Residential Real Estate Valuation Framework Based on Life Cycle Cost by Building Information Modeling

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Abstract: Real estate markets are ideal investment options that lead to the construction industry's and the economy's growth. Therefore, having appropriate investment and valuation strategies is a critical success factor. Most established valuation methods emphasize market value and economic factors and are ignorant about buildings' technical and structural attributes. Therefore, due to the process ambiguity and lack of information access, the estimated price usually differs from the real property value. In this research, a revised valuation framework is proposed based on the life cycle cost (LCC) of residential properties, focusing on the operation phase. LCC consists of all costs related to an asset during different phases of its lifecycle, and it helps determine the net present value of the property. For systematically storing and analyzing technical and financial information, building information modeling (BIM) was proposed. Despite being widely used in the design and construction phases, its application and competitive advantage to real estate developers and managers during the operation phase are not transparent. This research benefitted from the 5D BIM model with a level of development (LOD) of 300 to increase the transparency and validity of valuation. An 18.25% difference between the calculated price of two case studies in Tehran and their inflated market prices proved this assertion. **DOI:** 10.1061/(ASCE)AE.1943-5568.0000479.

Author keywords: Residential real estate; Valuation methods; Building information modeling (BIM); Life cycle cost (LCC); Project cash flow.

Introduction

Residential properties constitute a significant portion of construction projects worldwide due to the increasing demand for city dwellings (Kumar et al. 2018; United Nations 2016). Consequently, a large number of contracts and transactions are made for residential properties, an important element of which is the price. For estimating the property value and purposes like assessing investment portfolios' profitability, various valuation methods are utilized for different property types (Adamczyk et al. 2019b). Valuation is the quantifying of the effect of factors such as market conditions, legal rights, physical attributes of the building, property plan, financing, supply and demand rates, and macroeconomics on the value of a property (French 2004). It is essential for many stakeholders, including banks and financial institutions, owners, investors, real estate managers, and developers to make proper decisions and have successful portfolios (Domian et al. 2015).

Unlike consumer goods with a short lifespan, an asset's value for real estate is generally defined over a long period. Costs relate to actual expenditures such as materials and human recourse. On the other hand, price is the amount a person pays for something (IVSC 2019; Metzner and Kindt 2018). While cost and price can influence value, they do not determine the property value and can be biased. Therefore, more than 60% of appraisal operators believe that properties are overpriced (Price water house Coopers and Urban Land Institute 2015).

Conventional valuation methods are divided into traditional and advanced groups. Effective factors in valuation fall into three categories: structural–physical attributes, socio-economic factors, and environmental–geographical attributes (Dimopoulos and Moulas 2015; Pagourtzi et al. 2006).

Most of the valuation methods are based on the discounted cash flow (DCF) of future costs and incomes. A critical factor in property's cash flow is its life cycle cost (LCC), especially operation and maintenance costs, consisting of about 60% of a property's LCC (Wu and Clements-Croome 2007). A project life cycle cost includes the present value of construction, overhaul and renovation, energy, and annual operation costs (Ellingham and Fawcett 2006). However, the conventional methods do not reflect these costs precisely.

The lack of attention to properties' maintenance conditions and physical attributes prevents the reflection of properties' inherent value in conventional valuation methods (Omar and Heywood 2014). Therefore, if two properties of the same size and age, located in the same area, have almost the same market price, even if one of them is in a poorer maintenance condition, the lack of information access and ambiguity of the process results in a subjective appraisal (Klamer et al. 2018). Consequently, the lack of long-term technical information leads to increased operation and maintenance costs and unsustainable real estate management strategies (Vimpari and Junnila 2016). These factors, along with stakeholders' lack of knowledge about advanced methods, limit the widespread use of automated valuation methods (Abidoye et al. 2019).

Schneider (2016) believed that the art of appraisal is moving toward data application (Schneider 2016). Consequently, having complete information on appraisal, sales, and investment policies will contribute to the investment's success and valuation validity

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Note. This manuscript was submitted on November 6, 2020; approved on March 24, 2021; published online on May 26, 2021. Discussion period open until October 26, 2021; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Architectural Engineering***, © ASCE, ISSN 1076-0431.

(Tidwell and Gallimore 2014). Implementation of intelligent and data-driven decision-making systems by appraisers will increase the legitimacy of real estate markets (Jensen et al. 2012). These systems also help reduce the cost of collecting and processing information, which increases the valuation process's efficiency. However, due to the lack of appropriate decision support tools, it is hard to include factors, such as LCC, quality, productivity, efficiency, and design complexity, into decisions of decision-makers (Sharafi et al. 2018).

This research aims to provide a practical framework for calculating and analyzing LCCs of residential properties using building information modeling (BIM), which serves as the basis for a standardized, systematic, applicable, and unbiased valuation process. Due to its data-driven structure, a 5D BIM model with a level of development (LOD) of 300 provides an automatic cost breakdown structure and calculation of quantities, materials, and costs. Moreover, it benefits from interoperable formats for exporting the cost tables into excel spreadsheets for LCC calculation and final price estimation. Being based on as-built building information and maintenance conditions, BIM solves the ambiguity and bias problem in the valuation process.

This framework can assist asset managers and investors in their investment decision-making and gain costumers' trust by providing a visual, understandable, and comprehensive assessment process. Moreover, facility managers can extract the maintenance plan and verified vendor list for the operation phase from the BIM model, which will increase the property's productivity throughout its life cycle. Banks and financial institutions will be more confident in financing the projects with a more accurate estimate of future costs and incomes. The government can use this data in the taxation process.

Literature Review

Valuation Methods

Valuation methods are compared based on price estimation accuracy, conceptual integration, internal consistency, reliability and accuracy, time and cost efficiency, the variability of valuations, and required adjustments (Kauko and d'Amato 2008). Previous research works illustrated these methods' structure, and revised frameworks have been introduced using tools such as tables, databases, and information technology (Adamczyk et al. 2019a). Moreover, technology-based and data-driven valuation methods can help reduce the gap between a property valuation and its actual price (Abidoye et al. 2019). Conventional valuation methods in traditional and advanced groups are listed in Table 1.

After a comprehensive literature study on the conventional valuation methods, each method's advantages and disadvantages were surveyed. In general, traditional methods need less amount of data for reference, which causes ease of access, and ease of adjustments (Pagourtzi et al. 2003). Moreover, methods based on DCF pay attention to the time factor (Folger 2018), future revenue generation and growth potentials, and deprecation costs (Scarrett 2008). However, traditional methods reflect transaction prices made under similar circumstances rather than the property's real value and expected future growth (Naderi et al. 2012), which results in uncertain and biased assumptions (Folger 2018; Pagourtzi et al. 2003). Moreover, these methods are not applicable to all types of real estate properties (Folger 2018).

Advanced methods consider an extensive range of information and factors for valuation, which are unbiased, with a low error and uncertainty rate (McCluskey et al. 2013), and suitable for mass appraisals (Wersing 2011). They can analyze the nonlinear relations between variables and the final price (Balsera et al. 2018; Del Giudice et al. 2017a) and are not limited to any specific type of properties or market conditions (Del Giudice et al. 2017b). However, they require high statistical expertise and have a *black box* structure (McCluskey et al. 2013; Wersing 2011). Moreover, they are sensitive to selecting primary criteria and their types (Del Giudice et al. 2017b), and require a large number of data inputs for reference, which is complicated and time-consuming (Del Giudice et al. 2017a).

Valuation Criteria

The factors that influence a property's value include market value, growth rate, investment risk, market demand, depreciation, predictable future income, social security, architectural style, HVAC systems, structural system, energy consumption, economics, surrounding environment, and ecology (Fife 2017; Naderi et al. 2012). Technical and quality characteristics of buildings affect investments' long-term success (Wong et al. 2012).

