A project procurement model enabling competition by design concept by integrating performance-based assessment (PBA), process-based estimating (PBE), and cost network modeling (CNM) tools

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ABSTRACT

Handling the costs of vast and complicated construction projects has become a task that is more challenging than it was previously. Existing cost and time estimation approaches significantly impact clients and construction firms when cost and timing projections deviate significantly. Developing concepts such as "competition by design" enforce the performance-based assessment (PBA) method that pushes designers of the building and its subsystems to select new solutions that promote national research and development (R&D) activities in developing countries. Yet, this strategy necessitates more sophisticated, integrated, and inventive solutions in the project procurement processes, as contractors submit their designs rather than the client providing a single, unique design. This strategy significantly benefits customers, designers, contractors, and society, but it is inapplicable unless supported by components that function as an integrated system. None of the research and models in the literature comprehensively solve the challenge outlined above. This study presents a procurement model that enables the "competition by design" idea to serve the needs of all stakeholders in the construction industry by merging conceptual and practical components and tools. Throughout the construction of the proposed model, a "systems approach" was utilized. First, the problem and its constituents were investigated using the top-down method, and then the model was synthesized using the bottom-up method.

KEYWORDS: Competition by Design, Construction Projects, Project Procurement Process, Performance-based Assessment, Process-Based Cost Estimating.

INTRODUCTION

In today's world, when the problem of resource scarcity is expanding at an ever-increasing rate, the size and complexity of construction projects make cost management a much more significant issue than in the past. Competing on a worldwide market necessitates utilizing all available resources during all phases of building production. Instead of traditional systems, elements, components, and details, architects and designers of building subsystems can contribute to the competitiveness of their companies and the construction industry by employing creative solutions that promote sustainability in their designs. Yet, the construction sector's adoption of new techniques, methods, and technologies is hampered by the resistance of the vast majority of construction professionals involved in these operations. At the same time, changes and a complete transformation in the behavioral patterns of stakeholders would support research and development (R&D) efforts in their countries and increase sustainability in all dimensions of the environmental sustainability of the 3D Cartesian System, i.e., the built environment, economic environment, and social environment. This is one of the most critical concerns for developing nations to address to compete with the competitive advantages of established nations in their economies, construction industries, and procurement processes. In the past, it may have been reasonable to assert that this transformation was too challenging to achieve because the capabilities of information technology were not as advanced as necessary. However, any type of tool, such as information classification systems MasterFormat, UniFormat, OmniClass, etc. in the conceptual dimension and software solutions of Building Information Modeling (BIM), Enterprise Resource Planning (ERP) Systems, Management Information Systems (MIS), Scheduling System, etc., are now available.

As defined by McLuhan and Powers (1989), the increasing and inescapable connectivity of everything has converted the contemporary world into a single world and a single market that are inseparable and have almost removed borders. Before, the competition was limited to a small field but has expanded globally. Local contractors now confront worldwide competition in contracts within their own countries. Increasing competition has led to the execution of fewer profitable projects than in the past, raising the contractor's demand for more accurate and exact information for cost estimation, analysis, and management. In other words, more competition has reduced the margin for error in cost estimates among contractors. This circumstance compelled consumers and contractors to search for an all-encompassing expense computation and estimating method. Public authorities and business sector clients are adversely affected by the inaccuracy of the currently employed improper estimation methodologies and project procurement processes that employ these approaches. Conflicts induced by issues such as cost overruns, improper procurement techniques, etc., result in the parties' suspension or cancellation of some projects (Dada, 2013). Legal investigations and litigation conducted by the courts can often drag on for years and cost the economy additional time and money. Various researchers have examined various sets of parameters, such as flexibility, cost, speed, and accuracy, for the selection of the project procurement process (Alhazmi & McCaffer, 2000; Bennett & Grice, 1990; Chan et al., 2001; Franks, 1991; Ilori & Talukhaba, 2017; Kumaraswamy & Dissanayaka, 2001; Luu, Ng, & Chen, 2003a; Ng et al., 2002; Skitmore & Marsden, 1988).

Mohsini (1993) described a knowledge-based expert system for project procurement that describes the client's needs and the project's characteristics. Skitmore and Marsden (1988) designed and utilized the Procurement Route Decision Chart in another investigation. Love, Skitmore, and Earl (1998) reported a model for determining the conformance of various project procurement procedures. Tucker and Ambrose (1999) proposed a method for examining the suitability of a project procurement system using a three-dimensional matrix. Chan et al. (2001) employed a multi-attribute decision analysis approach in their investigation. Cheung et al. (2001) suggested a model that combines objective and subjective techniques for selecting the most appropriate project delivery system. Kumaraswamy and Dissanayaka (2001) described a decision-support system based on various regression approaches and artificial neural networks. Luu et al. (2003a) proposed a solution based on case-based reasoning. Alhazmi and McCaffer (2000) presented a paradigm that integrates Value Engineering and the analytical hierarchy approach (AHP). Chang and Ive (2002) converted subjective perception into objective guidelines for selecting a project procurement system. Luu, Ng, and Chen (2003b) presented a case-based reasoning model that compares previously seen solutions. El Wardani, Messner, and Horman (2006) assessed the performance of the design-build technique in terms of time, cost, and quality parameters. Although numerous scholars have examined the interactions between owners and general contractors, few have analyzed how to choose subcontractors. Tserng and Lin (2002) are the first scholars to have provided a conceptual model for general contractors that provides a trade-off between risk and profit for various subcontractor combinations.

Several studies address the issue of cost overruns due to the inadequacy of traditional cost estimation techniques, which are one of the troublesome aspects of the project procurement procedure. Many projects cannot be completed within their planned budgets because the methods used to estimate and manage costs do not generate sufficiently accurate results, especially in mega construction projects involving many stakeholders. According to Flyvbjerg (2014), nine out of ten megaprojects are over budget. According to Garemo, Matzinger, and Palter (2015), 35% of bridge and tunnel building projects are over budget, 20% of road projects are over budget, and schedule overruns are now nearly the norm.

In Turkey, Cantemir (2017) highlights the similarities between the problems caused by approximate cost estimation methodologies and the errors in cost estimation calculations. Comparing the unit price-based method to other approximate cost estimation methods, Bayram et al. (2016) identify similar issues. Malaysia has a 55% budget overrun, as stated by Kamaruddeen, Sung, and Wahi (2020), which highlights the significance of the cost estimation process. Simushi and Wium (2020) report the same issue with cost overruns as research conducted on large projects in South Africa.

On the other hand, clients in both the public and private sectors are unable to utilize the benefits of innovative solutions because the performance-based assessment of contractor-specific design solutions necessitates a reorganization of the entire construction industry and integrated solutions regarding both the conceptual and practical dimensions of the tools do not yet exist at an adequate level. As mentioned above, individual efforts and solutions focused on a specific aspect of the problem do not contribute to the issue's solution. Particularly in emerging nations, the construction industry should reconsider project procurement procedures and identify more effective solutions, including the help of information technologies.

Problem Statement

The traditional procurement procedure is based on competition for a single building design, which is reasonable due to its practical benefits. On the other hand, the performance-based procurement process is relatively more advantageous because it provides significant advantages for global competitiveness, such as supporting national research and development (R&D) efforts in developing countries. However, it requires reorganizing almost everything in the building production process, which is impractical unless a comprehensive and systematic solution that the majority of the industry can adopt is provided. None of those mentioned studies and models give an all-inclusive solution to the above-mentioned challenge.

The shortcomings of standard cost-estimating approaches, such as parametric methods and methods based on historical statistical data, such as the unit price-based method, also hinder the construction of this model type. The Turkish government and contractors frequently utilize the Unit Price-based Cost Estimation Method in cost estimation processes, even though it is generally imprecise but practical.

The process-based cost estimation method is inapplicable but is believed to be relatively accurate. Any model addressing the issue must have an accurate and workable mechanism for calculating building project costs during the procurement phase. Evidently, there is a trade-off between the accuracy and utility of the currently available approaches; essentially, accurate methods are impractical, and practical methods are insufficiently accurate.

Aim of the Study

After analyzing the cons and pros of currently available methods, the questions driving the solution are:

1. Is it possible to propose a project procurement system that supports sustainability by empowering research and development efforts in national economies? How?
2. Is it possible to propose a project procurement system that allows construction firms to submit their bid prices for their unique design proposals to utilize the advantages of competition by design? How?
3. Is it possible to compare these bid proposals based on the unique design solutions of construction firms? How?
4. Is it possible to increase the accuracy of practical cost-estimating methods and vice versa? How?

This study aims to design and propose an effective project procurement model for the clients/public authorities and contracting firms in private and public sector construction projects. This model must address the issues stated below:

Rule_01: The model must enable a competition-by-design approach/paradigm/philosophy to assist Research and Development (R&D) efforts in the building sectors of national economies to achieve international market competitiveness.

Rule_02: In the center of the model's solution must be an efficient assessment model that can compare design proposals by considering their costs and the performance of built environment entities at various hierarchical levels.

Rule_03: The model must present an accurate and practical technique for predicting costs, backed by models that analyze the interactions between cost components in the conceptual dimension and related information technology-based tools in the practical dimension.

