicate success have resulted in no universal method. Habibi et al. [28] concluded that design change is the principal cause of delay and cost overruns on projects, but the study does not provide a means for correlating design change, or other contributing factors, to project success, primarily due to limited project data factors.

There is very limited literature indicating the relationship between key attributes of construction projects and profit margin [29]. Construction projects collect a large amount of data concerning project factors, the process, and the outcomes. Often, that information is held internally by the contractor and not released or readily available for analysis outside of the company. As such, limited methods are available in the literature to analyze construction project data to indicate success. Big data approaches have been proposed to demonstrate project analysis, but have limited applications for indicating success for any given construction company on a given project [29]. With enough data, the Pearson correlation can be calculated to determine connections between project factors, including success [30]; however, there is typically not enough historical data to determine correlation [31].

Data analytics from sports offer a parallel to analyzing project success from performance factors. Recognized in the book *Moneyball* [1], statistical analysis of various in-game occurrences in baseball could indicate successful outcomes, such as games won, and be further used to build a more successful team. These types of analyses have been used in sports beyond baseball. Performance indicators (PI) can be analyzed with match outcomes, such as win-loss or score margin, in Australian (Rules) Football (AF) [32]. PIs can be classified as two types: (1) those gathered directly, and (2) those created from original PIs. Further collinearity, or the Pearson correlation, can be checked using a correlation matrix. In tennis, it appears that individual performance factors are correlated to overall performance regarding the win rate among tennis players [33].

This research targets the gap in the literature, analyzing construction company project data from actual projects to determine factors that indicate project success. The intent is to use a similar sports analytics approach to analyze the project data. The implication is that if PIs parallel project factors and match outcomes parallel successful projects, the key project performance factors can be identified. Similar correlation analysis could be performed for construction projects, where instead of win-loss or score margin, profit margin or projected project profit achievement could be used as project success indicators, and correlated project factors could be identified for a group of projects. A correlation matrix of project factors and outcomes can be created in an attempt to identify correlated factors of project outcomes that can be used as indicators of project success. This analysis could be the first step to further analysis in predicting project success based on project performance factors.

3. Methodology

This research targets the analysis of construction project performance data using a correlation matrix of project factors and outcomes to identify correlated factors that can be used as indicators of project success.

Correlations between price and duration have been studied in construction projects encompassing various sectors. There is a lack of studies on the correlation of performance indicators regarding a portfolio of construction projects related to project success, including profit and duration. This analysis investigates the correlation of performance indicator data in a portfolio of construction projects. This analysis will investigate the correlations among key performance indicators to determine if relationships exist between the duration, cost, and profit to other variables with the methodology shown in Figure 1.

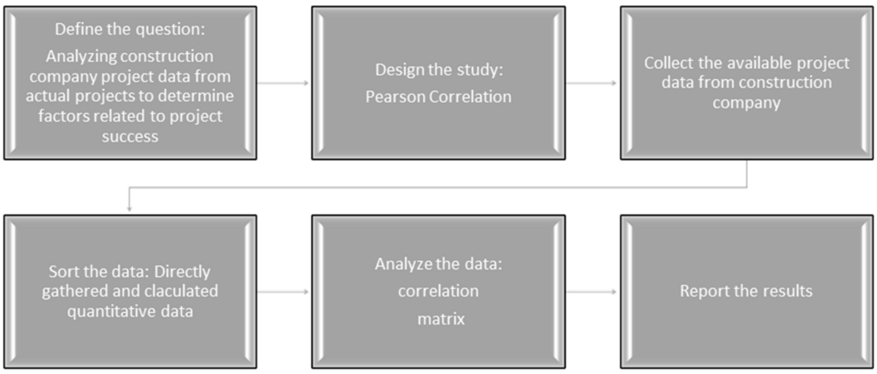

Figure 1. Overview of the methodology.

Correlation has been investigated between individual factors and overall performance in sports. These types of analyses have been used in sports, as outlined by Lewis [1] for baseball, and beyond baseball, including the correlation of individual factors to predict overall success in tennis [25], and PI can be analyzed with match outcomes, such as win-loss or score margin in AF [32].

3.1. Population and Sample/Data Collection

Data for 108 current commercial construction projects was provided for analysis to better understand project success and the factors leading to discrepancies in duration, project cost, and profit differential from those planned. The company data provided was separated into projects completed between May and September 2020 (including complete data). This resulted in 23 projects. Only projects with completed data were used in this analysis because it would not be possible to determine project success prior to project completion, which could artificially skew results. Additional data were requested twice, after an initial review and after the subsequent review, with the aim of providing a more complete analysis. The additional data was provided in December 2020 and March 2021. The 23 projects were then analyzed with the additional factors. The data factors were identified by category as nominal, qualitative, and quantitative. The quantitative data was used for this analysis. Certain factors, such as the contract price and contract days, are predicted data, where the actual final price and actual days are recorded data. Some of the predicted data comes from various stages of project preparation, from the estimate phase leading up to the proposal or bid, the contractual obligation, or the management planning following the award.

