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SYSTEM DYNAMICS APPROACH FOR WHOLE LIFE CYCLE COST MODELLING OF RESIDENTIAL BUILDING PROJECTS IN UNITED ARAB EMIRATES

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Abstract

Purpose **–** Project management field is experiencing many challenges to maintain its performance within planned budget. Latest research focused on cost modelling and estimation. The significance of cost modelling comes from the forecasted information value. It is needed in the United Arab Emirates to satisfy the future vision and strategies.

Methodology **–** This article aims to model project's whole life cycle costs of residential buildings in UAE at the preconstruction stage, choosing VENSIM system dynamics approach. The objective is to simulate dynamically cost over time for all outputs. The approach of this research is pure quantitative. It requires mapping diagrams and mathematical computation systems. DEMO simulation and real data verification modelling are used to ensure the outputs' validity. The mean absolute deviation and mean square error are used for measuring the estimation accuracy.

Findings **–** This research proved that VENSIM system dynamics approach can model and estimate residential building project's cost and cash flow dynamically through time, with high accuracy, in the United Arab Emirates.

Unique contribution to theory, practice and policy **–** This research provides the first cost estimation modelling for residential projects' whole life cycle using VENSIM system dynamics approach. It is opening new research opportunities in cost modelling and estimating fields. The theoretical-implications, practical-implications, and limitations are presented in the conclusion for future research.

Keywords: *Cost Modelling, System Dynamics, Project's WLC, CAPEX, OPEX, NPV, TOTEX, Estimation***.**

1. INTRODUCTION

This article introduces the first system dynamics approach for project's whole life cycle cost modelling. First, a detailed literature review to logically build a comprehensive understanding of the problem. Then, the Research problem, aim, objective, and questions are stated clearly. After that, system dynamics cost model development, validation, and verification process is detailed and analyzed. Finally, the originality of this research is presented along with its theoretical implication, practice implication, and limitations for future research.

2. LITERATURE REVIEW

Literature review of this article is covering (1) cost modelling and estimating in residential project's whole lifecycle industry, (2) the status of building projects and investments economy, (3) future economic developments in the United Arab Emirates, and (4) the need for cost models' development in the UAE projects industry.

2.1. Cost Modelling and Estimating in Residential Project's Whole Lifecycle Industry

In business investments fields, it is essential to target having and making maximum profit of invested money while overcoming all challenges and obstacles which might face the processes and operations of making and generating profits (Abdul-Rahman et al., 2013). This is due to knowing that the construction industry cost overrun became the most significant problem globally and due to the sustainability of investments, which had to be implemented in all kinds of businesses, especially in an uncertain market after the economic crises in 2008 (Wu et al., 2011; Abdul-Rahman et al., 2013). However, most developments in the developed and developing countries are focusing on the construction industry to provide the appropriate infrastructure and liveable cities; also, residential projects including, construction and operation, contribute to providing the required and necessary facilities and living requirements of sustainable waive of life for humanity (Nguyen et al., 2004; Cicmil et al., 2006; Winter et al., 2006; Leiringer, 2006; Pantouvakis & Vandoros, 2006; Santos & Ferreira, 2013; Shi, 2011; Memon & Abdul-Rahman, 2014; Wang et al., 2016). Thus, that can be the reason why it is essential to have large, complex, expensive, and significant built environment projects developments such as housing projects (Price, 2003; Oliver, Serovich & Mason, 2005; Kazaz et al., 2005; Jin et al., 2012; Kuricheva & Popov, 2016). Cost became the most critical issue due to the increase of demanding more quality of larger and more complex projects, like housing, in a shorter period (Wang & Mei, 1998; Lewis, 1998; Park et al., 2012; Horta et al., 2012; Sharma et al., 2013; Shehu et al., 2014; Hoffman et al., 2017). Thus, the modelling approaches of the future estimated costs of projects became essential for reaching business targets and achieve investments' purposes from all stakeholders' perspectives (Tang et al., 2004; Kim et al., 2004; Mawdesley & Al-Jibouri, 2009; Islam et al., 2015). Also, due to the long-time consumed in executing and operating projects (i.e., years), and large number of changing project parameters while values of those variables can change several times during the execution and/or operation processes of one project, the estimating cost modelling methods and approaches became researchers' concern to add more value and improve the industry outcomes throughout researching for more accurate and better cost estimation modelling in residential projects (Islam et al., 2015; Akter, Mahmud & Oo, 2017).

Cost modelling research investigated knowledge and information impacts and effects on the quality of residential projects estimated to cost at the pre-construction stage by analysing each criterion as per its significance (Hardcastle, 1992). Furthermore, it is evaluated mathematically to design and build the knowledge and information model concerning its cost on projects (Hardcastle, 1992). The research also covered project profitability studies based on modelling costs and their changing variables, affecting the actual final cost and deviating it from the estimated values (Cui, 2005). However, economic inflation and tax are considered the most significant and vital factors that affect the investments' profitability, which must be considered in construction businesses (NikoliC, 2003). Besides, estimating and studying risks impacting cost estimation values of residential projects was carried out in the early 2000s using a systematically related mathematical model (Isaksson, 2002). Later, the risk analysis and its impact on cost prediction started to gain more advanced analysis techniques, and mechanisms in 2014 throughout the construction stage, including mathematical equations implementation such as system dynamics, analytical network process, and Monte Carlo approaches (Boateng, 2014). The construction cost studies also investigated risk allocation identification and control using system dynamics and Monte Carlo modelling throughout the project's whole life cycle. These studies were carried out to have an appropriate and accurate cost estimation and prediction at the pre-construction stage compared with the actual cost at the end of projects. These studies were based on the relationships between projects' life cycle and risk events' impact on costs (Alzahrani, 2015). This articulated that the risk impact on estimating the construction costs was a concern in most of the conducted studies during the last three decades. Thus, regarding the cost modelling to estimate the projects' cost value at the pre-construction stage, artificial intelligence was used as a modelling tool. It claimed that accuracy was above 90%. These studies were based on building prediction value using the historical data of more than 1600 projects. However, it showed a weakness in estimating the cost of different construction projects type other than historical data (Ahiaga-Dagbui, 2014). The researchers also investigated the whole cost life cycle's net present value to evaluate the project's actual value based on time, operation, and execution costs. Thus, NPV calculation results provide a better selection of contractors at the pre-construction stage (Jang, 2011). However, the recent work on cost modelling estimated construction projects' duration based on 74 office and 113 residential buildings in the USA (Jarkas, 2016). This study used Bromilow's time cost multifactor model to accurately determine the forecast results (Jarkas, 2016). Thus, in UAE, no previous study included the required variables for this research, and it is mandatory to collect all common verified variables related to cost modelling and estimation from previous empirical studies and published literature. Then, verify its applicability on UAE projects. Integrating a new cost estimation model through this research for residential projects to include its construction and operations aims to create a simpler and more accurate model than all previous models.

