Price Fluctuations in Construction Budgets: A Monte Carlo Simulation Approach to Risk Analysis

Bernardo Winter
Instituto Superior Técnico, University of Lisbon, Portugal

Abstract – The construction industry is defined by its uncertainty and variability. Global and local factors heavily influence construction material prices . With this in mind, there is a considerable need to understand the markets and how it can be used to predict price volatility during a construction project time frame. This study aims to enrich this topic by using a Monte Carlo simulation, a powerful technique renowned for its capability to tackle uncertainty and predict complex systems behavior. The aim is to model the probabilistic distribution of material costs and analyze the impact of these variations on the overall cost of a construction project. This can be used by project owners and project management as well as by the general contractor. In acknowledging the impact of these market trends, this thesis aims to explore a range of mitigating strategies, some generic and other more specific to the materials identified as having the most influence on project costs. Various measures will be presented, such as strategic procurement approaches will provide insights to construction companies on optimizing their resource management and organizational policies in an unpredictable market.

Keywords: Budget, Material price variations, Monte Carlo simulation, Risk management.

1. Introduction

The construction industry operates in an environment defined by uncertainty, where accurate forecasting of material costs is a challenge felt by all. This unpredictability comes from the fact that material costs are heavily influenced by global and local factors such as supply chain dynamics, economic fluctuations and market volatility and, in turn, these variations impact the financial stability of construction projects and organizations.

Recently, the construction industry has witnessed an unprecedented surge in construction material costs, which has drawn significant attention from both academic and professional circles. Rapid changes in market dynamics, influenced by global events and geopolitical tensions, have brought about sharp increases in the price of vital construction materials, highlighting the critical need to mitigate these unexpected and often substantial economic challenges.

This was exemplified during the COVID-19 pandemic when global restrictions resulted in soaring prices, much to the detriment of construction companies. Similarly, major infrastructure projects in rapidly growing nations have triggered significant increases in demand for construction materials like concrete, steel, and glass, further increasing price variations. Moreover, geopolitical tensions such as the US-China trade war, have compounded these challenges, leading to increased inspection fees, and holding costs at ports, all of which contribute to the rise in market prices, even fluctuations in oil prices as a consequence of new environmental laws impact material prices since this is a fundamental good for all transportation and most constructions works.

As highlighted in the literature review, these variances are not theoretical but represent in the financial figures that shape the landscape of construction projects, concern about the financial robustness of construction projects and companies, strategies for managing economic risks have been proposed.

The persistent evolution of markets demands innovative approaches capable of overcoming the multifaceted nature of risk. This thesis is motivated by the pressing need for a methodical and quantitative risk analysis tool that examines the variability of material costs and offers a foundation for decision making, aiding investors and contractors by mitigating risk when budgeting. By understanding these market forces and proactively adopting such measures, construction companies can safeguard themselves against material cost volatility and maintain their competitive edge in an ever-changing industry landscape.

In acknowledging the impact of these market trends, this thesis aims to explore a range of mitigating strategies, some generic and other more specific to the materials identified as having the most influence on project costs. Throughout the thesis, analysis of various measures such as strategic procurement approaches will provide insights to construction companies on optimizing their resource management and organizational policies in an unpredictable market.

With material cost fluctuation being a risk factor that can inflate budgets and compromise the overall feasibility and profitability of a project, the aim of this thesis is to study the impact of material price variations on the total cost of construction projects. For this a quantitative approach was adopted. This thesis explores the use of Monte Carlo simulation, a powerful technique renowned for its capability to tackle uncertainty and predict complex systems behavior. By specifically focusing on the financial risks associated with material cost variations, the aim is to model the probabilistic distribution of material costs and analyze the impact of these variations on the overall cost of a construction project.

2. Literature review

2.1 Definition of risk

Every human activity at any level inherently involves decision-making. Even seemingly instinctive actions involve a choice among different alternatives. Given the unknown nature of the future, especially in today's constantly changing world, the decisions we make are based on limited information and several assumptions and expectations. Despite the efforts to decide on the optimal alternative, the chances are that it will turn out suboptimal or even fail. Thus, we can assert that every facet of life involves multiple risks.

Risk is a fundamental concept in numerous fields, including project management, finance, technology, insurance, and more (Tóth & Sebestyén, 2014; Tworek, 2009). Nevertheless, defining it remains a multifaced endeavor intrinsically linked to its context arising within specific situations, with nuances deriving from personal experiences.

2.2 Definition of risk management

Risk management is defined as the practice of analyzing exposures to risk of loss and minimizing potential losses acceptable to the organization. According to the ISO Guide 73 (ISO Guide 73:2009, 2009) risk management is the coordination of activities to guide and control an organization regarding risk. Wideman (Wideman, 2004) describes it as a structured approach aligning strategy, processes, people, technology, and knowledge to evaluate and manage uncertainties, while emphasizes a systematic way of looking at areas of risk. Wang et al. (2004) have also defined risk management as "*a formal and orderly process of systematically identifying, analyzing and responding to risks throughout the life cycle of a project to obtain the optimum degree of risk elimination, mitigation and/or control.*"

Risk management predominantly focuses on project-specific considerations, as seen in the definition of risk. This approach has every project as an independent entity not considering its temporary nature within the company life.

