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A DECISION-MAKING MODEL FOR OFFICE BUILDINGS' ENVELOPE RETROFITS APPLICATION IN CAIRO

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ABSTRACT

The building envelope has tangible impacts on energy consumption; thus, it is the most effective building layer to apply green retrofits. The decision-making process of selecting retrofit measures to apply is complex, it involves many objectives that are quantifiable and others that cannot be quantified. Retrofit analysis simulation tools can be used to identify some of these objectives such as energy savings and payback period. They are however not enough to rely on during the decision-making process because there are other objectives and variables that must be taken into consideration. Variables that are not easily identified in Cairo/Egypt include the availability of the retrofits in the Egyptian market and the installation process difficulty/duration. The research thus aims to improve the energy efficiency in office buildings constructed in Egypt by applying retrofit measures to the existing building's envelope. The developed optimized decision-making model for retrofits application in the Egyptian market based on a mathematical framework will support decision makers' selection based on their objectives. The model is applied to two case studies representing the majority of office buildings in Cairo, to investigate its applicability and compare its results with the results of simulation tools'.

KEYWORDS: Office buildings, external envelope, decision-making, retrofit simulation tools, retrofit variables, energy efficiency.

1. INTRODUCTION

The number of Egyptian buildings is about 12 million buildings, 60% of are residential while 40% are commercial and others [1]. Buildings are responsible for about 12% of the total Green House Gas (GHG) emissions and 55% of the annual electric energy consumption [2]. Office buildings are the major consumers of electric energy. In Egypt, the commercial sector electricity consumption has increased by 84% and in the residential sector by 59 % [3] between 2007 and 2017, as illustrated in Fig. 1. In addition, the energy prices are expected to increase over the next few years, after the subsidies are eliminated. Thus, investors and building owners have major

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opportunities to decrease the existing office buildings' operational costs especially that the office buildings consumption is located in the higher slot according to the consumption reports of the Ministry of Electricity.

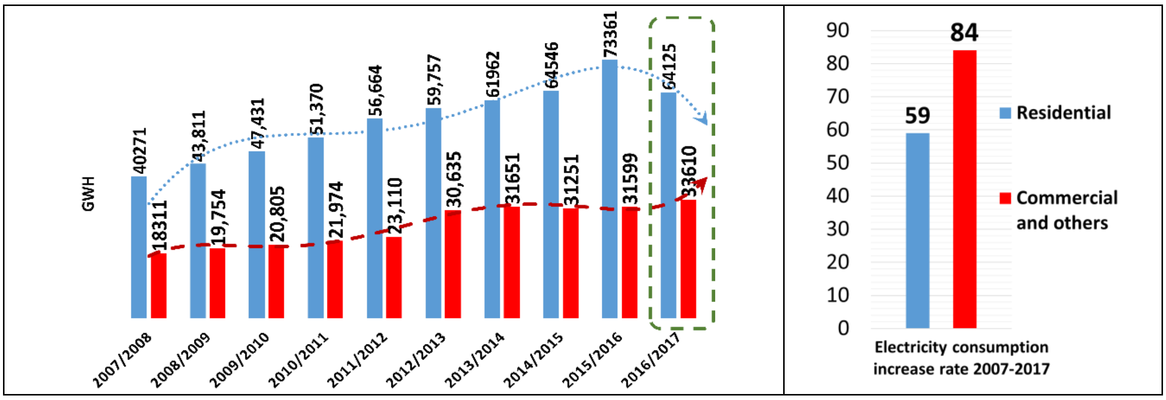


Fig. 1. Electricity consumption by sector in Egypt 2007-2017, [3].

If goals are set for energy consumption reduction, it will require major improvements in the energy efficiency of the existing buildings. These improvements have to take place in building envelope due to its impact on energy consumption that reaches up to 57% of commercial use [4]. However, the selection of measures and technologies to be applied is complex; it involves many objectives and considerations.

2. RESEARCH METHODOLOGY

The research seeks to contrive a decision-making model, to apply retrofit techniques/measures to existing office buildings' envelope. It follows the theoretical, comparative analysis, deductive and application approach, as illustrated in Fig. 2.

3. RESEARCH METHODS

The research is quantitative; it aims to develop a model based on a mathematical and statistical framework. A survey was conducted following non-probability sampling namely the purposive sampling method. The target group was experts in the field of the research to be tested. The key actors in the construction sector included architects, electrical/ environmental engineers, etc.; to identify retrofit application variables, their degree of importance and ranking. It also applied the developed model to case studies. The design builder simulation tool is used to calculate the effect of the retrofit alternatives application to the case studies.