2.2. The Status of Building Projects and Investments Economy

In this part, an overview of why more accurate cost models are required was summarized. These models are now necessary to study the sensitivity of construction costs after the economic crisis. Therefore, projects cost modelling and analysis can analyze the significant impact of the economy and determine the most accurate decision concerning costs. Therefore, understanding the impact of a project's cost economy is essential to decide and find more accurate financing methods (Stasiak-Betlejewska & Potkány, 2015). Project's investments are based on the economics' status throughout the project's whole life cycle, starting from its execution and ending with the last operational processes. This is necessary to achieve sustainable development, which is the primary concern globally for years (Stasiak-Betlejewska & Potkány, 2015). This threat to the economy is analyzed financially, including inflation, uncertainty, and market investment competition to find out and predict project failure. Hence, it is mandatory to set an appropriate strategic management map of the economy during sustainable development in GCC countries (Ibn-Homaid & Tijani, 2015). However, the studies showed that the whole life cycle of projects is affecting economy from the initiation of projects until its demolition (Santos & Ferreira, 2013; Rodrigues & Freire, 2017). Thus, project performance sustainability is assessed financially from the design stage, via execution and operation stage, until reaching the demolishing stage (Shen et al., 2007).

2.3. Future Economic Developments in the United Arab Emirates

UAE's direction is to increase the accuracy of estimated cost values to improve investments and economic strength while successfully achieving future plans such as the Abu Dhabi 2030 vision plan. This is from the country's new directions concerning its five and ten-year plans, which started in 2015 for EXPO 2020 and Dubai Vision 2021. Nevertheless, achieving large size developments within the required timeframe, quality, and optimum cost will help in keeping up with the UAE government directions and strategies to "dazzle the world with our culture and our excellence, to be the first of its kind in the history of Expos in terms of the preparation, organization, management and hospitality and respect for its guests" said by His Highness Sheikh Mohammed bin Rashid Al Maktoum, the United Arab Emirates Vice President, Prime Minister and Ruler of Dubai (Emirates 24|7, 2016). "The UAE serves as a role model for coexistence among different cultures that are represented by the millions who live in the UAE," said His Highness Sheikh Mohammed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi and Deputy Supreme Commander of the UAE Armed Forces (Ministry of Culture and Youth, 2017).

2.4. The Need for Cost Models Development in the UAE Projects industry

A country like the United Arab Emirates has been established since the seventies (i.e., 2nd December 1971) and experienced challenges through years up to date related to cash flow. For example, infrastructure had to be built and developed continuously besides buildings and structural developments that experienced significant enhancements and improvements countrywide. Nevertheless, nowadays, the country changed its visions and planned to provide a sustainable country by having sustainable developments forming sustainable cities; these changes happened due to the collapse of oil price and the demand of having a top developed country in the world while covering oil price collapse to minimize and eliminate its negative impacts by national income diversification.

Due to GCC countries' economic growth besides the modernization demand and burgeoning population, the building sector's sustainability increasing needs gained more experience and growth (Asif, 2016). Thus, since GCC countries are taking a very high position globally and the United Arab Emirate reached to be from the top countries in construction industries, it is significantly essential to realize the demand of the new developments which are changing continually in order to keep up with new innovations and future plans (Asif, 2016). The United Arab Emirates and the Kingdom of Saudi Arabia have taken around 80% of construction market investments in GCC countries (Asif, 2016). This made the factors of policy and legislation roles regarding construction businesses increase and become more critical for achieving sustainable developments required for implementing future plans of the emirates (Asif, 2016). Thus, cost modelling is essential because of the demanded expensive technologies and designs of modern buildings pushing development sustainability to reach higher than the existing minimum requirements (Radhi, 2010). Also, studies that are including residential buildings showed that it is important to reduce construction and operations costs; however, the Urban Planning Council (i.e., UPC) in Abu Dhabi requires less impact on the environment during operational construction stages residential buildings (Radhi, 2010). These requirements increased cost significantly while budgets are not increased at the same pace due to the economic issues (Radhi 2010). The new façade (i.e., external building cladding) design and execution in the United Arab Emirates had a big jump toward sustainability achievement by reducing the consumption of energy at operational stages; nevertheless, this is increasing costs because it demands more experts in the design stage, more resources/technologies in the execution stage, and more demand for manufacturing suppliers of expensive special materials (Radhi et al., 2013).

In the United Arab Emirates, the construction industry started to be the main business as a series of activities that generate money. However, the price of residential units reached over 2200 AED/SQF in 2008, and it dropped down to below 1000 AED/SQF in 2012 due to the recession, which resulted from the economic crises (Asteco Property Management, 2015). Nevertheless, it was expected to have prices increasing again, but it reached by the end of 2016 to about 1300 AED/SQF, which is approximately 60% of 2008 residential buildings prices (Deloitte 2018). On the other hand, inflation affects everything related to construction execution materials costs (Frimpong et al., 2003). This made the contingency margin and weightage of having construction costs underestimating very high in a way that might break down and fail organizations and projects. However, due to reducing bidding prices to get the project at the tender stage, the most critical decisions and changes in the construction industry and investments are based on businesses' capital and costs (i.e., projects) (Charles-Donovan & Corbishley, 2016). Also, after the drop in the oil price and the new directions of shifting the country's income from being based on oil to be based on several investments like healthcare, education, transportation, tourism, and construction; on the other hand, United Arab Emirate GDP growth experienced a drop of 14.9% from 2014 to 2015 (Annual Economic Report, 2016). As a result, this research significance comes from the need for residential project cost optimization. To sum up, this research will add value in understanding residential building development costs by using system dynamics, which considers risk and economic parameters.

3. RESEARCH PURPOSE

The purpose of this research is detailed to provide further clarification of the targeted investigation as the following: (1) research problem statement, (2) the research aim, objective, and questions, and (3) the research significance.

3.1. Research Problem Statement

This research cost model investigates the ability to utilize a system dynamics approach to develop a whole life cycle of the residential project cost estimation at the pre-construction stage. It is also investigating how mathematically cost risk change impacts the final cost estimation accuracy in the United Arab Emirates. Finally, the research investigates how the delivered model can adjust cost change dynamically to generate sensitive analysis scenarios for decision-makers.

3.2. The Research Aim, Objective, and Questions

This research study aims to provide more accurate projects' whole life cycle cost estimation model. This model will support the decision-making process of residential buildings in the United Arab Emirates. This model is developed from the client and developer point of view at projects' pre-construction stage to support sustainable developments in the United Arab Emirates.

3.3. The Research Significance

The research significance of this study is by developing a new cost estimation model using system dynamics for residential projects' whole life cycle while utilizing probability and quantitative mathematical approaches to enhance model accuracy. Therefore, clients have the following advantages at the pre-construction stage if they choose to use this research system dynamics cost estimation model:

1- Full cash flow estimation from start to end of residential project's WLC in UAE.

2- Present three curves of residential project's WLC costs cash flow at any selected time step.

3- Compare three curves of the adjusted project's WLC contract value cash flows, including minimum risks, mean risks, and maximum risks, in the same model simulation simultaneously.

4- Adapt the change of risks whenever required to simulate cash flows after any adjustment using the same model.

5- Present the net present value of residential project's whole lifecycle cash flows from start to end, including each time step value in each simulation.

