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Data-Driven Decision-Making: A Dashboard for Real-Time Market Analysis & Objective Quotation Evaluation

by

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Collaborative effort

This thesis project adopts a collaborative approach, driven by the exploratory nature of the research and the specific research question at hand. Individual component analysis was deemed impractical due to the interdependence of exploration and analysis. Table 1 in Appendix A presents a comprehensive overview of the research process, providing a detailed breakdown of the specific responsibilities, contributions, and individual activities associated with different parts of the research and the report.

Abstract

The construction industry is facing increasing pressure as it experiences the repercussions of the ongoing housing crisis. This forces companies within this industry to make cost-cutting efforts, which, to begin with, necessitates clear financial insight, a challenge for contractor firm Company X. We examined how internal and public data can be leveraged for the employees to gain real-time economic insight to be able to assess incoming quotations, ultimately enhancing informed decision-making. Public construction market data resources were combined into a pooled cost index, in which weights were calculated based on internal quotations from manufacturer partners. Using R's 'shiny' package, we integrated the pooled index into a dashboard that enables users to benchmark a quotation against another quotation of choice. Also, it enables users to recalculate a quotation to a different point in time to assess its price under the market's condition at that particular moment. To obtain economic insights, the dashboard incorporates a customisable visualisation of real-time market volatilities relevant to construction.

Keywords: R-Shiny, dashboard design, concrete cost index calculation, market insight visualisation

Introduction

The Netherlands has been facing a persistent housing scarcity issue, which has recently escalated and is projected to reach its peak by 2025 (NOS, 2023). “Next year threatens to be a disaster year for housing construction”, as cited by Minister of Housing de Jonge. While the full impact of the housing crisis has not yet reached construction contractors, it is anticipated to do so in the near future (Employee A, 2023). Currently, ongoing construction projects, contracted prior to the impending crisis, are slowly coming to an end, and as material costs are increasing, manufacturers are now securing new projects at much higher rates. Consequently, the pressure on contractors is increasing, forcing them to make cost-cutting efforts wherever possible.

Gaining control over their financial situation is crucial for companies in reducing expenses. However, as their financial expenditures are not centrally monitored, contractor firm Company X faces a challenge in this regard (Employee A, 2023). To illustrate, Company X establishes enduring partnerships with specific manufacturers, thereby eliminating the partners’ motivation to offer competitive pricing. Consequently, Company X assumes the responsibility of evaluating whether the quotations received from these manufacturing partners are fairly priced.

The current study aims to provide data-driven insights that can support this assessment. To achieve this, the study analyses Company X’s history of partner quotations and examines the past and present conditions of relevant markets in the construction industry. In this manner, Company X can gain financial insight in the historical as well as the real-time market dynamics within the construction sector which enables them to easily and objectively assess their received quotations. Based on these insights, Company X can engage in a data-driven conversation with partners and address abnormal quotes with objective substantiation.

The study specifically focuses on the assessment of quotations related to the construction component of prefabricated reinforced concrete (PRC). The selection of PRC has several reasons. Firstly, PRC is a substantial component in Company X’s construction projects, contributing significantly to a project’s total costs and presenting an opportunity for substantial cost reduction. Secondly, the composition of PRC only comprises concrete and steel, simplifying the analysis by minimising the involvement of underlying markets, enabling relatively easy comprehension of the PRC cost market as well as it allows easy comparison with PRC in other projects (Employee B, 2023). However, it is important to note that the long-term objective of Company X is to extend the analysis to encompass all construction components, providing a comprehensive framework for quotation assessment. In line with these objectives, the research question states:

"How can Company X leverage internal and public data to gain economic insights to enhance objective quotation assessment of prefabricated reinforced concrete?"

To answer the research question, a real-time, interactive dashboard (Appendix B) was developed that reflects the input price index of PRC as well as the underlying market volatilities of this cost index. It allows users to compare two quotations based on their price change over time and the corresponding market change. By comparing a fairly priced quotation with a new quotation, the divergence between price and market change is used to assess whether the new quotation is market comfortable or not.

The tool additionally offers the capability to recalculate quotation prices to different time periods. By utilising an initial fair quotation as a referencing point and factoring in market fluctuations over time, it enables informed discussions regarding price negotiations.

The last part of the dashboard includes a graph displaying the market volatilities used to calculate the PRC cost index, providing insights into the underlying factors driving market fluctuations. Users can identify specific markets that contributed to changes in the PRC cost index, enhancing their understanding and supporting effective communication with suppliers regarding the assessment of abnormal new quotations.

Through web scraping, an automated method of collecting live and up-to-date data, the dashboard ensures its users remain informed about recent market trends, thus maintaining its relevance and timeliness.

The dashboard serves as a data-driven foundation for price negotiation. It provides its users with customised information at one glance. This enables Company X's employees to present grounded arguments to their supplier based on accurate market data, an ability that was lacking prior to this research. Ultimately, the aim is to promote transparency, lower costs, and enhance operational efficiency, resulting in a competitive advantage within the industry.

Related work & Literature

Business intelligence

In the rapidly evolving modern business, data-driven insights have become crucial for organisations in achieving a competitive advantage. Business intelligence (BI) has emerged as a powerful approach that enables businesses to exploit their data to make informed decisions (Hamad, 2022). It involves collecting data from different sources, analysing it and presenting it to their stakeholders in an easily accessible and comprehensive format. In this manner, BI enables organisations to understand their operations, identify trends, uncover opportunities, and address challenges more effectively (AQasrawi, 2022).

Within the construction industry, BI is mainly used to enhance project management, optimising resource allocation, and improving overall efficiency (Al-Sulaiti et al., 2021). Company X has not fully utilised the potential of BI, resulting in significant problems within the company and hindering effective cost control (Employee A, 2023). Hence, this study presents an opportunity to implement BI to gain economic insights, facilitating objective PRC quotation assessment.

Construction industry price indices determination

Accurately determining price indices of PRC within Company X would offer valuable insights into establishing fair pricing by facilitating the ability to compare two quotations based on their price change over time and the corresponding market change. In the construction industry, price indices are used to monitor changes in the cost or price of construction (Kıbar, 2007). The Statistics Directorate of the OECD (1997) states that the price of the output of a construction activity is an operation that includes following factors:

- *Direct inputs*: materials, labour, plant & equipment, transport, energy and other costs. These generally vary in proportion to output
- *Indirect inputs and overheads*: depreciation, administrative expenses. These generally are fixed without varying directly with the volume of output.
- *Productivity*: refers to changes in the quantity of direct inputs per unit of output.
- *Profit*: the residual, influenced by the sales price and combinations of the three preceding factors. Varies widely and may be negative.

Price analysis

One way to determine the output of this operation is by determining the output price indices of PRC through price analysis, considering all four factors. Price analysis involves a comparative process that seeks to establish a threshold that signifies the point at which a price can be considered fair in relation to prevailing market conditions. (Smith, Buddress, & Raedels, 2006). Price analysis solely focuses on evaluating a product's market price without considering its different cost components or internal or external factors (e.g., profitability). With a clear understanding of the level of competitiveness within the market of a certain product, this threshold is estimated.

In highly competitive markets, prices are typically lower due to the presence of multiple suppliers competing for customers. This competitive environment compels suppliers to align their prices with the prevailing market value of the product, facilitating a relatively straightforward estimation of the product's market value. Conversely, in non-competitive markets, such as monopolies, suppliers face limited or no competition, granting them the ability to establish higher prices to gain additional profit. Therefore, price analysis is more unreliable in non-competitive markets.