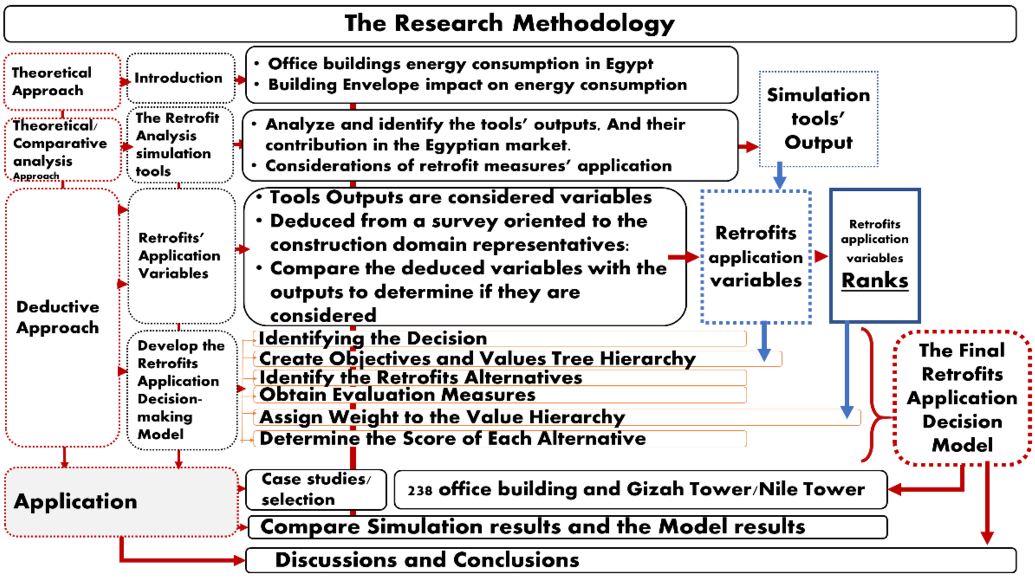


Fig. 2. Research methodology.

4. RETROFIT ANALYSIS SIMULATION TOOLS

The retrofit analysis tools are investigated to determine their outputs, to conclude the extent of their contribution in the selection process of the retrofits to be applied to a building and their compatibility to the Egyptian market, and to figure out the considerations of retrofit measures' application. Currently, there are 172 listed programs, dealing with all kinds of simulations in buildings, with different capabilities. They include Whole-building Energy Simulation, Lighting Simulation, and Solar/Photovoltaic Analysis. There are 89 tools under the category of "Retrofit Analysis" within "Whole Building Analysis" [5]. Table 1 presents the 6 tools that were selected as samples because each one encompasses different features and diverse outputs. The features include specialized retrofit analysis (Building Energy Asset Score, COMBAT), general tools that can perform retrofits (Energy Plus, Design-Builder, TRNSYS, ESP-r), developed by the public sector (Energy Plus, Design-Builder, ESP-r, Building Energy Asset Score, COMBAT) or by the private sector (TRNSYS), friendly interface (Design-Builder, COMBAT) and complicated ones (Energy plus), publicly accessible (Energy Plus, Design-Builder, ESP-r, Building Energy Asset Score, COMBAT) and non-public accessible (TRNSYS), programs with different targeted audience (Design builder targets Architects, building designers, COMBAT targets Building owners, energy managers), programs with different calculation engines (TRNSYS: The Kernel engine, ESP-r: ESP-r engine, Energy plus/Design builder/Building Energy Asset Score/COMBAT: Energy plus engine) [5-10]. The selection or the evaluation of retrofits measures to be applied is performed according to the amount of energy consumption reduced in the building. This is based on real calculations of already installed technologies or simulation programs' results that may identify very limited output considerations as illustrated in Table 1 to be taken into account neglecting many other retrofit application considerations or variables as elaborated in Table 2.

Table 1. Retrofit analysis tools' out-puts and retrofit variables compatibility.

Building Energy Simulation Tool	Developer / Sponsor	Programs' output/Retrofit Application variables
Energy Plus	Department of Energy, USA [6]	Building energy performance only [6].
Design-Builder	Department of Energy, USA	Energy performance, advanced cost-benefit design optimization in the early design stage. [7]
TRNSYS	"USA"	Energy performance and life-cycle costs [6].
ESP-r	University of Strathclyde [8] UK	Building energy performance only [8].
Building Energy Asset Score	Department of Energy [9]	Building energy performance, and efficiency upgrade Opportunities [9].
COMBAT(Commercial Building Analysis Tool)	China Energy Group [10]	Identify cost-effective measures, Payback period compares performance before and after retrofits, and Calculate energy savings [10].

5. RETROFITS' APPLICATION VARIABLES

The retrofits application variables impact the final result or the final decision of the retrofit technologies selection for application such as the duration of implementation, have been recognized and deduced based on the retrofit analysis tools' outputs namely energy savings and the other variables shown in Table 1. A survey was performed to investigate the degree of their importance or their weight to the decision-makers in the Egyptian market as illustrated in Fig. 3. These variables are also critical in the decision analysis process as objectives and criteria of evaluation. Thus, based on Table 1 and Table 2, the decision model is formulated to fill the gap of the retrofit analysis tools in considering the application variables and support the selection process as follows.