6- Provide separate curves of CAPEX cash flows individually, including its risk implementation curves and its net present value (NPV).

7- Provide separate curves of OPEX cash flows individually, including its risk implementation curves and net present value (NPV).

8- Provide estimation curves of TOTEX (i.e., CAPEX, OPEX, and Equipment Replacement), including its risk implementation curves and net present value (NPV).

9- Compare CAPEX and OPEX actual against estimated cash flow curves.

10- Provide modelling and simulating outputs with an accuracy of 96.728%.

4. RESEARCH METHODOLOGY

The approach of this research methodology is going to be a quantitative approach to enhance the results of the mathematical research model and outputs through System dynamics VENSIM, SPSS, and Monte-Carlo Analysis based on the following steps:

1- First, conduct a detailed literature review and validate the topic,

2- Identify and verify the model's variable risks and map them in classification groups.

3- Collection data through 55 completed face-to-face quantitative structured experts' surveys for each risk variable (i.e., 117 risks).

4- Validate the collected data using SPSS (i.e., conducting correlation, regression, outliers, and descriptive statistics analysis). Then compute the adjusting risks through Monte-Carlo analysis and feed it into the model's map.

5- Find out the time relationship between variables related to CAPEX and OPEX of the project whole life cycle.

6- Build the final system dynamics model and validate it.

7- Discuss the results and draw a conclusion clarifying the limitations and challenges of this research besides further research.

5. VENSIM SYSTEM DYNAMICS MODELLING

In this part of the article, VENSIM system dynamics cost model development is detailed, step by step, to explain how the final model is created. This will facilitate approaching VENSIM system dynamics modelling in future cost investigations and research. The development processes, of this research VENSIM cost model, are summarized as the following: (1) project's whole lifecycle system dynamics

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mathematics, (2) system dynamics cost model development, (3) system dynamics cost model validation (DEMO Model), (4) CAPEX system dynamics model validation, (5) OPEX system dynamics model validation, (6) TOTEX System Dynamics Model Validation, (7) Net Present Value System Dynamics Model Validation, (8) final residential project's whole lifecycle cost estimation validated model, (9) system dynamics model verification, and (10) system dynamics cost model error.

5.1. Project's Whole Lifecycle System Dynamics Mathematics

System dynamics can be defined as a set of variables and components interacting with each other through different relationships (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012). Modelling is essential to understanding the skeleton's problem and how decisions will impact its outputs (Choopojcharoen & Magzari, 2012). The beauty of system dynamics modelling is that it can clarify variables movements through time using linear and non-linear mathematical modelling (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012). It will allow us to see graphically (i.e., charts and diagrams) and numerically all events and changes within a modelled system. This mathematical modelling classification is under dynamical mathematics. This is because the VENSIM software program is based on differential equations and time-based analysis (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012). First, the used approach in this research is based on stock and flow dynamics as justified earlier. However, equations 1 to 3 clarify how VENSIM uses the previous mathematical models in stock and flow dynamical system (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012).

$$\frac{d(Stock)}{dt} = \text{Inflow(t)} - \text{Outflow(t)} \tag{1}$$

$$\text{Stock (t)} = \int_0^t [(flows_{\ total}(s)]ds \tag{2}$$

$$\text{Stock(t)}=\int_0^t [(\text{Inflow}(s)- \text{Outflow}(s)]ds + \text{Stock(0)} \tag{3}$$

t = System dynamics time steps (t = 0, 0.125, 0.25, 0.375, 0.5, …, 60).

The two types of system dynamics diagrams are open flow diagrams and causal loop diagrams (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012). Causal loops are not used in this research cost modelling. However, it has been introduced earlier in this study. On the other hand, open flow diagrams are used through the stock and flow dynamical systems. The previous researcher explained the approach of solving open flow problems based on identifying the problem's goals and situation (Sterman, 2003). Then analyze it to have a decision (Sterman, 2003). Then, implement the solution/decision to obtain desired results (Sterman, 2003). Figure 1 is explaining how to open flow problems should be handled (Sterman, 2003). Therefore, this research study identified the goal of building a cost estimation model using a system dynamics approach to solve the problem of having issues in projects' cost estimation. Finally, the results will be discussed in the following parts to obtain this research investigation answers.

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According to researchers, stock and flow systems are like water inflow and outflow from a basin, as shown in Figure 1 (Sterman, 2003). It is because of the differences between inflow and outflow rates (Sterman, 2003). The inflow and outflow can change to adapt linear and nonlinear mathematical models (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012). However, the stock results from inflows and outflows in an open flow system (Yuan et al., 2011; Marzouk & Azab, 2014; Sterman, 2003; Choopojcharoen & Magzari, 2012).

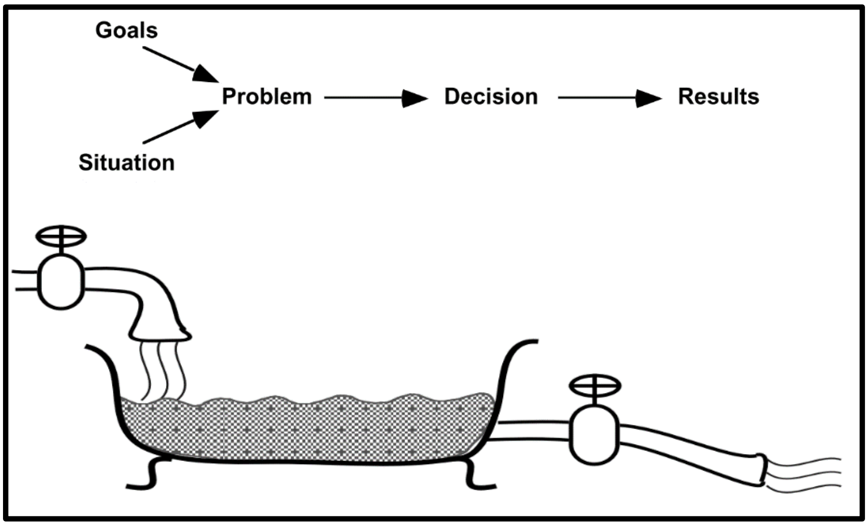

Figure 1. *System Dynamics stock and flow conceptual framework (Sterman 2003).*

In this research study, cost cash-flow and rate over time are considered the system inflow and outflow. On the other hand, total costs until any time step point are considered the stock of this research system. The overall main stocks are CAPEX, OPEX, and TOTEX. Mathematical equations are considered the valves of this research inflow and outflows.

5.2. System Dynamics Cost Model Development

System dynamics modelling system's development is developed for residential projects' whole life cycle cost estimation, including CAPEX and OPEX sub-models, based on exposing the initial project's construction contract value to changing cost risks. These risks are collected from literatures and empirical studies based on the Royal Institution of Chartered Surveyors (i.e., RICS) practice standard, the Australian government framework of total expenditure (i.e., TOTEX), and the Australian government forecasting methodology of capital expenditures (i.e., CAPEX). Cost risks values are collected through 55 experts' face-to-face survey questionnaires for each of the 117 cost risks. These risks' values represent the project's risks. Thus, to calculate the adjusting risks' values from client perspective, it is mandatory to find the error of each risk after considering it by contractors' experts. This is done by Monte-Carlo stochastic approach for each of the 117 risks. The tender contract value is considering the risks value and it will be exposed to the adjusting risks (i.e., errors) in VENSIM to estimate the actual costs. The final complete model will include the equipment replacement cost and the net present value (NPV) of each timestep point through the project's lifecycle. The mathematical equation modelling will be entered in the system dynamics model software program VENSIM based on the relationships between the mathematical equation variables.