Cost analysis

A method with which the input price indices of PRC can be determined is cost analysis. Cost is defined as the value of resources required to produce a specific good or service (Smith, Buddress, & Raedels, 2006). By conducting cost analysis, it becomes possible to measure changes in the price of PRC inputs by monitoring the cost of each individual input resource separately. Resulting in the compilation of a weighted index representing the cost of all direct and indirect resources.

To perform cost analysis effectively, it is essential to identify the set of underlying components directly influencing the cost of PRC. This requires specialised knowledge of the supplier's cost structure and access to accurate and up-to-date element cost indices. Within construction, these components mainly include materials, labour, equipment, transport, energy and other costs, referring to a manufacturer's costs for the processes besides the actual value-adding process (Employee A, 2023).

Cost analysis provides a comprehensive understanding of a product's costs by analysing each individual cost component. However, input price indices only provide a reflection of changes in the prices of construction inputs. The indices produced are production costs rather than production price indices. They do not provide information on price movements for finished construction work as they generally do not reflect the whole range of influencers that impact on market prices (The Statistics Directorate of the OECD, 1997). Determining the precise cost composition requires specialised knowledge of the supplier's cost structure and access to accurate and up-to-date information.

Validity and reliability considerations in the compilation of construction price indices

The Statistics Directorate of the OECD (1997) lists the following four reliability considerations in the compilation of construction price indices:

- Diversity of construction activity
- Changes over time
- Selection of appropriate prices
- Ensuring geographic representativeness of the index

Diversity of construction activity

One of the significant challenges in compiling construction price indices arises from the diversity of construction activities, which has a negative effect on comparability. In order to accurately display price changes using a price index, it is crucial for the data to pertain to consistent types of work. To achieve this, the index should be based on a specific, representative group of a particular type of building construction. These groups can be categorised based on characteristics that are known to influence price indices. One approach to mitigate the impact of this diversity is to include pricing components instead of considering the entire construction project. This involves selecting individual types of work that occur regularly and incorporating them into the price index calculation.

Changes over time

A second challenge in compiling construction price indices is maintaining comparability over time, considering the constant changes in both input and output factors of construction activity. Factors such as size, finish style, equipment used, and trends can influence these changes. To ensure that reported values for a specific price series reflect only "pure" price changes, it is important to keep all the factors that contribute to the price level (referred to as price determining characteristics) as consistent as possible for as long as possible. One commonly used method by OECD and European Union Member countries involves breaking down different construction projects into elementary components that are more comparable over time, thus allowing for effective comparison.

Selection of appropriate prices

When developing a construction price index, selecting the appropriate type of input prices is crucial. The choice depends on the pricing method being used. Some types have implications associated with them like gathering output prices based on bids or quotes. Firms may find it difficult to take the process seriously as they are not bidding for actual work and there is no negotiation involved, resulting in unreliable prices. To address this, applying input price indices is generally considered more objective. These indices exclude factors such as productivity and profit, focusing solely on the price itself.

Ensuring geographic representativeness of the index

Costs, prices, size, style, construction materials, and methods used in construction can be significantly influenced by regional variations, including rural/urban differences. It is crucial to recognize and account for these diversities when developing a construction price index. One effective approach to capture these variations is by integrating a rural/urban distinction within the index framework. This allows for a more accurate representation of the different cost factors and pricing dynamics associated with specific regions, enabling a more comprehensive analysis of construction prices.

Visualisation of price indices

To effectively communicate the PRC price indices, visualisation techniques can be utilised to simplify the complex data into easily comprehensible visual representations such as charts, graphs and maps. This facilitates a clearer and more accessible presentation of the price indices to the end-user.

Within BI, visualised data is frequently presented through reports, dashboards and analytical tools of which dashboards are mostly data visualisation driven (Zheng, 2018). Dashboards serve as user-friendly tools designed to effectively present data-rich information ensuring a low learning curve and minimising resistance (Gony et al., 2007). A dashboard allows quick detection of possible patterns and relations within data because of its visual nature and its role in ease of comprehending visual information. By leveraging visualisation techniques and BI dashboards, end-users can gain valuable insights from the simplified presentation of the price indices.

User requirements determinations

Functionality

To effectively implement business intelligence into this study, it is essential to meet the users' expectations. Meeting these expectations requires the integration of requirements right from the start of the study, increasing the likelihood of achieving success (Hollberg et al., 2022). Therefore, it is essential to obtain a comprehensive understanding of the specific functionality requirements that are necessary to perform the task desired by the end-user.

Usability

The primary audience for a BI dashboard typically consists of internal employees, and potentially external stakeholders. Given that not all individuals may be expertised in interpreting data, it becomes crucial for the dashboard to be user-friendly, enabling easy utilisation and comprehension by all interested parties. Therefore, the dashboard should meet specific usability-related user requirements to ensure understanding of its intended tasks.

Firstly, a requirement is that the dashboard should be intuitive and easy to navigate, even for users with low computer expertise (Kuzmenko, 2021; Mohammad et al., 2020; Mathur et al., 2022). Secondly, the dashboard should be efficient, meaning it should be able to perform its tasks quickly (Mohammad et al.; Pereira, 2020; Solsona-Berga et al., 2020). This especially is relevant when it includes large datasets. Thirdly, a dashboard should be customisable, meaning it can provide the user a tailored display of information (Pereira; Solsona-Berga et al.). Also, a dashboard should contain clear visualisations that facilitate easy comprehension of the provided information (Pereira; Solsona-Berga et al.). Ensuring inclusivity, another requirement is that the dashboard should be accessible to a wide range of users, including those with disabilities such as colour blindness (Kuzmenko). Additionally, a dashboard should also be compatible with a variety of devices in order to easily integrate into an existing technological infrastructure (Kuzmenko; Pereira).

The relevance of usability requirements may vary across different end-user groups (Reeves et al., 2004). Therefore, it is important to prioritise the requirements based on the end-user's needs. Also, it may be necessary to cater the usability requirements to specific needs of the end-users (Tan et al., 2020). To illustrate, when targeting older users, considering a larger font size to enhance readability might be important. Specific usability needs can be identified by collaborative engagement with end-users during dashboard development (Garmer, Ylvén & Karlsson, 2004).

Requirement alignment

Given the low data maturity level of the end-users, aligning their expectations with the realised requirements is deemed important within this study. To identify potential discrepancies between the researcher's interpretation and the end-user's interpretation of the realised requirements, the Build-Measure-Learn (BML) method can be integrated into the study. BML follows a process of building a minimal viable product, measuring the end user's reaction and making adjustments based on these findings to improve user interactions (Martinekuan, 2022). This allows adjustments or expansion of the user requirements if necessary, enabling continuous improvements throughout the development process.

