

Critical Aspects of a Business Intelligence Model Development for a Construction Company

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Abstract: - Contemporary business organizations focus on the analysis of their own data, transforming them into useful information through Business Intelligence (BI), a collection of methods, tools, and strategies. This research provides a comprehensive framework for the systematic integration of BI principles within a construction organization. Four main phases are defined for the adoption of BI principles in construction project management, while a case study from a Greek construction company corroborates the presented concepts. The research demonstrates the merits of BI for small-sized construction companies, challenging the perception that such Information Technology investments concern only large-scale corporations. Even simple BI solutions can transform scattered data into valuable information that can lead to usable strategic results. Further research could include new data and variables or interconnect the BI solution with the accounting department to provide high-level metadata.

Key-Words: - business Intelligence; case study; construction; data analytics; decision-making; information technology; modeling; small and medium-sized enterprises (SMEs).

Received: July 2, 2026. Revised: August 1, 2026. Accepted: August 23, 2026. Published: October 5, 2026.

1 Introduction

The contemporary business organizations, along with their executives, put particular focus on the research and analysis of probably their most valuable asset, which is their own data [1]. The processing of the corporate data leads to the inference of valuable information that is vital for the organizational sustainability [2]. The transformation of business data into useful information is achieved through Business Intelligence (BI), namely a collection of methods, tools, and strategies in which business organizations are particularly interested [2]. The integration of BI into the strategic planning leads to innovation, fulfillment of business objectives and informed decision making [3]. However, the construction industry has been rather reluctant to exploit the potential of BI within and across its projects and operations [4], [5]. This research aims to close the gap relating to both the theoretical concepts and the practical implementation of BI in contemporary construction management.

More specifically, the research objective is to provide a comprehensive framework for the systematic integration of BI principles within a construction organization. In that respect, four main phases are defined, which gradually lead to the seamless adoption of BI principles for managing construction projects. First, a comprehensive review of pertinent research aims at presenting the main methods and practical applications of BI in a corporate environment. Then, a descriptive analysis is conducted with respect to the business areas where BI seems to generate positive results, with a particular focus on the construction industry. Subsequently, a theoretical framework for applied BI in construction is developed against the backdrop of a construction company. A real case study from a Greek construction company is analyzed in order to corroborate the validity of the herein presented concepts. The study is concluded with the main inferences emerging from the real case study with respect to different BI dimensions and the suggestion of future research areas.

2 Theoretical Background

Digital technologies bring fundamental changes to the business model of contemporary organizations across the globe [5]. Especially in the European Union, the utilization of digital technology to the benefit of people and organizations has been officially set as an endorsed strategic objective for all member states [6]. The large volume of data managed by the organizations, in combination with the challenges of the ever-changing modern business environment, substantiates the need for developing intelligent information systems that aid business executives in making decisions through historical data manipulation and future prediction processes [7], [8]. BI, as a continuously developing scientific field, opts to cover the aforementioned strategic needs.

2.1 Business Intelligence in Contemporary Organizations

The term “Business Intelligence” is attributed a twofold interpretation within the context of the scientific literature: the first approach relates to human intelligence, as the ability to apply human cognitive interactions for managing business processes [9]. BI is a research field associated with the application of intellectual skills, as well as artificial intelligence technologies, for supporting decision-making of operational research issues. Secondly, BI reflects the organizational intelligence of a company in the form of information that is evaluated according to its accuracy and relationship with the business strategy [10].

For the clarity of the analysis, it is useful at this point to highlight what should be excluded from the concept of BI. First, BI is not a product per se, it is not a commodity that can be bought, installed, and operate autonomously, and certainly, it is not a panacea which will correct all faults in the business process instantly [1]. On the other hand, there is a plethora of related products in the market that can aid an organization in implementing certain aspects of BI. In addition, BI is not a single technology by itself. Of course, BI comprises many modern technological tools, relational databases, analysis platforms, and visualization suites which, when combined, can lead to even more exciting technologies such as artificial intelligence and machine learning. Lastly, BI does not represent a methodology solely. The organization should draft a detailed plan while giving management focus and attention to the effective implementation of BI. The latter is a prerequisite for harvesting the benefits of BI on an organizational level and was identified as a

key metric in the early stages of BI adoption across the industry [11].

BI is a technological infrastructure and technology-driven process for collecting, storing, and analyzing company data. Its application falls into the category of Business Intelligence Systems (BIS), which are specialized information systems that provide access to reliable information [9]. The quality of the provided information is improved, since BI ensures quicker access to information, easy submission of queries, robust reporting, and advanced data analysis. In the modern era, where data is overproduced, BI provides an overview of key company data utilized for decision making and process optimization by senior management [2].