Figure 2 is presenting the final developed VENSIM system dynamics model, including the mathematical equations system and the validated risks data, but without any simulation run. The desired function of the developed model will be validated and verified, in following stages of this article, using DEMO and real projects data.

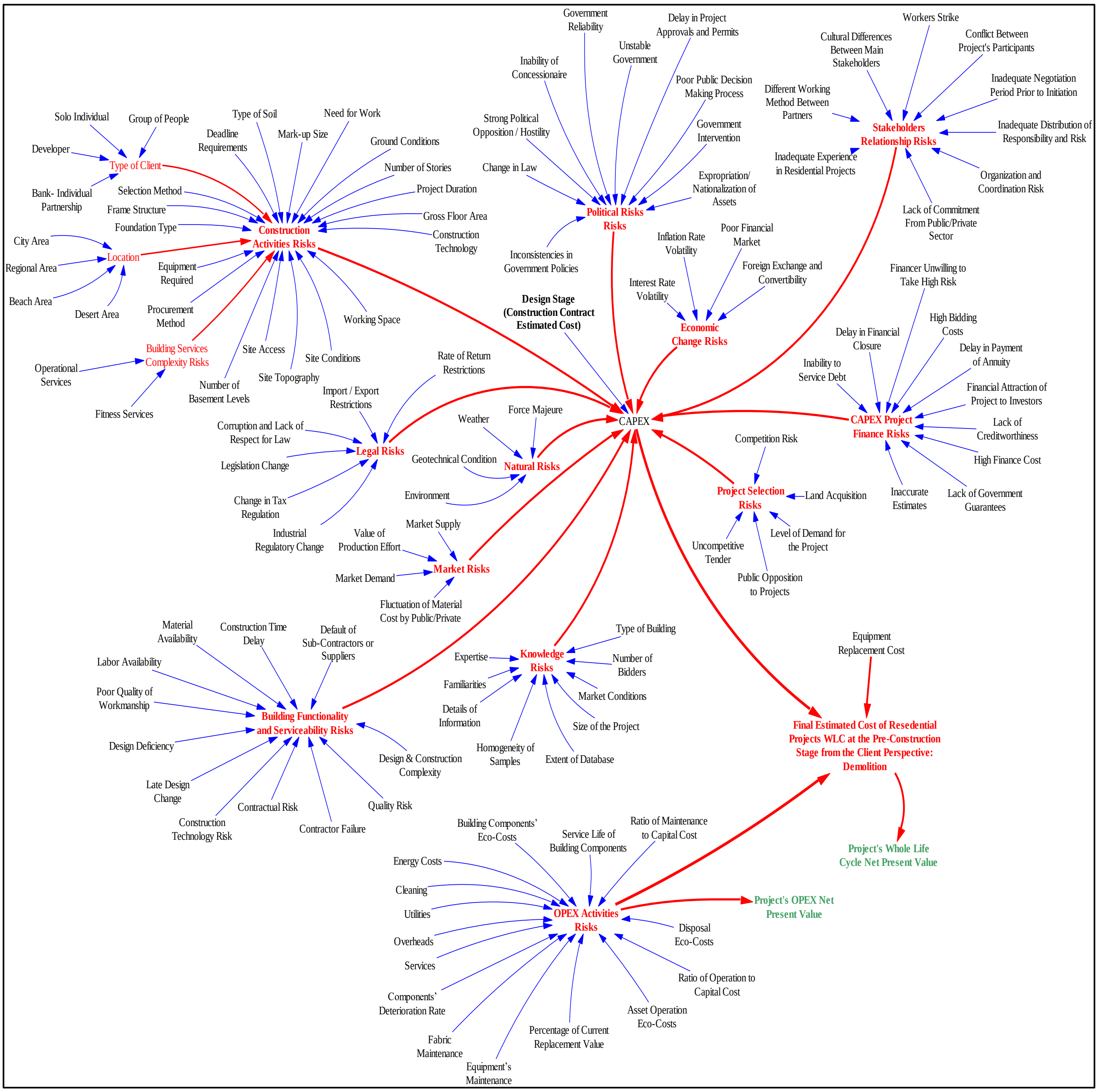

Figure 2. *Final cost estimation model mapping including both CAPEX and OPEX Risks from design to demolition, showing their interaction with each other in the proposed project whole life cycle cost estimation model.*

5.3. System Dynamics Cost Model Validation (DEMO Model)

In this part, system dynamics cost model is developed, validated, and verified. However, model validation can be defined as "conducting some tests after identifying and defining all variables and functions" (Marzouk & Azab, 2014, p.44). Validation is essentially required after the model's development processes (Alshamrani, 2017). Model verification (i.e., "parameter verification test") is the "test is to check whether the parameters in the model correspond conceptually and numerically to real-life" (Marzouk & Azab, 2014, p.45). other researchers defined model's verification as "the research process with continual checks of the credibility, plausibility, and trustworthiness of the findings" (Steinar, 1992, p. 24). This research study will approach DEMO methodology for validating all developed model's components; however, it is considered the best option for measuring model's validity across many fields, including construction and project management discipline (Federici et al., 2018; Bustreo et al., 2015; Meszaros et al., 2015; Bachmann et al., 2017; Gonçalves et al., 2013; Ruan, 2001). This research will then approach completed real housing projects to conduct the verification process and satisfy the model's real-life projects trustworthiness. Finally, error computation will be conducted to finalize this research results and discussion at the end of this article.

The system dynamics validation process is based on considering the developed VENSIM model as a DEMO model. According to previous literature, the DEMO process analyzes a designed system to describe its progress and performance, approaching the same desired technologies used in the real project (Federici et al. 2018). It is also an early assessment of technologies capabilities and economic impact of a designed project before its execution (Bustreo et al., 2015). Besides, researchers have introduced demos as the controlled analysis to evaluate a complex system through simulating real-life applications (Meszaros et al., 2015; Bachmann et al., 2017). Finally, the literature introduced DEMO as a methodology of representing systems complexity and behavior to understand its dynamics (Gonçalves et al., 2013; Ruan, 2001). Therefore, DEMO modelling can be defined in this research study as an early assessment of technology's ability (i.e., VENSIM) to model real designed systems (i.e., project's TOTEX) under controlled simulations to identify (1) performance dynamical behavior (i.e., outputs generation ability), (2) complexity analysis (i.e., mathematical applications), and (3) critical-integration issues (i.e., VENSIM mapping and algorithms) of the developed system dynamics model. After that, assigning a demo project's contract-value required to have a guideline. However, previous research declared that an "educated guess" is a forecast of variable measure which needs to be based on previous related data (Cane, 2019, pp 1768). Therefore, from previous similar research (i.e., "Design/Build/Operate/Transfer (DBOT) project"), a project worth 400 million US dollars was considered a large and complex to proceed with project management dynamical planning and control (Lee et al., 2006, p.92). In this research, irrespective of currency, the DEMO contract value has been set as 400 million to ensure the most valuable outputs from this research large and complex DEMO model validation before using it for real projects. However, in this case, the currency is an adjustable unit entered manually in the model as USD or AED, regardless, prior simulation. VENSIM software program will provide numerical outputs as cash flow data represented with the model's defined unit. The units are important because VENSIM will process them, and this will explain and identify possible issues if the final numerical values are not presented with the currency unit (i.e., AED in this model). The demo construction contract value has been chosen to be AED 400 million.