Dashboard visualisation tool comparison

There are several notable tools that can be employed to develop a dashboard for BI purposes, including PowerBI, Tableau, QlikView and the 'shiny' package from the R programming language. **PowerBI**, developed by Microsoft, is recognised for its user-friendly interface, smooth integration with other Microsoft products, and offers connectivity with various data sources such as Excel and databases (Cheng & Gu, 2022). However, a significant disadvantage is that a PowerBI interface is read-only, meaning you cannot save adjustments made in the dashboard to the database directly (Radečić, 2022). Also, it has, compared with other tools, limited options in terms of data preprocessing, customisation and advanced analytics (Eppler, 2019). **Tableau** is renowned for its robust visualisation capabilities and intuitive user experience (Hoelscher & Mortimer, 2018). It supports diverse data sources and offers advanced features such as data blending and real-time analytics, but does require skill to perform complex data manipulation. **QlikView** is a BI-platform that provides guided creation of analytics applications (Tapia Guerrero & Villacís Albán, 2015). Its associative search allows data exploration and its in-memory data processing facilitates fast analysis. However, it is limited in its options for customisation compared with other tools. The R programming language's **'shiny'** package is a versatile framework in terms of customisation and adaptability (Dong et al., 2022), has extensive analytical capabilities (Pardesthi, 2019), and the ability for data preparation and real-time data integration (Dipto, 2020). However, the drawback of Shiny is that it requires coding expertise and it is less design-focused than, for instance, Tableau.

In conclusion, each tool mentioned - PowerBI, Tableau, QlikView, and R's Shiny package - offers unique strengths and limitations for developing dashboards for BI purposes. Factors to consider when selecting the appropriate tool for a specific project include user-friendliness, data integration capabilities, customization options, and required skill sets.

Analysis data

Internal data collection

The internal data refers to data within, and solely accessible to, Company X. The **quotations dataset** involves structurally, by the cost-engineer updated, real-time data on all quotations Company X receives from their manufacturing partners (Appendix A). The values reflect quotation prices per construction parcel (columns) per project (rows), expressed in euros per square metre of the gross floor area (GFA).

External data collection

The external data refers to the data that is gathered from either external or public parties (Table 2):

- **Poured concrete market indices dataset**: annually contracted prices regarding poured concrete between Company B and its partner Manufacturer B. Collected from Company B.
- **BDB resources & materials dataset**: public monthly market indices regarding resources and components used in construction. This dataset could not continuously be extracted, hindering the data from being real-time. Collected from BDB Bouw(kosten)data, a supplier of construction cost data.
- **BDB construction cost market indices dataset**: subscription-based real-time data regarding monthly market indices about the construction market in general, differentiating between total labour costs, total material costs, and total contract price including VAT. Collected from BDB Bouw(kosten)data.
- **Steel market indices dataset**: public, real-time weekly market indices and prices about steel used specifically in concrete. It differentiates between rebars, cold-rolled wire, hot-rolled wire, and wire mesh and is referred to by the PRC supplier. Collected from Belmetal, the Belgian professional association of the metal trade.
- **British concrete & steel market indices dataset**: market volatilities about ready-mixed concrete, precast concrete products, and steel reinforcing bars. Collected from the British government.
- **Energy market indices dataset**: real-time data about monthly energy market indices. Collected from the Central Bureau of Statistics (CBS).

- **Fuel market indices dataset**: monthly market indices about diesel fuel. Collected from CBS.
- **CBS construction cost market indices dataset**: monthly market indices about construction costs, thereby differentiating in labour and material costs. Collected from CBS.

All extracted data was extracted from January 2018 onwards since that is where the youngest dataset, the poured concrete marked indices dataset, started. The real-time data was continuously extracted using API's or URL's, which facilitate information exchange of web-based applications (Lloyd & Nilsson, 2019).

Table 2. A representation of the collected datasets

Dataset	Source	Variables	Real-time	Public dataset
1. Quotations dataset	Company X	Projectname, Total price GFA per m2, Price of PRC skeleton, Price of PRC steel constructions, Total PRC price, Period	Yes	No
2. Poured concrete market indices dataset	Manufacturer B	Components, Index, Period, Development	No	No
3. BDB resources & materials dataset	BDB Bouw(kosten)data	Components, Index, Period, Development	No	No
4. BDB construction costs market indices dataset	BDB Bouw(kosten)data	Components, Index, Period, Development	No	No
5. Steel market indices dataset	Belmetal[1]	Components, Index, Period, Development	Yes	Yes[2]
6. British concrete & steel market indices dataset	British government[3]	Components, Index, Period, Development	No	Yes[4]
7. Energy market indices dataset	CBS[5]	Components, Index, Period, Development	Yes	Yes[6]
8. Fuel market indices dataset	CBS[7]	Components, Index, Period, Development	Yes	Yes[8]
9. CBS construction cost market indices dataset	CBS[9]	Components, Index, Period, Development	Yes	Yes[10]

Note. The column on the right labelled "real-time" denotes whether the dataset is automatically updated with the most recent available data.

[1] https://www.belmetal.be/site/files/files/IABSI.xlsx
[2] http://www.belmetal.be/nl/disclaimer
[3] https://www.gov.uk/government/collections/building-materials-and-components-monthly-statistics-2012
[4] https://www.gov.uk/help/terms-conditions
[5] https://opendata.cbs.nl/ODataApi/odata/83131NED/TypedDataSet
[6] https://www.cbs.nl/nl-nl/over-ons/website/copyright
[7] https://opendata.cbs.nl/ODataApi/odata/80416ned/TypedDataSet
[8] https://www.cbs.nl/nl-nl/over-ons/website/copyright
[9] https://opendata.cbs.nl/ODataApi/odata/83887NED/TypedDataSet
[10] https://www.cbs.nl/nl-nl/over-ons/website/copyright

Data pre-processing

Data was cleaned and pre-processed in order to ensure quality and consistency, enabling smooth integration and easy interpretation. To optimise efficiency, we selectively extracted the relevant factors, determined in the cost analysis, that have a direct influence on PRC pricing. To ensure comparability, relevant variables were standardised through transforming them into uniform variable names, adopting a consistent formatting for their values, including removal of special characters, setting dots as separators, and putting all dates in ‘yyyy-mm-dd’ format (Table 2). Also, all indices were indexed to January 2018 to establish a common reference point. It corresponds to the dataset with the latest commence, the poured concrete dataset. For convenient integration and visualisation, all datasets were reformatted from a wide to a long format, consolidating related information per column, enabling improving interpretability and facilitating data analysis. Finally, the datasets used in the visualisation of market indices (i.e., CBS fuel dataset, steel prices dataset, CBS energy dataset, CBS material labour dataset, poured concrete dataset, UK concrete dataset) were consolidated into a single comprehensive dataset called **PRC market indices dataset** by row binding (i.e., merging datasets vertically by appending rows from one dataset to another) them. A column called ‘source’ was added to the PRC market indices dataset, providing information on the dataset of origin for each row.

Methods

PRC cost indices determination

Within this study, the input price indices of PRC are determined through a cost analysis rather than the output price indices through a price analysis. Cost analysis is chosen because of the low competitiveness of the PRC supplier market, resulting in a scarcity of pricing data available from other suppliers offering similar products under various market conditions, making price analysis unreliable in this study.

The cost analysis was initiated by the identification of the components influencing the market price of PRC. This is done to subdivide PRC into price components for which the underlying markets, driving the cost price of PRC, can be identified. This allows for the determination of the weights associated with each individual market, ultimately allowing the calculation of the cost price of PRC over time. The factors influencing the cost price of PRC were determined using the seven individual quotations, which disaggregated the total PRC price among seven distinct cost components. The PRC price composition was found to, in each of seven PRC quotations, consist of the following components: engineering, columns &

floors, facades & walls, steel constructions, transport, assembly, and indirect costs & profit. The proportional inclusion of the indirect costs and profit component among the remaining six components ensures that the distribution of prices remains unchanged. As a result, these cost and profit factors can be disregarded in the analysis.