METHODOLOGY

The conceptual model's fundamental components are defined in Figure 1 and as follows. The study aims to define, develop, and integrate these components in conceptual and practical dimensions:

- The Paradigmatic/Philosophical/Model: The study's primary purpose is to produce a philosophical approach that supports the shared interests of the owner, builder, and society rather than the conflicts driven by the particular passions of the parties.
- The Process-Related/Organizational Model: The development of cost estimating and the defining of related issues, such as organizational entities to be included in the process, their functions, and their interactions, are additional objectives of this study.

- The Interoperability/Integration Model: Creating a bi-dimensional structure necessitates conceptual and operational relationships between elements. The resolution of conceptual and practical integration and interoperability challenges is another challenge of the study in this area.
- The Estimation/Assessment/Computational Model: Another purpose in this area is the definition of conceptual layers and constructing a process-based estimating system and its computational statements.

After constructing the components and relationships of the conceptual model using the "system approach," the fundamental components of the practical model and their integration issues are studied. In this instance, the problem and its components were investigated using the top-down method, and then the model was synthesized using the bottom-up method.

Two fundamental methodologies described by Sey et al. (2002) were utilized to investigate and construct the suggested model's information system. The first method is known as the "Asking Technique." Personnel of the organization is questioned regarding the functions for which they are responsible, their expectations of the information system, the information they require for the stated function, where they obtain the required information, to whom they send the output of their operations, etc. The second fundamental method used to analyze the information system is the Input-Process-Output (IPO) method, sometimes known as the "system approach." Using this technique, the information system's activities were examined. Similarly, subsystems are studied down to the level where information processing emerges as an activity (Sey et al., 2002).

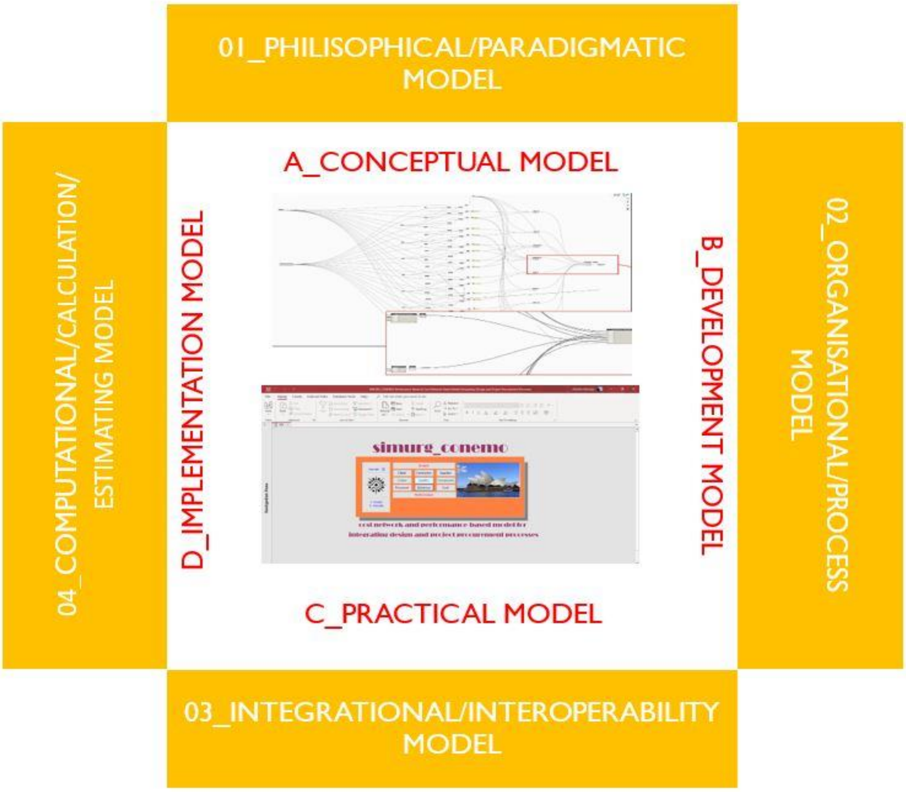

Figure 1: The components of the conceptual model as the objectives of the research of SIMURG_CONEMO

LITERATURE SEARCH

Studies Related to Performance-based Assessment Models

There is research on the performance-based evaluation of entities in the 3D Cartesian System of Sustainability. Minchin Jr and Smith (2005), Elyamany, Basha, and Zayed (2007), Oyedele and Tham (2007) and Doolen, Traxler, and McBride (2006) have proposed their models for performance-based assessment of various building production process stakeholders. Ulker et al. reported a comprehensive study that resulted from a meta-analysis of the relevant papers (2021). Any studies that focus on specific and limited aspects of the problem are helpful, but a more comprehensive model with a holistic approach is still required.

Studies Related to Project Procurement Models

Although new contractual approaches have been developed in response to issues such as increased project complexity and effort, traditional ways continue to be used (Barrie & Paulson Jr, 1992). Private-sector projects are observed to use a variety of procurement methods, but public-sector initiatives rely heavily on established systems (Ameyaw, Mensah, & Osei-Tutu, 2012; Ernest et al., 2016). Nonconservative clients are eager to experiment with innovative procurement strategies for their projects. The selection of the best suitable procurement method is crucial for all project stakeholders. The success of this decision impacts the achievement of the project's objectives. The chosen procurement strategy can reduce total construction costs by 5%. (Masterman, 2003).

SIMURG IDEPRO (Integrated Design and Procurement System module of SIMURG) is the sole model established by Arslan and Kanoglu (2018a, 2018b) for integrating performance-based evaluation and project procurement processes in the construction industry. Nevertheless, this model only supports traditional cost estimation techniques and does not account for the cost-affecting components and their interactions during construction production. Aside from that, it was an attempt to address the conceptual aspect of the sector's organizational challenges.

Studies Related to Cost-Estimating Models

Since cost overruns are one of the leading causes of construction project failures, cost estimation methods have traditionally been one of the most intriguing research topics. The "Introduction" portion of this paper references some of these works. Bledsoe (1992) identifies the unit price-based cost estimation approach, which is based on data obtained during the project's design phase, as the ultimate cost estimation method. Lu, Lai, and Tse (2018) illustrate the challenge of cost analysis and management by arguing that projects do not follow a predetermined sequence in practice. Wilson (1982) asserts that deterministic cost calculations, which are based on historical cost data and project numbers but do not identify project changes and uncertainties, do not reflect actual costs. According to Beeston (1987), a slight change in project design can significantly change the contractor's organization, affecting project costs. According to Bertelsen (2003), construction has a chaotic functioning due to its complexity. Hence deterministic methodologies cannot provide a solution. Williams (1999) states that the deterministic approach to estimating construction costs based on historical cost databases cannot be justified due to the unpredictability of design and construction processes and structural complexity. According to Hegazy and Ayed (1998), a parametric cost estimation model consists of one or more functions or estimation relationships between the dependent variable "cost" and the independent variable "cost controlling factors."

Creese and Li (1995) state that cost estimation and cost connections should be expressed mathematically. Due to their low accuracy, De la Garza and Rouhana (1995) say that parametric cost estimation models have limited application in construction cost estimation. Soutos and Lowe (2005) attempt to identify the cost components for a parametric cost estimate. According to Eppinger and Browning (2012) and Parviz (2002), a single individual or team cannot possess the knowledge of several disciplines required for effective cost estimating. When process-based cost approaches are analyzed, building production process management tools such as the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) have been established. These approaches calculate the least time required to accomplish the project. This allows for calculating project expenses based on the time value of money (Adeli & Karim, 2001).

These advancements in datasets and data processing have permitted the application of process-based cost prediction methodologies to build projects with near hour-by-hour or minute-by-minute precision (Kesavan, Elanchezhian, & Ramnath, 2009). The improvement of current solutions has resulted from the quest for solutions based on the in-depth development of existing cost estimate methodologies but without a paradigm change or technology advancements. As detailed in Potts and Ankrah (2008) and Boussabaine (2007), it falls short of providing contractors with the cost information required to gain a competitive edge.

SYNTHESIS OF THE CONCEPTUAL MODEL

The Philosophical/Paradigmatic Model

A model for integration focused on sustainability and performance Utilizing Relational database architecture to enhance the global competitiveness of the construction sector (SIMURG) is presented as a solution to the issue mentioned above (Kanoglu et al., 2022; Sey et al., 2002). It is the name of a Persian story that has parallels in Turkish culture, as well as in western and eastern cultures. It translates as "30 birds" hunting for their leader, SIMURG. After their voyage, they discover no bird named SIMURG; however, they are all SIMURG. In the context of the built environment, the indirect allusion to the concept of "government" in this story was one of the real inspirations for this investigation. Entities at all scales of the built environment must adopt human-centered methods by placing governance and sustainability at the heart of all solutions. In the past twelve years, the research team has created solutions for the performance-based assessment of entities and linked processes on all dimensions of the 3D Cartesian System of sustainability (Akturk & Kanoglu, 2018; Altındag & Kanoglu, 2018; Erdogan & Kanoglu, 2018; Konuk, 2019; Şerifoğlu & Kanoglu, 2019; Ülker et al., 2021; Yazıcıoğlu, 2015).