2.2 Advantages and limitations of Business Intelligence

The review of pertinent research has revealed both significant advantages and limitations of BI with respect to its organizational value. The main advantage is a deep understanding of (a) the market, (b) the clientele, (c) the suppliers, and (d) the competitors, by focusing on their needs and requirements [3]. In addition, BI can be combined with predictive analysis tools, so as to provide insights on new opportunities for senior management. In that respect, organizations can significantly improve their efficiency, competitiveness, and performance. On the other hand, each organization opting to adopt a pro-BI stance should be aware that there are significant acquisition costs involved with any BI solution, while additional investment costs are needed for knowledge transfer and human acquisition in case BI processes are officially integrated in the company [12]. Furthermore, usually the BI solutions are implemented concurrently with the existing IT infrastructure and culture, hence a proper transition and change management strategy has to be carefully planned and followed [13], [14]. Another limitation that has been observed relates to the human factor, since people should neither be reluctant and resistant to the adoption of the new BI approach, nor blindly rely on their output without a critical review of the provided context [15]. The latter is even more important if there is doubt about the reliability and accuracy of the input data. In other words, the principle “garbage in, garbage out”, which has been found to be valid for other construction modeling aspects [16], is applicable to BI systems as well. In essence, the complex nature of BI systems, if not managed properly, could lead to the failure of their implementation, as recent research suggests that successful BI implementation projects have to be

supported by management in an essential manner [17]. Despite these difficulties, though, there is a consensus about the major strategic benefits that BI brings to the organization, leading to a clear competitive advantage for the adopting companies [18]. Stemming from these fundamental merits, the next paragraph will delineate the pertinent applications of BI in the construction sector.

2.3 Business Intelligence in the Construction Sector

The construction sector is a peculiar market with many controversial characteristics. The main feature is its fragmented nature, since the vast majority of construction companies within the European Union (94.2%) is comprised of small enterprises employing less than 10 workers [6]. In fact, Greece presents an even higher percentage, equal to 98.10% [19], thus making it clear why 96% of all data goes unused in the Engineering and Construction Industry [5]. These findings denote that there is a substantial margin for improvement within the construction sector. Besides, the small size of the construction companies helps them stay flexible in a very fragile market with intense economic cycles.

In view of the above-mentioned figures, should BI be implemented only in large construction organizations? Current research agrees that there should be strong support from government and regulatory organizations (e.g., European Union) towards small-sized construction companies that wish to get acquainted with BI principles. There have even been suggestions for establishing subsidies in that respect, which would diminish the initial acquisition costs for smaller construction players [4]. Besides, research findings in construction projects cost analysis processes have indicated that the implementation of BI results in a significant reduction of reporting duration in comparison with the manual process [9].

3 Research Methodology

BI applications, in principle, can be interpreted as a hierarchical structure with a pyramid-like shape. At the bottom of the pyramid lie the data sources of the organization. On the next level directly above, the Data Warehouse (DW) is located where data can be extracted, transformed, and loaded through the use of Extract-Transform-Load (ETL) tools. The processed data advances to the next level, where data mining activities take place by Online Analytical Processing (OLAP) protocols. The pre-final level is associated with the visualization and reporting of the required

data, which are subsequently funneled to the final level: the decision-making processes that serve the business strategy. Although the aforementioned structure has been kept stable, each level has been adapted to the technological advancements of the last few years. As such, powerful, user-friendly suites and IT platforms have been developed, which offer access to valuable knowledge, provide data mining evidence and models for the optimization of the decision-making processes, along with the increase of organizational efficiency and productivity. Based on this framework, the research methodology is presented in a step-wise fashion in the following paragraphs.

3.1 Data Sources and Gathering

The first step is the definition of the operational and non-operational requirements for the BI system to be designed and developed. The requirements describe the functions (or else the logic) that are materialized by the system along with its qualitative characteristics. The primary data are often unsuitable for processing and inferencing in their initial state. In addition, the data may also be faulty in many ways: inconsistent codification and categorization, lost values, infiltration of “noise” in the form of random values without actual content.

3.2 Extraction, Transformation and Loading of Data (ETL)

All problems found in the pre-processing stage are addressed by the ETL tools. The latter comprises an inherent part of the DW design, and its objective is uniformity preservation, cleaning, and correct loading of a DW. This is presumably the most critical part of the research methodology, since without the existence of ETL tools, there can be no valid DW and, hence, no possibility for a correct analysis. The ETL process initiates with the detection of the data at its source and the use of routines for reading and extracting it. First, all pertinent data are extracted and transferred to an Operational Data Store (ODS), where the transformation and cleaning processes take place. All data modifications take place within the DW, where only subsequently useful information is filtered. For example, it may be necessary to unify data from different sources or set rules relating to the preferred number of digits or data format, etc. At this stage, data are transformed to the desired format and are ready to be loaded into their final destination, which is the DW. The ETL process is executed in an iterative fashion during the execution of the project and not only at its initiation, depending on new information and possible variations of the project’s requirements.

This process is particularly important for the proper adaptation to the SME context, since the sourcing of the data is performed at the project level with the aid of activity-level reports. These project management constructs are not complicated and can be generated at the on-site office by the project management team on a monthly basis. As such, it is ensured that no data management burden is added to the existing project management processes of the SME organization.

3.3 Data Warehouse

After the ETL process is concluded, the clean and unified data is stored in the DW. The DW is a complete and non-changing collection of data, with the purpose of supporting the analysis and the decision-making process on a strategic level. These main characteristics distinguish the DW from the classical databases, which are used by companies to store their operational data. The DW is deemed complete since it contains all available data, from multiple sources, without any inconsistencies or “noise”. Subsequently, smaller, subject-oriented slices of the warehouse built for targeted analysis (e.g., sales, finance) are created, which are called Data Marts. In addition, an essential part of the DW is the Metadata Repository, which represents the central place where all information about the data is stored—not the data itself, but the data’s meaning, structure, origin, and usage rules. More specifically, it contains technical metadata (“how data is stored and processed”), business metadata (“what the data means in business terms”) and operational metadata (“how the warehouse runs”).