Young et al. [32] identified performance indicators (PI) as represented by two types: (1) gathered directly, and (2) created from original PIs. In addition to the recorded data gathered directly, some differential calculations created from the recorded data were included in the analysis, as advised by the expertise of the contractor. In the analysis, six schedule differential calculations were included. These calculations produced the difference between schedule days at different documented points in the project progression. In addition, the analysis included one profit differential calculation showing the difference between actual profit less budgeted profit, in that order, so that a positive number represented a more profitable project than budgeted. All the data factors by category used are shown in Table 1.

Table 1. Project data factors sorted by categories.

Nominal Data	Qualitative Data	Directly Gathered Quantitative Data	Calculated Quantitative Data
Job Number	SILO	Building square footage	Estimated days–Actual days
	PM	Number of floors	Scheduled days–actual days
	Market	Site acreage	Estimated days–scheduled days
	Project type	Estimated days duration	Contract days–actual days
	Contract execution date	Contract days Duration	Estimated days–contract days
	3 Week Look-Ahead Schedule software used for project	Schedule days duration, ops team	Contract days–scheduled days
	Overall scope description	Actual days duration at completion	Actual profit–budgeted profit
		Contract price	
		Approved change order price	
		Final project price	
		Number of addendums and owner incorporated changes	
		Request for information and architect supplemental instructions	
		Number of punch list items	
		Overhead and general conditions Cost for the project	
		Budgeted profit	
		Actual profit	

3.2. Data Analysis

The data was compiled to include only quantitative data, with abbreviated column headings to be analyzed to find the Pearson correlation. The abbreviated column headings and the data factors are shown in Table 2. The analysis was performed using R Studio statistics software. A Pearson correlation analysis was performed to identify any significant correlations between data factors. In addition, a correlation matrix was produced to visualize the data. Correlation indicates the relative strength of a relationship between factors, but is not necessarily an indication of causation. Dancey and Reidy [25] identified correlation coefficients of +1 and −1 as perfect, and 0.9 to 0.7 and −0.7 to −0.9 as strong correlations.

Table 2. Project data factor abbreviations.

Abbreviation	Data Category
Job	Job Number
Bldgsf	Building square footage
Floors	Number of floors
Site.acre	Site acreage
Est	Estimated days duration
Cont	Contract days Duration
Sched	Schedule days duration ops team
Act	Actual days duration at completion
Est.act	Estimated days–Actual days
Sched.act	Scheduled days–actual days
Est.sched	Estimated days–scheduled days
Cont.act	Contract days–actual days
Est.cont	Estimated days–contract days
Cont.sched	Contract days–scheduled days
Price	Contract price
Co	Approved change order price
Fin.price	Final project price
Add.oic	Number of addendums and owner incorporated changes
Rfi.asi	Requests for information and architects' supplemental instructions
Punch	Number of punch list items
Oh.gc	Overhead and general conditions cost for the project
Bud.prof	Budgeted profit
Act.prof	Actual profit
Prof.dif	Actual profit–budgeted profit

4. Findings

The data mean, median, and range maximum for the project data for each data factor were calculated and are included in Table 3 below.

Table 3. Data factor statistical analysis for project group.

Data Factor	Mean	Median	Range Max
Building square footage	136,357	76,005	605,000
Number of floors	0	0	1
Site acreage	4	0	45
Estimated days duration	79	50	217
Contract days duration	95	64	227
Schedule days duration, ops team	86	58	240
Actual days duration at completion	78	55	205
Estimated days–actual days	1	−5	118
Scheduled days–actual days	8	6	38
Estimated days–scheduled days	−6	−12	109
Contract days–actual days	18	12	115
Estimated days–contract days	16	10	65
Contract days–scheduled days	10	5	106
Contract price	4,436,338	617,766	25,752,359
Approved change order price	131,441	0	2,041,377
Final project price	4,567,779	672,564	25,869,752
Number of addendums and owner incorporated changes	5	1	22
Requests for information and architects' supplemental instructions	23	7	136
Number of punch list items	64	23	359
Overhead and general conditions cost for the project	41,266	12,636	196,315
Budgeted profit	160,601	31,369	750,069
Actual profit	187,380	65,472	946,745
Actual profit–budgeted profit	26,779	4575	232,773

Analysis resulted in the correlation matrix, shown in Figure 2, displaying the correlation coefficients for each relationship. As the legend on the right side of the figure indicates, the coefficients range from +1, indicated with a dark blue color, to −1, indicated with a dark red color, with zero as white, and increasingly lighter shades of blue and red, respectively, as the coefficient approaches zero. Figure 3 shows the correlation coefficients graphically in black and white. As the legend on the right side of the figure indicates, the coefficients range from +1, with positive coefficients indicated with a black circle, to −1, with negative coefficients indicated with a white circle, with the size of the circle decreasing as the coefficient approaches zero.