To have a comprehensive list of valuation criteria, a vast literature review and semistructured interviews with real estate experts were conducted. Fifty-five criteria were mentioned in the previous studies, presented in Table 2, and 20 criteria were added from the interview, presented in Table 6. Attributes mentioned in Table 2 are categorized into three categories: building-technical, financial-legal, and environmental-local, all of which

Table 1. Traditional and advanced valuation methods

Methods	Valuation method types
Traditional	Sales comparison approach (Cupal 2014; McDonald and McMillen 2011; Pagourtzi et al. 2003)
	Discounted cash flow method (Damodaran 2012; Scarrett 2008)
	Investment/income method (Pagourtzi et al. 2003)
	Direct capitalization method (Cap method) (KTI & IPD 2012; French 2004)
	Profit method (Scarrett 2008; French 2004)
	Contractor's/cost method (Pagourtzi et al. 2003)
	Development/residual/cost method (Folger 2018; Damodaran 2012)
	Multiple regression analysis (Damodaran 2012)
Advanced	Hedonic pricing model (Metzner and Kindt 2018)
	Autoregressive integrated moving average (ARIMA) (Tse 1997)
	Artificial neural network method (Balsera et al. 2018; Tabales et al. 2013)
	Spatial analysis method (Balsera et al. 2018; Ahlfeldt 2011)
	Genetic algorithm (GA) (Del Giudice et al. 2017b; Ma et al. 2015)
	Fuzzy logic (Del Giudice et al. 2017a)

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Table 2. Effective attributes in a property's valuation

Property's valuation categorization	Effective attributes
Building-technical	Floor Interior design Storage area Air conditioning View Number of units Façade Natural lighting Number of living rooms Parking area Green area Number of floors Open spaces Lift Number of units in floor Material quality (Naderi et al. 2012) Lot size and price Terrace (Pagourtzi et al. 2003)
Financial-legal	Mortgage rate (Naderi et al. 2012) Fixed costs Variable costs (Pagourtzi et al. 2003) Growth rate Investment risk Inflation rate Discount rate (Folger 2018; Scarrett 2008) Contract special conditions (Des Rosiers et al. 2000) Previous transaction history Demand rate (Del Giudice et al. 2017b) Financing methods Payment conditions Macroeconomics Market conditions (Ma et al. 2015) Facilities Construction quality Building age Deprecation
Environmental-local	Safety Property type Property's area Distance from work Price range Number of bedrooms Noise Access to local facilities Social class Air pollutions Access to public transport Distance from city center Access to main roads Population density Quality of neighboring houses Nonresidential properties in neighborhood (Naderi et al. 2012) Zoning Topography (Ahlfeldt 2011)

are considered in the proposed valuation framework. These categories are defined based on previous studies (Dimopoulos and Moulas 2015; Pagourtzi et al. 2006). Naderi et al. (2012) research work serves as the basis of this table because it specifically focused on Tehran's real estate market and its valuation criteria. Therefore, most of the noted attributes in Table 2 are referred to that study.

Life Cycle Cost

LCC includes all costs related to constructing, operating, and maintaining, and disposing of a construction project over its life cycle (Likhitruangsilp et al. 2019). The LCC analysis is an integrated monitoring approach to consider cost information throughout an assets' lifespan for various purposes like decision-making and quantifying environmental costs (Ianchenko et al. 2020; Sigg 2016), which goes beyond initial pricing (Likhitruangsilp et al. 2019; Vimpari and Junnila 2016). For this purpose, the net present value (NPV) is calculated based on the discount rate, forecasted cost trend, and components' lifespan (Kehily and Underwood 2017; Sigg 2016). The first step is the project's lifespan prediction based on design quality, construction quality, interior and exterior spaces, service life predictions, utilization, and maintenance conditions (Ianchenko et al. 2020; Ghosh et al. 2015; Vimpari and Junnila 2016). Due to the long service life of buildings and uncertainties engaged with lifetime prediction, it is challenging to apply LCA in the built environment (Ianchenko et al. 2020). However, this issue is not as challenging in Tehran because residential buildings' lifetime hardly exceeds 50 years due to the poor building quality, poor demolition and development decision-making, and economic factors.

LCC is directly related to the property (Likhitruangsilp et al. 2019) and affect its value. LCC analysis is used for both existing buildings and the evaluation of various design alternatives for real estate investment (Santos et al. 2019). Considering the lifecycle of projects for long-term decisions improves the efficiency of stakeholders' communication and involvement. However, its implementation is challenging due to information scarcity and unreliability (Ghosh et al. 2015).

Besides depicting LCC's benefits in valuation and investment decision-making, a practical framework for its implementation is required (Muñoz and Arayici 2015). Virtual reality, web, object-oriented technologies, CAD methods, multiple regression models, and artificial neural networks have been suggested in previous studies (Alqahtani and Whyte 2016). Standards like UniFormat and MasterFormat and coding systems like TBT and GB50500 have been utilized for cost breakdown structure (Ma et al. 2013). However, many studies discuss that BIM is the best integrated support system for lifecycle processes performed by stakeholders (Likhitruangsilp et al. 2019; Soust-Verdaguer et al. 2017). The up-to-date BIM model provides an accurate estimation of costs using data exchange formats, estimates risk, and growth and depreciation rates in real estate investments (Wilkinson and Jupp 2016) and provides accurate, graphical, and understandable economic information to the owner (Amiri et al. 2019). Fig. 1 presents the cost components of LCC listed in previous research works.

BIM Application for LCC

Kehily and Underwood (2017) and Likhitruangsilp et al. (2019) proposed methods to add the LCCA component through a 5D BIM model. An automated system for LCCA using visual programming via Dynamo or Excel spreadsheets for Autodesk Revit was proposed (Likhitruangsilp et al. 2019; Kehily and Underwood 2017). Hojatpanah et al. (2019) presented a template for implementing unit prices in Revit for automated cost calculation, which is a simple task due to the parametric and intelligent nature of BIM (HojatPanah et al. 2019). Manganelli et al. (2019) used BIM to calculate real estate depreciation as an efficient decision support tool for developers and real estate managers. Dynamo was used to estimate deprecation costs through a simple visual programming language (Manganelli et al. 2019). Soust-Verdaguer et al. (2018) developed a method based on LCA that integrates BIM to assess