2.3 Risk management framework

A risk management framework serves as the center piece for managing risk in an organization, integrating risk management processes with other management activities. This establishes the bases for designing, implementing, monitoring, reviewing and systematically improving the management of risk throughout the organization. The framework must be ingrained in the organization's strategy, policies and practices to ensure its effectiveness.

The risk management framework encompasses various components outlined in standards such as ISO 31000:2009 (ISO 31000:2009, 2009), including policies, objectives, mandates, and commitments to manage risk. It should also involve plans, processes and activities tailored to the organization's specific context. This integrated approach allows for the gathering of risk information while maintaining the ability to have different risk assessment units across the organization.

For the successful implementation of risk management within the organization's operations is crucial that all levels of staff are engaged in it. This can be achieved by incorporating risk management accountabilities and expectations into internal performance systems.

Figure 1: Risk Management Framework, adapted from Sousa et al. (2012).

ISO 31000 describes the risk management framework as systematic application of management policies and procedures to the activities of communication, identification, analysis, monitoring and reviewing risk. This framework is done in 7 steps as seen in Figure 1 above. These steps are all interconnected and should be dealt with as an iterative practice because in different stages of a project there are different amounts of information, new information may lead to a better understanding and evaluation of each risk. Every stage of the framework relies on the previous and may change as the circumstances of the project are updated.

Risk identification is a critical aspect of project management, particularly in the construction industry. During the initial phase of the project, performance objectives are established such as schedule, cost, and quality. Within this phase the risk identification process revolves around systematically and continuous recognition of major potential sources of risk to the project objectives. Identification as the first and one of the most important steps of the risk management process, is caried out with diverse tools and techniques such as, checklists, interviews and group discussions, brainstorming, examination of similar projects, surveys and questionnaires, simulations etc. (Borghesi & Gaudenzi, 2012; Murray-Webster, 2017).

2.4 Risk analysis

In the rapidly changing business environment, we live in today is important to prepare for unexpected scenarios that may impact the organization. This chapter will develop on the topic of sensitivity analysis and how it can be used to assess and identify the key variables that have the most impact on the financial results of an organization and mitigate those risks.

Sensitivity analysis is a mathematical tool that helps decision-makers assess how variations in the inputs or parameters of a model affect the output or outcome. One of the fundamental purposes of this tool is to find the variables that the model is more sensitive to and help quantify what changes in the input lead to in terms of effects on the results (Kleijnen, 1997).

Risk management can benefit a lot from the use of this tool, when the key variables are identified it is easier to allocate resources and find strategies to manage them effectively.

Fluctuations in the prices of raw materials can have a significant impact on the total cost of the project, as explored more in dept on a following chapter. For this reason, it is essential to understand the volatility of the most sensitive materials and prepare for it.

2.4.1 Techniques

Sensitivity analysis can be done with various techniques to assess the impact of input variables on cost estimates.

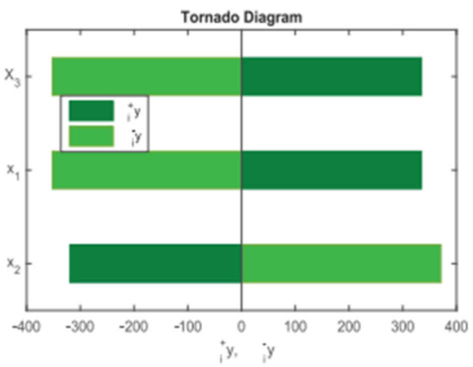


Figure 3: Tornado Diagram, reproduced from (Borgonovo & Plischke, 2016).

The tornado diagram visually encapsulates the sensitivity of cost estimates to various variables, arranging them in descending order of impact. This visual representation aids decision-makers in swiftly pinpointing the most influential variables, directing focus on critical elements that hold substantial sway over the overall cost structure (Borgonovo & Plischke, 2016), as seen in Figure 2 above.

Monte Carlo simulation is a model that simulates possible outcomes and presents their probability of occurrence. In the simulation each input is iterated within a predetermined range, in the case of this thesis the range will be each materials triangular distribution, that uses the time series values to find a realistic range. The frequency at which the values from the iterations happen the model builds, not only a most probable value, but a distribution of the output. This technique provides a nuanced understanding of uncertainty and variability associated with cost estimates. Decision-makers can explore diverse scenarios, gaining insights into the range of potential outcomes and associated risks (Borgonovo & Plischke, 2016).

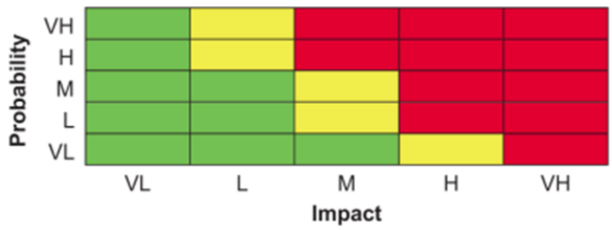


Figure 2: Risk Matrix, reproduced from (Mahamid, 2011).