Literature-based procurement models emphasize process-related functionality and stakeholder satisfaction concerning project-specific considerations in general. This study stresses the notion of "sustainable" on both the national and international levels and the design of the proposed model. So, the following tools are presumed to constitute the solution's primary components:

- A performance-based evaluation strategy that promotes the "competition by design" philosophy, which facilitates innovation efforts in developing nations in particular
- Cost networking approach for modeling and visualizing the elements influencing cost and their interactions programmatically to account for the dynamic nature of project-specific factors;

- Process-based estimation method for calculating project costs that yield more precise and dependable estimates, hence preventing cost overruns and contract cancellation;

The Organizational/Process-Related Model

The proposed project procurement process is given in the flowchart in Figure 2. It starts with the client announcing the tender, which adopts a performance-based assessment process.

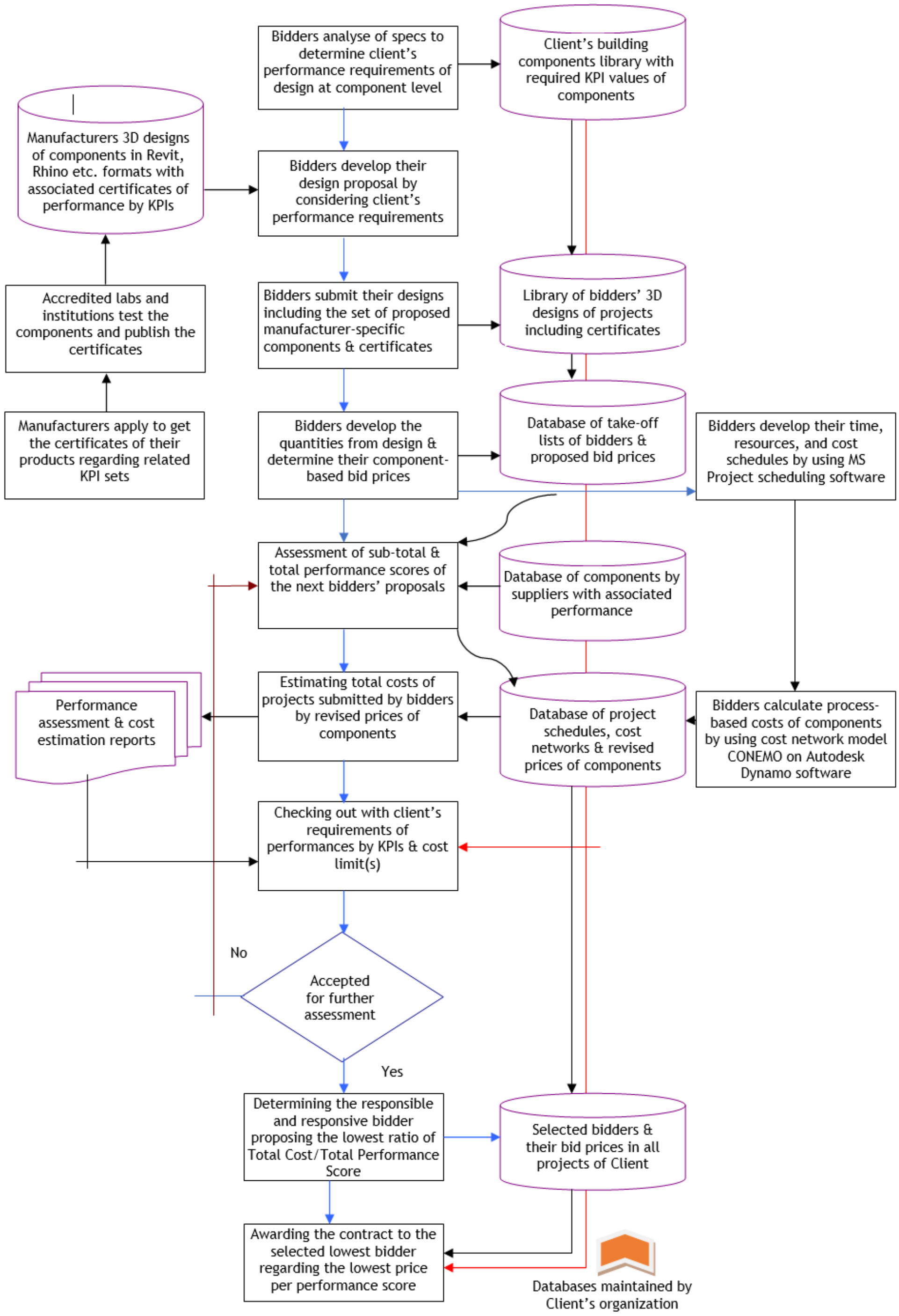

Figure 2: Flowchart of the process model

Potential bidders develop their designs by taking into account the performance requirements of the client stated in the specifications regarding the Key Performance Indicators (KPIs) and by utilizing the smart objects of the components in 3D design and various formats such as Rhino, Autodesk Revit, etc. provided by manufacturers/suppliers or information providers' web sites such as BimObject.com, etc. The certification of all entities at all hierarchical levels of the built environment and on the other two dimensions of the 3D Cartesian System of Sustainability, namely the Social and Economic dimensions, is one of the most critical aspects of the process model. SIMURG suggests reorganizing the building industry's certification systems for these companies.

The 3D models of the manufacturer-specific components must be certified by reputable labs or testing and approval bodies, and they must include the client-required KPI performance data. While the customer invites bids to develop their designs according to "competition by design" concepts, the outputs of the design processes of the prospective bidders will not be unique. Hence, conventional evaluation methods cannot be utilized to compare the submitted offers.

Using scheduling software such as Primavera Project Planner, Microsoft Project, etc., each contractor submitting a bid for the project should create schedules for time, resources, and costs. The Cost Network Model (SIMURG CONEMO) developed in this study using the Microsoft ACCESS relational database development platform and Autodesk Dynamo software must be used in the next step to estimate project costs due to the inability of these software packages to consider and program the dynamic relationships of cost factors concerning project-specific parameters.

In the decision-making process, the customer examines the total costs and performance scores of the bidders' projects, as non-unique design documents cannot be compared. The 3D models of the manufacturer-specific components must be certified by reputable labs or testing and approval bodies, and they must include the client-required KPI performance data. While the customer invites bids to develop their designs according to "competition by design" concepts, the outputs of the design processes of the prospective bidders will not be unique. Hence, conventional evaluation methods cannot be utilized to compare the submitted offers.

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The Computational/Estimation Model

Traditional cost-estimating methods, such as parametric and unit-price-based methods, are practical and preferred for the early phases of the building production process. However, they are unsuitable for construction companies that are required to submit bids for a construction project because they lack the required accuracy.

The process-based cost estimation method considers project-specific elements that influence construction costs. Consequently, it gives some of the essential estimating precision, but it does not provide the development of dynamic linkages between cost elements, as project-scheduling tools lack decision structures. Due to the limited time available for bid preparation, process-based scheduling models are effective unless innovative information technologies supplement them. Solving this problem requires not only a theoretical model incorporating novel tools, such as the Design Structure Matrix (DSM), Cost Network Modeling (CNM), and Process-Based Estimating (PBE), etc. in the conceptual dimension but also a solution model incorporating the novel as mentioned above technologies such as Decision Support Systems (DSS), Artificial Intelligence (AI), etc. in the practical dimension. Since that interoperability is one of the fundamental difficulties in integrating processes and tools, it is vital to integrate complementary tools on both the conceptual and practical levels.

A comparative evaluation of the two cost-estimating methods may be necessary to select the one for our proposal. This would necessitate information from numerous completed building projects. Given that this method is based on actual data from previously completed building projects, it might be argued that it yields a more reliable outcome. Nevertheless, this strategy only enables a focus on the cost variances of the project's production items; the root causes and their interactions that trigger each other cannot be explored because these data are not kept in any database model designed for this purpose.

In contrast, a comparison based on considerably smaller sample sizes may allow for a more in-depth analysis that helps to explain why the results offered by the two methodologies differ. Comparing the results of the Unit Price-based cost estimate, which is obtained by using historical statistical cost data based on specific building elements, and the result of the Process-based cost estimate, which retrieves the factors affecting cost during the construction phase and their interactions from a structured database and considers them in the estimating process, would help us to understand the mechanism of the d better

The Integrational/Interoperability Model

Interoperability at the conceptual level: The information classification systems

Information technologies have facilitated data collection and processing. In addition, organizations such as Construction Specifications Institute (CSI) and National Building Specification have encouraged standard data development and exchange (NBS). The support of building information categorization systems such as MasterFormat, UniFormat, OmniClass, and Uniclass by the International Organization for Standardization (ISO) and Building Information Modeling (BIM) has enabled the development and exchange of data jointly.
Hence, more and more data required for very accurate and precise cost computations are being generated. Since OmniClass provides a comprehensive classification system for all tangible and intangible building production process entities, it is ideal for this study's proposed model.