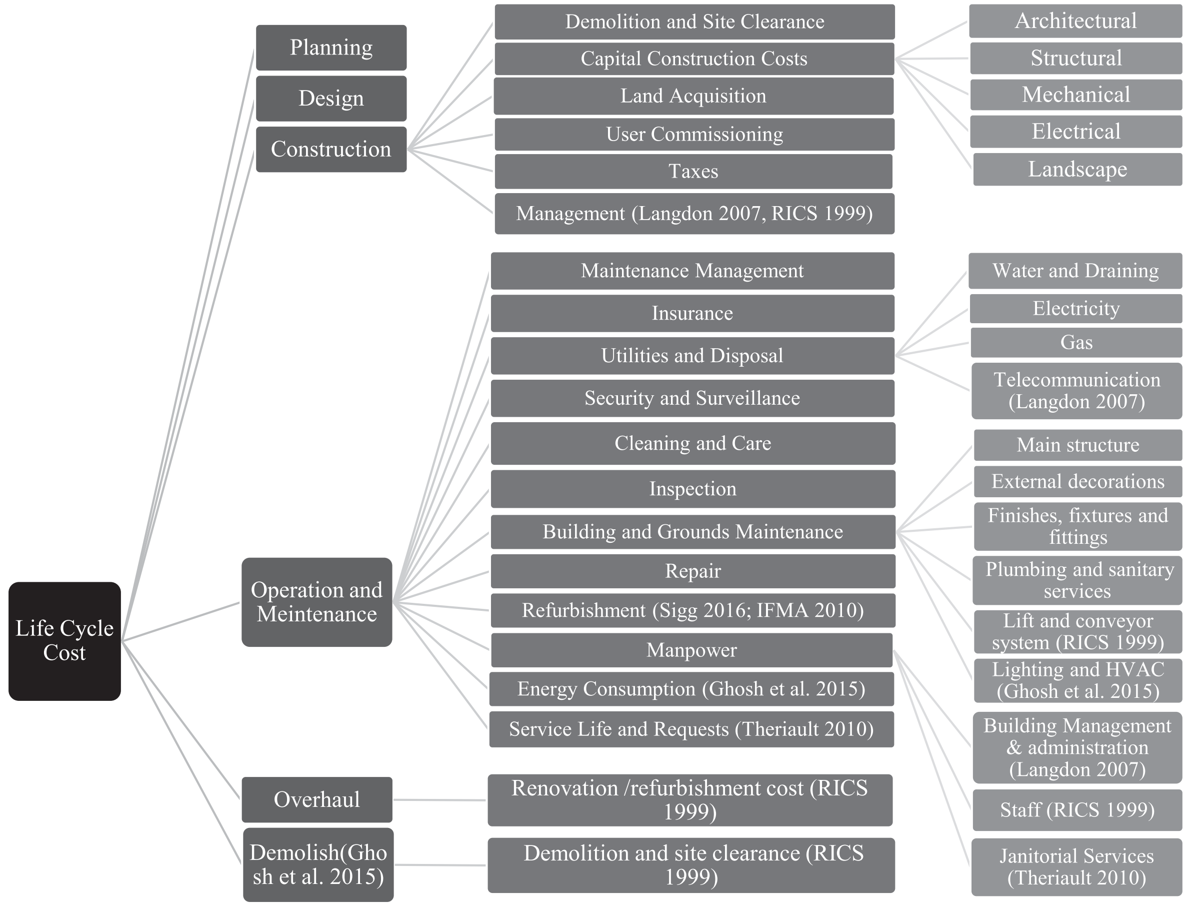

Fig. 1. Cost breakdown structure and components of LCC construction projects and properties.

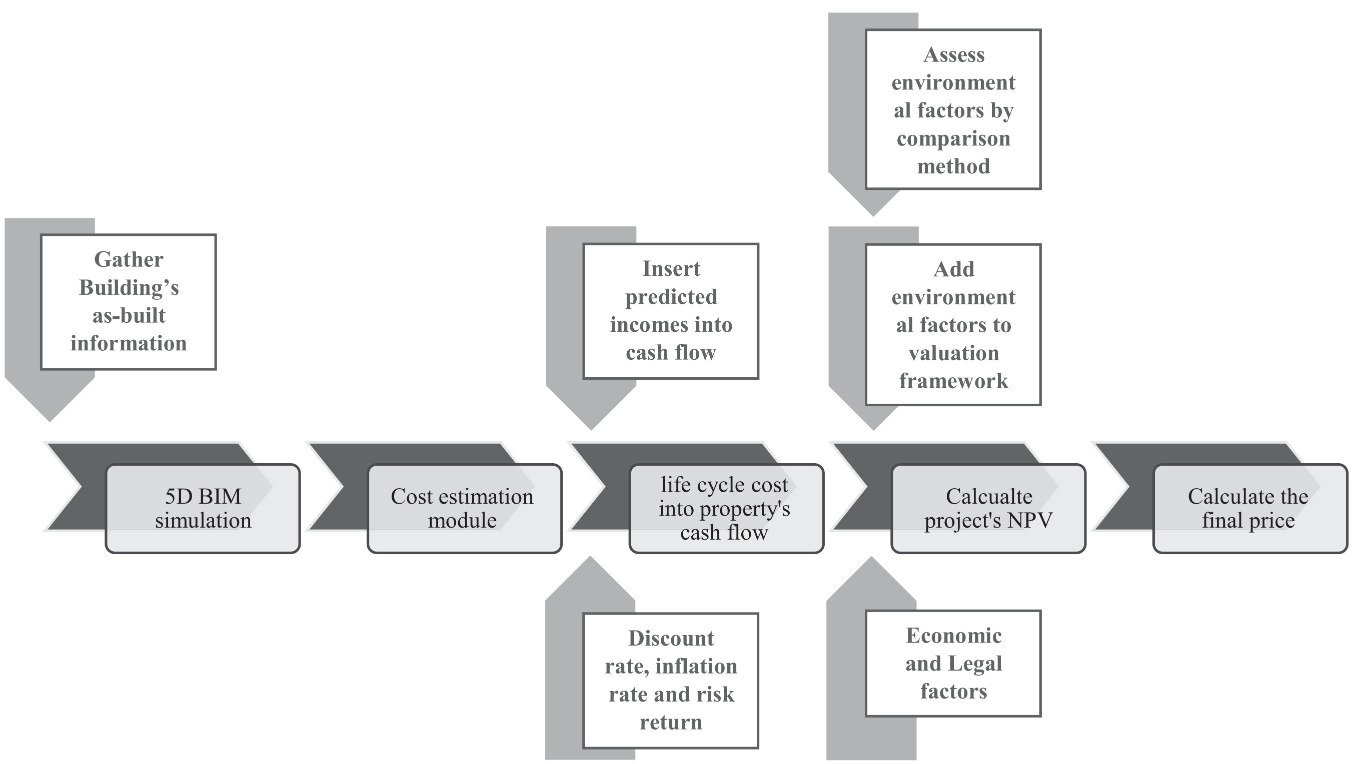

Fig. 2. Methodology's data flowchart.

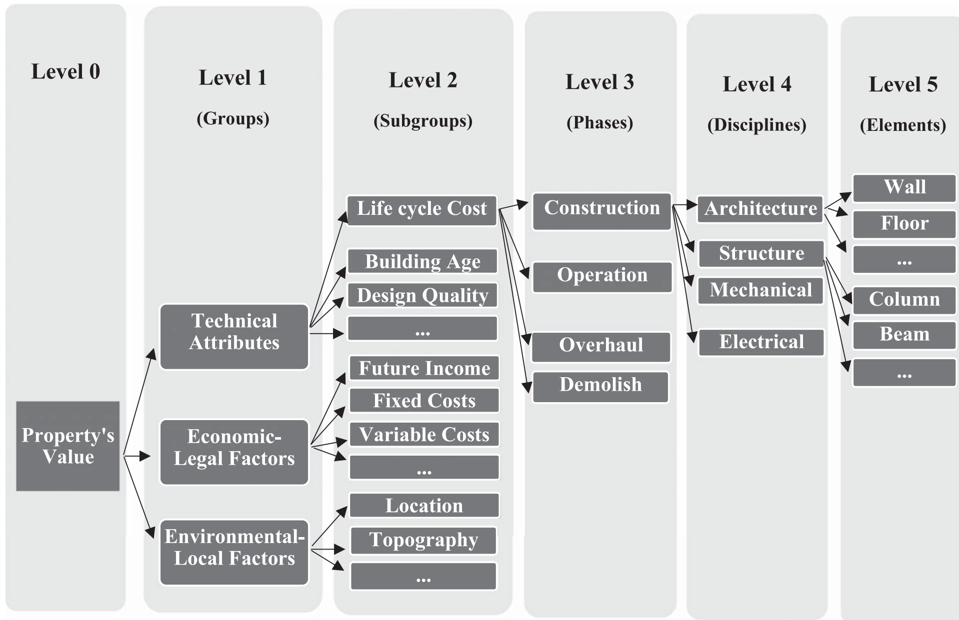

Fig. 3. Cost breakdown structure of the framework.

Table 3. Maintenance plan of an average residential property in Tehran

Maintenance	Payment frequency	Service frequency
Architectural		
Façade and exteriors		Every 5 years
Finishes, fixtures, and fittings		Every 5 years
Interior renovations		Every 10 years
General repairs		Every 20 years
Minor refurbishments		Every 40 years
Lift and conveyor maintenance	Each month	Every 2 years
Structural		
Structural maintenance		Every 10 years
Strengthen against earthquake		Every 20 years
Mechanical		
Utilities	Each month	Every 2 years
Plumbing maintenance		Every 2 years
HVAC maintenance	Each year	Twice a year
Disposals and wastewater	Each month	Every 10 years
Electrical		
Utilities	Each month	Every 2 years
Lighting		Every 6 months
Security services	Each year	Every year
Landscape		
Gardening services	Each year	Every 3 months
Pavement maintenance		Every 5 years
Operation services		
Insurance	Each year	Every 2 years
Building management and administration	Each month	Every 6 months
Janitorial services	Each month	Every year
Cleaning services	Each month	
Revenue taxes	Each year	Every 3 months

environmental impacts during the early stages of design and building envelope alternatives for decision-making throughout the lifecycle of the building (Soust-Verdaguer et al. 2018). Hartmann et al. (2012), inspired by the cost breakdown structure steps of Halpin and Woodhead (2011) , used a WBS-based CBS in BIM with a specific LOD for calculating the costs (Hartmann et al. 2012).