Table 2. The retrofit application variables identified by the retrofit analysis simulation tools.

Retrofit application variables	Application in retrofit analysis tools
Aesthetics	(Neglected)
Duration of the implementation	(Neglected)
Affordability (primary cost)	√ (considered)
Durability	(Neglected)
Maintenance cost	√ (considered)
Payback Period	√ (considered)
Availability in the Egyptian market	(Neglected)
Installation process (how difficult to install in an existing facility)	(Neglected)
Energy use reduction	√ (considered)
Special features (i.e. fire resistance, safety improvements ….)	(Neglected)
Compatibility with GPRS (Green Pyramid Rating System in Egypt)	(Neglected)
Existing envelope elements/component life span remaining	(Neglected)
The life span of the new applied technology	(Neglected)
If the new applied product is certified EPD's (Environmental product Declaration)	(Neglected)

6. DEVELOPING THE RETROFITS APPLICATION DECISION-MAKING MODEL

The main steps to develop the retrofits application model using the value hierarchy method with value function integration will be presented. A value function is a real-valued mathematical function defined over an evaluation criterion that represents an option's measure of goodness over the levels of the criterion, which reflects the decision maker's judged value in the performance of an option [11].

6.1 Identifying the Decision

Identifying the decision to be taken is the most important step in the process, to ensure that all the next steps are on track. This decision is to select the applicable and most appropriate green retrofits to the external envelope of office buildings in Cairo/Egypt, using the variables of retrofit applications illustrated in Table 2.

6.2 Create Objectives and Values Tree Hierarchy

A value hierarchy illustrates the variables important to the decision-maker that will affect the decision-making analysis. Variables are structured in hierarchical order in the visual representation of Fig. 3.

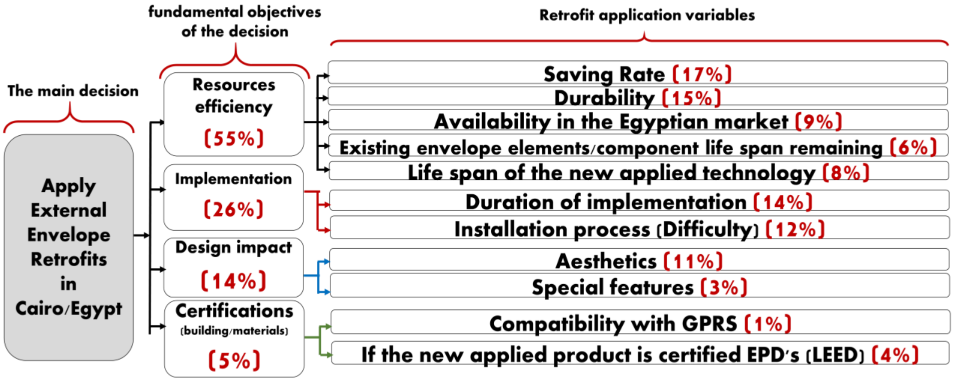


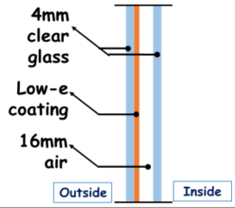
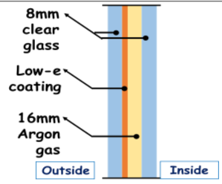
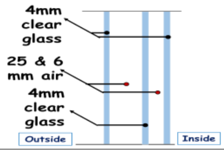
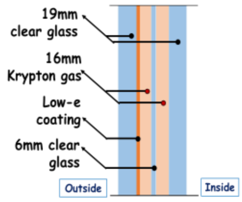
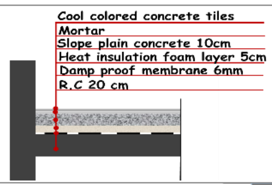
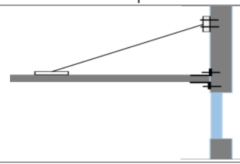
Fig. 3. Hierarchy of variables for an existing office building envelope retrofits application in Egypt including weights using global hierarchy technique.

The top tier is the main decision followed by the fundamental objectives of the decision or the main evaluation criteria. The last tier represents the variables concluded. The retrofit application variables listed in Table 2 include affordability (primary cost), maintenance cost, payback period, and energy use reduction. These variables are replaced with the (saving rate) - calculated using Eq. (1)- which will be added to the resource efficiency fundamental objective as it indicates the total installation costs. This cost includes the average maintenance costs in a ten years period (the maximum acceptable payback period based on the survey of the market representatives). The weights are assigned to the hierarchy of variables based on the direct weight elicitation technique, applying the rank-sum technique as illustrated in section 6.5.