This research validation DEMO is conducted to observe the simulation results to fix any fault, which may happen in the outputs, to avoid any impact on the final model's accuracy. Therefore, the validation will be conducted for contract value cash flow at zero adjusting risks, minimum adjusting risks, mean adjusting risks, and maximum adjusting risks. CAPEX applications will be ensured to comply with cash

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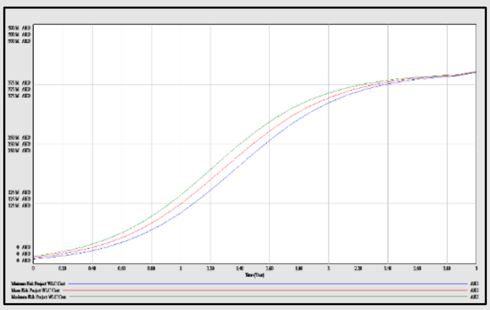
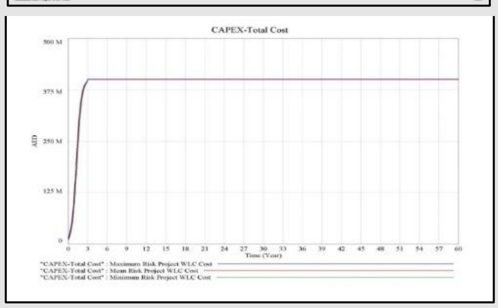
flow increasing S-Curve behavior and risk decreasing S-Curve behavior. Each CAPEX risk's cost group (i.e., a total of 11 groups) will be checked independently as shown in table 2. OPEX trend behavior will be checked separately and combined with remaining outputs, including CAPEX cash flow, equipment replacement pattern (i.e., pulse impact every 25 years), and net present value (NPV). Finally, the projects' whole life cycle cost model is evaluated and validated for further use in real applications.

5.4. CAPEX System Dynamics Model Validation

In CAPEX validation, the AED 400 Million contract value is entered in the model and simulated to check the several points. First, check the behavior of the mathematical equation of contract value cash flow at zero adjusting risk. It has been found to shape the cost cash flow as per the developed S-Curve, as shown in Table 1 from system dynamics simulation. Second, checking the outputs of adjusted cash flow curves subject to a minimum, mean, and maximum risks impact.

According to the built mathematical system, there should be three curves, including minimum risks cash flow, mean risks cash flow, and maximum risks cash flow, as shown in Table 1. Third, checking the mathematical modelling constraints, which should stop the cash flow increment after the last construction time step. Moreover, maintain CAPEX cumulative value constant for the remaining projects' whole life cycle (i.e.57 years out of 60 years in this system dynamics model). However, this should be valid for the zero adjusting cost risks, minimum adjusting cost risks, mean adjusting cost risks, and the maximum adjusting cost risks S-Curves as shown in Table 1. Finally, the validation process will check the differences between risk values to ensure that the model utilizes all functions aimed at its development. In other words, the minimum, mean, and maximum risks impact S-Curves should be, respectively, different from each other. For example, the maximum risk costs curve is the highest, mean risks curve is the middle values, and the minimum risks are the lowest curve. Nevertheless, all cost S-Curves, which are impacted by risks, should be more than the zero risk S-Curve shown in Table 1.

Table 1. *It is showing the CAPEX Cost S-Curve of the DEMO cost model over 3 and 60 years.*

CAPEX Description	System Dynamics Demo Cost Model Outputs
CAPEX Based on 3 years Simulation. Including 3 adjusting risks	
CAPEX Based on 60 years Simulation. Including 3 adjusting risks	

5.5. OPEX System Dynamics Model Validation

In the OPEX validation process, the system dynamics model is tested against having cost cash flow outputs starting after the project's construction completion (i.e., CAPEX = 3 years). In other words, it should equal zero from time step 0 to 3 years. It is also testing if the model can adapt to adjusting cash flow risks over the 57 years of operations.

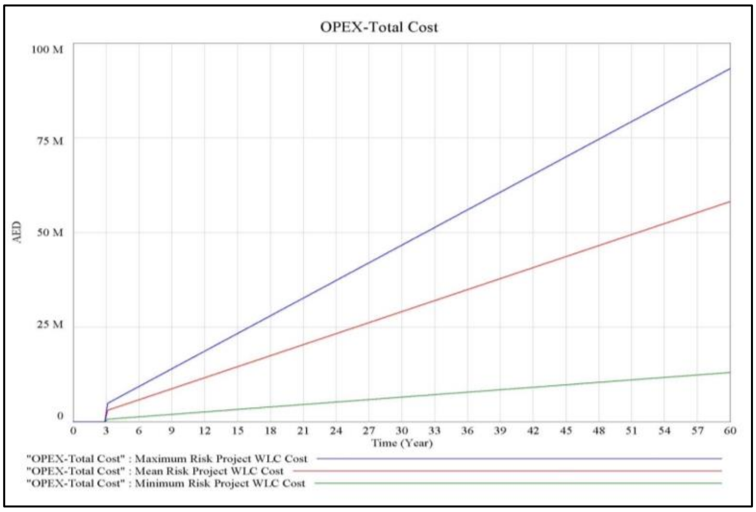


Figure 3. *It is showing OPEX cost flow at minimum, mean, and maximum adjusting risks using the validation DEMO project cost. DEMO cost is assigned equal to AED 400 million over 57 years operation time.*

5.6. TOTEX System Dynamics Model Validation

The validation of the final estimated cost system dynamics model (i.e., TOTEX) is investigating the model's functionality to integrate mathematically and graphically the final costs of capital expenditure based on increasing S-Curve from 0 to 3 years. Moreover, based on operational expenditures, linear relationship from 3 to 60 years. Moreover, based on equipment replacement, pulse costs impact every 25 years over the project's lifecycle. However, it is also investigating if the model will operate successfully while adapting three different adjusting risks simultaneously.