A typical structure of a DW is indicatively presented in Figure 1 which depicts all previously mentioned constructs, such as the ODS, the central DW, the Data Marts, as well as the Metadata Repository. From this point onwards, the DW data is available for Business Intelligence analysis in a twofold fashion: (a) via the submission of queries and the compilation of reports or (b) by using OLAP protocols and Data Mining techniques. The DW is a special-purpose database, whose design is differentiated from the typical relational database principles. The DW has been specifically adapted for the SME context in the sense that it contains readily available data, produced on a daily, weekly, or monthly basis within the organization from different sectors (e.g., technical department, accounting office, treasury department, etc.). The main rationale is that the BI infrastructure is tailored to fit within the existing information management processes of the SME context, so as not to create any bottlenecks or

add supplementary processing time to the organization.

3.4 Analytical Data Processing

The analytical data processing follows the design and completion of the DW. The analysis may be conducted in many ways, depending on the requested and available tools:

1. Queries: The submission of queries is done directly to the DW. The query tools provide the user with the opportunity to pose specific questions and receive specific answers depending on the predetermined criteria.

2. OLAP systems: This approach relates to systems that aim to provide an analysis through complex queries across multidimensional data models that are called cubes. Their advantage lies in their ability to utilize multiple association levels.

3. Exploratory Data Analysis: This approach is utilized by the majority of BI platforms, since they analyze data with the use of illustrative and graphical means for visualization purposes. The information is presented as an image, which is more easily interpreted by the human brain, in comparison to presenting information solely in text or tabular format, as a result of complex analytical analyses.

4. Data Mining: It is a technique that has been recently introduced in BI models. It combines methodologies stemming from the Machine Learning domain, Statistics, and Information Technology, with the objective of discovering knowledge through vast quantities of data.

5. Data Visualization: Similar to the Exploratory Data Analysis, this technique combines many BI aspects such as the data structure and nature, available dimensions, and effects. The visualization tools comprise the most important part of BI, since they offer many possibilities with the aid of interactive and dynamic illustrative methods on multiple digital dashboards. The adaptation to the SME context is realized through a field-connected sourcing of data, which is simple enough for non-data-specialists and capable of combining engineering, financial, and scheduling information. Within the proposed research framework, the visualization process entails project-specific information such as site zones, building levels, work fronts, and geographic locations. For ease of reference, the SME-compatible visualization strategy should be based on low cognitive load, mobile accessibility, minimal clicks, and fast interpretation.

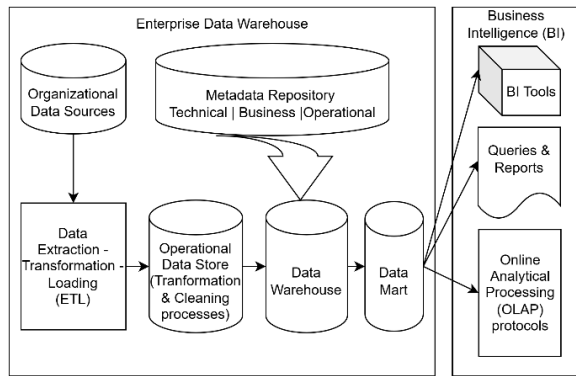


Fig. 1: Data warehouse architectural layout
Source: created by the authors

3.5 Mathematical Formalization of the BI Framework

The Business Intelligence framework developed in this study can be mathematically formalized as a multi-stage data transformation and analytical process. More specifically, let:

$$D = \{d_1, d_2, \dots, d_n\} \quad (1)$$

represent the initial dataset (D) composed of n project records (d) collected from Company A. Each project record is defined as:

$$d_i = \{P_i, C_i, A_i, T_i, S_i\} \quad (2)$$

where P_i is the Project identifier, C_i is the total project cost (€), A_i is the activity category, T_i is the project duration (days), and S_i is the project surface area (m^2).

In that respect, the ETL process can be expressed as:

$$DW = L(T(E(D))) \quad (3)$$

where E is the Extraction function, T is the Transformation and cleansing function, L is the Loading function, and DW is the Final Data Warehouse.

The productivity indicator (PI) for each project is estimated through:

$$PI_i = \frac{S_i}{T_i} \left[\frac{m^2}{days} \right] \quad (4)$$

Similarly, the unit construction cost (UC) is estimated as:

$$UC_i = \frac{C_i}{S_i} \left[\frac{\epsilon}{m^2} \right] \quad (5)$$

Conclusively, the BI pipeline developed in this research may be represented as:

$$BI = f(D, ETL, DW, OLAP, V) \quad (6)$$

where D is the initial dataset (or raw data), ETL represents the Data extraction-transformation-loading procedures, DW is the data warehouse, OLAP stands for the analytical processing, and V is the visualization layer.

The comparative evaluation among projects is performed through statistical and clustering analysis, enabling the identification of hidden patterns and abnormal cost deviations, as will be explained in the following section.