6.3 Identify the Retrofits Alternatives

The selection of alternatives depends on selecting the ones that can be applied to the building envelope – either facades/roofs and fenestration/opaque – in the first place, and testing its different conditions based on the variables deduced. These include availability in market, different specifications, replaced or newly installed elements, etc. Four out of six of the selected alternatives are glazing because of the common use of highly glazed facades in existing office buildings in Cairo [12]. The results are therefore divers and involve realistic alternatives and cases. The technical specifications of the alternatives are the manufacturers' information details as illustrated in Table 3.

Table 3. Retrofit alternatives that are applied to the case study.

		Retrofit Alternatives	Technical Specifications		Illustration
Fenestration alternatives	Alt. [1]	“PLANITHERM TOTAL+” *Saint-Gobain Glass Egypt* Double glazing, clear glass, 4mm glass, 16mm air. Replaced element.	SHGC	0.704	
			$T_{vis-glass}$	80%	
			U-value	1.4 W/m^2 K	
			Tints, Coatings	Low-e coating on the 2nd face from outside.	
	Alt. [2]	“COOL-LITE SKN 144 II” *Saint-Gobain Glass Egypt.* Double glazing, clear glass, 8mm glass, 16mm Argon. Replaced element.	SHGC	0.23	
			$T_{vis-glass}$	40%	
			U-value	1.1 W/m^2 K	
			Tints, Coatings	Low-e coating on the 2nd face from outside.	
	Alt. [3]	Triple glazing, clear 4mm glass, 25 and 6 mm air. Replaced element.	SHGC	0.67	
			$T_{vis-glass}$	73%	
			U-value	1.95 W/m^2 K	
			Tints,	Blue color	
	Alt. [4]	“Pilkington section” Triple glazing- low-e, 19mm clear glass outer panes, 6mm clear glass middle pane, 16mm Krypton gas filled. Replaced - imported element.	SHGC	0.19	
			$T_{vis-glass}$	80%	
			U-value	0.9 W/m^2 K	
			Tints, Coatings	Low-e coating on the 2nd face from outside	
Opaque alternatives	Alt. [5]	Cool roof Cool colored concrete tiles. Replaced element.	U-value	0.883 W/m^2 K	
			R-value	1.272 m^2 K/W	
	Alt. [6]	External horizontal shading on the southern façade, 0.7m horizontal louvres. New installed element.		Aluminum Horizontal shading louvre fixed with tie-rod.	

6.4 Obtain Evaluation Measures/Scales

It is important to develop evaluation measures to understand how the alternatives meet the objectives and to quantify the variables hierarchy to be able to compare in a mathematical framework. Evaluation measures are applied to the lowest tier of the hierarchy (variables). These evaluation measures may have different scales i.e. saving rate and life-span, or no scale at all i.e. aesthetics; which makes it impossible to get a total numerical score for each alternative. To solve this issue, a Single Dimension Value Function “SDVF” is developed [11]. This function transforms the units of each measure into unit-less values on a scale from zero to one. To derive the function consider an x-y graph, the x-axis represents the evaluation measures, and the y-axis represents the variables' value *v(χ)*. It has two types; linear and exponential value functions [13]. In the research each variable will have a linear SDVF, using direct rating approach; in which the value function of the specified variable with the least preferable level will have [zero] value, while the top preferable variable will have [one] value. The summary of assigning SDVF values to the variables of the model by applying the direct rating approach is illustrated in Table 4.

Table 4. Single direct rating value functions for the retrofit application variables.