After the identification and assessment process of all potential risks, it is crucial to prioritize them according to their severity, given that there are limited resources for risk management, it is not possible to tackle all risk at the same time.

A widely used method for risk prioritization is to employ a risk matrix, like the one seen above in Figure 3. This tool helps organizations in assessing the severity of the risk by examining the likelihood of occurrence and the potential impact. Typically, the risks represented graphically on a grid, with one axis indicating the likelihood of happening and the other axis represents the impact, the level of categorization on this type of matrix can differ depending on the data and the detail needed.

2.4.2 Material price variation

Prices gradually rise naturally with inflation over the years, but since mid-2020 material prices skyrocketed because of the covid-19 pandemic and all the restrictions put in place to control it. This was only made worst in the beginning of 2022 with the war between Russia and Ukraine.

According to ANCI (2022) report Spain Consumer Price Index (CPI) reached 10,2% as of June 2022 negatively affecting most production sectors including construction.

According to the UK Office of National Statistic (ONS) (*ONS*, 2022), the cost of construction materials in July 2022 was 24% higher than the year before, this following the more than 20% inflation on the same time framed the year before. In total construction materials cost increased over 46% from the beginning of 2020 to July 2022.

A report done by CBRE (2022), shows the same data, based on the Producer Price Index (PPI) the construction costs have risen 41% from march 2020 to march 2022, having the costs of steel mill products, some plastic piping and plywood more than doubled in this time frame. At the end of 2021 a survey from the U.S. Chamber of Commerce shows that 97% of contractors reported that material cost fluctuations had a moderate to high impact on their business, having had a higher concern about steel and wood product prices (*Q4-2021-CCI-Report.Pdf*, n.d.).

For the construction sector, the cost of construction work consists of 60-70% of material costs, labor costs account for 10-20%, and the remaining 10-20% refers to machinery costs (El-Gohary & Aziz, 2014), taking into consideration the variability shown in the last paragraph regarding material costs and the big part of the budget these materials take, is clear the massive impact this can have on the overall costs of a construction project.

3. Methodology

The primary objective of this thesis is to analyze the impact of material price variations on the overall cost of a construction project. This is done by leveraging the Monte Carlo simulation technique, known for its prowess in handling uncertainty and predicting the behavior of complex systems, will be used to model the probabilistic distribution of material costs. The data used on the Monte Carlo simulation is developed from the cost breakdown of a construction project and time series of material price indicators.

This type of analysis is essential for a project, from the investor's side for an estimate on project feasibility and profitability, and for the contractor when budgeting for a new project. It helps companies mitigate potential cost overruns enhancing their financial resilience.

3.1 Construction project cost breakdown

The basis of the data was a cost breakdown of a real construction project by percentages of the major expenditure areas. Below shows the cost distribution for the 4 categories the costs were divided into.

- Construction Site – 14.34%
- Direct Labor – 4.34%
- Direct Materials – 12.93%
- Subcontractors – 67.90%

Table 1: Most Influential Materials.

Most Influencial Materials		
6,4%	M12	Steel rods and beams
5,7%	M24	Pine wood
5,0%	M26	Wood derivatives
3,6%	M46	Electrical installation materials
2,7%	M39	Aluminum frames
2,3%	M10	Tiles and mosaics
2,1%	M49	Geotextiles
2,0%	M23	Glass
1,7%	M42	Steel piping and plumbing accessories

For this thesis the scope was narrowed to exclusively material costs, for this there was a need to break down the costs included in each of these 4 groups.

Since this thesis focuses on material costs, only direct materials and the material cost percentage of the subcontractors was taken into consideration.

Direct materials are materials bought directly by the general contractor, these are mostly materials used for the structure of the building, includes sand, concrete, steel rods, bricks, etc., because the previous materials were bought directly the data needed no treatment and the values were used directly.

Subcontractors was the category where most of the materials were used, and it is shown by the percentage it holds from the total budget. Some of the most significant subcontractors were works like carpentry, which involves an expensive raw material, wood; Metallic structures and electric installations. Since these percentages corresponded to the total subcontractor, there was the need to break it down into 3 main categories: material cost, labor cost and equipment.

3.2 Material price indicators time series

Price indicators are used as an economic indicator to reflect the variation of prices. The ones used in this thesis are material price indicators but, in the construction sector, labor and equipment are also types of indicators commonly used.

IMPIC (Instituto dos Mercados Públicos do Imobiliário e da Construção) was the source of these price indicators, which were arranged into a time series for each material. The analysis aimed to track the price movements of key materials over time, providing patterns and trends to be analyzed using the Monte Carlo simulation.

The time series is comprised of monthly indicator values for each material, from the beginning of 2010 to the 3rd quarter of 2023 and includes materials like sand, glass, different kinds of wood, steel, etc.

Once the raw material costs are separated from the other components of the cost breakdown of the construction project, it is possible to start grouping them in the corresponding indicators from the time series. Materials that fit in the same indicators were added, and once every material was categorized it was possible to rank them by percentage of cost from the overall budget, as seen in Table 1 below. The sum of the 9 materials chosen adds up to 31,47%, this is the original budget for this group of materials.