Table 3. variances within the price proportions per PRC component

PRC price component	Variance (σ^2)
Columns & Floors	2.70^{-3}
Facades & Walls	5.06^{-3}
Transport	1.34^{-4}
Engineering	1.60^{-3}
Assembly	1.44^{-4}
Construction steel	8.60^{-5}

Variances within the price proportions of all components were low, implying that the price proportions per component exhibit minimal variability and are highly consistent (Table 3). This implies a stable pattern, indicating that these proportions are likely to remain rigid and not undergo significant changes in future projects, provided that the construction method remains unchanged. Hence, given the assumption that the average proportions remain representative of future projects, we converted the prices to proportions of the total PRC price and subsequently calculated the weights by taking their average per PRC component.

$$c_{a1} = (c_{i1} + c_{i2} + c_{i3} + c_{i4} + c_{i5} + c_{i6})/n$$

In close collaboration with Company X's cost engineer, the PCR components were further disaggregated into subelements to enable valid representation by an underlying cost index. Eventually, all six components were subdivided into distinct markets.

Dashboard development

In collaboration with the dashboard's end-users (i.e., Company X's employees), the following project-specific user requirements regarding the dashboard were determined:

Functionality requirements:

- Comparing quotations
- Recalculating quotations to another time period

- Insight in PRC cost structure and its underlying markets

Usability requirements:

- Interpretability

These requirements were defined to operationalise realising the overarching objective of empowering the end-user in their task to gain economic insights, enhancing objective quotation assessment of PRC.

The functionality requirements were established through a collaborative effort with the cost engineer, carefully describing the necessary functionalities. Among the usability requirements, the most prioritised aspect was identified as the ability to provide easily interpretable economic insights. This usability requirement is deemed as most important due to the need for a low learning curve, given the relatively low data maturity and experience within company x and the need for the supplier to be able to easily interpret the dashboard to facilitate more effective price negotiations.

To meet these specific requirements, the R programming language was chosen, in particular its ‘shiny’ and ‘shinydashboard’ packages. The decision to choose RShiny was driven by its outstanding level of customizability, surpassing other BI tools in this regard. High customizability played a crucial role in precisely aligning the end result with the specific needs of the end-user.

To meet the functionality requirements, a dashboard was developed using the pooled PRC cost index price and the PRC market indices dataset, which contains all market indices that are included in the pooled index. The first two end-user requirements, namely comparing quotations and recalculating quotations to another time period, were addressed by leveraging the pooled index in combination with the quotations dataset. The last functionality requirement was met by utilising the PRC market indices dataset to visualise real-time market volatilities.

The Build-Measure-Learn (BML) approach was applied throughout the development of the dashboard to test whether the functionality requirements were met and to gather specific usability improvements. This involved a total of 3 iterations of sharing the dashboard to the cost engineer within the company and asking for feedback. The focus was on evaluating whether the formulated functionality requirements could be successfully executed and addressing any concerns related to interpretability.

Data validation plan

In order to improve the reliability of the study, various measures are undertaken, taking into account the validity and reliability considerations discussed in the literature regarding the compilation of construction price indices. The three additional measures are outlined below:

Scrutinising input data

To assess the reliability of the input data, all input datasets are examined to scrutinise the accuracy of any abnormal values. Abnormal values are data points that deviate significantly from the expected points. Outliers were detected by plotting all indices on a line graph and visually inspecting for any abnormal jumps or fluctuations in the indices. When abnormal values were identified, their accuracy was assessed to determine whether they were genuine data points that should be considered or if they were errors or outliers that need to be addressed or removed.

Validating indices

In order to compensate for the static data (i.e., not real-time continuously extractable) in the BDB resources & materials dataset, the CBS construction costs dataset was utilised as a substitute. The validity of this proxy was established through a statistical comparison between the material and labour indices of the CBS dataset and the BDB dataset.

To mitigate possible bias and considering the "selecting appropriate prices" consideration, a second validation process was conducted for the internally used concrete and reinforced steel datasets. The poured concrete dataset was compared to the UK concrete dataset and the Belmetal steel prices dataset was compared to the Office of National Statistics (United Kingdom) concrete reinforcing bars dataset.

The validation processes ensured that the datasets are valid representations of the targeted markets and deemed suitable for accurate calculation of the PRC cost indices. The validation process is outlined below.

- The first step involved computing the correlation coefficient for each comparison to evaluate their degree of similarity. Given that our analysis revolves around financial data, we sought a correlation greater than 0.9 for the proxies to be deemed reliable. This high correlation standard is chosen to ensure greater precision when calculating the aggregated cost indices for PRC. For the non-proxy comparisons a correlation greater than 0.8 is deemed acceptable given that the external cause of the dissimilarity is found. Failing to meet these standards would have necessitated finding a new indices dataset.

- The second step involved plotting the indices on a line graph, allowing for a visual comparison over time. This step primarily aimed to compare the behaviours of the indices and identify non-parallel fluctuations. It supported in finding context when investigating the reasons behind potential deviations.

Checking output data

In order to ensure the absence of errors or inaccuracies in the created output table, a visual inspection was conducted. This inspection involved reviewing the output plot and comparing it to the input plot. The goal was to identify any errors that have occurred during the creation of the output table. If any possible issues were identified, further investigation or correction was undertaken.

Data validation

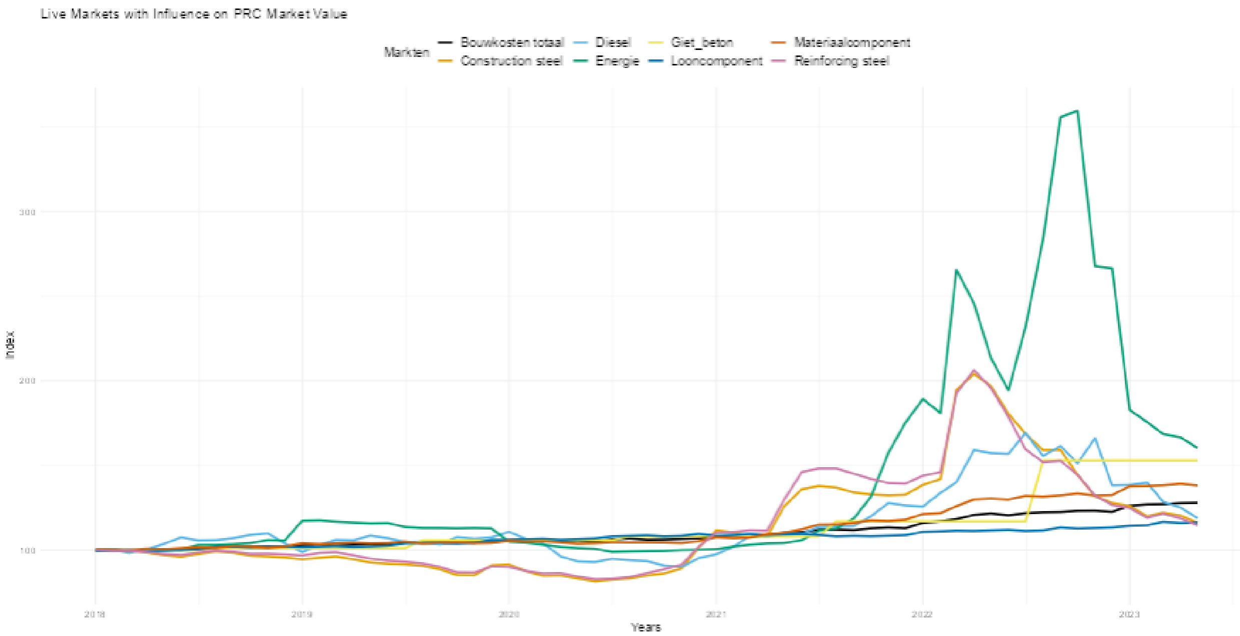

Figure 1. Validation the input dataset with indices set to 2018.