Table 4. Cash flow and NPV of the second target property's LCC components

Criteria	Yearly cost ($)	Cost NPV ($)
Architectural		
Construction		349,840
Façade and exteriors	1,500	19,750
Finishes, fixtures, and fittings	2,500	33,000
Interior renovations	1,800	23,750
General repairs	500	6,600
Minor refurbishments	500	6,600
Lift and conveyor maintenance	1,000	13,200
Demolish	20	260
Total		453,000
Structural		
Construction		143,000
Structural maintenance	1,000	13,200
Strengthen against earthquake	1,000	13,200
Demolish	50	600
Total		170,000
Mechanical		
Construction		51,000
Utilities	350	4,600
Plumbing maintenance	1,000	13,200
HVAC maintenance	1,000	13,200
Disposals and wastewater	280	3,700
Demolish	25	300
Total		86,000
Electrical		
Construction		49,700
Utilities	350	4,600
Lighting	750	9,900
Security services	500	6,540
Demolish	20	260
Total		71,000
Landscape		
Construction		4,050
Gardening services	100	1,300
Pavement maintenance	40	520
Demolish	10	130
Total		6,000

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BIM Application for Asset Management and Facility Management

BIM has been the topic of many previous studies about asset management and facility management (Pishdad-Bozorgi et al. 2018; Kassem et al. 2015) as a centralized and visual database that stores and processes all geometric and nongeometric information related to the operation phase and as a platform for information exchange and communication management between stakeholders (Cavka et al. 2017). BIM application in the operation and maintenance phase includes ten subgroups: locating components and equipment, instant access to information, visualization and marketing, maintenance service scheduling, storage management, planning and feasibility study on demolition and reconstruction, crisis management, energy consumption monitoring, and staff training (Becerik-Gerber et al. 2012).

Maintenance costs equate to 60% of projects' total LCC; however, BIM implementation is less than 10% in this phase (Guillen et al. 2016). Despite the many benefits in terms of productivity, efficiency, and quality control that BIM can bring to facility and asset management, its practical application in these areas is limited. It happens due to facility managers' lack of involvement in the design process, lack of knowledge about the benefits of BIM-FM integration, interoperability problems, lack of standardized definition for FM data requirements, and poor technical knowledge about BIM (Dixit et al. 2019, Wilkinson and Jupp 2016).

BIM is an effective management tool at the project, portfolio, and organization level (Muñoz and Arayici 2015). As conventional information formats provide excessive information, and while owners do not access the required information most of the time, real-time data-driven decision-making systems like BIM-AM systems are beneficial to asset management (Tidwell and Gallimore 2014).

Methodology

This is an applied research and implements the concept of LCC in real estate valuation practices. A comprehensive list of effective valuation criteria was extracted by an evaluation data collection method, referring to an extensive literature review and semistructured interviews with Tehran's real estate market experts.

The proposed framework consists of three parts. The first part is the property's BIM model, simulated in Autodesk Revit, a widely used software in the Iranian AEC sector. The model corresponded to the as-built status of the property and its elements' real attributes. In a 5D BIM model with an LOD of 300, cost information for each building element and project's phasing for future maintenances was inserted. The second part is the LCC estimation module. LOD 300 has a sufficient amount of information and details for valuation, and

<Wall Cost of Quantities-Construction Phase>

A	B	C	D	E	F
Family and Type	Area	Cost	Construction Cost	Length	Phase Demolished
Basic Wall: Exterior - Brick on Mtl. Stud					
Basic Wall: Exterior - Brick on Mtl. Stud	24.44 m²	$15.00	$366.54	8.00 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	29.66 m²	$15.00	$444.96	8.00 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	7.91 m²	$15.00	$118.65	3.90 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	16.53 m²	$15.00	$247.93	4.40 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	23.22 m²	$15.00	$348.23	8.10 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	29.82 m²	$15.00	$447.30	8.40 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	35.21 m²	$15.00	$528.15	12.20 m	Demolish
Basic Wall: Exterior - Brick on Mtl. Stud	15.20 m²	$15.00	$227.94	4.70 m	Demolish
Basic Wall: Generic - 150mm					
Basic Wall: Generic - 150mm	12.84 m²	$10.00	$128.38	5.70 m	Demolish
Basic Wall: Generic - 150mm	7.10 m²	$10.00	$71.01	2.59 m	Demolish
Basic Wall: Generic - 150mm	4.74 m²	$10.00	$47.37	2.26 m	Overhaul
Basic Wall: Generic - 150mm	7.08 m²	$10.00	$70.80	2.40 m	Overhaul
Basic Wall: Generic - 150mm	5.90 m²	$10.00	$59.00	2.16 m	Demolish
Basic Wall: Generic - 150mm	6.36 m²	$10.00	$63.63	2.26 m	Demolish
Basic Wall: Generic - 150mm	6.97 m²	$10.00	$69.68	2.62 m	Demolish
Basic Wall: Generic - 150mm	1.08 m²	$10.00	$10.80	0.52 m	Operation and Maintanance
Basic Wall: Generic - 150mm	1.08 m²	$10.00	$10.80	0.36 m	Operation and Maintanance
Basic Wall: Generic - 150mm	7.86 m²	$10.00	$78.64	3.40 m	Demolish
Basic Wall: Generic - 150mm	1.24 m²	$10.00	$12.39	0.50 m	Overhaul
Basic Wall: Generic - 150mm	2.40 m²	$10.00	$24.04	1.52 m	Operation and Maintanance
Curtain Wall: Curtain Wall					
Curtain Wall: Curtain Wall	4.08 m²	$50.00	$204.00	1.70 m	Overhaul
Curtain Wall: Curtain Wall	4.05 m²	$50.00	$202.50	2.70 m	Demolish
Curtain Wall: Curtain Wall	4.05 m²	$50.00	$202.50	2.70 m	Operation and Maintanance
Curtain Wall: Curtain Wall	2.70 m²	$50.00	$135.00	1.80 m	Demolish
Curtain Wall: Curtain Wall	2.55 m²	$50.00	$127.50	1.70 m	Overhaul
Grand total: 25			$4247.75	94.56 m	

Fig. 4. Wall cost of quantities of the first target property in the construction phase.

<Wall Material Takeoff-Operation and Maintenance Phase>					
A	B	C	D	E	F
Family and Type	Material: Cost	Material: Volume	Total Wall Cost	Length	Phase Demolished
Basic Wall					
Basic Wall: Generic - 150mm					
Basic Wall: Generic - 150mm	$45.00	0.07 m^3	$2.97	0.60 m	Demolish
Basic Wall: Generic - 150mm	$55.00	0.15 m^3	$7.99	0.60 m	Demolish
Basic Wall: Generic - 150mm	$45.00	0.09 m^3	$3.89	0.95 m	Overhaul
Basic Wall: Generic - 150mm	$55.00	0.19 m^3	$10.47	0.95 m	Overhaul
Basic Wall: Generic - 150mm	$45.00	0.08 m^3	$3.78	0.73 m	Overhaul
Basic Wall: Generic - 150mm	$55.00	0.18 m^3	$10.17	0.73 m	Overhaul
Basic Wall: Generic - 150mm	$45.00	0.12 m^3	$5.48	1.61 m	Demolish
Basic Wall: Generic - 150mm	$55.00	0.27 m^3	$14.72	1.61 m	Demolish
Basic Wall: Generic - 150mm Masonry					
Basic Wall: Generic - 150mm Masonry	$40.00	0.23 m^3	$9.20	0.52 m	Demolish
Basic Wall: Interior - 126mm Partition (2-hr)					
Basic Wall: Interior - 126mm Partition (2-hr)	$60.00	0.08 m^3	$4.53	0.40 m	Demolish
Basic Wall: Interior - 126mm Partition (2-hr)	$45.00	0.08 m^3	$3.40	0.40 m	Demolish
Basic Wall: Interior - 138mm Partition (1-hr)					
Basic Wall: Interior - 138mm Partition (1-hr)	$60.00	0.58 m^3	$35.10	2.98 m	Demolish
Basic Wall: Interior - 138mm Partition (1-hr)	$45.00	0.31 m^3	$13.73	2.98 m	Demolish
Grand total: 13			$125.44		

Fig. 5. Wall material costs of the first target property in the operation and maintenance phase.

additional technical information only complicates the model and the process. This is an advantage of the proposed framework in terms of straightforwardness and pertinence. Different phases' costs, including replacement costs, periodic service schedule and costs, components' expected lifespan, and so on, were inserted from the BIM model into the property's cash flow in Excel and were converted to the present value by DCF method. Therefore, the BIM model's phasing and cost tables served as the basis for the property's LCC calculation.