Below is shown the study done from which these percentages were calculated.

M12 – Steel rods and beams (6.38%)

It comes as no surprise that steel is the material with the biggest share of material costs, since it is a very expensive material and is used in the structure of the building, as part of reinforced concrete.

The percentage 6.38% comes from adding A500 steel with 10mm (0.73%) and 12mm (0.84%) diameter used in the structures with metal beams and rods from a subcontract (4.81%). This was an easy fit for the price indicator M12 (Steel rods and beams) presented in the IMPIC database.

M24 – Pine wood (5.73%)

Pine wood percentage comes from the division of the general carpentry in 60% material cost and 40% material, since this type of work demands expensive raw material but also skilled labor.

This item includes works like doors, door frames and some other structural/architectural pieces, that is the reason why pine wood was chosen over wood derivatives like glued laminated wood, since items such as door frames and architectural pieces are not commonly made from wood derivatives.

3.3 Monte Carlo simulation

The concept behind the Monte Carlo simulation approach is to capture the output uncertainty of a system, in this case, the total cost of the project, influenced by the variation of the chosen materials. Monte Carlo simulation selects random values to simulate a model, for each uncertain variable a distribution is defined and with it a range. Then, a simulation is run to calculate multiple scenarios, in this case 1000 iterations, sampling random values for each variable according to the distribution by means of a specifying probability distribution for the relevant input parameters. Conducting a very large number of draws from these distributions computing for each draws the resulting output, in this case the total cost of the project.

The utilization of a triangular distribution for modeling the data in the Monte Carlo simulation was influenced by the nature of the study on material price fluctuations. The possibility of asymmetry on this distribution is important, since variations in the price indicators are, naturally, mostly in the positive direction, accompanying general inflation. The range of variation is also important, a triangular distribution has maximum and minimum variation values fixed, this were chosen using the real variation values for the time series, therefore a distribution such as a normal distribution would not fit this model since a range from $-\infty$ to $+\infty$ would not be realistic for price variations.

Table 2 below shows 2 of the 9 materials chosen and the corresponding indicator value from each of the materials, as of January for each year. This assumption was done to be closer to a real duration of the construction of a project like the one used, but still short enough intervals to have enough data points.

Table 2: Example data for Monte Carlo simulation.

	M12		M24	
Year	Value	Variation	Value	Variation
2010	216,5		139,7	
2011	270,4	19,93%	139,3	(0,29%)
2012	272,7	0,84%	141,1	1,28%
2013	270,6	(0,78%)	141,1	-
2014	270,7	0,04%	143	1,33%
2015	270	(0,26%)	143	-
2016	264,6	(2,04%)	148,4	3,64%
2017	270,9	2,33%	157,1	5,54%
2018	274,9	1,46%	157,1	-
2019	274,8	(0,04%)	165,7	5,19%
2020	261,9	(4,93%)	167,5	1,07%
2021	316,1	17,15%	179,2	6,53%
2022	404,3	21,82%	242,9	26,22%
2023	393	(2,88%)	285	14,77%
Min	216,5	(4,93%)	139,3	(0,29%)
Max	404,3	21,82%	285	26,22%
Median	270,8	0,04%	152,75	1,33%

For this thesis the only data used on the model was the 9 most relevant materials in terms of percentage of the total budget, for this reason every other value included in the cost breakdown is considered was considered fixed in terms of cost.

4. Results and Discussion

4.1 Time series data analysis

Before moving to the results from the model it is interesting to see the individual indicator yearly maximum variations, shown in Table 3 below.

Table 3: Indicators max variation.

Budget		Variation		Max budget variations	Budget extremes
M12	6.38%	Min	(4.93%)	(0.31%)	6.07%
		Max	21.82%	1.39%	7.78%
		Median	0.04%		6.39%
M24	5.73%	Min	(0.29%)	(0.02%)	5.71%
		Max	26.22%	1.50%	7.23%
		Median	1.33%		5.80%
M26	5.00%	Min	(8.56%)	(0.43%)	4.57%
		Max	35.82%	1.79%	6.79%
		Median	2.22%		5.11%
M46	3.59%	Min	(7.10%)	(0.26%)	3.34%
		Max	14.73%	0.53%	4.12%
		Median	0.81%		3.62%
M39	2.68%	Min	(4.07%)	(0.11%)	2.57%
		Max	22.18%	0.59%	3.27%
		Median	0.07%		2.68%
M10	2.34%	Min	(12.83%)	(0.30%)	2.04%
		Max	26.51%	0.62%	2.97%
		Median	(0.18%)		2.34%
M49	2.08%	Min	(2.26%)	(0.05%)	2.03%
		Max	10.78%	0.22%	2.30%
		Median	0.30%		2.09%
M23	2.00%	Min	(13.59%)	(0.27%)	1.73%
		Max	23.60%	0.47%	2.48%
		Median	0%		2.00%
M42	1.66%	Min	(0.40%)	(0.01%)	1.65%
		Max	12.18%	0.20%	1.86%
		Median	0%		1.66%

The first 2 columns, *Budget* and *Variation*, are the data from the time series, *Budget* showing the original budget value for each of the price indicators on the left, and *Variation* representing the maximum and minimum yearly variation of the indicators (values used for the triangular distribution on the Monte Carlo simulation).