Interoperability at the computational level: The cost networking approach

The cost networking strategy offers a further crucial instrument for the integration/interoperability of the calculation/estimation model with process modeling and management information systems. Using decision trees, it illustrates the interactions among the project-specific cost components and their interactions. The cost networking strategy can define and depict the relationships between cost variables.

Interoperability at the practical level: Integration of software solutions

In addition to its integration function of the building production process and the building, i.e., its physical topic, Building Information Modelling (BIM) is one of the significant difficulties for any model to be introduced for the solution of the specified evaluation model. The process-based approach will correspond to the BIM 5D dimension.

Although Building Information Modeling (BIM) promotes the ideas of Integration and Interoperability in the construction sector, it does not change the paradigm. In the construction industry, advancements in data collecting, such as Radio-Frequency Identification (RFID) technology and the Internet of Things (IoT), have permitted the development of a massive volume of data known as Big Data (Lu et al., 2018).

SYNTHESIS OF THE PRACTICAL MODEL

Listed below are the primary components of the practical (computer/software) model. Defining the software and reporting system's processes and components must be another purpose of the study.

- The Model for Management Information Systems: In a Management Information System (MIS) model, project-specific data such as the type of building, location, pricing method, etc., cost-related data such as the rates of the resources, unit prices of production items, etc., performance data and KPI sets for performance-based assessment must be organized, processed, and reported.
- The Method Model: The practical model must include process modeling software to define the activities of the project and the logical linkages between the activities. In addition to a typical scheduling software, the suggested architecture requires extra software to configure process linkages graphically and programmatically.
- The Cost Network Model: Unlike standard cost estimation techniques, process-based estimation must consider the project-specific cost components and their relationships. The practical model must employ a software cost networking model to specify these project-specific cost components and their relationships.

The model's required data can be retrieved using various techniques and methods, including government databases, private databases of manufacturers, suppliers, information providers, etc. The proposed model suggests using government databases as plug-ins for retrieving cost data and private databases such as BIMObject.com, etc., that provide performance-based information associated with 3D drawings of building components and elements in the required formats, including Revit, Autodesk, Rhino, etc.

The Management Information System (MIS) Software

The support of information technology is crucial for resolving challenges of consistency and intelligibility, which might lead to reliability issues during the process. The data required for performance-based assessment requires Building Information Modeling-supported web-based database services (BIM). In a previous Ph.D. dissertation (Arslan & Kanoglu, 2018b) and paper (Kanoglu et al., 2022; Sey et al., 2002), an attempt was made to develop a performance-based assessment model for integrating design and procurement processes. The studies are now being conducted under the "SIMURG" Master's Research Project.

The master project began in 2010, and while specific modules (subprojects) have been completed and published, others are still being worked on in ongoing projects. In contrast to conventional cost estimation methodologies, process-based estimation must consider project-specific cost components and their interconnections. The practical model must define these relationships using a software model for cost networking. SIMURG CONEMO is the Management Information System model designed for this study's performance-based procurement process of construction projects (Figures 3-10).

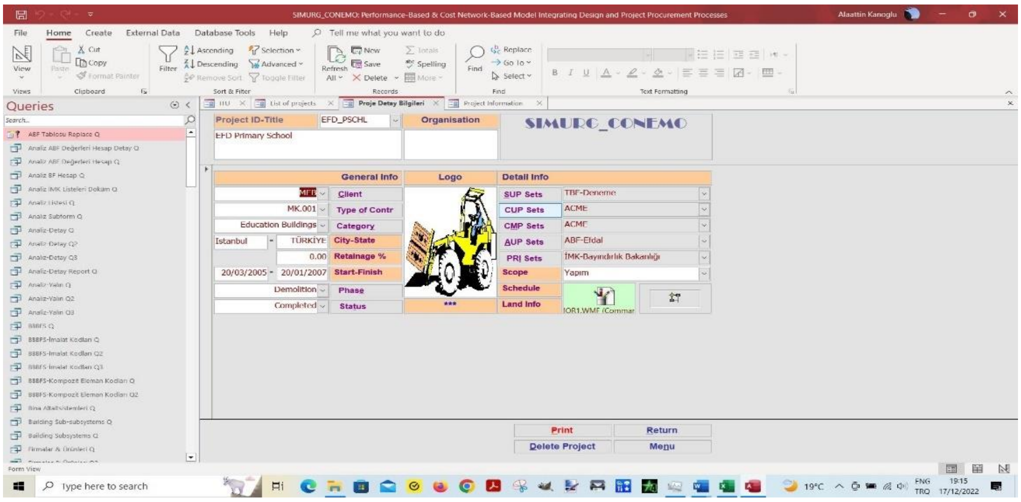

Figure 3: Project info (hypothetical)

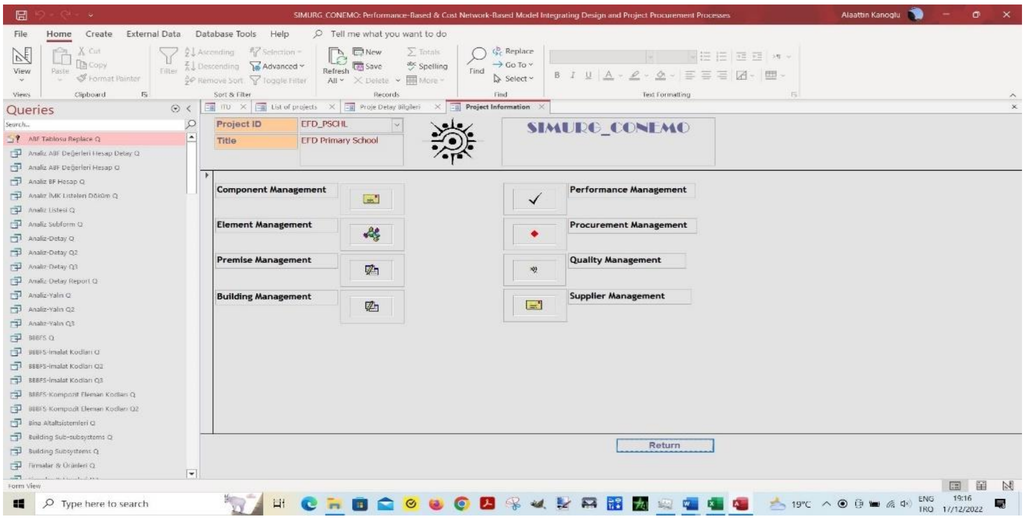

Figure 4: Management modules of SIMURG_CONEMO

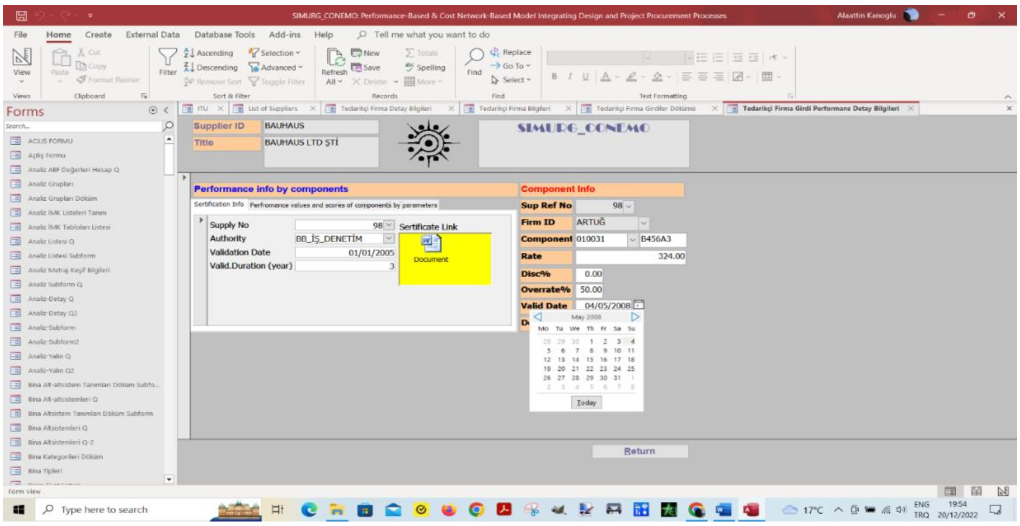

Figure 5: Manufacturer and component-based certificates of performance published by accredited labs or institutions