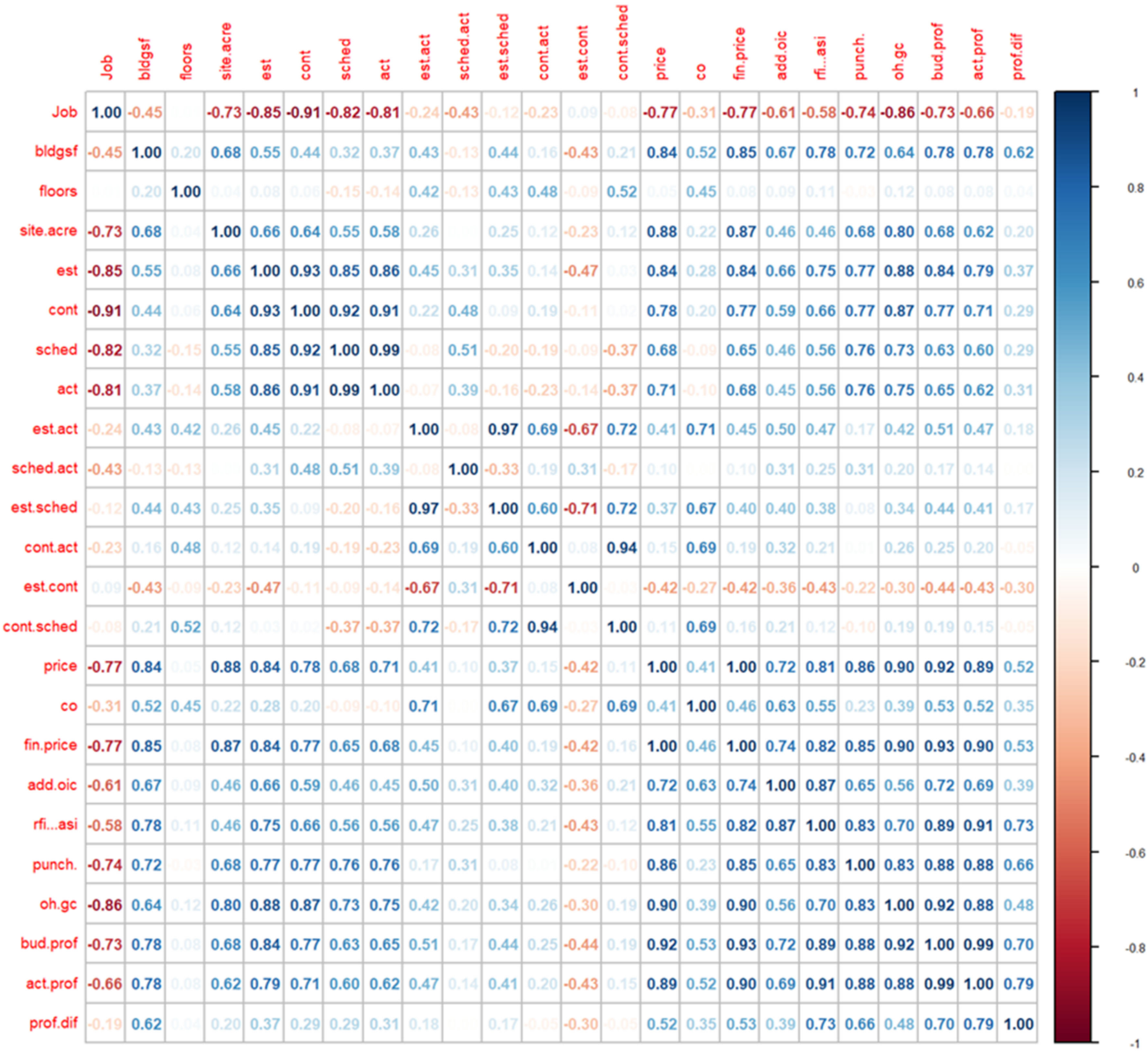

Figure 2. Correlation matrix of project data factors.