As expected, the Variation column in Table 3 shows that the positive variation (Max) on all materials as a higher value than the negative variation (Min), since the prices are expected to go up with inflation if nothing else.

The third column from Table 3, Max budget variations, shows what the maximum percentage variation for each indicator were in the space of 1 year. Taking the first value from this column (-0.31%) as an example, it results from the multiplication of the original budget value for M12 (6.38%) by the maximum negative variation (-4.93%). This means that according to the time series, the maximum negative expected variation for M12 is 0.31% of the current value. This column exemplifies the great impact these variations can have.

The fourth column Budget extremes incorporates this variation shown in column 3 with the original budget for each material, resulting on the maximum and minimum values each material would reach on the maximum variation calculated before.

M12 (Steel rods and beams) and M24 (Pine wood) indicators, even though they don't show the highest yearly variations, the fact that they occupy the top spots on the original percentage of the budget, results on the 2nd and 3rd highest influence variations on the final budget with 1,39% and 1,5%, respectively.

The first line on Table 4 bellow is the result of adding all the maximum/minimum indicator values on the *Max budget variation* column of Table 3, this shows the variation on these materials budget if every material has the worst/best year on the same year. Once again, the highest variation is the positive one with 7,33% from the median value of these materials budget, while only 1,75% decrease on the negative end.

Table 4: Material budget extremes.

Budget		
Min	Med	Max
(1.75%)		7.33%
29.72%	31.69%	38.79%

The second line is the sum of the values on the first with the original budget for these 9 materials (31.47%), This results in the maximum/minimum budget that can be achieved with these time series, if all other materials remain equal. Since the triangular distribution has well defined minimum and maximums the model cannot show values outside this range.

The tornado diagram shown bellow in Figure 4 was built from the *Max budget variation* column values in Table 3 (Indicators max variation). This column represents the maximum value variation in the time span of 1 year for each of the 9 materials, since every material indicator had at least one with a negative variation and one year with positive variation, this diagram shows the

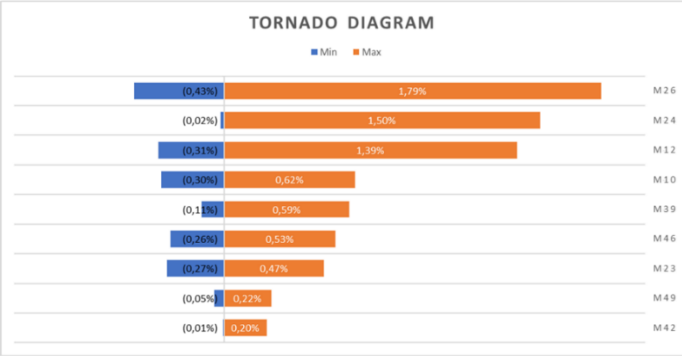


Figure 4: Tornado diagram – time series.

biggest negative and positive value variation for each of the 9 material indicators.

From this diagram it is possible to see that there is a big separation between the top 3 most impactful material indicators and the rest of the indicators. This is a combination of these 3 indicators ranking as some of the most volatile ones, having some of biggest yearly variations out of the 9 materials group, and that these are also the 3 materials with the highest percentage of the total budget. The combination of big variations and a high percentage of the budget makes these 3 indicators (M26 - Wood derivatives; M24 - Pine wood; M12 - Steel rods and beams) the ones that should be controlled and put preventive measures for, if talking purely in terms of possible impact on the overall budget.

Following the tornado diagram and with the objective of complementing each other, the risk matrix shown in Figure 5 was built. As explained before, the tornado diagram does not have a probability aspect to it, taking only into account the maximum impact each material indicator can have, that is why a risk matrix is used, it gives not only the impact aspect but also the corresponding probability of occurrence.

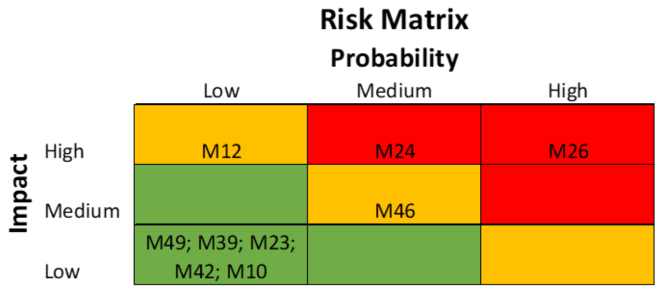


Figure 5: Risk matrix - Time series.

When analyzing the risk matrix, it is possible to see that the 3 indicators present on the top row, the high impact row, are the same top 3 most impactful indicators on the tornado diagram, these values are M26, M24 and M12. Since both analyses show these same materials as the most dangerous for the project, extra attention should be taken when dealing with them. Besides these 3, M46 – Electrical installation materials appears as a medium impact and medium probability indicator, this means that this indicator should also be the target of analysis and preventive measures.