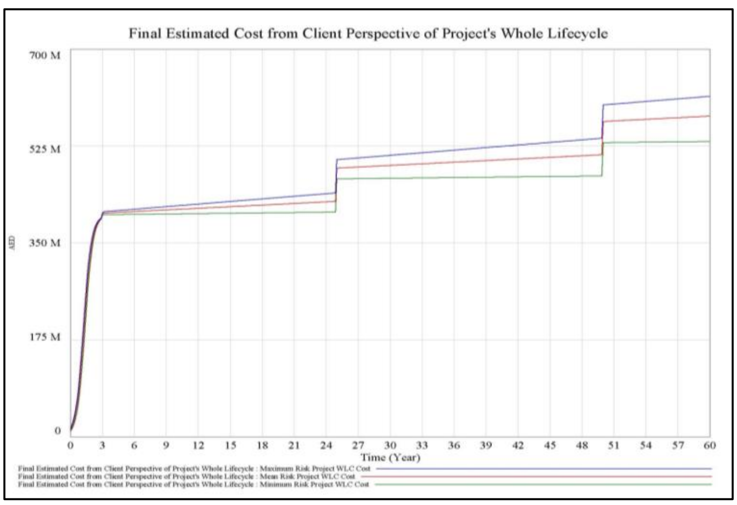


Figure 4. *It is showing TOTEX cost flow at minimum, mean, and maximum adjusting risks using the validation DEMO project cost. DEMO cost is assigned equal to AED 400 million over 60 years projects whole lifecycle.*

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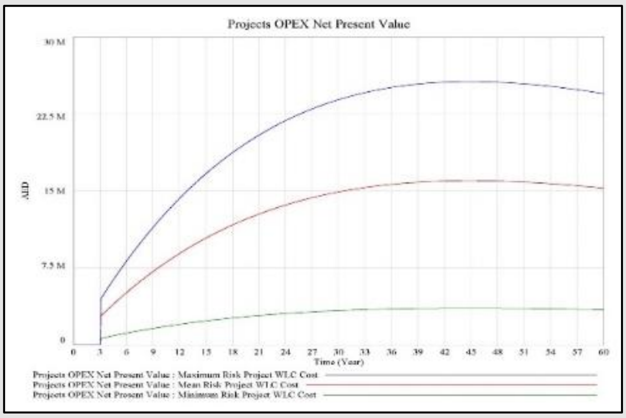
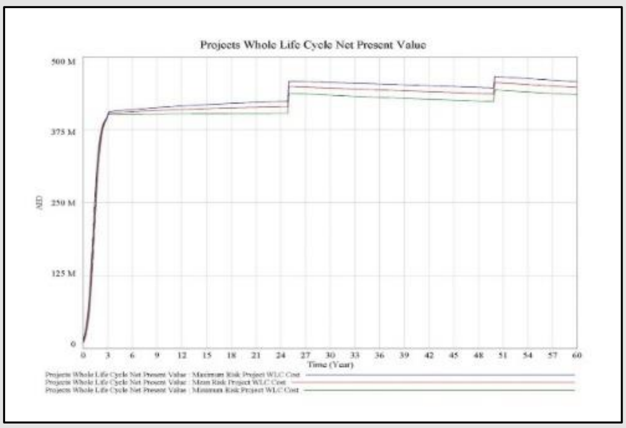
5.7. Net Present Value System Dynamics Model Validation

The net present value validation is divided into two stages. First, validating the net present value of OPEX modelled costs over the 57 years of operations (i.e., 3 to 60 years cash flow). This will be by providing, numerically, NPV detailed schedule for each time step and graphically as shown in Table 2. Therefore, the model simulated costs dynamics successfully and used the UAE EIBOR-Central Bank discount rate for calculating the accurate NPV. Second, calculating the project's whole lifecycle costs, NPV is about investigating if the model can adapt the net present value calculations, including the S-Curve equations and operation linear equations. Also, it should concurrently adapt the pulse impact of equipment replacement equations. Therefore, NPV provided successfully numerical values for each time step and graphical charts shown below.

Table 2. *OPEX & TOTEX VENSIM NPV outputs of the DEMO cost model.*

NPV Description	System Dynamics Demo Cost Model Outputs
OPEX NPV. Including 3 adjusting risks	
Project Whole Life Cycle NPV. Including 3 adjusting risks	

5.8. Final Residential Project's Whole Lifecycle Cost Estimation Validated Model

Finally, by presenting Figure 5, the validation process is fully completed, and the Final System dynamics Model for Residential Projects' Whole Lifecycle Cost Estimation is ready to move to the next stage (i.e., verification).

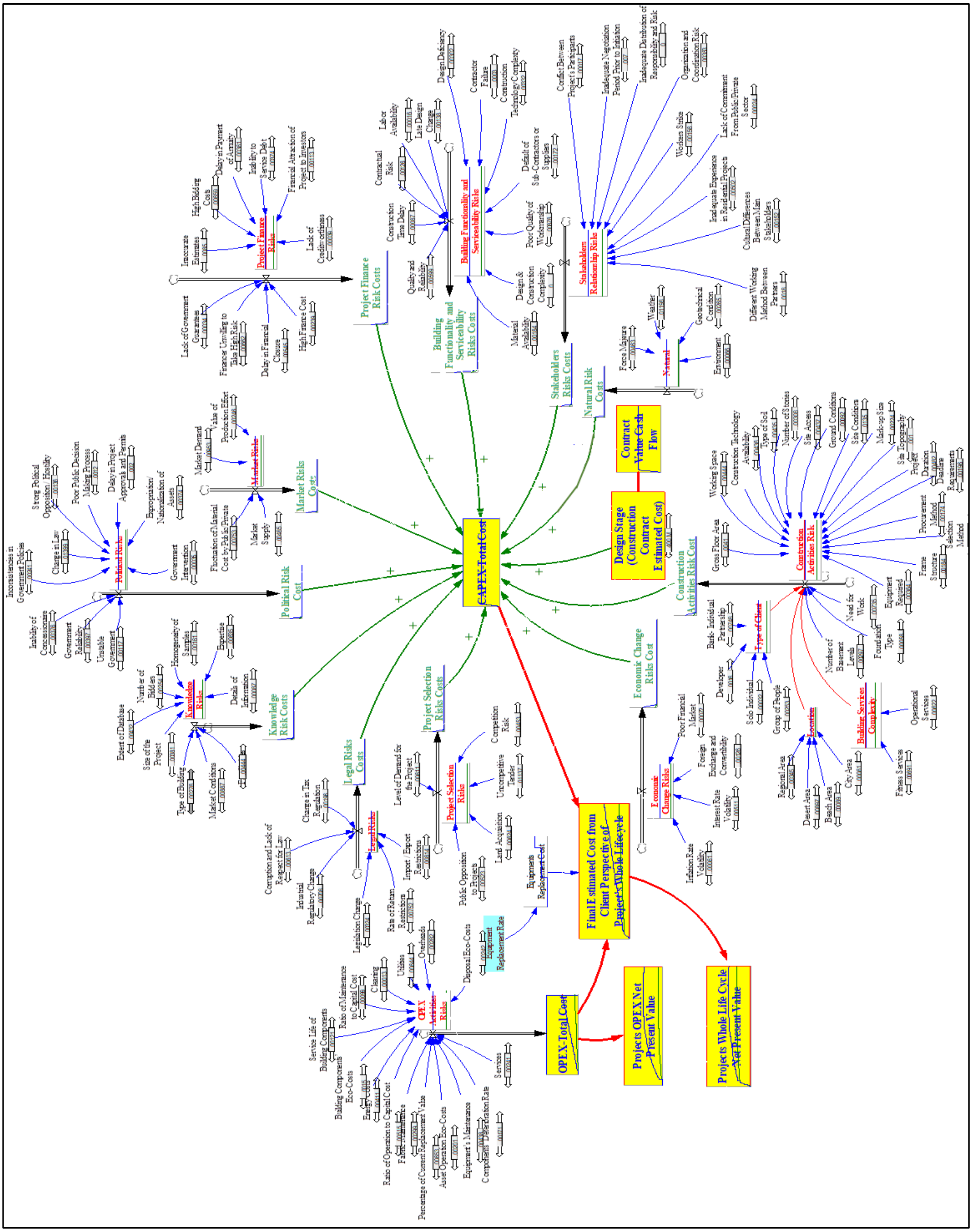


Figure 5. *Final model validation simulation using the DEMO project cost equal to AED 400 million over 60 years projects whole lifecycle.*