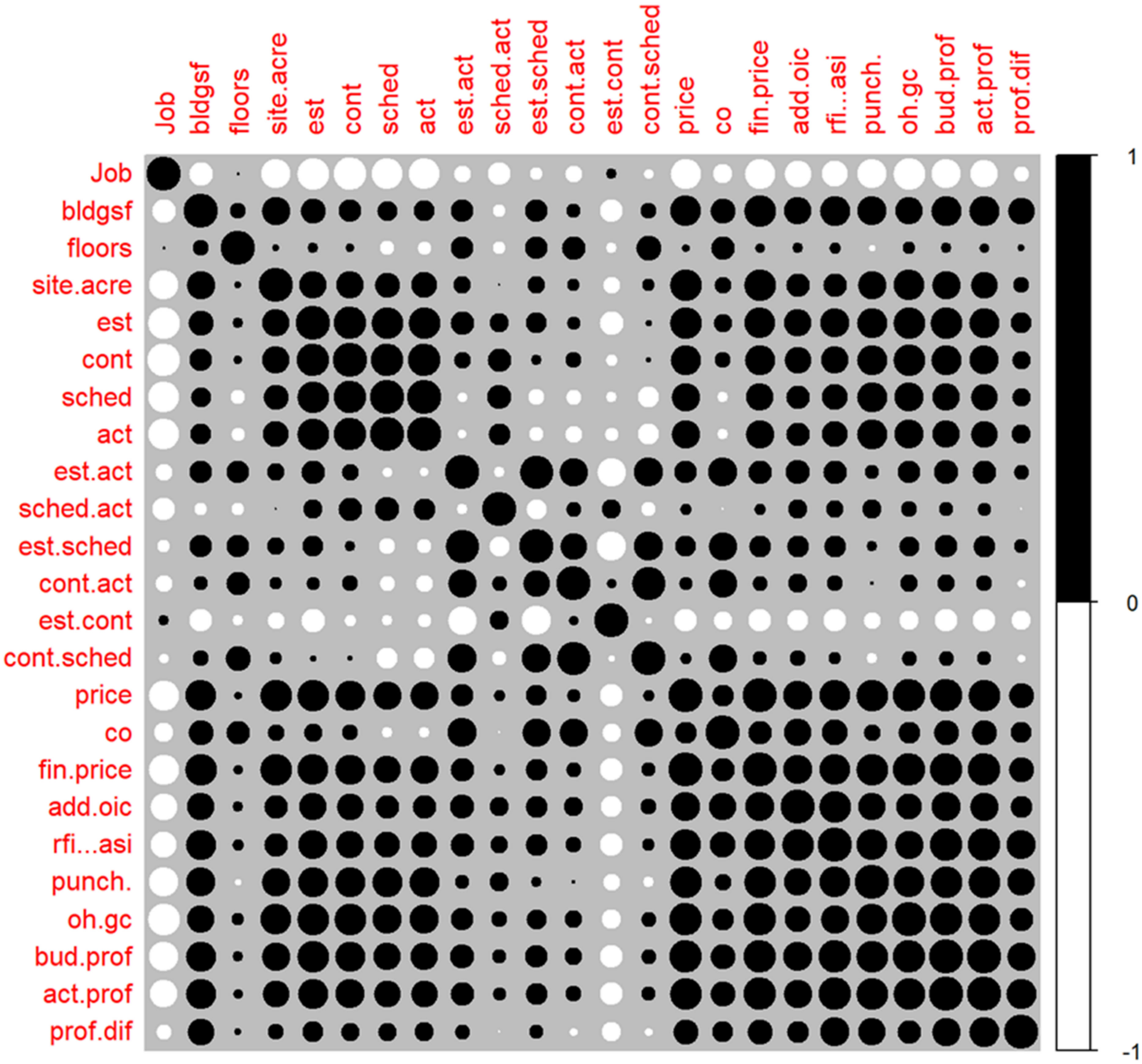

Figure 3. Correlation matrix of project data factors, shown graphically.

There were 23 factors tested for correlation. Each factor has a correlation of 1 with itself, resulting in a total of 253 possible relationships between factors. The threshold of |0.7|+ indicates a strong correlation [34] and is considered significant for this analysis. The statistical analysis of the data factors from this project group resulted in 66 significant correlations among all factors, and these are shown in Table 4.

Table 4. Project group dataset significant correlation factors |0.7|+.