3.6 Statistical analysis for the BI Framework

To further strengthen the analytical depth of the BI model, statistical analysis was integrated into the comparative evaluation process. More specifically, descriptive statistical measures including mean value, standard deviation, variance, and coefficient of variation may be combined for an in-depth analysis of the unit construction costs. The mean unit cost ($\overline{UC}$) is estimated through:

$$\overline{UC} = \frac{1}{n} \sum_{i=1}^n UC_i \quad (7)$$

while the corresponding standard deviation (σ) is calculated as:

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (UC_i - \overline{UC})^2} \quad (8)$$

These measures enable the identification of abnormal project behavior and high-cost outliers. In addition, the evaluation of the robustness of the developed BI framework was based on prediction accuracy metrics, which were incorporated into the analytical workflow. The comparison between predicted and actual project costs was evaluated using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The MAE and RMSE metrics are defined as:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - z_i| \quad (9)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - z_i)^2} \quad (10)$$

where y_i stands for the actual observed value, and z_i is the predicted value.

The incorporation of such validation metrics increases the reliability and scientific robustness of the BI framework. All the aforementioned concepts are demonstrated in a practical format via the case study that is presented in the following section.

4 Development of Business Intelligence Application: A Case Study

Initially, the company that served as a case study is presented along with a description of the reasoning substantiating its selection. Then, a narrative of the tools (software) follows. The objective is to describe the implementation of the research methodology in a step-wise fashion. The source data that are imported into the system represent financial data of the

construction company. These data are gradually transformed into a multi-dimensional system, capable of offering additional knowledge to senior executives.

4.1 Characteristics of the Case Study Organization

The selected construction company (“Company A”) employs fewer than 10 people (a small-sized company). Its primary scope of work includes the renovation of commercial, as well as residential buildings. The company operates all over Greece, providing technical support services and developing a network of shops. The company employs specialized personnel of all types, in order to be in a position to complete its project portfolio with the minimum use of subcontractors. Its headquarters are located in Athens, while its personnel move depending on the project’s needs between the established construction sites. Due to its small size, the company uses basic IT equipment and software (e.g., spreadsheets), since there is no economy of scale to justify their technological upgrade. Hence, the company is deemed ideal for implementing the BI solutions delineated in this research.

4.2 Stage B: Productivity Estimation and Comparative Evaluation

A number of tools are used for the development of BI solutions in Company A. More specifically, it should be noted that Microsoft Excel is not actually used for the development of the BI solution, but rather as an initial data depository stemming from the company’s original financial archive. It is also highlighted that Company A, due to its small size and basic technological infrastructure, does not possess any uniform Data Repository to be utilized within the BI framework. Besides, the creation of such an infrastructure is very costly and resource-intensive; thus, its implementation should be a fundamental strategic decision that falls outside the scope of the current research. In that respect, the Data Repository is created by the use of a Relational Database Management System based on the SQL Server Developer Edition by Microsoft. The database access is facilitated through SQL Management Studio. The execution of the necessary ETL processes is facilitated with an open-source tool, i.e., the Pentaho Data Integration-Community Edition [20]. The Exploratory Data Analysis is used for the analytical data processing. In addition, Data Visualization is used via the BI Desktop platform developed by Microsoft.

4.3 Data Gathering

Company A has provided the financial data of 20 projects realized in the period 2018-2019. The data were divided into project budgets, project cost estimations, and company turnover. The 20 projects were transformed into tabular format as presented in Figure 2, with the inclusion of four columns:

1. Project code, which determines which code is used for each project;
2. File type code, which distinguishes between the project budget (“Π”), the project cost estimation (“C”) and the company turnover (“T”);
3. Activity code, which determines the code associated with each activity included in the project time schedule; and
4. Value (€), which reflects the value of each activity corresponding to the respective codes mentioned above.

Each project file includes about 40 records, which means that all 20 projects sum up to about 800 records. In addition, beyond the projects’ records, the company also provided evidence in the form of three additional spreadsheet files, detailing the geographical area of each project, its total surface (m²), its start and end dates, as well as information about the execution regime (e.g., subcontractor involvement, own resources, etc.).

ProjectId	Cost	Income	Start_Date	End_Date	Square_meters	Franchise	Home	OutSource
0819T	41,344.00	59,452.35	Monday, July 29, 2019	Monday, August 26, 2019	210	True	False	True
0818T	22,346.50	48,962.85	Sunday, September 2, 2018	Tuesday, September 25, 2018	171	False	True	False
0719T	51,663.00	89,365.69	Monday, May 20, 2019	Thursday, June 13, 2019	125	True	False	False
0318I	14,588.55	23,253.03	Sunday, March 4, 2018	Friday, March 23, 2018	99	True	False	True
0218I	22,882.85	50,659.84	Sunday, February 25, 2018	Thursday, March 22, 2018	95	False	True	False
0619C	32,257.50	48,113.36	Monday, April 1, 2019	Wednesday, April 24, 2019	92	True	False	True

Fig. 2: Projects’ tabular format codification

Source: created by the authors

4.4 Database Design

The 20 projects’ file, when unified, comprises the main BI database, namely the Fact Table titled “Projects” as shown in Figure 3. The ancillary data in the three additional tables, which describe the fact properties and set the analysis’ parameters, comprise the Dimension Tables (titled “ProjectNames”, “PriceTypes” and “Functions”). As such, the main database comprises four main tables, while its shape is compatible with the basic features of a star-shaped DW. In this setting, the Fact Table is positioned in the center, and all other Dimension Tables are positioned around it since there is no reason to adopt a more complicated structure.