4.2 Model data

The analysis of the data used for the model, in the last chapter, showed mostly the extreme situations that the model can reach, taking the single worst and best-case scenarios for each material, making a very unlikely group of data. With the probabilistic Monte Carlo simulation from RiskAMP, the data collected is not the worst/best situation but a wide range of possibilities, represented by each iteration.

It can happen that all materials have a sharp increase in price in the 1-year time frame of this study, this can happen when there is a global problem affecting all markets, such as happened during Covid. But material prices also fluctuate according to the specific market they are included in, for example if the construction market slows down, steel rods might have lower prices to fit the market, or if there are some years with small amount of rain and big forest fires, then pine wood might see a big increase in price.

For those reasons the model plays an important role in this work, as it is possible to see in the example of M12 (Steel rods and beams) distribution in Figure 6 below. Since the model follows the triangular distributions on the materials, the further away from the median value, the less likely it is to happen.

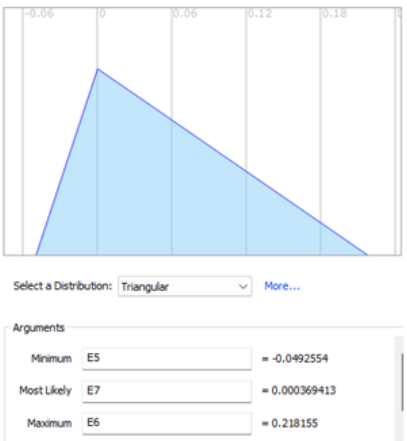


Figure 4: M12 triangular distribution.

Once again, the distribution in Figure 6 shows that the prices are more likely to go up than down, since the maximum point is further away from the median, the area on the positive variation area is bigger, consequently there will be more iterations that show positive variations.

Table 5: Model results overview.

Nº of trials	1000
Max	4.56%
Min	0.03%
Median	1.89%
Range	4.53%

Comparing these maximum, minimum and median values of Table 5 with the ones in Table 4 from the time series analysis, it is possible to see a big spread of 2,8% between the 2 maximum numbers (7.33% on the time series to 4.56% on the model), exactly by the fact that is very unlikely that most of the materials are close to the maximum possible in the same iteration. The same rationale can the used for minimum value with a spread of almost 1,8%, this value from the value showing to be almost the same as the median from the time series. Both the maximum and minimum model values got closer to the median value.

The median value also saw a change of almost 1,7%, this is explained by the higher probability of having a positive variation than a negative one, making all the values happen more on the positive side of the time series median.

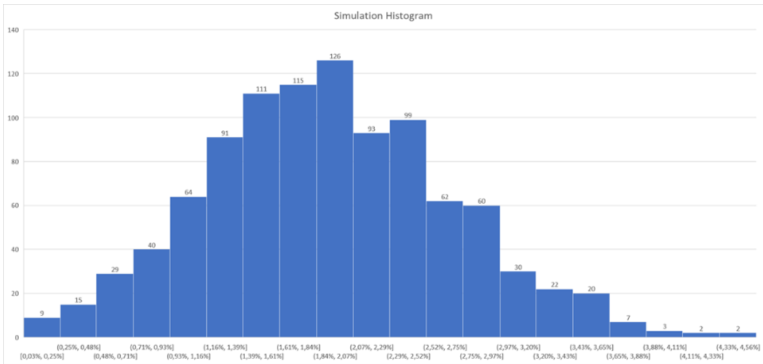


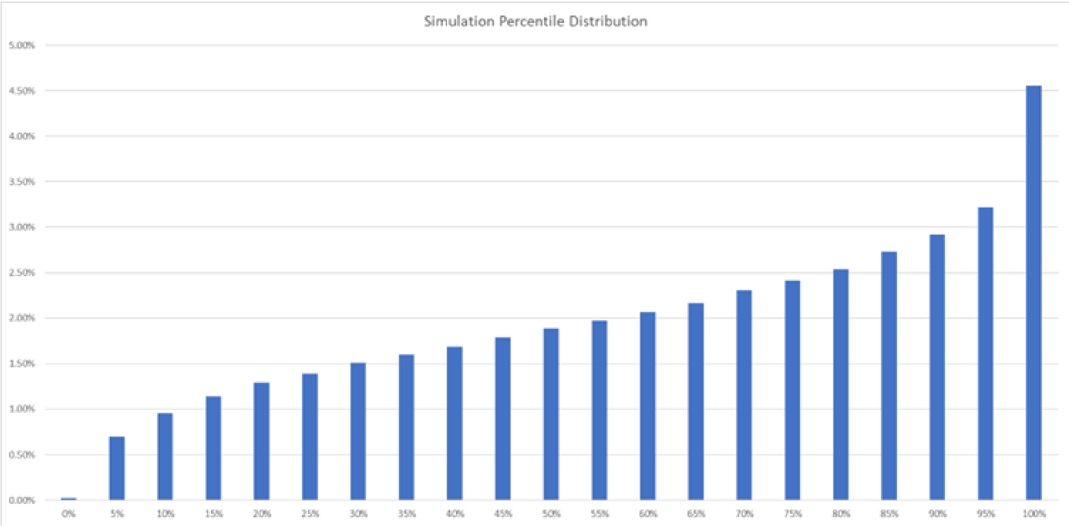
Figure 5: Simulation histogram.