Correlation	Factor 1	Factor 2
1	Price	Final Price
0.99	Scheduled days	Actual Days
0.98	Budgeted profit	Actual Profit
0.97	Estimated days–actual days (dif)	Estimated days–scheduled days (dif)
0.96	Estimate days	Actual days
0.94	Contract days–actual days (dif)	Contract days–scheduled days (dif)
0.93	Estimate days	Contract days
0.92	Contract days	Scheduled days
0.92	Overhead/General conditions	Budgeted profit
0.92	Budgeted profit	Final price
0.91	Contract days	Actual days
0.91	Budgeted profit	Price
0.91	Actual profit	RFI ASI
0.9	Actual profit	Final price
0.89	Overhead/General conditions	Price
0.89	Overhead/General conditions	Final price
0.89	Budgeted profit	RFI ASI
0.89	Actual profit	Price
0.88	Site acre	Price
0.88	Overhead/General conditions	Estimated Days
0.88	Budgeted profit	Punch list
0.88	Actual profit	Punch list
0.87	Site acre	Final price
0.87	Addendums/OIC	RFI ASI
0.87	Overhead/General conditions	Actual profit
0.86	Punch list	Price
0.86	Overhead/General conditions	Contract days
0.85	Building square footage	Final price
0.85	Estimate days	Scheduled days
0.85	Punch list	Final price
0.84	Building square footage	Price
0.84	Estimate days	Price
0.84	Estimate days	Final price
0.84	Budgeted profit	Estimated days
0.83	RFI ASI	Punch list
0.83	Overhead/General conditions	Punch list
0.82	RFI ASI	Final price
0.81	RFI ASI	Price
0.8	Overhead/General conditions	Site Acres
0.79	Actual profit	Estimated days
0.79	Actual profit	Profit Differential
0.78	Contract days	Price
0.78	RFI ASI	Building square footage
0.78	Budgeted profit	Building square footage
0.78	Actual profit	Building square footage
0.77	Contract days	Final price
0.77	Punch list	Estimated days
0.77	Punch list	Contract days
0.76	Punch list	Scheduled days
0.76	Punch list	Actual days
0.75	RFI ASI	Estimate Days
0.74	Addendums/OIC	Final Price
0.74	Overhead/General conditions	Actual days
0.73	Profit Differential	RFI ASI
0.72	Estimated days–actual days (dif)	Contract days–scheduled days (dif)

Table 4. *Cont.*

Correlation	Factor 1	Factor 2
0.72	Estimated days–scheduled days (dif)	Contract days–scheduled days (dif)
0.72	Addendums/OIC	Price
0.72	Punch list	Building square footage
0.72	Overhead/General conditions	Scheduled days
0.72	Budgeted profit	Addendums OIC
0.71	Actual days	Price
0.71	Estimated days–actual days (dif)	Change orders
0.71	Actual profit	Contract days
0.7	Overhead/General conditions	RFI ASI
0.7	Budgeted profit	Profit differential
−0.71	Estimated days–scheduled days (dif)	Estimated days–Contract days (dif)

4.1. Directly Gathered Quantitative Data

Final project price, actual construction days, and actual profit are the three outcomes identified to indicate project success, to some degree [4–12,14–16]. All 22 correlations were shown for the final price in Table 5, the actual construction days in Table 6, and the actual profit in Table 7 for further analysis of the factors, with or without strong correlations. None of the analyzed projects were in litigation or dispute, or headed to litigation or dispute. The final price is the actual price agreed upon by both parties and paid to the contractor from the client upon satisfactory completion of the contracted scope of work. Actual construction days equal the duration from notice to proceed to project acceptance by the client through the provisions of the contract, indicating completion of the scope of work, acceptance by the municipality of jurisdiction (certificate of occupancy), and within the specified and agreed upon tolerances (appropriate quality). Additionally, regarding a completed, accepted, and payment received project, actual profit is a good indication of project management success for a project from the contractor's perspective, and in this case, success across a portfolio of projects.

Table 5. Correlations for final price.

	Final Price
Price	1
Budgeted profit	0.93
Overhead/General conditions	0.9
Actual profit	0.9
Site acres	0.87
Building square footage	0.85
Punch list items	0.85
Estimated days	0.84
RFIs and ASIs	0.82
Contract days	0.77
Addendums and OIC	0.74
Actual days	0.68
Scheduled days	0.65
Profit differential	0.53
Change order price	0.46
Estimated days—actual days (dif)	0.45
Estimated days—scheduled days (dif)	0.4
Contract days—actual days (dif)	0.19
Contract days—scheduled days (dif)	0.16
Scheduled days—actual days (dif)	0.1
Floors	0.08
Estimated days—contract days (dif)	−0.42