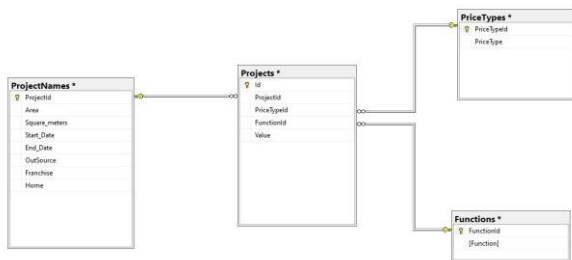


Fig. 3: Star-shaped Data warehouse layout
Source: created by the authors

Then, the principles of Exploratory Data Analysis are implemented through the use of SQL Server Management Studio in order to create a new database called “Analytics BI,” as shown in Figure 4. Each table is drafted from scratch, and -for brevity reasons- the creation of the main Fact Table called “Projects” is going to be analytically presented in the next paragraphs. First, four columns are created which correspond to the project code (“ProjectID”), the file type (“PriceTypeID”), work type (“FunctionID”) and work value (“Value”). An additional field is defined (“Id”), which takes unique values with automatic numbering in order to function as the primary key of the created table. The data format is specified according to each category, namely integer (int) for the Id and the FunctionId, numerical data (real) for the Value, and Unicode type up to 50 characters (nvarchar(50)) for ProjectId and PriceTypeId due to the possibility of containing Greek alphabet letters. The implemented Fact Table is illustrated in Figure 5. In the same manner, all other Dimension Tables are created, while the primary keys of each one of these tables are foreign keys of the Fact Table (ProjectId, PriceTypeId, FunctionId). Upon completion of the previously described process, the star-shaped “Analytics BI” database is fully defined, which allows the initiation of the ETL functions.

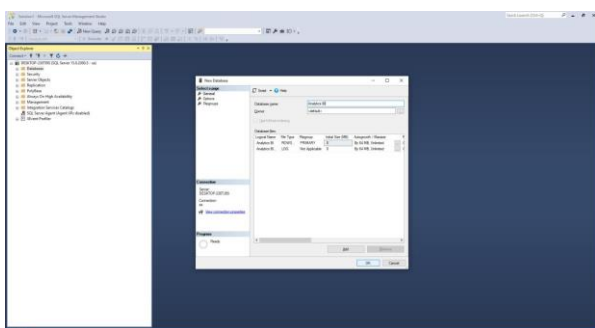


Fig. 4: New database “Analytics BI” snapshot
Source: created by the authors

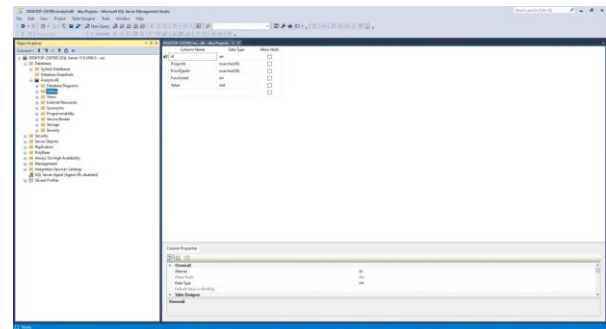


Fig. 5: Creation of fact table “Projects” snapshot
Source: created by the authors

4.5 Extraction, Transformation and Loading of Data for the Case Study

The ETL processes are realized with the use of the Pentaho Data Integration (Version 8.3) [20]. Its utilization allows the extraction of data from the initial source files (spreadsheets), executes all necessary transformations, where necessary, and finally loads all data into the newly created database tables through specific processes called “Jobs”. It is an iterative process and is repeated each time new data is imported (e.g., a new project is awarded to the company).

4.6 Extraction, Transformation and Loading of Data for the Case Study

The gathering of all source data and their integration into the BI model through an agile logic creates the background against which Company A may now decide what aspects of their business should be further analyzed. For example, it was deemed necessary to have an inference about the unit cost per m² (€/m²), which was not included in the initial dataset.

The analysis was based on a combination of queries within the BI model through the use of EDA tools. The estimation of the required metrics could be realized in three ways: (a) use of EDA and Visualization tools directly in the BI model, (b) use of ETL processes, and (c) use of queries directly in the DW. The third option was chosen due to the limited number of available data, which allowed the flexibility to pose queries in the BI model while using the provided data concurrently with other systems. The predefined queries will be created and set within the database in order for the information to be ready for analysis, comparison, and presentation. The SQL Server Management Studio is utilized to create the desired queries, so as to end up with the respective Views. More specifically, the first View is called “CostM2” and represents the unit cost per m² for each project code. The respective query uses three main tables, since it associates the project

codes (ProjectId) and the surface in m² (ProjectNames) in order to combine them with the cost calculations (PriceTypes) per project and for all projects (Projects). The total cost per project is divided by its surface, and the requested unit price is depicted in a specific View, as shown in Figure 6.

4.7 Data Visualization for the Case Study

The needs of the Exploratory Data Analysis as well as the Visualization are accommodated by a versatile tool, namely the Power BI Desktop [21]. Its features range from analyzing and modeling large amounts of data either on the cloud or on-premises to producing visualized and effective reports compatible with any hardware device (e.g., desktop, laptop, mobile devices).