5.9. System Dynamics Model Verification

After validating the system dynamics model, the verification process using actual projects data cash flow will be conducted to check its trustworthiness and applicability on real-world applications. Therefore, the verification process will be focusing on the most critical calculations. So, since OPEX and equipment change in the model is considered as functions of CAPEX (i.e., F(X), X=CAPEX)). Therefore, the CAPEX verification will be considered a verification of CAPEX, OPEX, and Equipment replacement. On the other hand, the project's whole lifecycle system dynamics model is built to cover 60 years lifecycle while the United Arab Emirates is less than 50 years old. Therefore, the accuracy of OPEX cannot be done using real data. However, OPEX verification will be considered done based on its validation and CAPEX validation and verification. This is because OPEX mathematics is based on functions of CAPEX. Next, in this part of the article, the verification process will be using the actual cash flow of 3 real housing projects completed in 2016, 2017, and 2019 as inputs of the developed and validated model. The researcher will then compare the model's outputs with the actual data to check its performance and accuracy.

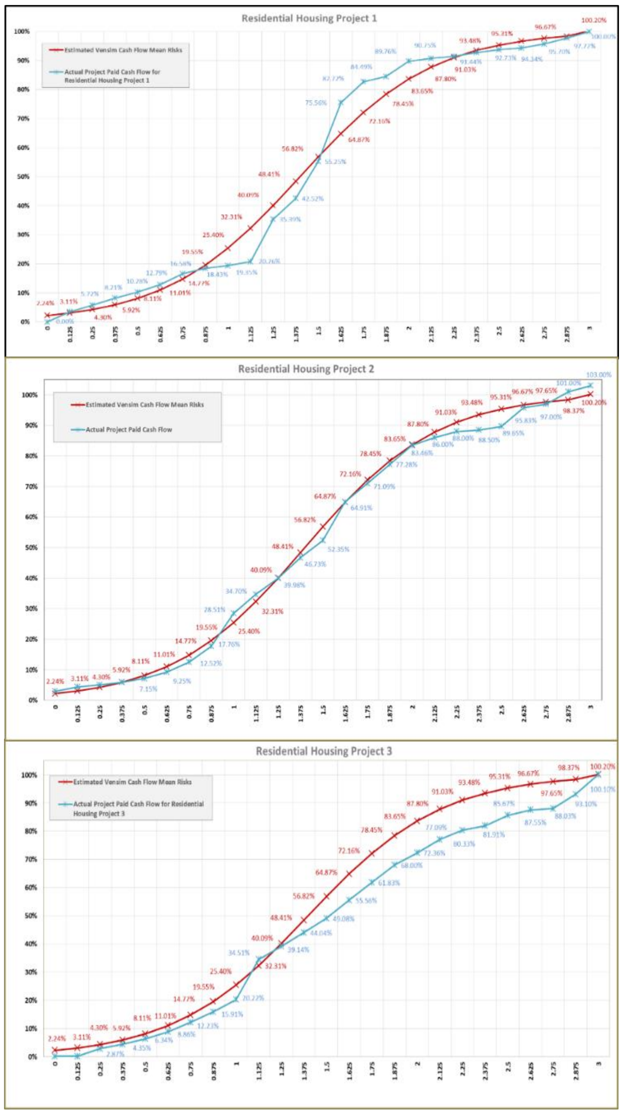


Figure 6. *Comparing 3 projects' cost (model vs. actual cost) cash flows in percentage during CAPEX stage.*

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For project 1, a megaproject costing more than AED 4 billion (i.e., more than USD 1 billion) is executed over 3 years (completed in DEC 2016). For project 2, it is a large project and cost between AED 750 - 800 million (i.e., between USD 200 – 250 million) and it is executed over three years (completed in MAR 2019). For project 3, it is a large project and cost between AED 650 - 700 million (i.e., between USD 170 – 200 million) and it is executed over 3 years (completed in MAR 2017). Finally, the details of projects' cash flow values and percentages following this research system dynamics model time steps (i.e., 0.125 years) is summarized in Table 3 and Figure 6.

Table 3. *Housing projects' model vs. actual cost summary including the percentages of costs at completion compared with contract value. (Contract value is considered 100%).*

Cost Description		Contract Value	Finish Cost
Actual Cost-Residential Housing Project 1		100%	100%
Actual Cost-Residential Housing Project 2		100%	103.262%
Actual Cost-Residential Housing Project 3		100%	100.097%
VENSIM Estimated Cost	Minimum Risk	100%	100.043%
	Mean Risk	100%	100.204%
	Maximum Risk	100%	100.365%

5.10. System Dynamics Cost Model Error

Next, in table 4 & 5, the error calculations of the final model's cost estimation based on the verification projects (i.e., three projects) are detailed to reach a final model accuracy equal to 96.728%. Therefore, this accuracy can change and be more précised if the verification projects are increased to reach above 30 projects to validate the accuracy by grouping the projects with similar challenges and using SPSS to exclude outliers (Konior & Szóstak, 2020). This will finalize the accuracy of system dynamics cost modelling accuracy. Nevertheless, the equations used to calculate error and accuracy of this research model are equations 4 to 7 (Koo et al., 2010; Xu & Moon, 2013; Shahandashti & Ashuri, 2013; Odeyinka et al., 2013; Huang et al., 2015; Hyari et al., 2016; Murillo-Hoyos et al., 2016). Measuring accuracy error is commonly used in quantitative and modelling research after validating forecasting systems using real data (Koo et al., 2010; Xu & Moon, 2013; Shahandashti & Ashuri, 2013; Odeyinka et al., 2013; Huang et al., 2015; Hyari et al., 2016; Murillo-Hoyos et al., 2016).

$$Error = A_t - F_t \tag{4}$$

$$MAD = \frac{\sum_{n=0}^{t} |A_t - F_t|}{\mathrm{T}} \tag{5}$$

$$MSE = \frac{\sum_{n=0}^{t} (A_t - F_t)^2}{\mathrm{T}} \tag{6}$$

$$MAPE = \frac{\sum_{n=0}^{t} [A_t - F_t]}{\mathrm{A_t}} * \mathrm{T} \tag{7}$$

MAD = Mean Absolute Deviation.