Scrutinising input data

Upon examining figure 1, the only potential abnormal values are the high energy values in 2022. According to Statista (2023) and the Ministerie van Algemene Zaken (2023) these values can be attributed to Russia's invasion of Ukraine in February 2022 and the resulting energy crisis in the Netherlands in 2022. Resulting in these input values assessed as accurate and valid. No other outliers were identified in the input dataset.

Validating indices

- The correlation coefficient between the CBS material index and the BDB material index is 0.997.
- The correlation coefficient between the CBS labour index and the BDB labour index is 0.969.
- The correlation coefficient between the Office for National Statistics Uk concrete index and the Manufacturer B concrete index is 0.918.
- The correlation coefficient between the Office for National Statistics Uk concrete reinforcing steel index and the Belmetal reinforcing steel index is 0.928.

All suggesting a strong correlation, surpassing the threshold of 0.9. The last two comparisons the scores were not as high as the previous scores. This difference is potentially explained by the consideration of ensuring geographic representativeness of the index, which is discussed in the literature. It could be the case that regional market differences cause disparities between the concrete and steel markets in the United Kingdom and the Netherlands.

Figure 2. *Validation of market trends with indices set to 2018.* (a) BDB and CBS construction material indices over time. (b) BDB and CBS labour indices over time (c) Manufacturer B and Office of National Statistics (United Kingdom) concrete indices over time (d) Belmetal and Office of National Statistics (United Kingdom) reinforcing steel indices over time.

Visually, the comparison suggests that the CBS and BDB construction material indices exhibit overall similarity with minor differences observed (Figure 2a). The labour data from the BDB is more stable with fewer fluctuations and occasional insignificant increases compared to CBS data, potentially attributed to its correlation with the CAO (Collaborative Labour Agreement) salary increases (Administrator, 2022; see Figure 2b). Internal annual concrete rates are more stable than UK precast concrete rates, with closely matching fluctuations in the yearly jumps of the poured concrete dataset and Uk concrete dataset indices (Figure 2c). The Belmetal steel prices closely track the UK concrete reinforcing steel dataset, except for a faster price drop in Belmetal after Q1 2022 (Figure 2d). Despite extensive efforts, the reasons behind the varying rates of decline in the UK and EU steel markets since Q1 2022 remain unknown. No alternative index for concrete reinforcing steel could be found to validate the Belmetal index. Consequently, the Belmetal index continues to be utilised as the primary reference.

PRC pooled cost index

Table 4. Overview of the price composition of PRC.

PRC	34% columns & floors	40% concrete	
		30% labour	
		25% steel	70% wire mesh 30% cold rolled wire
		5% energy	
	30% facades & walls	40% concrete	
		30% labour	
		25% steel	70% cold rolled wire 30% wire mesh
		5% energy	
	13% assembly	85% labour	
		10% fuel	
		5% equipment	
	10% transport	40% fuel	
		35% salary	
		25% equipment	
	9% engineering	90% labour	
		10% equipment	
	4% construction steel	70% steel	
		25% labour	
		5% energy	

The columns and floors, facades and walls and for the steel constructions component were further disaggregated into subelements in the quotations. Columns and floors and facades and walls, which are the only two components actually consisting of PRC material, were both subdivided into concrete, reinforcement steel and production. steel constructions, implying the steel that is not used as reinforcement steel for the concrete, was subdivided into steel and production. Also, the prices of these subcomponents were presented in the quotations, which were converted into weights (i.e., proportions).

Subsequently, the following components still required subdivision to enable valid representation by an underlying cost index. These included, reinforcement steel, steel constructions, production of PCR (i.e., columns & floors and facades & walls), engineering, assembly and transport.

The underlying markets of the reinforcement steel and steel constructions were determined using the unprocessed Belmetal steel dataset that contains market indices for all four types of steel (i.e., rebars, cold rolled wire, hot rolled wire and wire mesh). The reinforcement steel in columns and floors exist for 30% out of cold rolled wire and 70% out of wire mesh, as indicated by Company X's plan developer (Employee C, 2023). Facades and walls consist of 70% out of cold rolled wire and 70% of wire mesh (Employee C). The steel constructions consist fully of rebars (Employee C).

As indicated by Company X's costs engineer, the production of the PCR materials columns & floors and facades & walls includes energy, labour and equipment costs. The both components weight values were determined to have the same distribution, which includes 40% concrete, 30% labour, 25% steel and 5% energy. Production costs for steel and concrete are already included in their individual cost index. However, the PCR still has to be produced by combining these two materials, which adds additional labour and energy costs.

Costs for steel constructions were estimated to consist for 70% out of steel rebars, and for 25% out of labour and for 5% out of energy related to the rebar production.

Engineering, assembly and transport costs were indicated by the cost engineer to consist for the majority out of labour costs and also for a part out of equipment costs. Additionally, transport and assembly costs also consist of a portion of fuel costs. The distribution of the engineering component was estimated to be 90% and 10% for labour and equipment costs, respectively. For assembly, the weights for labour, equipment and fuel costs were estimated at 85%, 5% and 10%, respectively. For transport, the distribution was estimated at 25% for equipment costs, 35% for labour costs and the remaining 40% for fuel.

Thus, all PRC price components were thus subdivided into six distinct markets, namely costs of (reinforced) steel, concrete, labour, fuel, equipment and energy.

Once the price composition of PRC (i.e., its components and corresponding weights) was determined, each (sub)component's weight was multiplied by its corresponding cost index from the collected datasets. Each subcomponent is represented by the following market:

- Steel: Belmetal steel prices dataset
  - Rebars variable
  - Cold rolled wire variable
  - Wire mesh variable
- Concrete: concrete prices dataset
- Labour: CBS construction costs dataset
  - Labour variable
- Fuel: CBS fuel prices dataset
- Equipment: CBS construction costs dataset
- Energy: CBS energy prices dataset

Subsequently, the pooled cost index for PRC was calculated by multiplying each PRC price component by its weight. The pooled index can be used to compare to a past quotation or to recalculate a quotation's pricing to another time period, providing an estimation of how the same quotation would have been priced based on the cost index at a different point in time.

Quotation comparison

To compare quotations, the percentage in price was calculated by dividing the price of the past quotation by the price of the quotation that was being assessed and multiplying this by 100. For market change, the index of the past quotation was likewise divided by the price of the quotation that was being assessed and multiplied for 100. To calculate the price difference not explained by the market difference, the price change was subtracted from the market change.

Quotation price recalculation

To recalculate a quotation's pricing to the time period of a past quotation, the index of the quotation that is to be recalculated was multiplied by its own cost index, and subsequently divided by the cost index of the selected period. This results in a new price estimated that is in line with the PRC cost index of that time period, according to the estimated PRC pooled cost index.