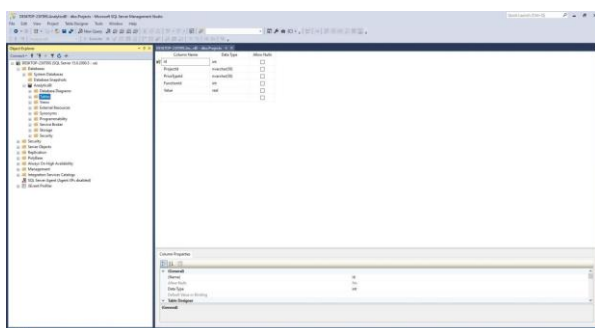


Fig. 6: View “CostM2” snapshot
Source: created by the authors

Focusing on the specific question of associating costs and surfaces for the projects’ portfolio, it is evident from Figure 7 that there is no proportional rule of increasing costs for larger surfaces. For example, the second most expensive project has a total surface area of 69m². As such, the first inference is that there should be a grouping of projects according to their surface (e.g., small, medium, large), in order for the comparisons to be valid.

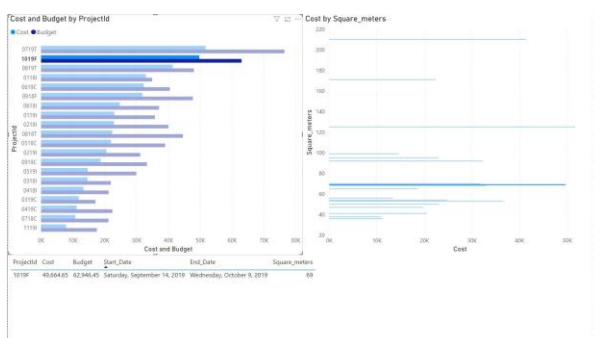


Fig. 7: Comparative evaluation of Costs vs Surface for the selected project portfolio
Source: created by the authors

A more enhanced visualization approach for the same dataset is illustrated in Figure 8, where additional information is being presented for each project: start and end date, whether it is a franchise store, project location in relation to the company base and subcontractor involvement. The three latter characteristics are shown in the format of binary (True/False) information. The analysis presents a comparative illustration of the projects’ total cost in relation to their surface, as well as the unit cost (€/m²) per project.



Fig. 8: Enhanced visualization of comparative metadata for the selected project portfolio
Source: created by the authors

4.7.1 Numerical Example for BI Model

A representative subset of six projects from the examined portfolio was selected for the practical implementation of the proposed mathematical formalization and the respective statistical analysis, as presented in Figure 2 (0819T, 0818T, 0719T, 0318I, 0218I, 0619C). Table 1 presents the main indices represented by Equations 1-5.

Table 1. Calculation of key project indices

[1]	[2]	[3]	[4]	[5] = [4]/[3]	[6]=[2]/[4]
P _i	C _i [€]	T _i [days]	S _i [m ²]	PI _i [m ² /day]	UC _i [€/m ²]
0819T	41,344,00	29	210	7,24	196,88
0818T	22,346,50	53	171	3,23	130,68
0719T	51,663,00	24	125	5,21	413,30
0318I	14,588,55	50	99	1,98	147,36
0218I	22,882,85	26	95	3,65	240,87
0619C	32,257,50	53	92	1,74	350,63

Source: created by the authors

The analysis was subsequently expanded to the selected project subset in order to estimate descriptive statistical metrics. The resulting mean unit construction cost was calculated as:

$$\overline{UC} = \frac{1}{6} \sum_{i=1}^6 UC_i = 246,62 \text{ €/m}^2 \quad (11)$$

while the corresponding standard deviation (σ) is calculated as:

$$\sigma = \sqrt{\frac{1}{6-1} \sum_{i=1}^6 (UC_i - 246,62)^2} = 113,49 \quad (12)$$

In order to demonstrate the practical implementation of the proposed validation metrics within the BI framework, a simplified comparative scenario between estimated and actual unit construction costs was developed for six representative projects of the examined portfolio. Table 2 contains the actual UC_i values complemented by estimated predictive values (UCP_i) that were produced by the company's estimators.

Table 2. Actual vs predicted unit construction cost values

[1]	[2]	[3]
Pi	UC_i	UCP_i
0819T	196,88	185
0818T	130,68	140
0719T	413,30	390
0318I	147,36	155
0218I	240,87	250
0619C	350,63	335

Source: created by the authors

The Mean Absolute Error (MAE) was estimated as:

$$MAE = \frac{1}{6} \sum_{i=1}^6 |y_i - z_i| = 12,82 \quad (13)$$

while the Root Mean Square Error (RMSE) was calculated as:

$$RMSE = \sqrt{\frac{1}{6} \sum_{i=1}^6 (y_i - z_i)^2} = 13,89 \quad (14)$$

The calculated MAE and RMSE values indicate relatively limited deviations between the estimated and actual unit construction costs across the examined project portfolio.