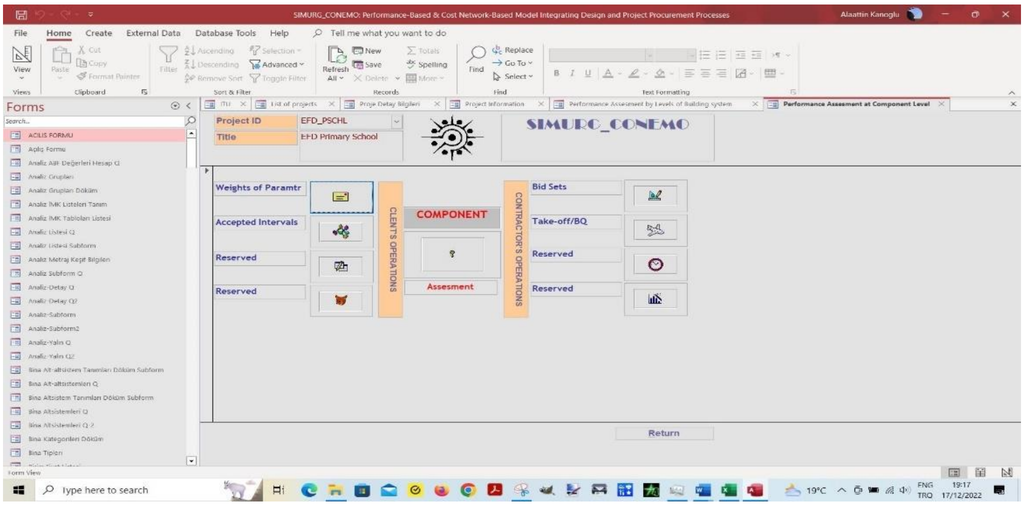

Figure 6: Component-based integrated assessment of performance and cost

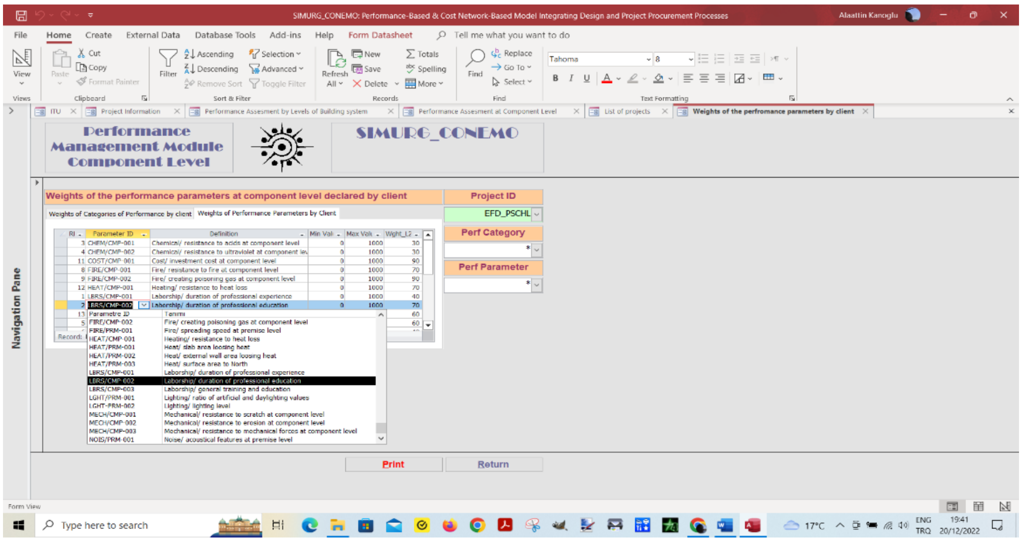

Figure 7: Performance weights of the selected project by KPIs

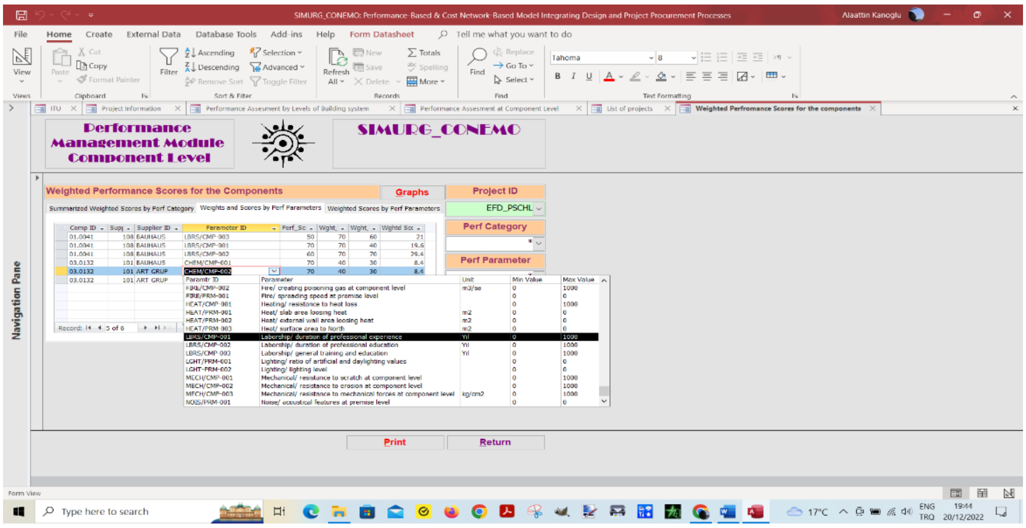

Figure 8: Weighted performance scores of the selected project by KPIs (hypothetical)

As depicted in Figure 4, the model permits performance evaluation and management at four hierarchical levels of the built environment: building components, building elements, building premises, and building levels. All entities at these levels must be accredited by labs or organizations (Figure 5).

Currently, the proposed model can handle performance-based assessment at the building component and building element levels (Figure 6-8); the other levels will be added.

In addition to the weights of parameters or Key Performance Indicators (KPIs), as shown in Figure 7, the threshold minimum or maximum values set by regulations can be defined. Figure 8 depicts the calculation of weighted scores following an expert's definition and assignment of ratings for associated built environment entities.

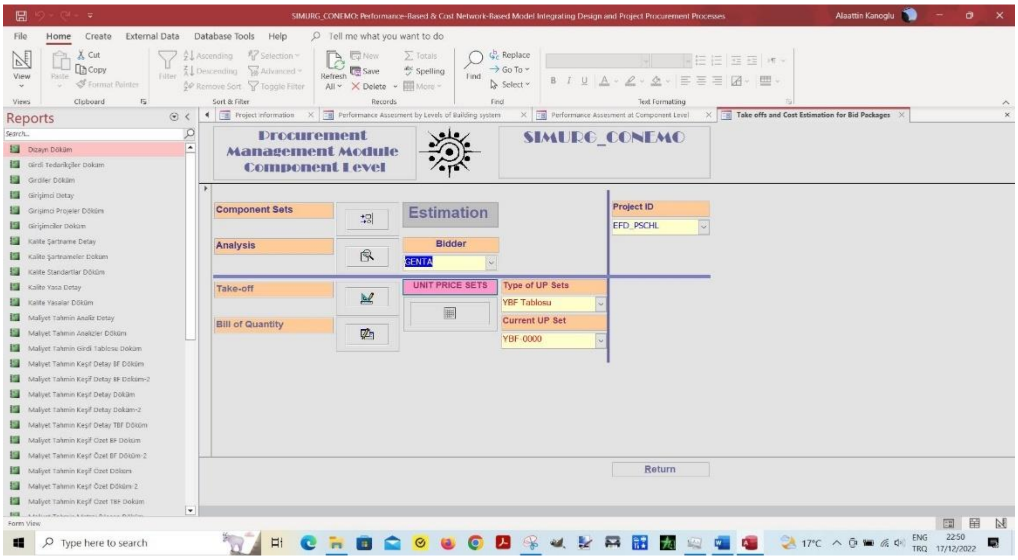

Figure 9: Cost estimation section of SIMURG_CONEMO

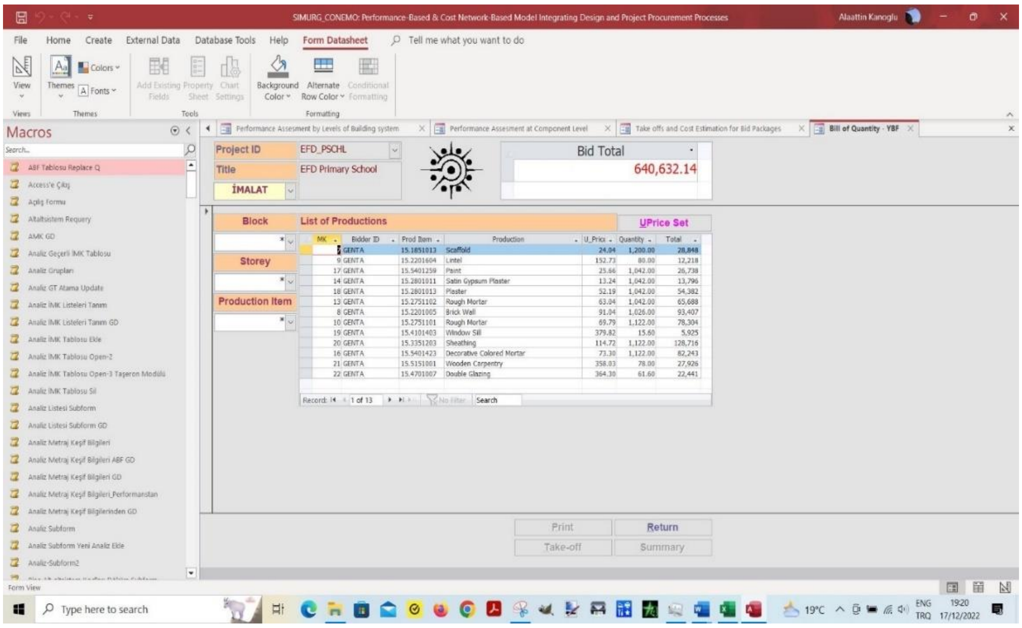

Figure 10: Take-off and Bill of Quantity of the bids (hypothetical)

The model's cost estimation module can utilize unit pricing sets provided by national/local authorities, subcontractors, or competing general contractors (Figure 9). Bid totals and performance scores for each bidder are used to create the Bid Price/Performance Score ratio, which is used to determine which contractor will be awarded the project.