MSE = Mean Squared Error.

MAPE = Mean Absolute Percentage Error.

At = Actual Value at t time.

Ft = Forecast Value at t time.

T = The number of time periods.

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However, using mean absolute deviation and mean square error have been proved very effective in calculating system dynamics and mathematical modelling error percentage (Koo et al., 2010; Xu & Moon, 2013; Shahandashti & Ashuri, 2013; Odeyinka et al., 2013; Huang et al., 2015; Hyari et al., 2016; Murillo-Hoyos et al., 2016).

Table 4. *The Absolute Error calculation table including the System dynamics VENSIM model and all 3 verification projects.*

Project	Actual Cost	Forecast Cost with Mean Risks	Error Actual-Forecast
Residential Housing Project 1	100%	100.204%	-0.204%
Residential Housing Project 2	103.262%	100.204%	3.058%
Residential Housing Project 3	100.097%	100.204%	-0.107%

Table 5. *The Error % calculation table to get the final estimation cost modelling accuracy which is equal to 96.728%.*

Project	Absolute Error	Absolute % Error	Final Model Accuracy
Residential Housing Project 1	0.002040000	0.204%	99.796%
Residential Housing Project 2	0.030582723	2.962%	97.038%
Residential Housing Project 3	0.001066264	0.107%	99.893%
Σ (Total)	0.033688987	3.272%	96.728%

6. RESEARCH FINDINGS

This research investigated the ability of VENSIM system dynamics to model and estimate residential project’s whole life cycle costs in the United Arab Emirates. However, it is clearly found that approaching VENSIM system dynamics for cost modelling can be successfully accomplished. This approach can provide accurate estimates of the project’s total cost and cash flow. It can adapt the dynamical behaviour of each interacting variable used in the developed model, including construction cash flow increasing s-curve, construction risks decreasing s-curve, operations linear increasing cost, and equipment replacement pulsing. Finally, VENSIM system dynamics model can adapt multiple scenarios simultaneously in each simulation.

7. CONCLUSION

To sum up, the result of system dynamics approach investigation revealed that it can model project's total expenditure (TOTEX) dynamically over time, including cash flow and NPV. This research output is opening the future research doors to utilize system dynamics (i.e., VENSIM) approach in modelling projects’ costs at the pre-construction stage. Following summaries will present the theoretical and practical implications. Finally, limitations and future research will be listed in 6 points.

7.1. Theoretical implications

The final system dynamics cost model is incorporating TOTEX cash flow and net present value estimates for each time step across the project's whole life cycle at the preconstruction stage. This is achieved by applying adjusting risks on project's initial cost at the preconstruction stage with respect to cost and risk behaviours at each time step. Cost impact is following an increasing S-Curve behaviour during CAPEX time and risk impact is following a decreasing S-Curve behaviour during CAPEX lifetime. Both cost and risk impacts are linearly increasing during OPEX lifetime. And NPV is following a negative exponent behaviour over TOTEX lifetime. The applied adjusting risks are comprising three value levels. Minimum, mean, and maximum cost risks. Simulated costs under adjusting risks' levels can be presented in the same exported data sheet. All cash flow scenarios, under three cost risks levels, can be trended in the same chart, simultaneously, including all project's lifecycle time steps.

7.2. Practical implications

TOTEX and NPV accurate estimation outputs are the most important criteria for future investments decisions (Akter et al., 2017; Florio et al., 2016). In addition, modelling project's cash flow is the most helpful approach to apply stochastic area method (easy-to-apply) analysis (Konior & Szóstak, 2020). Multiple scenarios provide better understanding of future events. Therefore, it is recommended for client's project managers to ensure that all cost risks values are updated periodically. And to ensure that all future projects' total cost and NPV are estimated accurately. This will support successful investment decisions. Finally, client's project managers are advised to approach the area method to estimate the project's cash flow fluctuation at the preconstruction stage. This will expose the forthcoming challenges of project's financing against its cost during the execution / construction stage.

7.3. Originality / value

This research significant contribution to the project management body of knowledge is accomplished by providing the first cost model, approaching system dynamics, for residential building projects' whole lifecycle.

7.4. Limitations and Future Research

The limitations of this research have been collected and summarized as the following:

1- This research study is achieved from the client's perspective in the UAE. However, according to the researcher's best knowledge, there is no cost estimation and modelling using system dynamics VENSIM modelling in previous research. Therefore, it is recommended to use this approach to model costs from the contractor's and consultant's perspective. Also, it is recommended to ensure that system dynamics cost modelling approach can model and estimate costs from contractor's and consultant's perspectives, including different projects in different regions.

2- The demolition is not included within this research model's calculations separately. This is because many published literatures declared that the demolition process is a part of reinvestment activities. Therefore, this research study considers demolition as a part of construction CAPEX activities and will be treated like construction wastes as justified earlier. However, building projects' demolition is a huge argument that requires many investigations about it. This research discussed only related arguments to the topic and recommended further research to approach demolishing, including different perspectives. These perspectives include, but not limited to, considering demolitions as a part of the CAPEX process (not for residential projects in UAE). It includes demolition as a profitable process (i.e., a project for contractors and salvage value for clients). And, it includes demolition as a transition stage shifted to many years due to converting the building to a historic property.

3- This research study developed a system dynamic cost modelling approach for regular and normal residential buildings in the UAE. It does not include special building considerations such as historical buildings converting possibilities, although the final model can adapt to these changes. Therefore, further research will be required for special projects such as the Head of state buildings (e.g., Al Watan Palace = Presidential Palace in UAE) and other important buildings (e.g., Octagon Building = Egyptian Ministry of Defense).

4- The used mathematical model in this dynamical research model is based on estimating OPEX, MEP (i.e., Mechanical, Electrical, and Plumbing System) costs and O&M (i.e., operation and maintenance) costs using published literature percentages of construction costs. Therefore, it is recommended to develop a stochastic approach from real separated MEP CAPEX data and real O&M data related to the residential project. I should be at least 30 sets to conduct a more accurate estimation, as explained earlier.

5- This study's system dynamics model is covering 60 years project's whole life cycle and three years of CAPEX construction time. So, the operational stage is equal to 57 years. Therefore, to verify the model's OPEX outputs, it must have actual data for residential buildings' operational expenditures in the United Arab Emirates. Unfortunately, this is not available because the United Arab Emirates age is less than 50 years old. Also, no housing / residential project's data was found that operated long enough to replace and change its equipment (i.e., MEP- Mechanical, Electrical, and Plumbing System). As a result, the OPEX part of this research model is only developed and validated. Therefore, further research using real data is recommended to verify OPEX accuracy.

6- This research system dynamics model is based solely on the stock and flow VENSIM dynamical approach. Therefore, it is recommended to investigate cost modelling response against causal loops dynamical approach. Variables and outputs scenarios may vary as applicable. However, as mentioned in points 1 and 2 of this research limitations, this investigation can be done from the client's, contractor's and consultant's perspectives, including deferent types of projects in deferent regions.

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