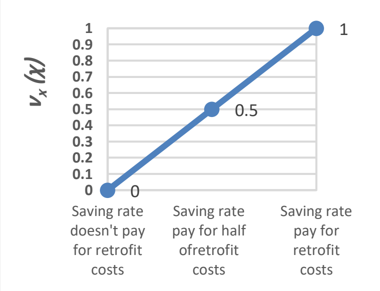
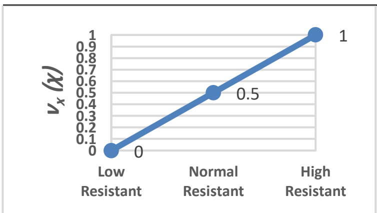
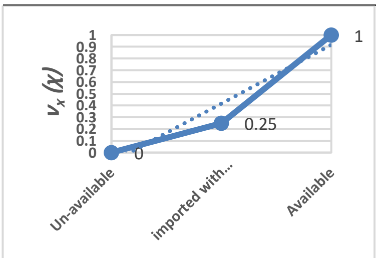
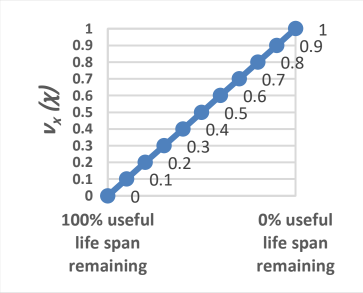
Saving rate	
 Saving rate indicates the total installation cost of the retrofits, including the primary, maintenance, and installation cost and energy savings over an assumed period of 10 years as a payback period - Concluded from the survey "decision makers may abandon retrofits if it exceeds 10 years".	Energy savings were calculated using Design builder simulation tool and by applying the Eq. (1): *Savings Rate = Energy Savings / [Installation/uninstallation Costs + Maintenance Costs]* (1) To be able to calculate the saving rate accurately, the inflation rate in Egypt has to be considered, in 2019, the average inflation rate of electricity prices in Egypt amounted to about 15.2 % compared to the previous year with 14.9 % [14]. See Eq. (2). *Present Value* $=\sum_{n=no.of\ years}(fv)(1+i)-n$ (2) Where, fv = Future value of maintenance cost or energy savings (L.E), *i* = rate of inflation (assumed to be 15.2). *n* = year of annual cost or savings A savings rate of value (1) means that the energy savings would pay for the retrofit costs within 10 years (2019-2029), or have a 10-year payback. Cost are estimated from contractors or companies
Durability	
	Durability indicates toughness of the product. It can be measured in three categories; Low, Normal, and High resistant, based on the features of the product. The value "High resistant" is preferred to "Low resistant". Durability values are estimated based on the specifications of the product and information from the manufacturer.
Availability in the Egyptian market	
	If the retrofit technology and its maintenance are available in the Egyptian market. This will affect the speed of installation, cost, and maintenance quick response. The values can vary according to the transportation distance as well, inside Egypt, the closer the product from the site; the higher its value. If the product's maintenance is available but the product is imported it takes a value (0.25)

Table 4. Single direct rating value functions for the retrofit application variables, (Cont.).

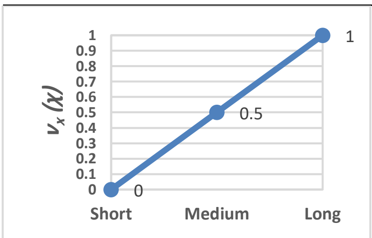
Existing envelope elements/component life span remaining



It considers the life span of the element that is being replaced, and how much its life span is remaining. The less life span remaining will be preferred, there will be a loss in replacing new elements in the building.
Life span of the existing envelope will be estimated in percentage. i.e. if the existing glazing is in the building for 5 years out of 20 years life span; the percent will be 75% remaining life span, i.e. it takes value (0.75).

Data varies according to the facility documents/installation dates of the products in the construction.

Life span of the new applied technology

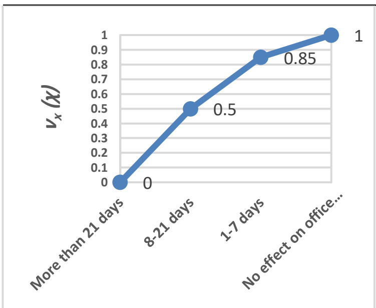


The longer the new product's life span, the preferred the option for installation.
-100% takes value (1).

This can be estimated in percentage compared to the office building overall life span which is estimated to be 73 years [15] according to US D.O.E.
Products' life span = or > remaining building's life span is the most preferred.
If the products' life span is less than the overall building's life span it is the least preferred.
It is calculated in percentage:
= Life-span of the product / life-span remaining of the office building.

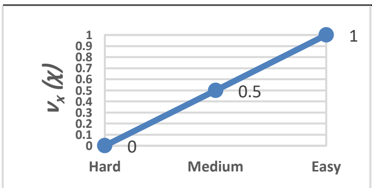
Life span data are determined from the products' specs or known average life-spans.

Duration of the implementation



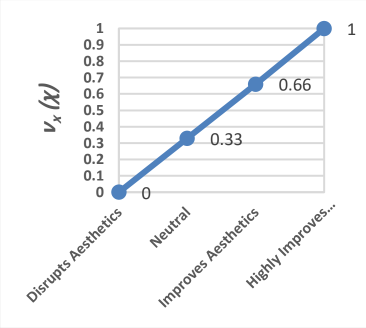
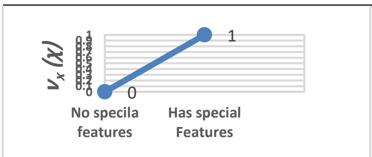
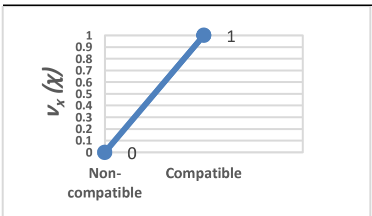
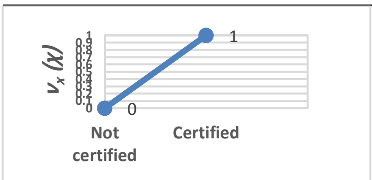
If the installation process does not affect the operation in the office building. This is the most efficient and desired – even if it was a long period. Takes value (1).
1-7 Days: the installation time will not exceed 7 days is preferable for existing operable office buildings.
8-21: an intermediate time, which may be accepted.
More than 21days: may stop the upgrading of the whole project. Installation time estimates were derived through a combination of local contractor estimates, and owners.