The graphic in Figure 7 above is the histogram for the results of model, showing the frequency of results happening in a specific range of values.

In this case, according to the simulation done, each of the 1000 iterations shows the sum of the random number given by the model on each iteration. The numbers on top of every bar in the histogram below represent the number of iterations in which the sum of the budget for the 9 materials was within the range on the bottom of the bar.

For example, from the first bar on the left it is possible to see that 9 iterations had the median budget increase of between 0.03% and 0.25%. This is a very surprising number, since a simulation with no increase would show 0%, this means that according to the model the original budget value would not be enough to do buy the materials necessary for the project if it was done in 2024.

By the shape of the histogram, it is possible to see that most iterations land in a small spread of about 2%, between 1% and 3% increase, this indicates that the variability is not very high, making it a more predictable result. The histogram still shows some outliers reaching the 4.5% on the maximum variation, but the tilt of the distribution is mostly on the left side, making it more likely that the budget will fall there, this was expected to happen since all triangular distributions had this left tilt, as it is possible to see in Figure 7.



Percentile	Value
0%	0.03%
5%	0.70%
10%	0.96%
15%	1.14%
20%	1.29%
25%	1.39%
30%	1.51%
35%	1.60%
40%	1.69%
45%	1.79%
50%	1.89%
55%	1.97%
60%	2.07%
65%	2.16%
70%	2.30%
75%	2.42%
80%	2.54%
85%	2.73%
90%	2.92%
95%	3.22%
100%	4.56%

Figure 6: Simulation percentile distribution.

Figure 8 above, complemented by the table on the right side show the data for the percentile distribution of the results from the model.

As seen in the histogram, this graph shows a positive number in the minimum value meaning it is higher than the original budget. By this graph the conclusion would be that the budget would be exceeded 100% of the times.

A common indicator used from this type of probabilistic distributions is the 95% percentile, in this case that value would be 3.22%, this means that 95% of the time, the cost increase of this group of materials will be lower than 3.22%. These values of 90% and 95% percentile are often used on budget estimations or by project managers when calculating the risk of the project, according to how prone to risk the organization is the percentile used for this end can be lower.

The 50% percentile corresponds to the value calculated for the mean and is 1.89%, meaning that 50% of the time, the budget increase for these 9 materials will be lower than 1.89%.

Table 6: Risk matrix - Model percentages.

	Probability
M26	8.09%
M24	7.77%
M39	5.63%
M12	4.62%
M42	3.66%
M10	3.57%
M23	2.69%
M49	2.55%
M46	2.05%

	Impact
M12	6.38%
M24	5.73%
M26	5.00%
M46	3.59%
M39	2.68%
M10	2.34%
M49	2.08%
M23	2.00%
M42	1.66%

Following the steps of what was done for the data from the time series a risk matrix was built from the model data, as seen below in Table 6. To be consistent and comparable to the results from the time series the probability values represent the median relative percentage variation on each materials budget, not the percentage in the final budget, this was done to not consider the material budget share two times in this analysis.

Table 6 shows on the right the impact that is translated by the percentage on the global budget, this remained the same from the time series.

On the left, the probability shows values much higher than the probabilities on the time series, this is expected and is explained by the distribution used on the model. As explained before, the values on the triangular distribution show a bigger probability of an increase in value yearly, this is supported by the reality of our economy where rising prices are expected every year even if it is just a result of inflation and there are no more global incidents that influence the prices.

Risk Matrix

Impact \ Probability	Low	Medium	High
High		M12	M26;M24
Medium	M46		
Low	M42; M10; M23; M49	M39	

Figure 7: Risk matrix - Model.

As it is possible to see in Figure 9 above, even though the percentages are very different, from a maximum of 2.22% to 8.09%, the distribution of the materials are mostly on the same risk level, with M26, M24 and M12 occupying again the top risk spots.

These 3 materials are once again steel and the 2 types of wood materials, reinforcing the conclusions taken before that these 3 materials are the ones that should be prepared for, and preventive measures should be taken.

4.3 Impacts and preventive measures

In the construction material cost variation is regarded as one of the main challenges, affecting project deliverables, financial stability, and overall market dynamics. This chapter will examine the impacts of rising material costs on individual construction projects, the companies that oversee them and the industry that these are included in.

4.3.1 Material cost variation causes

The variation in material costs in the construction industry can be influenced by a variety of factors, many times even a combination of different factors. Understanding these causes will help to anticipate changes and implement effective strategies.

One of the most important causes is supply chain disruptions, these are mostly caused by unexpected events, but seen around the world, with a variety of dimensions of disruption, going from local shortages to global price spikes. The most impactful in the last years was Covid-19 pandemic, it stopped or reduced the production of key materials like steel, cement and lumber leading to shortages in these materials, it also impacted global supply chains by restricting international travel. Another good example of an unexpected event was the cargo ship that blocked the Suez Canal in Egypt, while it was only there for 6 days it significantly affected trade between Europe and Asia.