4.8 Case Study Analysis with the Use of Queries

The analysis goes on with the creation of two additional Views, one for the modification – replacement of the project characteristics table (ProjectNames) and a new one which includes the cost estimations and gross income of each store (e.g., project) on a daily basis. More specifically, the first View is called “Projects” and is shown in Figure 9. It alters the column titles from the original tables (e.g., m², start date, end date), associates the binary values with descriptive titles (e.g., outsource/insource, inbrand/franchise, away/home), groups all projects into small (<50m²), medium (50-70m²), and large (>70m²), and estimates the projects' duration. The second View (whose visual representation is omitted for brevity) is called “Cost_Income_per_Day” and

associates fiscal values (cost, daily gross income) with each store per its surface. Upon the completion of the two Views, the database has four virtual tables, and the analysis may proceed to the next stage of EDA in Power BI.

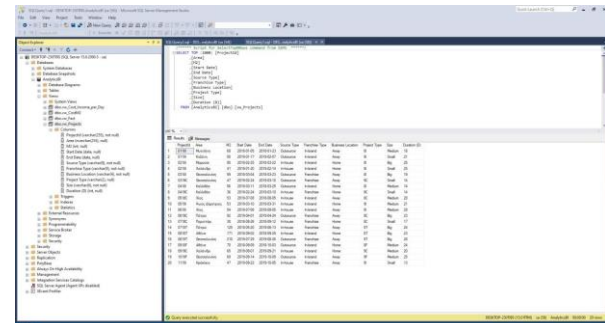


Fig. 9: Enhanced project portfolio data visualization snapshot

Source: created by the authors

4.9 Visualization Analysis for the Case Study

Having created the necessary information that was highlighted in the previous sections, the platform is provided with the necessary information to continue the analysis. All transformed data is included in the Power BI database. The latter provides many possibilities for shaping the analytical information through many different graphical and design representations, as well as coloring options that enhance the presented trends. The visualization of the Company's data is implemented through five different snapshots because each one of them contributes in a complementary way to the improvement of business operations. First, a more general approach is created (“Dashboard”) by providing an overview of company data and certain cumulative metrics in order to create the framework against which the company will be analyzed (Figure 10). The second visualization snapshot (“Spend Analysis”) provides valuable information regarding the related costs per project or per activity in relation to the construction method (Figure 11). In a similar fashion, Figure 12 shows the next snapshot, which represents the “Geographical Analysis” of the company's portfolio associated with the respective budgets, project size, etc. A very useful feature is the possibility to dynamically interact with the information provided by each one of the presented snapshots, by using built-in filters that refine the provided information according to the analyst's needs. For example, if the analyst would like to delve into specific categories of work, then the system provides this possibility. More specifically, if electrical works were of particular interest, then the Spend Analysis presented in Figure 11 can be

modified as illustrated in Figure 13. In this way, the analyst may see how much turnover is generated from electrical works that are executed all over Greece, divided into specific geographical regions. In a similar manner, a senior executive may wish to see which projects are executed in a specific prefecture of Greece (e.g., Attica), and for that reason, Figure 14 would be created to provide such input. Looking at this figure, it is evident that projects executed around the headquarters of the company yield a significant part of the total turnover; therefore, strategic management focus should be directed at this portfolio segment. Of course, the research does not aim to demonstrate all possible features of the selected platform. The presented examples aim to make clear how the information is interrelated within the created database and how it can be developed into a useful tool for effective corporate governance. In that respect, senior management acquires an overview of the business operations, while at the same time has the ability to dig into more detailed informational views upon request. The completion of the visualization routine essentially denotes the conclusion of the Business Intelligence approach. From that point, the decision-making process is based on accurate and valid information, which aids the implementation of the business strategy.



Fig. 10: Dashboard visualization snapshot
Source: created by the authors

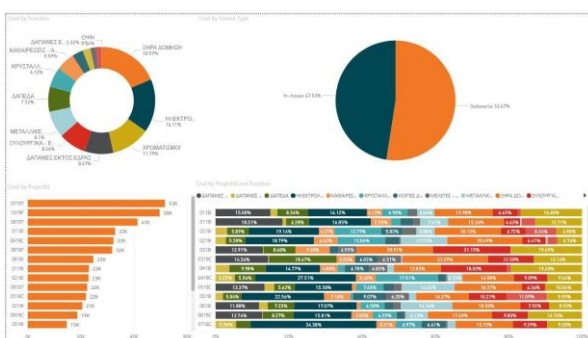


Fig. 11: Spend Analysis visualization snapshot
Source: created by the authors



Fig. 12: Geographical Analysis visualization snapshot
Source: created by the authors



Fig. 13: Spend Analysis for electrical works snapshot
Source: created by the authors



Fig. 14: Geographical Analysis for projects within the Attica Prefecture snapshot
Source: created by the authors

5 Discussion

The concluded analysis has produced a large number of results, which allows the comparison of the original source data with the information gathered after the completion of the processing routines. BI aids in creating a taxonomy of business data that can be independently confirmed, evaluated, and measured with increased accuracy. That is the main contribution of this specific technology in the daily operational processes, which, in the absence of BI, were arbitrary and based on theoretical assumptions.