Installation process (Difficulty)



Easy (replacement of quick installation parts; i.e. glass), Medium (implementing additional construction to the envelope, i.e. external wall or shading equipment), Hard (replacing the whole building envelope with another one or a different system

Table 4. Single direct rating value functions for the retrofit application variables, (Cont.).

<table>
<tr><td colspan="2">Aesthetics</td></tr>
<tr><td>
</td><td>Highly Improves Aesthetics: a tangible new technology/design for the building envelope, very appealing to designers or occupants, i.e. enhances natural day lighting Improves Aesthetics: The new building envelope technology is appealing to the occupants. Neutral: unnoticeable to occupants. Disrupts Aesthetics: unappealing to occupants. Values for this measure can only be obtained by the designer/architect's perspective in the design of the new building envelope technology.</td></tr>
<tr><td colspan="2">Special features</td></tr>
<tr><td>
</td><td>(Yes): Has special features: i.e. fire protection, blast protection enhancement, and special coating layers.
(No): does not have special features.
Will be determined from the retrofit specifications.</td></tr>
<tr><td colspan="2">Compatibility with GPRS</td></tr>
<tr><td>
</td><td>Compatible: The product/technology fulfills points in the GPRS.
Non-compatible: doesn't fulfill points in the GPRS.
This is estimated according to the GPRS checklist and based on the effect of the new technology on energy savings, or its material specifications.</td></tr>
<tr><td colspan="2">If the new applied product is certified EPD's (LEED)</td></tr>
<tr><td>
</td><td>Certified: the product is an EPD certified product or registered.
Not Certified: the product is not registered nor certified.
Will be determined from the specifications of the product or retrofit technology.</td></tr>
</table>

6.5 Assign Weight to the Value Hierarchy

The retrofits application different variables must have weights to determine the levels of importance of each variable. There are two techniques to assign weights; Global and local weight techniques [16]. The global weight technique was applied to the value hierarchy model of the variables. This refers to how much weight each of the lowest row objectives contribute to the main decision at the top of the hierarchy as illustrated in Fig. 3. The higher the value of the weight, the more its importance. Note that in the first and second tier the sum of all weights equals 100%. The decision-makers agreed to these weights according to the survey ranks. To be able to deal with numerical variables. The direct weight elicitation technique is used to assign weights to the measures, applying rank-sum technique [17] illustrated in Table 5, in which the variables are arranged in descending order, then is used for assigning weights; according to Eq. (3).

$$Wt_i = k - r_i + 1 \,/\, \sum_{j=1}^{k} k - rj + 1 \quad (3)$$

Where; r_i = the rank of the i^{th} objectives/variables, (illustrated in Table 5.)

K = the total number of objectives/variables, (11 variables - values tree hierarchy).

Table 5. Variables/objectives weight according to rank-sum technique.

Variable/Measure	Rank	Weight	Weight (%)
Saving rate	1	0.166666667	17
Durability	2	0.151515152	15
Duration of implementation	3	0.136363636	14
Installation process	4	0.121212121	12
Aesthetics	5	0.106060606	11
Availability in the Egyptian market	6	0.090909091	9
Life span of the new applied technology	7	0.075757576	8
Existing envelope elements/component life span remaining	8	0.060606061	6
If the new applied product is certified EPD's	9	0.045454545	4
Special features	10	0.03030303	3
Compatibility with GPRS	11	0.015151515	1
Total weights summing up		1	100%

6.6 Determine the Score of Each Alternative

The score of each alternative can be determined by applying Eq. (4), the final result is a numerical value, between zero and one.

$$Score = \sum Rating * Weight \ [18]. \quad (4)$$

Where Score=total score rating for each retrofit technology, Weight=Weight of each measure. Rating=criteria score for each variable, which is the SDVF in the model.

6.7 The Final Retrofits Application Decision Model

The final formulated model based on the hierarchy of variables, SDVF, and the weights in Table 5 according to the decision makers and key actors is illustrated in Table 6.

7. MODEL APPLICATION ON CASE STUDIES

The selection of the case studies has to represent the majority of existing office buildings in Cairo - that introduce the highly glazed facades with poor shading elements or green measures [12]- for the model application. "LEED" and "GPRS" certified office buildings are excluded from the selection, because they do not represent the majority. In Cairo, there are only 10 LEED certified projects [12].

Two variant office buildings are selected to test different existing conditions and give more general, comprehensive, and reliable results. The selection included buildings in different locations in Cairo (Downtown and new settlements), a newly constructed building, and another old one (more than 20-30 years since its construction), select a tower (Classified as a tall building compared to the urban norm) and another building within the norm heights (not more than 14 story-building). Thus, the first office building selected as a case study is the [Giza tower/the Nile tower]. The second case is [238 office building] as shown Table 7 and Figs. 4-6. The alternatives are applied to the selected case studies to test the different selection circumstances according to the different application variables of the model, and compare it to the retrofit analysis simulation tools results.