The final part is the value estimation module. Thus, all effective factors categorized in building-technical, financial-legal, and environmental-local groups were considered in the property's value. Environmental factors were calculated by the comparison to three similar properties in the vicinity of the target property, which were previously sold. Each of these criteria affected the estimated price by the weight and formula extracted from the semi-structured interviews with real estate experts and agencies in Tehran. These formulas serve as the market regulation and norms in Tehran real estate market. A case study approach was utilized for the verification of the proposed framework. Two target residential apartments of two different sizes in Tehran's central area were selected for this purpose. The estimated value of each property was compared to its market price to determine the framework's accuracy and validity. Fig. 2 presents the methodology's data flowchart.

First Part: Property's BIM Model

For creating the BIM model, Autodesk Revit was used. One of the BIM's most significant advantages is its automatic cost breakdown into categorized groups, disciplines, and smaller units. Because each building element contains cost and time information, it is related to a specific discipline. Therefore, there was no need for additional cost breakdown standards. The cost breakdown structure of the entire framework is presented in Fig. 3.

The first step was defining the property's phasing based on its lifespan. The average residential lifespan of residential properties is 50 years in Tehran. Four general phases were defined for this period: construction phase (year 0), operation and maintenance phase (year 0–30), overhaul phase (year 30–50), and demolish phase (year 50). In addition to these four phases, planning, programming, and design costs are added separately to the asset value (Ghosh et al. 2015). Based on this phasing, each building element was assigned a creation and a demolish phase by reference to their lifespan and required maintenance plan. Table 3 represents the maintenance plan of an average residential property in Tehran, composed based on the information of field studies and interviews with 22 building managers. Table 3 indicates the schedule and time frame for each maintenance action. Besides, Table 4 in the LCC Module section will present the average yearly cost of each of these actions. Because most of these actions were not happening on a yearly basis, we separated the tables for more clarity.

Table 5. LCC calculation of the second target properties

Discipline	Cost ($)	Cost per m^2 ($)	Percentage
Structure	170,000	68.38	21.60
Architecture	453,000	182.22	57.56
Mechanical	86,000	34.59	10.93
Electrical	71,000	28.56	9.02
Landscape	6,000	2.41	0.76
Property's LCC	**787,000**	**316.57**	
LCC of each floor	131,000		

Moreover, a group of this costs like utility bills are paid by a preplanned routine as monthly or yearly apartment fees by the tenants. For determining the costs and the payment frequency of this type, we referred to the information provided by the building managers. The other group is maintenance and repair costs extracted from the BIM model and specific to the target property. These costs do not have an established payment frequency, but it is anticipatable that how often will happen.

Accordingly, four different 2D drawings and 3D models were generated, indicating the changes occurring in each phase. This

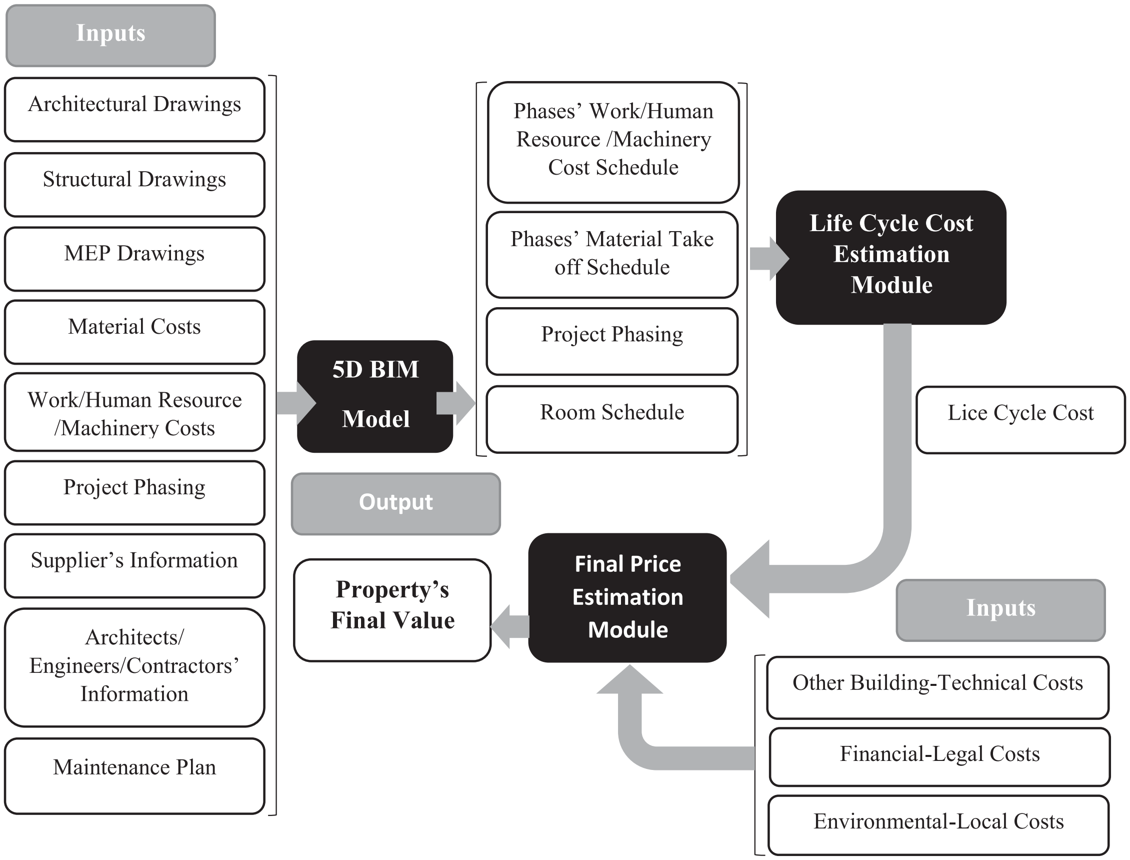

Fig. 6. Inputs, outputs, and components of the framework's parts.