For the final price, eleven factors with strong correlations were identified: price, budgeted profit, overhead/general conditions, actual profit, site acres, building square footage, punch list items, estimated days, RFIs and ASIs, contract days, and addendums and OIC. In addition, two factors, actual days and scheduled days, are included in the significant threshold at 0.68 and 0.65, respectively, if rounded to one significant digit. Since there is often a strong relationship between the schedule and the cost [5], we could include them in future analysis. Most expected factors show a strong positive relationship with the final price, and that is expected. Change order price does not show a strong correlation to final price, indicating that the value of change orders is different for each project and changes the final contract price at a different rate per project, depending on a number of factors, which could be evaluated in future research. In addition, actual profit and budgeted profit both show strong correlation to the final price; however, profit differential does not show a strong correlation to the final price, indicating that the factors responsible for the difference between the budgeted and actual profit are not captured in this analysis and should be investigated further.

Table 6. Correlations for actual construction days.

	Actual Days
Scheduled days	0.99
Contract days	0.91
Estimated days	0.86
Punch list items	0.76
Overhead/General conditions	0.75
Price	0.71
Final price	0.68
Budgeted profit	0.65
Actual profit	0.62
Site acres	0.58
RFIs and ASIs	0.56
Addendums and OIC	0.45
Scheduled days—actual days (dif)	0.39
Building square footage	0.37
Profit differential	0.31
Estimated days—actual days (dif)	−0.07
Change order price	−0.1
Floors	−0.14
Estimated days—contract days (dif)	−0.14
Estimated days—scheduled days (dif)	−0.16
Contract days—actual days (dif)	−0.23
Contract days—scheduled days (dif)	−0.37

For actual construction days, six factors with strong correlations were identified: scheduled days, contract days, estimated days, punch list items, overhead/general conditions, and price. In addition, final price is included in the significant threshold at 0.68 and budgeted profit at 0.65, if rounded to one significant digit, and these could be included in future analysis, as they should have a strong relationship with actual construction days. Different variations of the schedule, such as scheduled days, estimated days, and contract days, have a strong positive relationship to actual construction days. Price and final price should also have a strong positive relationship to actual days, although the relationship for final price is slightly less than for price, and this could indicate another influencing factor. The strong positive relationship between actual construction days and the number of punch list items is of note and warrants further investigation. Of note, but not completely surprising, the actual days to complete the project do not show a strong correlation to the size of the building in square footage, the number of floors, or the size of the site in acres. This could indicate a number of factors influencing the actual duration of the project, not the least of which is building complexity, from either the interior or exterior finishes or mechanical systems, or a number of other potential factors.

Table 7. Correlations for actual profit.

	Actual Profit
Budgeted profit	0.99
RFI and ASIs	0.91
Final price	0.9
Price	0.89
Punch list items	0.88
Overhead/General conditions	0.88
Estimated days	0.79
Profit differential	0.79
Building square footage	0.78
Contract days	0.71
Addendums and OIC	0.69
Site acres	0.62
Actual days	0.62
Scheduled days	0.6
Change order price	0.52
Estimated days—actual days (dif)	0.47
Estimated days—scheduled days (dif)	0.41
Contract days—actual days (dif)	0.2
Contract days—scheduled days (dif)	0.15
Scheduled days—actual days (dif)	0.14
Floors	0.08
Estimated days—contract days (dif)	−0.43

For actual profit, ten factors with strong correlations were identified: budgeted profit, RFIs and ASIs, final price, price, punch list items, overhead/general conditions, estimated days, profit differential, building square footage, and contract days. In addition, addendums and OIC is included in the significant threshold at 0.69, if rounded to one significant digit, and should be included in future analysis.

In this analysis, building square footage is strongly correlated to actual profit, at 0.78, and is consistent, as budgeted profit also strongly correlated, at 0.78, to building square footage. Actual profit and budgeted profit are very strongly correlated, at 0.99, with actual profit and profit differential strongly correlated at 0.79. Actual profit is also strongly correlated with the price, at 0.89, and final price, at 0.9. Overhead/general conditions is strongly correlated to actual profit, at 0.88; however, overhead/general conditions are more strongly correlated to budgeted profit, at 0.92.

Actual profit is not strongly correlated to actual days, at 0.62, but is more strongly correlated to estimated days, at 0.79 and contract days, at 0.71. This may indicate that there is another influencing factor in the relationship of actual profit and actual days.

RFIs and ASIs at 0.91, addendums and OICs at 0.88, and punch list items at 0.69 are all strongly correlated to actual profit. Budgeted profit is also strongly correlated to RFIs and ASIs, at 0.89, addendums and OICs, at 0.72, and punch list items, at 0.88. Further analysis should look at the relationship between these items, as these items are likely unpredictable prior to their occurrence on a project, and thus, are beyond the control of the contractor.