Table 6. The final decision-making model for retrofits application selection.

	Fundamental Objectives	Variables "criteria"	*Wt*%	SDVF value "Rating" Alt(n)	Total Value	Model Values Alt(n)
Retrofit Application Variables Model	Resources efficiency	Saving Rate	17	……	Rating∗ $W1$	……
		Durability	15	……	Rating ∗ $W2$	……
		Availability in the Egyptian market	9	……	Rating ∗ $W3$	……
		Existing envelope elements/component life span remaining	6	……	Rating ∗ $W4$	……
		Life span of the new applied tech.	8	……	Rating ∗ $W5$	……
	Implementation	Duration of the implementation	14	……	Rating ∗ $W6$	……
		Installation process (Difficulty)	12	……	Rating ∗ $W7$	……
	Design impact	Aesthetics	11	……	Rating ∗ $W8$	……
		Special features	3	……	Rating ∗ $W9$	……
	Certifications	Compatibility with GPRS	1	……	Rating ∗ $W10$	……
		If the new applied product is certified EPD's (LEED)	4	……	Rating ∗ $W11$	……
	Retrofit Alternatives (n) values		100 %	Total Sum before weights	Total Score =∑ Rating*Wt	……

Table 7. The office buildings selected for application identification and description.

Name	238 office building.	Giza Tower/Nile Tower
Client	(Rental office spaces) UPM Group and others	Different companies i.e. Misr Iran Company and CIB bank branch.
Founded in	2016 [12]	1982 [19]
Location	North Teseen St., New Cairo.	Charles de Gaulle street, Giza
Area (floor)	750 m^2	46600 m^2 (Total gross area) 1944 m2 (Floor gross area)
Operation hours	9:00 am – 5:00 pm	8 am- 7 pm.

Table 7. The office buildings selected for application identification and description, (Cont.).

Description	Constructed from a flat-slab concrete system, with normal bricks, no insulation or thermal break. The building is composed of 8 typical and one basement floors, the first 3 floors are commercial use, and the next top 5 floors are offices.	It takes a rectangular shape with sides 72m and 27m. Constructed from steel structure with curtain walls and glass facades with no mullions or insulation wall. The building is composed of a ground floor, one mezzanine floor, and 23 typical floors of open space offices. It has no basement floor
External Envelope	Fenestration: First 3 floors: clear transparent single glazing 6mm. Top 5 floors: reflective blue double glazing with no thermal break. Opaque: Matt Aluminum cladding, white and silver colors.	Fenestration: Double glazing reflective silver glass. Opaque: Silver Matt Aluminum cladding.

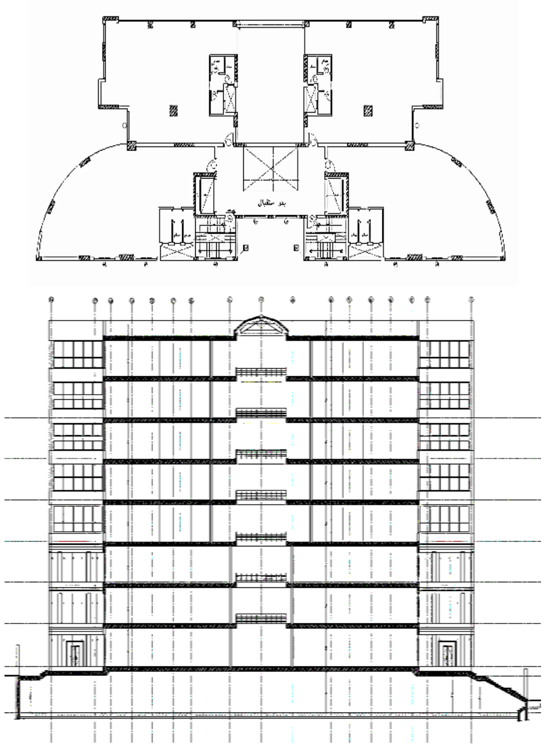


Fig. 4. Typical floor plan and section of the 238 building [12].