Current markets

Each of the market indices datasets used in the calculation of the PRC pooled cost index were visualised. However, for the reinforcement steel, different proportions of cold rolled wire and wire mesh were utilised. In collaboration with Company X's cost engineer, we determined that it would be confusing for users for have multiple types of reinforcement wire in the visualisation, which is why we chose to visualise one line for reinforcement steel that consists for 50% of the cost index for cold rolled wire and for 50% of the cost index for wire mesh. The correlation coefficient between the cold rolled wire and wire mesh indices equals 0.99, which is logically sound as both indices are composed of the same material. Given their strong correlation, it is reasonable to utilise a single line to represent both indices.

Dashboard development

Quotation assessment

Functionality

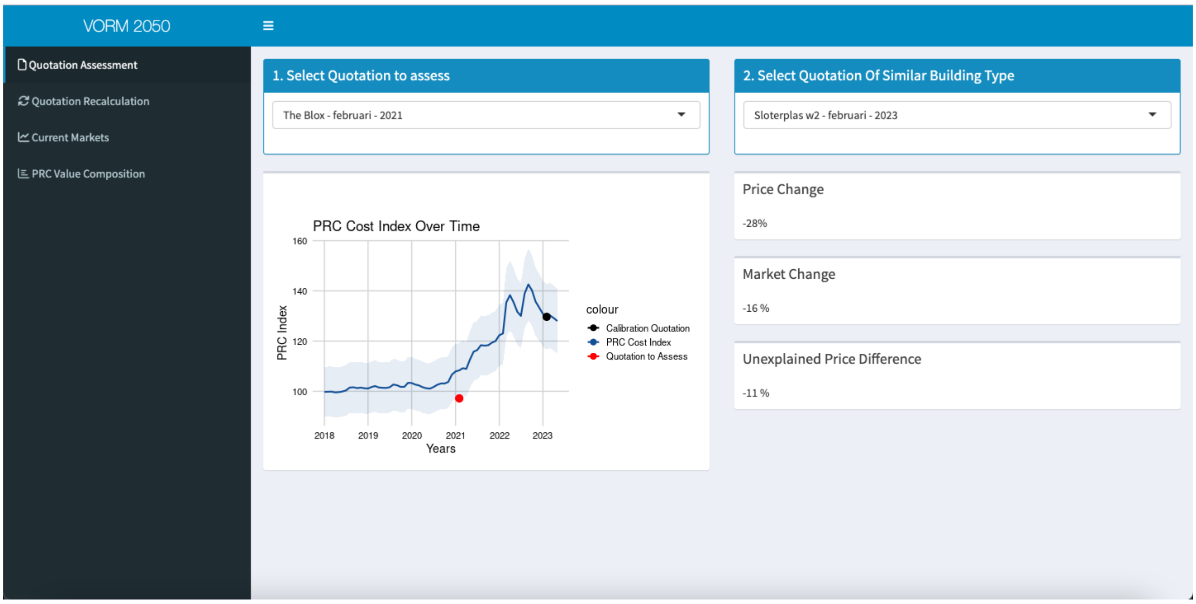

Figure 3. *The dashboard's 'Quotation Assessment' tab.*

The first tab '**Quotation Assessment**' enables comparison of two PRC quotations of the user's choice, which can be selected in the two blue boxes titled 'Select Quotations to assess' and 'Select Quotation of Similar Building Type', respectively (Figure 3). After selecting two quotations, the tab presents the percentage differences between the quotations in price (Price Change), in the PRC market value according to the pooled index (Market Change), and the difference in price that cannot be attributed to the difference in cost index (Unexplained Price Difference). Note that this comparison does not indicate what price would be assumed a fair pricing, as this is unknown. This comparison calculates price and market developments relative to the past quotation, thereby not implying that the past quotation had a perfectly fair price.

In graph ‘PRC Cost Index Over Time’, this comparison is visualised. The black dot represents the past quotation against which the recent quotation is compared, which is represented by the red dot. The blue line reflects the pooled cost index of PRC over time. The blue shade surrounding this line is a ten percent deviation above and below the cost index, which also reflects a ten percent increase or decrease in PRC price since the measuring unit is displayed in indices. This serves as the threshold, which was set by Company X’s cost engineer, that indicates when a pricing substantially deviates, and might hence be reconsidered by the manufacturing partner. Thus, when the red dot is located outside of the shade, this indicates substantial price deviation.

This feature enables employees at Company X to make objective comparisons between a new quotation and a previous one. A positive unexplained price difference implies that the price of the recent quotation is higher than the price for the selected past quotation, relative to the current market value of PRC. This can serve as evidential support in favour of negotiating a price reduction with the manufacturing partner.

Usability

In the dashboard’s ‘Quotation Assessment’ tab, the presence of two blue boxes featuring so-called ‘drop-down menus’, indicated with arrows, effectively communicates to the user the input fields available for retrieving desired information, thereby enhancing intuitive navigation through this tab. For clarity, the project’s dates are added to them in the drop-down menus. Each information element is placed in a white box, indicating that a separate element of information is provided. The graph was designed in a minimalistic manner to not divert the user’s attention from pertinent information, contributing to clarity and intuitiveness. A legend was added to describe all data elements presented in the graph. In the dashboard’s menu on the left, a ‘file’ icon was added that refers to an assessment form, providing a visual cue for recognition (McDougall, de Bruijn & Curry, 2000).

This feature enables employees at Company X to make objective comparisons between a new quotation and a previous one. A positive unexplained price difference implies that the price of the recent quotation is higher than the price for the selected past quotation, relative to the current market value of PRC. This can serve as evidential support in favour of negotiating a price reduction with the manufacturing partner.

Quotation recalculation

Functionality

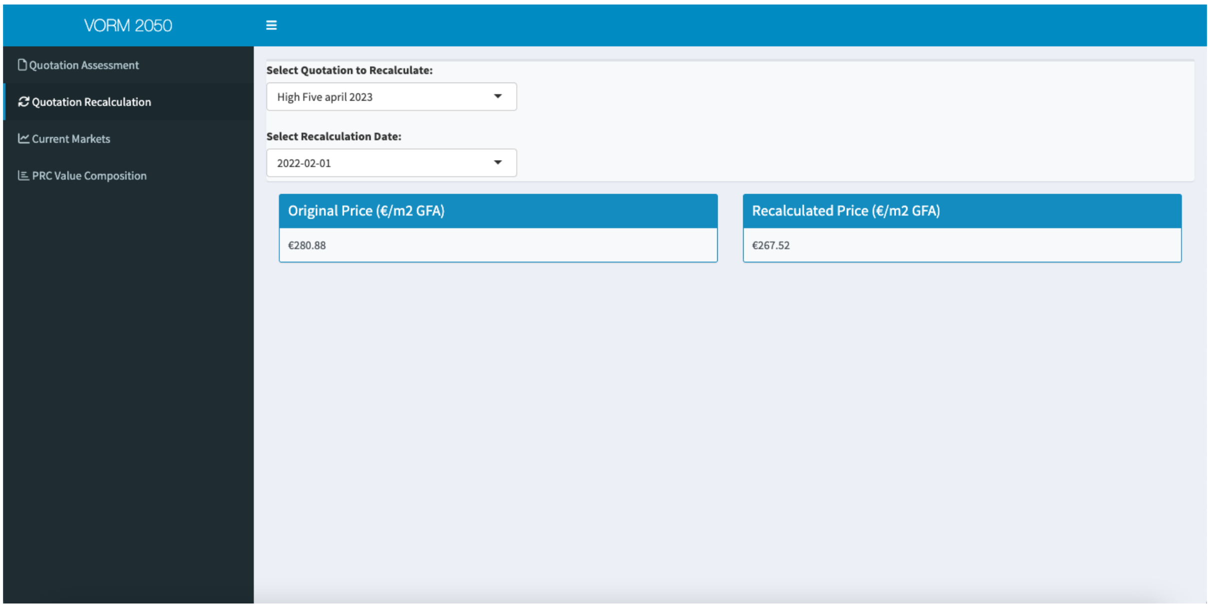

Figure 2. *The dashboard's 'Quotation Recalculation' tab.*

The second tab of the dashboard '**Quotation Recalculation**' is aimed for price recalculation (Figure 2). It allows users to assess the price of a quotation of choice to a different period of time that is also to be chosen by the user, according to the market. After selecting a quotation as well as a time period, the box 'Recalculated Price' displays the price of the quotation according to the estimated PRC pooled cost index at that specific period in time.