4.2. Calculated Quantitative Data

Following analysis of the quantitative calculated data, several schedule version differentials demonstrated a significant relationship with another schedule differential. All of the schedule day data factors are strongly correlated, so it follows that differentials calculated from the same factors would show strong correlation. Ultimately, estimated days, contract days, and scheduled days are all predictions for actual days.

Only one schedule differential showed a significant correlation to a recorded data factor. That was estimated days–actual days (dif) and approved change order price (r = 0.71). A total of 18 of the 23 projects (78%) in this group had at least one change order. This relationship represents that an increase in approved change order price is strongly related to the difference between the estimated days and actual days for the project. That factor should be investigated in any additional project group analyses to see if it is consistent or an anomaly within this set of projects. Since there is no data point to capture the increase in contract time associated with an approved change order, only a change in contract value, that additional data point should be included in future studies to better understand this relationship.

Profit differential was the calculation of actual profit less budgeted profit. Only three significant correlations were found, as shown in Table 8. As could be expected, actual profit and budgeted profit are two of the three significant correlations for the calculated differential. The third correlation is interesting, as RFIs and ASIs is found to be strongly correlated to profit differential. There are many possible reasons that could account for this, such as the pricing and clarification of quantified risk. The relationship between RFIs and ASIs and profit differential is of note and should be explored in greater detail.

Table 8. Significant correlations for profit differential.

	Profit Differential
Actual Profit	0.79
RFIs and ASIs	0.73
Budgeted Profit	0.70

5. Discussion

Project success is attributed to several factors, including client satisfaction, which generally results from a number of project outcomes such as time and cost, as well as personal interactions on a project many, of which are hard to quantify. For a contractor, project success often comes down to the actual profit obtained on a project, or more specifically, the positive profit differential. Understanding what PIs lead to this success has been challenging to identify, and this aspect is not well represented in the literature regarding commercial building construction projects. Current methods for determining project success from the contractor's perspective are difficult to correlate with quantitative project factors, or for use as PIs, due to the lack of historical data readily available for analysis, as well as the limited literature indicating the relationship between project factors and profit margin [11,25,28,29]. Construction projects collect a large amount of data concerning project factors, the process, and the outcomes. Often, that information is held internally by the contractor and not released or readily available for analysis outside of the company. As such, limited methods are available in the literature to analyze construction project data to indicate success. Big data approaches proposed to demonstrate project analysis have limited applications for indicating success for any given construction company regarding a given project [29]. These are typically meta-analyses of the costs of public projects by type of project, or a compilation such, as analysis based on RS means data, and do not contain the internal project factors. With enough data, the Pearson correlation can be calculated to determine connections between project factors and success [30]; however, there is typically not enough historical data to determine correlation [31]. This study, with access to extensive project data on 23 completed projects from an ENR top 400 contractor, identified correlated factors of the completed construction project data that indicate project success by looking for correlations between project outcomes and contributing factors. The strength of these correlations can provide recommendations for project areas to closely manage and for further analysis.

Data analytics used in sports offer a parallel for analyzing project success according to performance factors. Recognized in the book *Moneyball* [1], statistical analysis of various in-game occurrences could indicate successful outcomes, such as games won, and be further used to build a more successful team. In a similar way, construction project factors could be observed, analyzed, and managed to deliver project success. In addition to their use in baseball, these types of analyses have been used in AF and tennis, where PIs can be analyzed using match outcomes, such as win-loss or score margin [32]; in tennis, it appears that individual performance factors are correlated to win rate among tennis players [33].

In this case, we parallel actual profit identified regarding construction projects to the win rate and look for correlation with contributing factors of other project recordables. The Pearson correlation of PIs, checked using a correlation matrix, indicated eleven factors with strong correlations to actual profit that could indicate a contribution to success, such as the size of the building in square footage, the estimated construction days, the contracted construction days, the initial price, the final project price, the budgeted profit, budgeted overhead and general conditions, the positive project profit differential, the number of addendums and owner incorporated changes, the total number of RFIs and ASIs, and the number of punch list items. The building square footage and number of addendums and owner incorporated changes are typically beyond the control of the contractor. Items such as the number of RFIs and ASIs, and number of punch list items, are areas over which the contractor does not have complete control, but over which he has some ability to manage the effects. The estimated construction days, contracted construction days, initial price, final project price, budgeted profit, budgeted overhead and general conditions, and the positive project profit differential are all factors within the contractor's realm of influence, and these could be determined by effective project leadership. Quantifying these effects and collecting future data should help project teams quantify factors that lead to success on a project, from the contractor's perspective.