At this point, it should be clarified that the present work has been built upon the authors' experience in

similar research areas (e.g., construction productivity, digital twins, optimization of business processes) but essentially represents an innovative approach in the field of Business Intelligence, never tackled before. More specifically, the authors' previous research work does not present any association with Business Intelligence applications per se but has helped shape the generic research framework for developing the selected models. In other words, the authors' work, as reflected by the cited research, lays the cognitive foundation upon which the Business Intelligence model and research methodology were formulated. However, the authors have never developed a Business Intelligence model before, and the present research presents their first and sole effort in that respect. This research presents a novel approach for BI in two areas: (a) it is a cost-centered and productivity-centered model with tailor-made information valuable to the project manager, and (b) it proves that BI can be particularly useful for SME in the construction sector operating in the contemporary construction framework.

In that sense, valuable inferences emerge from the numerical implementation presented in section 4.7.1. First of all, the relatively high standard deviation ($\sigma=113,49$) indicates significant variability among the examined projects, highlighting the existence of differentiated project typologies and operational characteristics within the company's portfolio. Furthermore, Project 0719T presented the highest unit construction cost value, suggesting increased project complexity or abnormal cost behavior requiring additional managerial investigation. In addition, the examination of Table 2 gives a notion about the importance of validating predictive data. The relatively low error values indicate satisfactory agreement between estimated and actual project costs, demonstrating the capability of the proposed BI framework to support preliminary cost estimation and comparative project evaluation procedures within the SME construction environment. Of course, it should be highlighted that the robustness of the model's predictions is closely associated with the reliability of the predicted data. Therefore, special attention should be given to developing a credible historical productivity database.

The visualization presents a general view of the company's performance as well as the variations of its key parameters. The latter can be properly interpreted by the company's executives, who can put the provided BI information into the corporate context. The company's senior personnel are the only suitable data receivers who may utilize the data in order to make informed decisions, since the analyst

and the BI architecture designers evaluate the yielded results from a purely scientific viewpoint.

The "Spend" and "Geographical Analysis" snapshots evidently show that almost half of the company's portfolio is constructed through subcontracting agreements, while a similar preference is observed for the projects geographically located outside of the company's headquarters region (i.e., Attica Prefecture). Irrespective of the execution method, the most cost-prone and profitable activities seem to be (a) drywall installation, (b) electrical works, and (c) painting works. As such, based on the BI information, the company could consider a further investment in setting up its own crews or even improving its current work methods for these specific work segments, since they seem to provide a competitive advantage.

The analysis has demonstrated that BI reveals relationships and dependencies that were not evident from a first glance and confirms inferences that were hypothesized by senior executives. The research is limited within the boundaries of a small-sized construction company; however, the main concepts and merits of BI applications in a construction setting have been sufficiently proven.

6 Conclusion

The developed approach represents an attempt to demonstrate a practical application of BI concepts in the construction management sector. An analytical development process has been adopted by establishing a complete database of corporate data accompanied by comprehensive ETL processes. The selected platform for the drafting of the BI processes provided many data manipulation and visualization options. Instead of directly uploading the source data in the Power BI platform, the research demonstrated the analytical step-wise process for creating all intermediary databases that are needed to secure information integrity.

It must be acknowledged that the possibilities of a fully commercial BI application would offer other data management options as well; however, such an approach would require extensive devotion of the company's resources over an extended period of time, which would exceed the timeframe for the completion of this research. Besides, the current research contribution to the body of knowledge lies in demonstrating the merits of BI for small-sized construction companies, hence departing from the established perception in the industry, which dictates that such IT investments occur only in large-scale corporations. In fact, it is recommended that the

presented BI approach could act as a testbed against which a company could get an overview of business intelligence solutions at a small intervention scale. Upon the gained experience, if deemed successful, the company could then launch a more cost-effective and timely process for a fundamental reengineering of its BI processes.

The research represents an effort to apply the theoretical model in a stepwise fashion. It should be noted that the presented functionalities reflect only a segment of BI possibilities; however, a full exploitation of BI potential requires a more comprehensive commercial analysis and significant implementation costs. Hence, it is believed that the presented approach could function as an introductory testbed for evaluating the usefulness of a BI approach with minimum cost investment requirements.

Furthermore, the integration of mathematical formalization, descriptive statistical analysis, and validation metrics enhanced the scientific rigor of the proposed BI framework. The practical implementation of productivity indicators, unit cost estimation procedures, and predictive validation metrics (MAE and RMSE) demonstrated that the developed approach is capable of supporting quantitative analysis, comparative project evaluation, and preliminary forecasting procedures within SME construction environments. The numerical examples of the case study verified that even lightweight BI implementations may generate measurable analytical value and contribute to evidence-based decision-making processes in construction management.

The presented research corroborates the merits presented to small and medium-sized enterprises by the adoption of a BI solution. Even in their simplest form, BI tools transform initially scattered data into valuable pieces of information, which, when combined, lead to usable strategic results. Future research directions could include the insertion of new data and variables into the analysis (e.g., labor work hours) or even the interconnection of the BI solution with the accounting department in order to provide high-level metadata. If coupled with machine learning algorithms, BI solutions have proven to be very useful for predicting future inventory needs, scheduling human resources requirements, and adjusting cash flow information depending on the company's project backlog.

The specific study can also be extended by a questionnaire survey that could map the users' responses to using the BI approach. The yielded responses can fuel a feedback cycle that will refine the organizational needs, the existing infrastructure, and the availability of new technologies, which

subsequently can trigger respective changes in the BI approach.

Acknowledgement:

The authors would like to thank all personnel and engineers who were actively involved in the data gathering process during the course of this research.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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