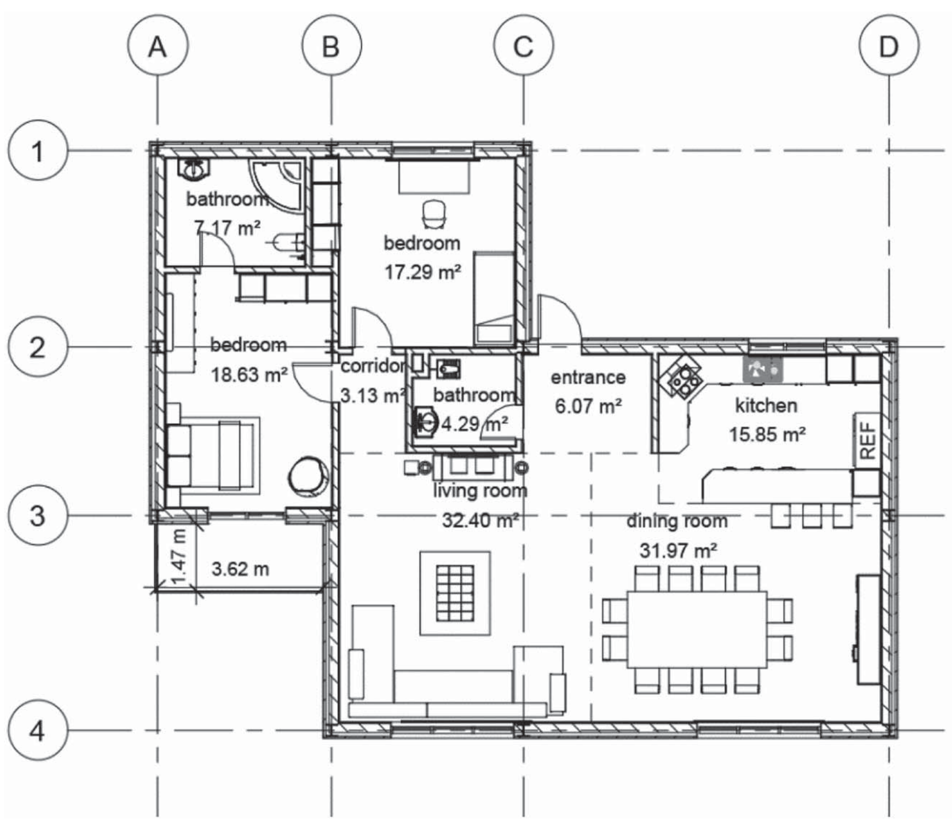

Fig. 7. Architectural plan for first target property.

phasing helped differentiate future costs based on time factors, which served as the basis for the property's cash flow.

The next step was adding cost information to the properties section of the building elements. There are two types of costs: the cost of quantities of work and material costs. The first one is per area, and the latter one is per volume. BIM automatically calculates the costs based on the created model. For instance, when drawing a specific type of wall element, it automatically calculates the length, area, volume and dimensions of its layers. Therefore, by inserting the per area and per volume costs associated with each layer, BIM automatically calculates the entire cost of quantities and materials related to that specific element. Moreover, it creates general schedules containing all the samples of the given element in the project.

Schedules/quantities were used for demonstrating the cost table of each phase. For calculating the work/human resource/machinery costs, the discipline type, creation phase, element's family and type, price per unit, and area were determined, and the total cost was calculated by multiplying costs by the area. These schedules were generated for each of the four phases separately. Fig. 4 shows an example of the wall element's quantity cost table in the first target property's construction phase. Moreover, Material Takeoff was used for demonstrating the elements' material costs in each phase separately. In addition to the mentioned attributes, material volume and material price per volume unit were required, and the total cost was calculated by multiplying the material cost by its volume. In Fig. 5, the wall material cost table in the first target

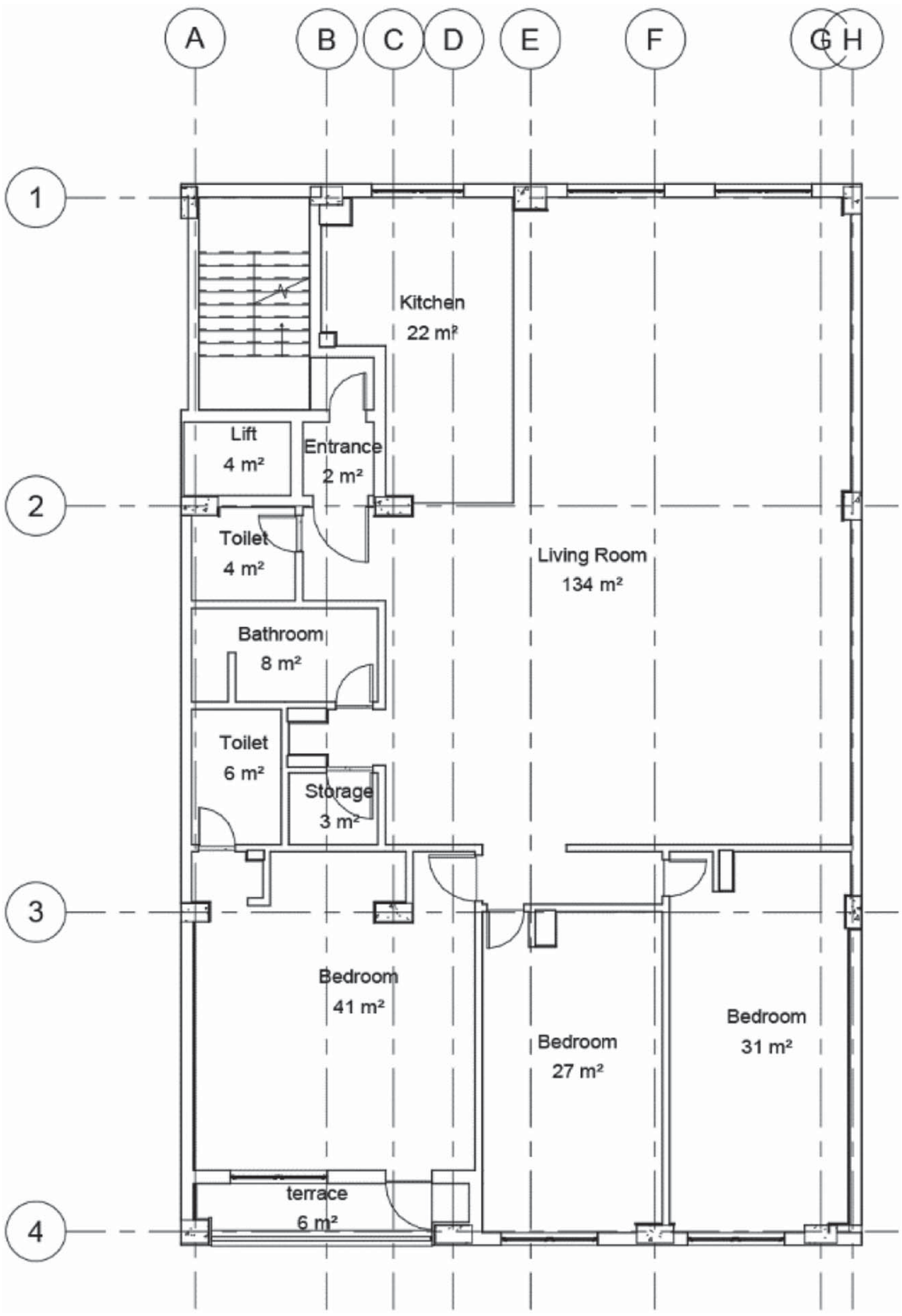

Fig. 8. Architectural plan for second target property.

property's operation and maintenance phase is presented. It is noteworthy that except for the cost information of the elements that are inserted separately, other table components like area and element type are extracted from the BIM model for further applications like composing a maintenance plan.

Besides the mentioned information, the room schedule was extracted from the BIM model. It helped determine the exact assignable area of each room and the total area of the property.

Second Part: LCC Module

For determining the components of LCC, a field study was conducted. Real estate agencies in the 22 districts of Tehran were asked to suggest a residential property with the district's average quality aged above 15 years. Building managers of these properties were asked to list the yearly expenses categories and the amount of them. These categories that are mostly periodic maintenance, service, and utility costs were classified into the five disciplines of architecture, structure, mechanical, electrical, and landscape. The schedule and occurrence frequency of these costs is presented in Table 3, and the yearly costs of each action is presented in Table 4. Although most of them do not happen yearly, the costs have been converted to a yearly basis so that all of them have an identical timeframe and can be easily used in the property's cash flow for calculating the LCC. After calculating the average cost per unit for an average quality residential property in Tehran, this information was used to determine the property's future costs during its operation and overhaul phases in the BIM model. For this purpose, the cost tables of each category were inserted into Excel separately. Using the DCF method, the NPVs of the costs were calculated in a 50-year lifespan and by a discount rate of 8%. The discount rate was 8% based on the market's inflation rate average of the past 5 years (18%) (I.R. Iran's Central Bank 2020b), return rate, and risk. Moreover, the BIM model's phasing was used for composing the cost tables. Table 4 presents the second property's LCC components, the average yearly costs, and their NPVs. The cost of each discipline consists of the construction cost (which is extracted from the as-built BIM model) and other costs that the property will have during its operation and maintenance and overhaul phases (which are obtained from the interviews with building managers and were inserted into the BIM model cost tables). By aggregating these costs, the LCC of the entire property was calculated. Table 5 presents the LCC and its subgroups of the second target property.