Further, we can parallel profit differential on construction projects with win margin or win rate, looking for contributing factors of other project recordables. Since there is very limited literature that indicates the relationship between key attributes of construction projects and profit margin [29], this study provides the most comprehensive look at such a relationship, discovering that, in this instance, positive profit differential, or the amount above budgeted profit, is strongly correlated to only one factor, the number of RFIs and ASIs on a project, as indicated in Table 8. Although actual profit and budgeted profit are also strongly correlated to profit differential, that comes as no surprise, since those values create the profit differential factor. A deeper evaluation of how a larger number of RFIs and ASIs are correlated with higher actual profit than budgeted could be valuable to construction companies, influencing the leadership and priorities regarding construction projects.

Another outcome of interest to construction companies is the actual construction days for a project and the factors that affect this outcome. Actual construction days may be associated with many project-related factors that could also affect cost, ranging from contractual obligations and liquidated damages to general conditions and the daily charges for labor, equipment, and services. The Pearson correlation of PIs, checked using a correlation matrix, indicated eight factors with strong correlations to actual construction days. These factors including three other schedule values: the number of days estimated for the project in the proposal phase, the number of days included in the contract, and the number of days scheduled by the project team following project award. In addition, these five factors demonstrated strong correlations to actual construction days: overhead and general conditions, initial project price, final project price, budgeted profit, and the number of punch list items. Of those factors, the finding that a higher number of punch list items is related to a higher number of actual construction days seems to be an aspect of the project that should be quantified and examined to inform and influence successful project leadership.

This research targeted the gap in the literature concerning the analysis of construction company project data from actual projects to determine factors that indicate project success using an approach similar to sports analytics. The implication is that if PIs parallel project factors and match outcomes parallel successful projects, the key project performance factors can be identified. Similar correlation analysis was performed here for construction projects, where instead of win-loss or score margin, actual profit, profit differential, and actual construction days, along with other factors, were evaluated and analyzed as project success indicators, and correlated project factors were identified for this group of twenty-three projects. This data indicates that the number of punch list items, and the number of RFIs and ASIs, are PIs that affect project outcomes and indicate or influence the quantification of project success.

6. Conclusions

Current methods for determining project success from the contractor's perspective are difficult to correlate with quantitative project factors or use as performance indicators, due to the lack of historical data readily available for analysis, as well as the limited literature indicating the relationship between project factors and profit margin [11,25,28,29]. This study analyzed construction company project data from a portfolio of actual commercial building projects to determine factors related to project success using the Pearson correlation in an approach similar to that used in sports analytics. In what appears to be the first analysis of this type in the literature, 66 of the 253 relationships between the factors explored were found to have significant correlation. This analysis identified high correlation between final price and actual days, supporting Habibi et al.'s [28] assertion that construction project success can be attributed to effective time and cost performance. In addition, in this analysis, actual construction days has a strong correlation with the number of punch list items. Profit differential (actual profit less budgeted profit) demonstrated a strong relationship with the number of RFIs and ASIs on a project. Since RFIs and ASIs are indicators of incomplete design and/or design clarification, potentially affecting project scope, this result indicates that the successful pricing and clarification of scope leads to a more profitable project for the contractor, indicating project success.

Construction management as a highly competitive, project-based field of complex specialized services, creating or altering the built environment for a client. For construction management firms and contractors to be successful, understanding the relationship of performance indicators with project outcomes, such as cost, time, and profitability, are essential. For this ENR top 400-ranked construction firm, this data analysis can help in collecting and analyzing data for future projects to help achieve success. Despite the contributions of this study and valuable insight provided for this construction firm, it contains certain limitations. This study provides empirical results indicating the correlation of project outcomes and certain performance indicators; however, the results do not provide detailed information on the cause of these relationships. The research sample was limited to one construction firm and data previously collected.

6.1. Additional Data Collection for Future Research

In addition to the data collected from the projects in this dataset, future projects should collect any schedule change in days associated with change orders, as well as any approved contract days associated with the change order. Only change order cost was included in this data. Identifying the cost and schedule implications of RFIs and ASIs could help in clarifying the significance of their relationship with profit differential. Actual construction days, with a strong positive relationship to number of punch list items, should be explored further for any possible cost or schedule efficiencies.

6.2. Recommendations for Future Research

These findings are the first step of analysis leading to future research that could evolve into predictive indicators of success for building projects. Further research is needed to quantify the effect a performance factor would have on a project outcome and to identify the strength of the indication. Moreover, future research could look at additional samples of projects and data from additional construction firms.

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