Using this tab, two types of recalculations can be conducted. The price of a new quotation can be recalculated to a price of a past time period, but an old quotation can also be recalculated to the current month. The latter can prove useful even before a quotation is received. In cases where a future project lacks definitive confirmation but shares similarities with an existing quotation, estimating its market-conform PRC price beforehand can circumvent the need to already engage a manufacturing partner. This estimated price can then serve as a proposed rate when collaborating with a partner.

Usability

In terms of usability, this tab is similar to the 'Quotation Assessment' tab. The drop-down menus are indicated with arrows, inviting the user to select the desired information in the boxes. The blue boxes indicate the two separate prices.

Current markets

Functionality

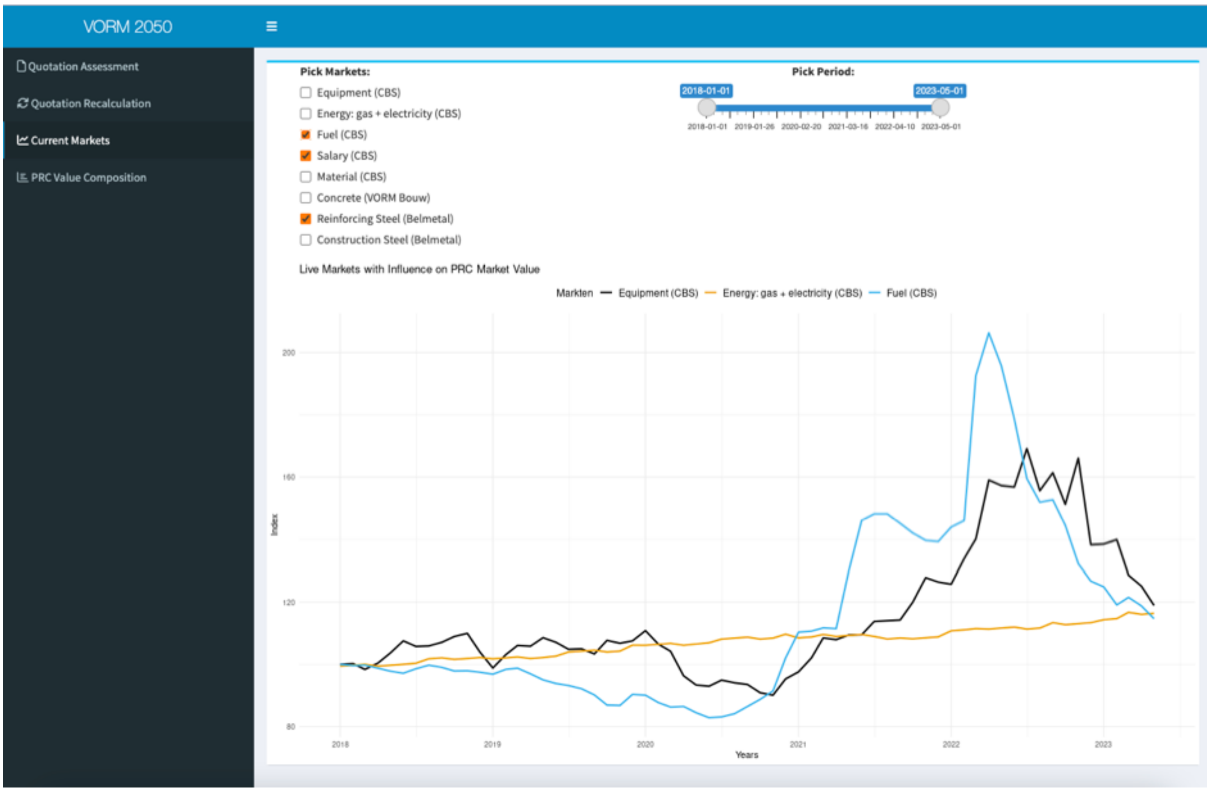

Figure 3. *The dashboard's 'Current Markets' tab.*

In the third tab of the dashboard '**Current Markets**', the market indices underlying the PRC pooled cost index are visualised (Figure 3). The graph provides a comprehensive display of market trends, thereby providing the user economic insight in one glance. The tab allows users to select and deselect markets as well as it allows time frame selection, allowing a broad overview as well as in-depth trend exploration.

Usability

The 'Current markets' tab allows two sorts of customisation. The tick boxes enable the users to selectively determine the markets they wish to visualise. The slider allows users to select a preferred time frame, automatically adjusting the X-axis of the graph to align with the chosen time frame. For the line colours in the graph, a colour palette from a study by Wong (2011) was implemented that was designed specifically so individuals with either deuteranopia colour blindness or protanopia can clearly distinguish them.