Third Part: Final Value Estimation Module

After calculating the LCC of the property, other criteria' impact was estimated and added to the property value. In addition to the criteria extracted from the literature review and presented in Table 2, semi-structured interviews from 44 real estate agencies in Tehran, two agencies per each of Tehran's 22 districts, were conducted to complete the criteria list. Private real estate agencies and developers constitute 70% of Tehran's market. Therefore, real estate developers and appraisers with at least ten years of experience in the industry were interviewed as experts. These agencies were chosen randomly among the ones that met the experience, annual transactions, and reputation requirements. Although one agency per each district would suffice, two were chosen to prevent the potential disagreements. They mentioned the most critical criteria of residential real estate valuation in each category (technical-building, financial-legal, and environmental-local), their suggested category divisions, the impact percentage of each category on the value, and the formula to calculate each factor's effect. Averagely, the interviewed experts believed that the building-technical factors have a 44% impact, the financial-legal factors have a 29% impact, and the environmental-local factors have a 26% impact on the value. Table 6 presents a list of criteria mentioned in the interviews that were excessive to Table 2. All the attributes mentioned in Tables 2 and 6 are considered in the final pricing model.

According to national reports, the real estate market consists of around 5% of Iran's GDP. Moreover, 20%–40% of annual investments in Iran is in the real estate sector (Mahmoodi et al. 2014). Therefore, as a significant part of economics, this market is greatly affected by economic factors. Most of the economic factors' values were based on the Central Bank of I.R. Iran's monthly reports on the real estate market (I.R. Iran's Central Bank 2020a). The annual rents and incomes were measured based on the market rate and transaction histories. The environmental-local factors were measured by comparison to three benchmark properties in the vicinity of the target properties (French 2004), geographical maps, and land-use and urban plans of Tehran. At least three benchmark properties are required for accurate price adjustments by comparison. Moreover, some regulations specific to Tehran, like limited mobility access during specific hours of the day, affected the property's value negatively or positively. Fig. 6 concludes the framework structure and the inputs and outputs of each part.

As previously mentioned, the 5D BIM model plays a key role in this framework due to its inherent cost breakdown structure, automatic calculation of quantities, materials and costs, and phase-based information classification. These characteristics help store, retrieve, control, and analyze LCC information of the properties in a simple, graphical, comprehensible, and transparent manner. Afterward, by using interoperable formats, cost tables of the building disciplines were extracted from the BIM model and were used for calculating the property's LCC and final price in Excel spreadsheets.

Framework Verification

For verification of the proposed framework, a case study approach was used. Two newly constructed residential properties of two different sizes in the central part of Tehran were selected. The first target property was 142 m^2, located on the second floor of an apartment, with a

Table 6. List of criteria in a property's valuation mentioned in the interviews

Property's valuation categorization	Valuation criteria
Building-technical	Maintenance condition
	Share from lot
	Exclusive yard
	Energy use
	Security
	Permit to change the property
	Function
	Operation costs
Economic-legal	Permit costs
	Similar transactions in the area
	Average price per square meters in area
	Survey date
	Legal documents
	Asset liquidity
Environmental-local	Direction
	Surrounding streets
	Climate
	Accordance to urban plan
	Environmental sustainability

Table 7. Final value estimation module for first target property

Property's valuation categorization	Criteria	Formula	Value ($)
Building-technical attributes	Life cycle cost		65,300
	Assignable area	136.8 m^2	
	Building age	(1.5%) * property price * age	0
	Parking area	60% * cost per m^2 * number of P · s * 11	12,276
	Storage	35% * cost per m^2 * area	3,906
	Exclusive yard	5% * property's price	0
	Terrace	35% * area * cost per m^2	5,580
	Unit's location in floor	5% * property's price	12,722
	Floor	2% * property's price * (floor 1)	5,090
	Design quality	15% * LCC (15 out of 20)	10,095
	Facilities and security		0
	Lot price	Lot area (420) * cost per m^2	1,260,000
	Share from lot	Lot price/(number of units * 10)	12,600
	Property type and number of units	30 units > residential-10 units	
	Function change permit		0
	Previous property demolish cost	Based on formal price list	430
	Entire cost		**127,998**
Economic-legal attributes	Property's market price	Price per m^2 (1,860$) * property's area	253,900
	Average Tehran's market price	Price per m^2 (960$) * property's area * 5%	6,566
	Demand rate	Transactions of this year/transactions of last year	1.42
	Price increase rate	Price per m^2 this year/price per m^2 last year	1.63
	Payment condition	Net in three payments	
	Contract special conditions	None	
	Survey date	Newly constructed property	
	Date and price of previous transactions	None	
	Legal documents and title deed	2% * property's price	5,089
	Return rate	23.40%	
	Investment risk	20.73%	
	Inflation rate	18%	
	Discount rate	8%	
	Municipality expenses	Expenses/number of units = 6,180/10	618
	Future income	500$ per month	65,286
	Fixed costs	315$ per month	(43,506)
	Variable costs	75$ per month	(10,234)
	Entire cost		**23,819**
Environmental-Local Attributes	Neighborhood	COST per m^2 * property's area * 18% (18 out of 20)	45,964
	Proximity to graben	NA	
	Topography	Flat	
	Environmental sustainability	Average	
	Social sustainability	High	
	Access to public transport and roads	2% * property's price	5,107
	Location in traffic limited area	Yes	
	Access to local facilities	1% * property's price	2,554
	Property's direction and number of entrances	1.5% * property's price	5,107
	Accordance to Tehran's urban plan	Yes	
	Surrounding properties' type	Residential	
	Entire cost		**58,733**
	Properties' final value		**210,550**

market value of 1,869 $ per m^2, and the second one was 310 m^2, located on the fifth floor, with a market value of 1,730 $ per m^2. All the steps mentioned in the methodology section were implemented for the two case studies. Figs. 7 and 8 show the plans of the properties. Tables 7 and 8 present the properties' final value estimation tables. The contribution of each attribute to the property value was presented in USD ($) currency. Moreover, the formulas for calculating the contributions were presented in front of each attribute.

Results

As a result of the verification process, the calculated property values were less than the market values. It was a predictable outcome, given the inflated market conditions and economically biased valuation methods in Tehran's market. However, it is not possible to determine the attributes that caused this difference. Additionally, the existing valuation methods do not have a classified and standardized structure to compare. An average of 18.25% value difference proves the inflation of Tehran's real estate market and prices. Additionally, if the operation phase costs presented in Table 4 are not systematically controlled, this difference can rise up to 30%. Table 9 demonstrates the difference percentage between the properties' market value and their framework value.