The model computes the bid price totals for each bidder (Figure 10) and matches them with the weighted performance scores of related designs (Figure 8) to calculate the value of the "price per score" that is used to compare bids in terms of the performance-based evaluation.

The Building Process Modelling (BPM) Software

For the typical scheduling functions of the proposed paradigm, any scheduling application, including Primavera, OpenProject, Microsoft Project, etc., is suitable. In addition to MS Project, process linkages will be built graphically and programmatically, and Autodesk Dynamo software will be used to describe and calculate the project process cost model.

SIMULATION OF THE MODEL BY A CASE STUDY

Among the existing cost estimation approaches, the Unit Price-based estimation method is commonly utilized by the Turkish Ministry of Construction in public construction projects due to its presumed comparable practical benefits. Despite its practical advantages, this strategy is frequently deceptive since it fails to account for the influence of project-specific factors on construction costs. In building projects, most variables creating cost variances are rejected, while the public authority pays few.

Due to the limitations of the unit Price-based method in estimating, several studies advocate the Process-based cost estimation method for construction businesses during the bidding process. Nevertheless, there is no comparative analysis of the cost estimation precision of these two approaches. This study uses the outside wall element of a fictitiously designed structure to compare the findings of unit Price-based and Process-based cost estimation approaches.

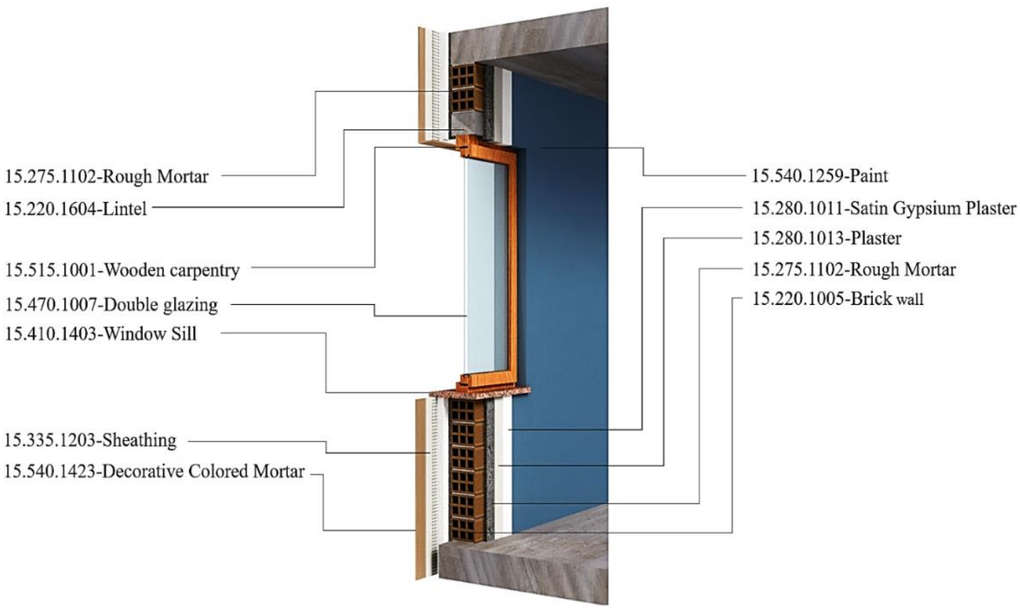

Figure 11: Building element design and structural components (Özçullu, 2022)

The comparison results demonstrate that the Unit Price-based cost estimation method produces inaccurate results that eliminate the contractor's profitability and cause accountability issues and other severe consequences, such as legal investigations for the responsible personnel of local agencies of public authority accused of material improprieties or neglecting their responsibilities.

To test the falsifiability of the proposed model's conclusions, a case study was conducted on a building component that is widespread in residential construction practices in Turkey and whose manufacturing process details are known. As defined by the Turkish Ministry of Construction, the components of this structural element are labeled and classified in Figure 11.

Labor expenses in the production process were calculated using the labor volumes and rates from the Turkish Ministry of Construction data set for 2022. However, to assess the change in project costs based on current pricing, the change in labor expenses was computed using the current minimum wage data published by the Turkish government.

In the process-based cost estimation calculations, the same data and additional transportation, handling, loading, and unloading expenses were included. BIM standards' LOD300 information level was used to calculate the process costs of the building parts. It is considered that construction operations are limited to the contractor level.

When evaluating the impact of the environmental conditions where the project is located and the project schedule on the working conditions, it is assumed that the environmental conditions, such as precipitation and temperature, will not harm the production processes and that the mandatory changes necessitated by adverse conditions will not affect the project schedule. In other words, it is assumed that the elements identified by Kamaruddeen et al. (2020) as having the potential to generate variances in the project's length and budget do not exist.

The take-off quantities at the project level were determined based on the specified dimensions of the fictitious construction element. Quantities of building element components at the project level are based on a 10-story school building with 100 m2 of floor space. In this building, each level is believed to have eight windows measuring 65 cm by 150 cm.

Unit Price-based Cost Estimation

The approach of cost computation utilized by the Turkish Ministry of Construction is comparable to the RSMeans method described by Mubarak (2020). This strategy is based on the production sources: labor, materials, machines, and equipment.

Similar Unit Price-based calculations based on resource costs are utilized by the Dutch Association of Cost Engineers (DACE), The Service of the Royal Institution of Chartered Surveyors (RICS), The Building Cost Information Service (BCIS) in the United Kingdom, The US Army Corps of Engineers in the United States, and the General Construction Cost Review Guide (GCCRG) provided by public institutions like the US Federal Department. According to Nguyen Ngoc (2010), although the cost calculation approach employed by the Turkish Ministry of Building may appear local in a particular context, it is conceptually utilized worldwide.

The calculation of a hypothetical contractor's bid prices and the Unit Price-based project cost based on the quantity of components in a building element is provided in Table 1 and in the screenshot of the MIS model SIMURG CONEMO, which has a relational database architecture provided by Microsoft Access.

Table 1: Project cost calculation according to production items by unit price method

Production Item	Project Quantity	Unit	Unit Cost	Project Cost
15.540.1259-Paint	1.042	m²	25.66	26,738
15.280.1011-Satin Gypsum Plaster	1.042	m²	13.24	13,796
15.280.1013-Plaster	1.042	m²	52.19	54,382
15.275.1102-Rough Mortar	1.042	m²	63.04	65,688
15.220.1005-Brick Wall	1.026	m²	91.04	93,407
15.275.1101-Rough Mortar	1.122	m²	69.79	78,304
15.410.1403-Window Sill	15,6	m²	379.82	5,925
15.335.1203-Sheathing	1.122	m²	114.72	128,716
15.540.1423-Decorative Coloured Mortar	1.122	m²	73.30	82,243
15.515.1001-Wooden Carpentry	78	m²	358.03	27,926
15.470.1007-Double Glazing	61,6	m²	364.30	22,441
15.185.1013-Scaffold	1.200	m²	24.04	28,848
15.220.1604-Lintel	80	mt	152.73	12,218
			Total	$ 640,632

Process-based Cost Estimation

The construction duration of the project's tasks/activities is defined by the project's completion date. The number of crews and durations of project activities are computed in Table 2 based on the productivity of laborers provided by the Turkish Ministry of Construction cost data analysis.

According to the project schedule, the outside scaffolding required for "Sheathing" and "Decorative Plastering" productions will be utilized for 211 calendar days. The cost of renting the scaffolding was established based on this duration.

Using the quantity and price data of production processes of the components, the processes that comprise the process cost were calculated using unit price data from the Turkish Ministry of Construction for the year 2022. The Turkish government's official data sources were used to assess transportation expenses.

Business Process Model and Notation were used to model production processes to compute each construction component's process-based cost (BPMN). The process model of "Paint Activity with Turkish Ministry of Construction System Code 15.540.1259" is depicted in Figure 13.