PRC cost composition

Functionality

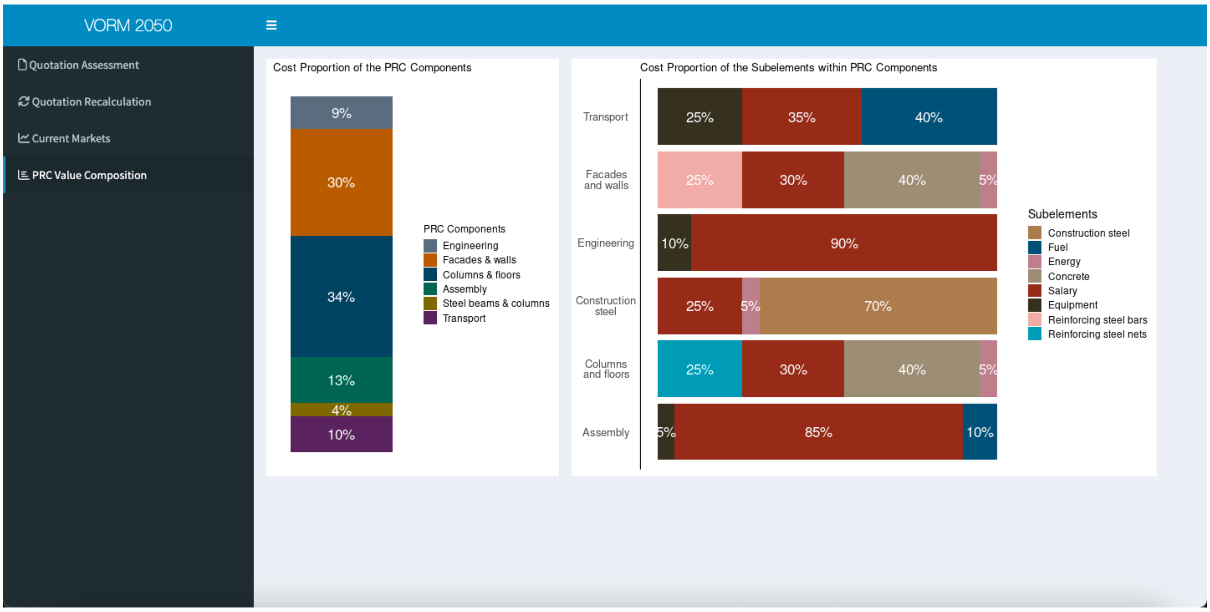

Figure 4. *The dashboard's 'PRC cost composition' tab.*

The fourth and last tab of the dashboard displays the cost composition of PRC (Figure 4). Its primary objective is to provide users with detailed information regarding the composition of the pooled index and the respective weights assigned to its components. This tab proves valuable in situations where users, for instance, observe notable growth in particular market trends on the 'Current Markets' tab. By referring to this cost composition tab, users can assess the extent of the impact resulting from the observed trend increase on the PRC pooled cost index.

Usability

The 'PRC cost composition' tab is not an interactive or customisable tab and thus can only provide the static information that is already represented. Distinct colours were selected for the two graphs to mitigate any potential false associations between elements sharing the same colour.

Discussion

In this study, we aimed to explore how Company X could leverage internal and public data to gain economic insights in order to enhance decision-making. We developed a dashboard that supports employees of Company X in objective quotation assessment of new prefabricated reinforced concrete quotations.

The data collection and integration process was confirmed by the input data check, data validation process, and output data check. These steps ensured the reliability and accuracy of the collected data.

One crucial consideration within this study that significantly influences the accuracy of our findings is the type of projects that Company X will build in the future. In this study, we relied on seven quotations to determine the cost structure. The accuracy of the current index calculation largely depends on whether these seven projects are a representative sample of the exact types of PRC frameworks that Company X plans to construct in the future. If the future projects align closely with the PRC characteristics like strength, consistency, and sustainability labels of these seven quotations, then the current cost structure is likely to be accurate. However, if Company X starts to deviate from these seven building types, the accuracy of the current cost structure may be compromised over time due to variations in PRC characteristics. Therefore, the future-proofness of the design is contingent upon the extent to which the seven quotations accurately represent the future projects.

In order to ensure the accuracy of the cost structure calculation, it is important to consider the potential impact of a change in building type. Merely selecting a comparison quotation with a similar price is not sufficient. Instead, the end-user should be required to choose a quotation that closely aligns with the project's PRC characteristics that are being considered. By selecting a quotation from a similar project, the benchmark used for assessment remains relevant and comparable, even in the case of a change in building type. This approach ensures that the cost structure calculation remains as accurate as possible. It is recommended that the index calculation is revised if Company X observes a shift in the types of buildings they plan to construct. This would ensure that the cost structure remains accurate and relevant for future buildings.

Additionally, the determination of cost proportions for construction components lacks scientific literature, necessitating the involvement of experts to validate these proportions. This drawback highlights the need for domain expertise and industry knowledge to ensure the accuracy and relevance of the calculations. Changing the proportions assigned to different cost components can have a substantial impact on the overall assessment, potentially leading to misleading results if not carefully validated. Engaging experts who possess deep knowledge of construction cost structures and can provide guidance on the appropriate allocation of costs within the dashboard would mitigate this limitation. Collaborating with professionals experienced in cost engineering or related fields would enhance the reliability and validity of the dashboard's assessments, facilitating more informed decision-making processes.

The ‘shiny’ package within R was chosen for developing the dashboard due to its high level of customizability, needed to align the dashboard with the specific needs of the end-users. The downside of this choice was that Company X has future plans of using Power BI and two BI tools were deemed impractical. This increased the risk of the solution not being maintained or improved in the future due to lack of expertise or using different BI tools. To ensure the information provided in the dashboard is secured and future-proof, steps were taken to internally share the solution and code with a Power BI specialist. Contributing to a smooth implementation into Power BI if and when desired by the company.

In conclusion, while the study's findings demonstrate the potential of leveraging data to enhance economic insights in the construction industry, it is important to acknowledge and address the limitations. Expanding the scope of the dashboard, increasing the number of quotations, and involving experts in determining cost proportions are crucial steps towards improving the tool's effectiveness, reliability, and usability in supporting evidence-based decision-making within Company X

Conclusion

By pursuing this research Company X can effectively address the need for cost reduction and financial scrutiny without compromising their current approach of working with permanent partners, ultimately contributing to their long-term sustainability and commitment to innovation.

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Appendix A

Table 1. *A delineation of the allocation of responsibilities across various domains within the study.*

Responsibility	L.P. Bunnik	M.T. Koenraad
Interviews	Taking notes	Structuring findings
Literature study	Explore methods, review existing research/case studies	
Introduction	Cost analysis, price analysis, BML	User requirements, Business intelligence, Visualisation of market indices, reference management
Data collection	BDB material labour dataset, Steel prices dataset, Fuel dataset, Energy dataset	Web Scraping datasets: BDB resources dataset, Concrete & steel market indices, Construction costs dataset
Data clean	Quotations dataset, Fuel dataset, Poured concrete, Energy dataset	Steel prices dataset, Concrete & steel market indices, Construction costs dataset
Visualisation	Concrete market value graph, validation graphs, ‘Quotation Assessment’ dashboard tab, ‘Quotation Recalculation’ dashboard tab	Market insights graph, Price proportion graph, Construction price components graph, ‘Current Markets’ dashboard tab, ‘PRC price composition’ dashboard tab
Analysis	Cost index calculation, Dataset validation	Price proportion variances across projects
Writing	Methods: Concrete market value determination, Data analysis plan	Introduction, Data, Methods: Method of data communication, Development tool, Discussion
Other	Internal and external mail contacts, interview planning, hosting dashboard	Poster, references, APA lay-out, day-to-day planning, presentation design, mind mapping

Table 6. *Quotation prices per construction parcel (columns) per project (rows), expressed in euros per square metre of the gross floor area (GFA).*

Projectnaam	M2.BVO.totaal	Maand	Jaar	B2.1.Prefab.casco	B2.2.Constructiestaal	prijs_B2_per_BVO	Perioden
High Five	35573	april	2023	9825434.35	166380	280.8819709	45017
The Blox	31916	februari	2021	11066190	435510	360.374107	44228
Zeeburgerdijk	5319	maart	2023	2245508	73366	435.9605189	44986
Sloterplas toren	15078	februari	2023	7086719	182956	482.137883	44958
Sloterplas g	18214	februari	2023	6873959	318743	394.8996376	44958
Sloterplas w1	6102	februari	2023	2885582	77068	485.5211406	44958
Sloterplas w2	4505	februari	2023	2190819	52131	497.8801332	44958
Sloterplas w3	4612	februari	2023	1886698	43003	418.4087164	44958

Note. projectname, total square metre GFA, month, year, price in euros per for the skeleton, price in euros for steel constructions, price per square metre GFA, periods in excel notation.

Appendix B

Dashboard

https://thesisads.shinyapps.io/dashboard/

Code

https://github.com/1arsUU/ThesisADS