Moreover, the share of criteria groups in the final value is noteworthy. As presented in Table 9, the average of categories' effect on the two target properties' value is different from the opinion of the industry experts. The building-technical group has more

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Table 8. Final value estimation module for second target property

Property's valuation categorization	Criteria	Formula	Value ($)
Building-technical attributes	Life cycle cost		131,000
	Assignable area	310 m^2	
	Building age	(1.5%) * property price * age	0
	Parking area	60% * cost per m^2 * number of P·s * 11	11,440
	Storage	35% * cost per m^2 * area	9,040
	Exclusive yard	5% * property's price	0
	Terrace	35% * area * cost per m^2	3,640
	Unit's location in floor	5% * property's price	26,867
	Floor	2% * property's price * (floor-1)	21,493
	Design quality	15% * LCC (15 out of 20)	23,580
	Facilities and security	Security system cost 4,000$	667
	Lot price	Lot area (518) * cost per m^2	1,554,000
	Share from lot	Lot price/(number of units * 10)	25,900
	Property type and number of units	30 units > residential-6 units	
	Function change permit		0
	Previous property demolish cost	Based on formal price list	1,267
	Entire cost		**254,893**
Economic-legal attributes	Property's market price	Price per m^2 (1,730$) * property's area	537,333
	Average Tehran's market price	Price per m^2 (960$) * property's area * 5%	14,880
	Demand rate	Transactions of this year/transactions of last year	1.42
	Price increase rate	Price per m^2 this year/price per m^2 last year	1.63
	Payment condition	Net in 3 payments	
	Contract special conditions	None	
	Survey date	Newly constructed property	
	Date and price of previous transactions	None	
	Legal documents and title deed	2% * property's price	10,747
	Return rate	23.40%	
	Investment risk	20.73%	
	Inflation rate	18%	
	Discount rate	8%	
	Municipality expenses	Expenses/number of units = 25,020/6	4,170
	Future income	550$ per month	133,819
	Fixed costs	500$ per month	(78,290)
	Variable costs	110$ per month	(25,585)
	Entire cost		**59,741**
Environmental-local attributes	Neighborhood	Cost per m^2 * property's area * 18% (18 out of 20)	96,720
	Proximity to Graben	NA	
	Topography	Flat	
	Environmental sustainability	Average	
	Social sustainability	High	
	Access to public transport and roads	2% * property's price	10,747
	Location in traffic limited area	Yes	
	Access to local facilities	1% * property's price	5,373
	Property's direction and number of entrances	1.5% * property's price	8,060
	Accordance to Tehran's urban plan	Yes	
	Surrounding properties' type	Residential	
	Maintenance quality of surroundings	Well maintained	
	Climate quality	Good	
	Entire cost		**120,900**
	Properties final value		**435,535**

Table 9. Difference between calculated properties' value by the framework and their market values

Property	Calculated value ($)	Price per m^2 on market ($)	Market value ($)	Value difference ($)	Difference percentage
Target property #1	210,550	1,860	255,360	44,810	17.54
Target property #2	435,530	1,730	537,330	101,799	18.95

impact on the proposed framework's value, making the valuation more precise and reliable. Table 10 presents the share of criteria groups in the properties' values.

Tables 11 and 12 present each subgroup's share in the building-technical criteria group's value, which is the most influential group. These attributes are the same ones presented in Tables 7 and 8 under the building-technical criteria group, which monetarily affect the property price. The LCC consists of almost half the cost of this category, becoming the most significant criteria.

The proposed valuation framework estimates an unbiased and precise value for residential properties by emphasizing the LCC and using a detailed cost breakdown structure. However, it has

Table 10. Share of each criteria group on property value

Property	Technical criteria (%)	Financial criteria (%)	Local criteria (%)
Case study #1	60.79	11.31	27.89
Case study #2	58.52	13.71	27.75
Framework average	59.65	12.51	27.82
Experts' opinion	41.85	31.15	26.95
Difference	17.8	−18.64	−0.87

Table 11. Share of the building-technical subgroups in the first target property

Attribute	Attribute cost ($)	Share in technical cost (%)
Life cycle cost	65,300	51.01
Building age	0	0.00
Parking area	12,276	9.59
Storage	3,906	3.05
Exclusive yard	0	0.00
Terrace	5,580	4.36
Unit location in floor	12,722	9.94
Floor	5,089	3.98
Design quality	10,095	7.89
Facilities and security	0	0
Share from lot	12,600	9.84
Function change permit	0	0.00
Previous property demolish cost	430	0.34
Entire building-technical cost	**127,998**	

Table 12. Share of the building-technical subgroups in the second target property

Attribute	Attribute cost ($)	Share in technical cost (%)
Life cycle cost	131,000	51.39
Building age	0	0.00
Parking area	11,440	4.49
Storage	9,040	3.35
Exclusive yard	0	0.00
Terrace	3,640	1.43
Unit location in floor	26,867	10.54
Floor	21,493	8.43
Design quality	23,850	9.25
Facilities and security	667	0.26
Share from lot	25,900	10.16
Function change permit	0	0.00
Previous property demolish cost	1,267	0.50
Entire building-technical cost	**243,893**	

its challenges and shortcomings as well. Table 13 presents the negative and positive points of the framework.

Conclusion

The proposed framework links the stakeholders engaged during the property's lifecycle and uses their technical knowledge to conduct a data-driven and accurate valuation. Preparing a comprehensive list of criteria categorized in three groups of building-technical, financial-legal, and economical-local factors helps take into account all the aspects of a property. Moreover, the time factor is emphasized, and the appraisal is not merely limited to the current market value. LCC plays a key role in the process and has the greatest weight among the effective criteria, which helps integrate different phases and disciplines of a property.

Table 13. Advantages and disadvantages of the proposed valuation framework

Point of view	Valuation framework aspects
Advantages	Ease of information access
	Graphical presentation of information, condition, and spaces
	High interoperability between utilized software
	Ability to add time-related information by defining the project's phasing
	Automatic and accurate calculation of materials, amount of work, and costs
	Being based on up-to-date material and work-related costs
	Offering a detailed cost and revenue breakdown for further applications like scheduling for future phases and calculating tax amount
	Being based on actual technical information, resulting in an accurate and unbiased valuation
	Having a transparent and systematic valuation process
	Having a comprehensive list of effective factors based on a vast literature review
	Functioning as a data-driven investment decision support tool
Disadvantages	Lack of access to information and as-built drawings in old buildings
	Differences in design and construction details
	Requirement to experts and advance methods for extracting information from buildings without precise drawings
	Requirement to architectural, structural, and MEP knowledge for developing the BIM model
	Possibility of real estate specialists' resistance in implementing new methods
	Requirement to excessive time and budget for the valuation process
	Lack of complete independence from economic and market conditions
	Reference to property's market value for calculating the effect of some factors

Novel data-driven technologies like BIM are utilized for calculating the LCC, which is the innovative aspect of the research. BIM offers automated calculation of materials and amounts of work and costs related to them by referring to actual and up to date information. Moreover, it provides a graphical presentation of the property and its modifications during its lifespan. The 5D BIM model with LOD 300 meets all the valuation process's information requirements and simplifies the calculations. The price valuation module helps thoroughly determine each criterion's effect on the value, making the process easier to control. Additionally, if any changes in the market conditions, technical aspects, or regulations happen, the module can be easily updated.

Legal procedures and documents are required to implement the proposed research framework in Tehran real estate market. Besides, it demands particular specializations and an additional budget. Therefore, the BIM model's LOD and attributes and its data flow between related stakeholders should be determined. This research focuses on newly constructed buildings due to ease of access to as-built drawings and information. Two solutions are proposed for including the BIM model in property-related transactions:

1. Defining the BIM model as a required document to obtain the property's legal permit. In this case, the design team and project's consultant create the BIM model, and the owner is responsible for providing it to the municipality office. Afterward, real

estate appraiser should refer to the BIM model in their valuation process. The advantage of this solution is the systematic control over the accuracy and validity of the model. However, the model LOD might not correspond to the valuation requirements of the real estate appraisers.

2. Defining the BIM model as a required document for transaction and possession transition. In this case, the real estate agency creates the BIM model. If the real estate agency does not have a group of experts who can create the model, they have to assign the task to a consulting group by contract. The risk of this solution is the lack of control over the accuracy of the model. However, the model will be made based on appraisal requirements.

The required budget for creating the BIM model and implementing the framework in practice is economical because it uses established software and specializations in the industry. For instance, only 120 h of work are required to implement the framework on the second target property. The average salary of a 3D visualizer is 15$, which totals 1,800$. It is a small amount of money compared to a 101,000$ value difference it assessed.

Lack of similar research for comparison, limited technical knowledge in MEP discipline, ever-changing inflation rates, and unstable market and economic conditions were the main research limitations. As a suggestion for future research, the framework can be applied to evaluate old residential properties, where advanced technologies are required for data collection from their current condition, and other types of real estate properties.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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