Table 2: Calculation of project teams and project production durations

Production Item	Quantity	Measurement Unit	Ratio of Laborship	Measurement Unit of labors	Duration of team (Hour)	Number of teams	Duration of the team (day)
15.540.1259-Paint	1.042	m²	0,40	Hour	417	2	26
15.280.1011-Satin Gypsum Plaster	1.042	m²	0,20	Hour	208	2	13
15.280.1013-Plaster	1.042	m²	0,70	Hour	729	2	46
15.275.1102-Rough Mortar	1.042	m²	0,90	Hour	938	4	29
15.220.1005-Brick wall	1.026	m²	1,24	Hour	1.272	4	44
15.275.1101-Rough Mortar	1.122	m²	1,00	Hour	1.122	4	35
15.410.1403-Window Sill	15,6	m²	4,50	Hour	70	1	9
15.335.1203-Sheathing	1.122	m²	1,20	Hour	1.346	4	42
15.540.1423-Decorative Coloured Mortar	1.122	m²	0,90	Hour	1.010	4	32
15.515.1001-Wooden Carpentry	78	m²	0,80	Hour	62	1	8
15.470.1007-Double glazing	61,6	m²	0,80	Hour	49	1	6
15.185.1013-Scaffold	1.200	m²	0,40	Hour	480	4	15
15.220.1604-Lintel	80	m	0,40	Hour	32	1	4

According to the number and productivity of the teams in Table 2, the project schedule in Figure 12 was created.

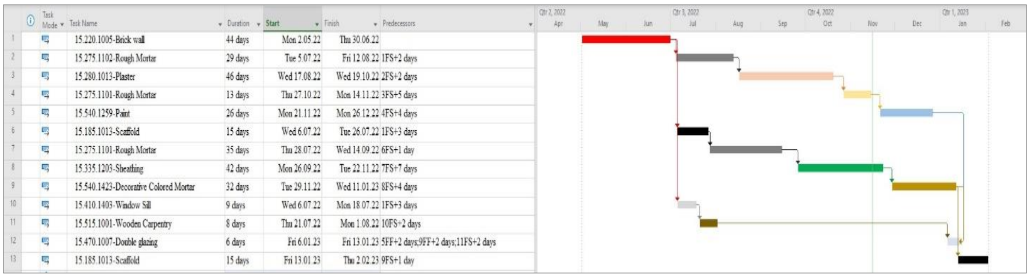

Figure 12: Project Gantt diagram of the structural element in the case study

Like the "Paint Fabrication with Code 15.540.1259" example, production process models have been developed for various building element components. As shown in Figure 14, all production process models were incorporated into a single network model, and a process model for the entire project was developed. Each manufacturing item in this process model was developed following the project timeline (Figure 14). Using Autodesk Dynamo software, the project process model's process-based costs were calculated.

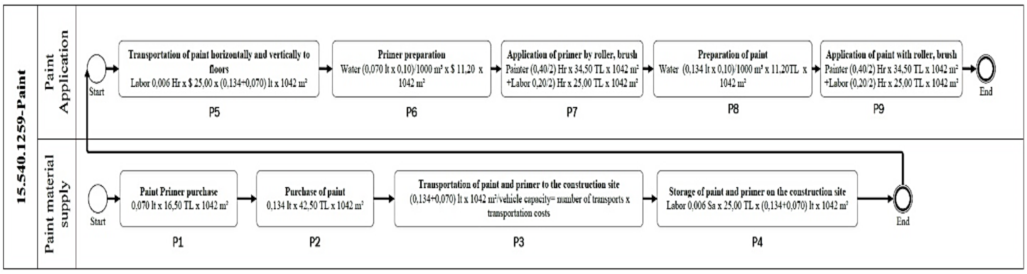

Figure 13: 15.540.1259- Paint activity process-based cost model

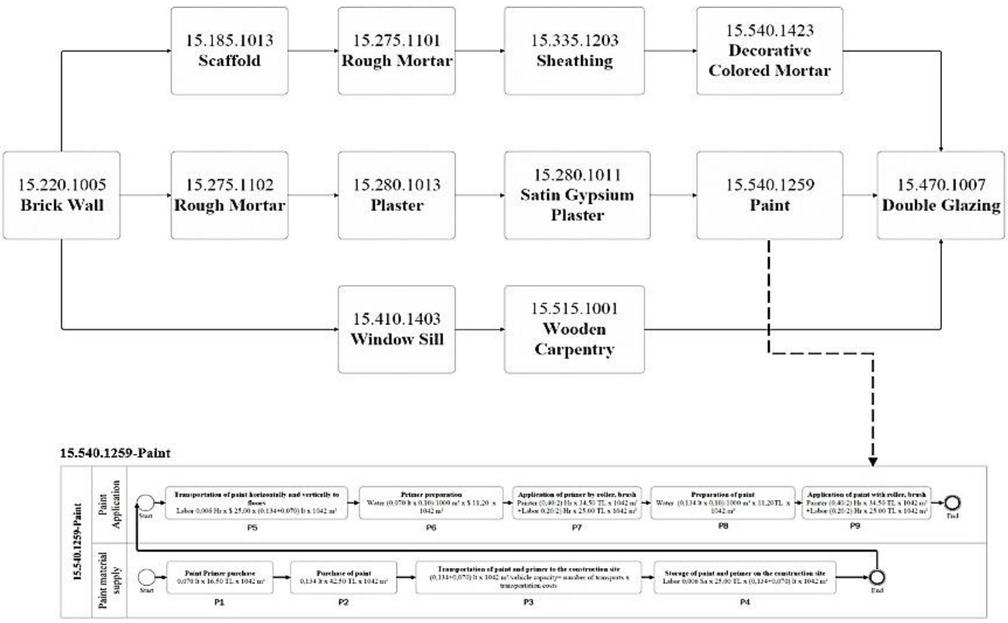

Figure 14: Cost relationships in the production process

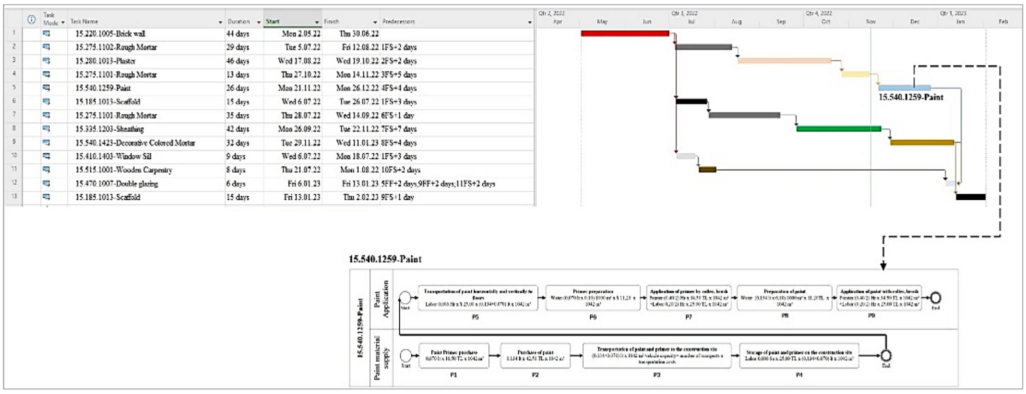

Figure 15: The project process model of the building element in the case study

Comparison of Both Cost-Estimating Methods

Utilizing Autodesk Dynamo software, which enables visual and programmatic configuration of process linkages, the project process cost model was characterized and estimated as depicted in Figure 15—a comparison of the Unit Price-based and Process-based cost calculations.

The unit prices of manufacturing items computed with the Process-based and Unit Price-based cost estimation methodologies differ by 4% to 31%, as shown in Table 3.

It should be emphasized that this calculation does not include any process expenses other than the essential process costs, such as transportation and handling, required for the production to be realized. It is feasible to assert that unit pricing discrepancies would be more significant if other enterprise-level process expenses were considered.

When the components of the building elements are examined in the context of the overall project, the cost of the Lintel is included in the cost of the Brick Wall since Lintel manufacture is included in Brick Wall production. The cost of the scaffolding was included in the comparison of overall project costs when it was connected to the project duration.

Table 4 shows a 47% discrepancy between the project costs estimated using the unit pricing technique and the process-based method.

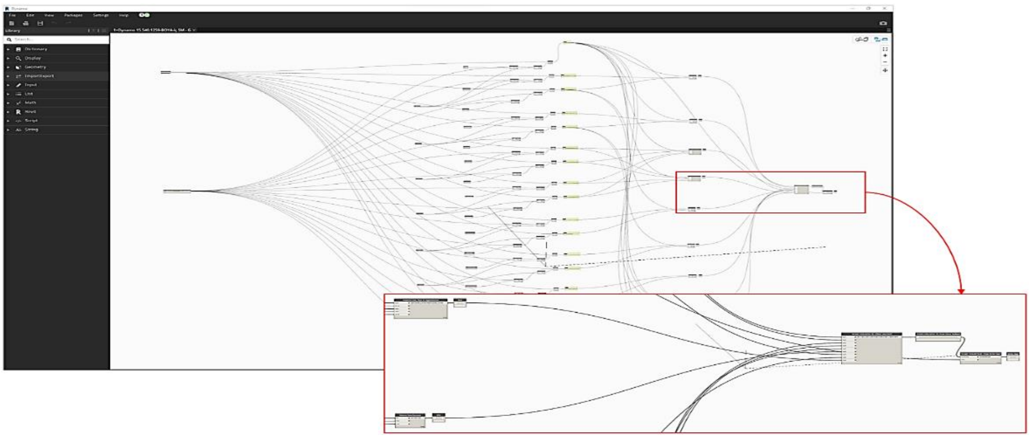

Figure 16: Example and detail of manufacturing process model with Autodesk Dynamo software diagram

Table 3: Comparison of unit prices of both cost estimating methods, unit price-based and process-based models

Production Item	Parametric Method Unit Price	Process-Based Method Unit Price	Difference
15.540.1259-Paint	25,66	26,67	4%
15.280.1011-Satin Gypsum Plaster	13,24	14,13	7%
15.280.1013-Plaster	52,19	59,14	13%
15.275.1102-Rough Mortar	63,04	73,96	17%
15.220.1005-Brick wall	69,79	82,48	18%
15.275.1101-Rough Mortar	379,82	433,45	14%
15.410.1403-Window Sill	114,72	127,84	11%
15.335.1203-Sheathing	73,30	96,12	31%
15.540.1423-Decorative Coloured Mortar	358,03	391,46	9%
15.515.1001-Wooden carpentry	364,30	391,29	7%

In Table 4, the 167% cost difference in manufacturing the "15.220.1005 - Brick wall" component can be attributed to the transportation process costs and the process costs associated with the preparation of masonry mortar, which is overlooked by the unit price-based estimation technique.