Increase in demand of specific materials can also have a significant impact on costs, especially in fast growing countries like China and India, who have large-scale infrastructure construction projects with a need of big amounts of materials like concrete, steel and glass. These big surges in construction can lead to an increase in prices resulting from a shortage of these materials in the supply chains.

Geopolitical tensions like the US-China trade war also causes increases on transportation costs since imported materials like steel is higher, besides that materials can have a heavier inspection at ports that influence holding costs and supply chains, ultimately leading to a rise in market prices.

The calibration of the developed software is of great importance for the following study. Four literature examples were chosen for this calibration. Yet, for two joint cases (i.e., K gap joint with SHS chord and CHS braces; K overlap joint with SHS chord and SHS braces) for which direct examples were not found, similarities in terms of cross-section area of the members were considered.

4.3.2 Material cost variation impacts

All the factors introduce disruptions in the dynamics of the market, from shortages of materials to extra spending on their production, the result is the increase of prices for the consumer, in this case the final consumers are the construction companies who feel these impacts on their individual projects and the organization itself.

During a construction project the impact that the increase of material costs has is straightforward, these variations impact the project budget directly, these unforeseen costs mostly result in a cost overrun of the project budget. That is why budgeting and project bidding are one of the most difficult and important steps of any project, if the company choses to include bigger margins to protect itself from these variations, then the budget might be too high and they will lose the bidding, if it is too low the company will be in risk from the price variations. The tight margins and volatile nature of the construction industry make the study of price variations a must for every company.

4.3.3 Material cost variation measures

The volatility of material costs poses a significant challenge for the construction industry. To navigate this volatility, it is crucial for the companies, project owners and managers to adopt proactive measures.

This section explores some strategic approaches to minimize or prevent the impacts of these variations, specific strategies will be presented for steel and wood materials since the results show that these are the most influential on the project in analysis.

Strategic procurement

These are practices used by construction companies to lock material prices and ensure supply of materials.

For steel strategic procurement can be put into practice by measures such as bulk purchasing, where construction companies secure steady favorable prices based on economy of scale, by buying a large volume of steel corresponding to multiple projects the company has at the same time, it is possible to negotiate lower prices and steady supply.

Long-term contracts with suppliers can also provide price stability, mitigating the impact of short-term price variations. These types of clauses are usually linked to some specific price index to protect against sudden price variations.

In the case of wood, given its price volatility, diversification of suppliers is a good practice, by sourcing from different suppliers the construction company will not be as dependent on a single source of materials and can also leverage competitive prices on the market. Local suppliers and choosing local available materials can also have a positive impact on the project.

Sustainable sourcing for wood can help in 2 ways, the first is being a more attractive brand in the market since sustainable construction is being more and more requested, the other is that sustainable certified suppliers are less likely to have supply disruptions from environmental concerns or regulatory changes that might threaten mass production.

Flexible contracting

Flexible contracting means contracts have material cost variation clauses, protecting contractors from having to bear significant material cost increases and sharing these responsibilities and risks between contractor and project owner.

This can be used in steel and wood in the same way, these clauses can protect both sides of the market since it ensures contractors do not include margins too big to mitigate a possible price increase at the cost of the project owner, and also protects contractors from fixed price contracts proposed by the project owner, where the contractor bears all the risk in the transaction.

To put all the measures above in place, there is a need for developing a budget estimation model which integrate the past prices of the building materials with the inflation rate and foresee the material prices variation on the project time frame, this way the most influential materials can be detected and use some of the measures above to control their impact, setting up the project budget rather than making an adjustment through the construction phase.

5. Conclusion

This thesis explored the intricate nature of construction project budgets, focusing particularly on the volatility of material costs and their significant impact on the financial health of projects, through research and application of Monte Carlo simulation the probabilistic distribution of material costs was analyzed, this method offered a systematic and quantitative tool that proved invaluable in assessing financial risks attributable to cost fluctuations and how such fluctuations can affect overall project expenditures.

While the results obtained give some insights into financial risk management within construction project planning, it must be underscored that the conclusions drawn stem from a model with inherent limitations.

Showing the individual materials and their potential variations and impacts from the scope of the time series gave a good base of comparison for the values gotten from the model.

As expected, the values with the biggest share of the budget showed the most impactful since the same percentage variation on the materials would result in a bigger impact on the budget. Once again steel and wood showed both the most impactful in terms of budget share but also show some of the bigger relative variations.

Making use of the probabilistic properties of the Monte Carlo simulation the data was simulated based on individual triangular distributions for each material for 1000 iterations, giving a wide range of results and making this more reliable than the time series values.

In conclusion, the combined theoretical and practical contributions of this study to the field of construction project management should serve as a foundation for future exploration. It is expected that the techniques and methodologies presented here will be further investigated, refined, and applied in real-world scenarios, contributing to more resilient and financially sound construction projects.

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