The labor expenses of the methods are compared as a second factor. In this comparison, labor expenses included in total project expenditures and costs incurred during project processes were calculated using the most recent available data.

Table 4: Comparison of total costs of both methods; Unit Price-based and Process-based methods

Production Item	The total cost of the unit price-based method	The total cost of the process-based method	Difference
15.540.1259-Paint	26.738	27.790	4%
15.280.1011-Satin Gypsum Plaster	13.796	14.723	7%
15.280.1013-Plaster	54.382	61.624	13%
15.275.1102-Rough Mortar	65.688	77.066	17%
15.220.1005-Brick Wall	105.625	282.377	*167%*
15.275.1101-Rough Mortar	78.304	92.543	18%
15.410.1403-Window Sill	5.925	6.762	14%
15.335.1203-Sheathing	128.716	143.436	11%
15.540.1423-Decorative Coloured Mortar	82.243	107.847	31%
15.515.1001-Wooden Carpentry	27.926	29,138	4%
15.470.1007-Double Glazing	22.441	24.103	7%
15.185.1013-Scaffold	28.848	77.472	169%
Total	**$ 640.632**	**$ 944.882**	**47%**

In the Autodesk Dynamo project process model, project process costs were calculated using the current 2022 values of $42.9 for unskilled labor wage, $43.58 for foreman assistant labor wage, and $55.34 for foreman wage. Using current worker wages to compute project process costs resulted in a 43% cost increase, as shown in Table 5.

As indicated in Table 4, the outcome of the project cost calculation using the Unit Price-based technique and historical statistical labor cost data is $640,632. As indicated in Table 5, the result of the Process-based method's project cost calculation utilizing current labor cost data is $1,352,180. The difference between these two results is 111%. This discrepancy might be attributed to the utilization of current cost data and the precision of the process-based cost estimation method.

Table 5: Comparison of current project costs

Production item	The total cost of the process-based method	The current total cost of the process-based method
15.540.1259-Paint	27.790	40.259
15.280.1011-Satin Gypsum Plaster	14.723	24.555
15.280.1013-Plaster	61.624	89.848
15.275.1102-Rough Mortar	77,066	124.008
15.220.1005-Brick Wall	282.377	430.686
15.275.1101-Rough Mortar	92.543	139.907
15.410.1403-Window Sill	6.762	9.483
15.335.1203-Sheathing	143.436	196.994
15.540.1423-Decorative Coloured Mortar	107.847	155.563
15.515.1001-Wooden Carpentry	29.138	33.046
15.470.1007-Double Glazing	24.103	26.048
15.185.1013-Scaffold	77.472	81.783
Total	**$ 944.882**	**$ 1.352.180**
	Difference	**43%**

The case study results support the notion that the Process-based estimating method supported by cost network modeling tools is more reliable and suitable for use in an integrated model than conventional methods, since all interactions between project-specific cost parameters are considered.

DISCUSSION

Because of its conservatism, the construction industry does not readily adopt new solutions. The workforce is poorly educated, projects are complicated, procedures are fragmented, industrial operations are risky, managers are unwilling to modify their routines, and price-based strategies account for the majority of the competition in comparison to most other industries. In the 21st century, research and development (R&D) efforts are crucial for emerging nations, and the construction industry is expected to be one of the most significant contributors to the national economies of these nations. Thus, paradigm shifts are necessary.

SIMURG CONEMO intends to contribute to the construction industry's transformation. The model's logic is founded on the ideas of governance and sustainability. Yet, it is difficult for the construction sector to accept such a sophisticated solution because they require a well-organized implementation process until building experts recognize their benefits. Since the model is expected to contribute significantly to national economies, governments must adjust, particularly in public projects.

The information included inside the databases of the SIMURG CONEMO program enables the creation of Data Mining and Artificial Intelligence applications. In addition to relational database tools, relationship-based software products such as Neo4J enable artificial intelligence tools to examine cost correlations (Hodler, Needham, & Graham, 2019). By analyzing the dynamic analysis of data in the datasets connected with the Cost Network Model with the Deep Learning method and developing data sets for use with the Cost Network Model, the Cost Network Model can perform instant cost analysis and computations.

DSM (Design Structure Matrix), which is used to define and analyze cost relationships in the Cost Network Model, enables the creation of process models of new projects using past project data and artificial intelligence tools, as evidenced by the findings of Medoh and Telukdarie (2018), Hossain and Chua (2010) and Hossain et al. (2018).

Using the process data in the SIMURG CONEMO relational database model, Machine Learning and Deep Learning artificial intelligence techniques can generate new process variations based on the project's conditions and decision situations. Process Mining research on process models developed using artificial intelligence, Process Improvement for improving processes, and the development of processes according to the principles of Lean Construction Management can be accomplished. With the combination of Autodesk Dynamo and Autodesk Revit in the model testing example, the parametric cost-based design of the project's architectural design may be accomplished within the specified cost-design cycle. With the combination of SIMURG CONEMO, the Autodesk Dynamo software, and Autodesk Revit, it is possible to shape the design based on economic considerations.

According to the project schedule, the Oracle Primavera V6 and Autodesk Navisworks connection mimics the construction of the building in the virtual environment. This simulation only provides a one-way information flow and a time relationship between the 3D model of the building and the project work plan, similar to a computer game. Because modern games, particularly strategic computer games, employ highly complex mathematical models and artificial intelligence methods and tools (Schwab, 2009), it will soon be possible to create software similar to a strategic computer game using SIMURG CONEMO. In this situation, the project is being completed.

Beyond a construction simulation based on a construction plan, it will be possible to visualize and analyze project and cost relationships shaped by an impact-response relationship. As computer players participate in a cooperative game over the Internet, project stakeholders could dynamically use such software to interact and alter the project cost network. As a result of this interaction, project stakeholders could obtain their cost information, just as each computer player receives points. The proposal that the Cost Network Model can be translated into a model similar to a strategic game is supported by the studies of Bargstädt and Blickling (2004) and Li et al. (2003). It can be implemented in the construction machinery simulation-based game instances (Url-1).

In addition, Augmented Reality (Url-2) technologies and apps will enhance the utility of this form of software. It is also plausible to assert that the information technologies analyzed by Lu et al. (2015) will contribute to expanding the Cost Network Model beyond what is envisioned here.

The model requires additional research to boost its dependability and practical adaptability. Future success requires incorporating and contributing Artificial Intelligence (AI) into the model.

CONCLUSIONS

Nowadays, the accountability of decisions made by governmental agencies tasked with generating sustainable solutions for their built environment organizations is seldom observed nowadays. Commercial firms and governmental institutions require a new human-centered vision, a paradigm congruent with this vision, and instruments that enhance the legitimacy of decision-making processes. The issue is a lack of vision and instruments that facilitate this vision in all aspects of life. The building business provides an excessive amount to the global economy's growth. Nonetheless, asserting that the industry embraces and facilitates innovation in product and process dimensions is difficult. Conventional materials and methods are always desirable, and construction professionals are generally conservative.

Today, the advancements in information technology compel the construction industry to reevaluate its current methods, approaches, and tools and to adopt new solutions for every aspect of the manufacturing process. Innovative changes must be prioritized in the project procurement procedure. If sustainability is a priority in our lives to preserve the planet for our children, we must enable all of these technologies at every production stage. On the other hand, as architects and builders of building systems, we must avoid resident practices that waste the world's scarce resources. Presumably, "competition by design" is the primary principle that can aid designers in achieving this objective.

The models in the literature (1) primarily address the problems of clients and ignore the difficulties of construction companies; (2) aim to rank the selection parameters of procurement systems that are incorrectly generalized and assumed to exist for all projects; (3) deal only with the computational part of the model by focusing on calculations; and (4) do not address the applicability of the model (Kanoglu & Gulen, 2013).

This paper aims to: (1) suggest a new paradigm that prioritizes the common interests of society; (2) increase the versatility of the model with minimal additional effort and cost by retrieving the required information from other functional tools; (3) permit the use of the competition by design concept; (4) provide an integrated model that AI applications will soon support; and (5) permit both computers and experts in the project procurement area to participate.

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