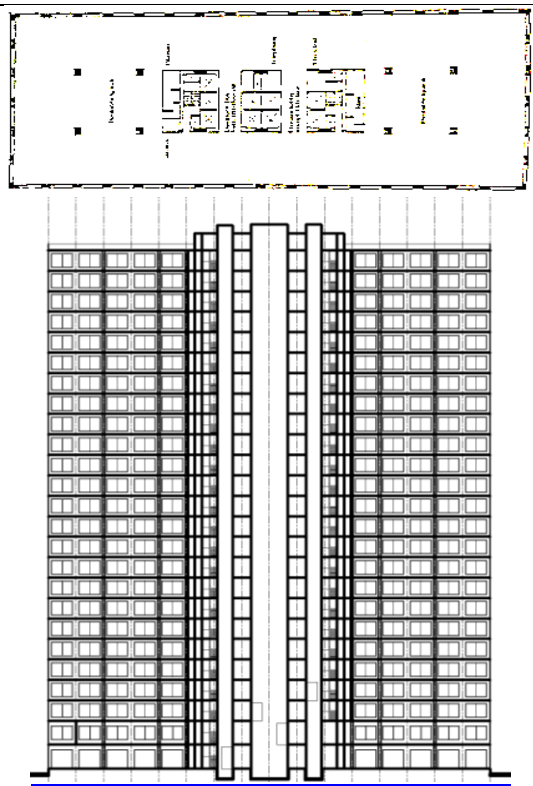


Fig. 5. Typical floor plan [19] and section of the Nile tower.

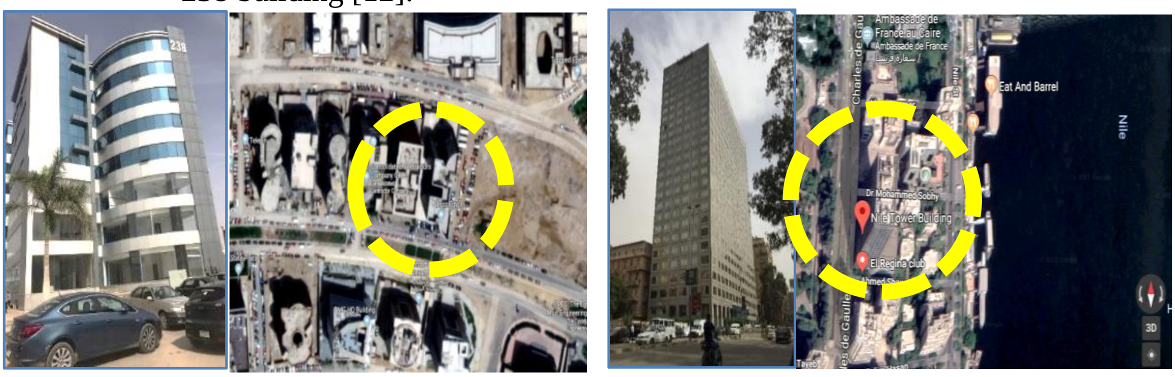


Fig. 6. The two-office building under application in google maps. left: 238 building, Right: the Nile tower

To apply the model, the SDVF must be applied to the alternatives, the first variable is the saving rate, which requires using the design-builder simulation tool to be calculated within a period of 10 years, calculating the primary cost, installation/uninstallation cost and maintenance cost of each alternative with the inflation rates. The base case energy simulation models for the existing building condition before applying the retrofit alternatives are illustrated in Fig. 7, and the simulation results in Fig. 8.

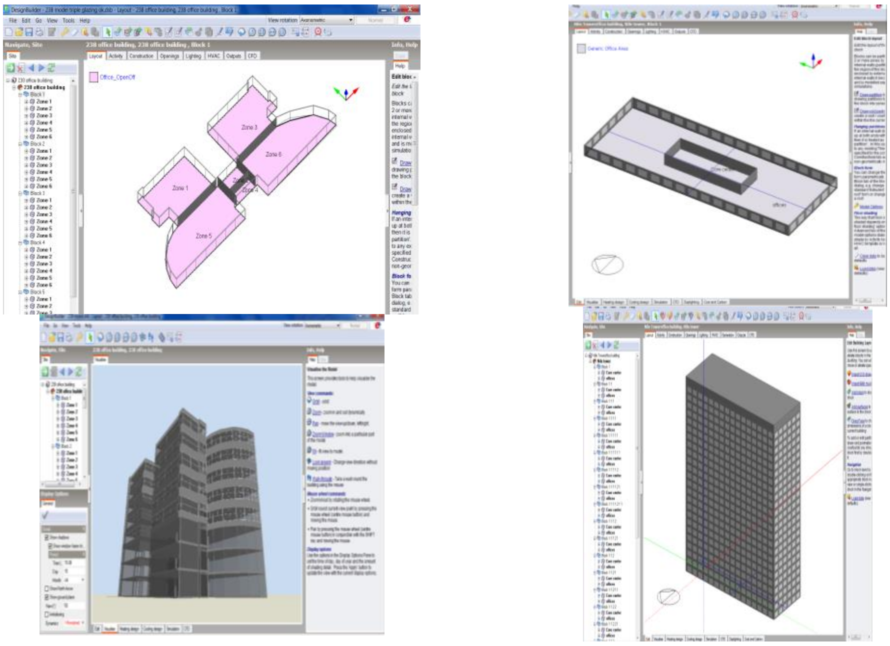
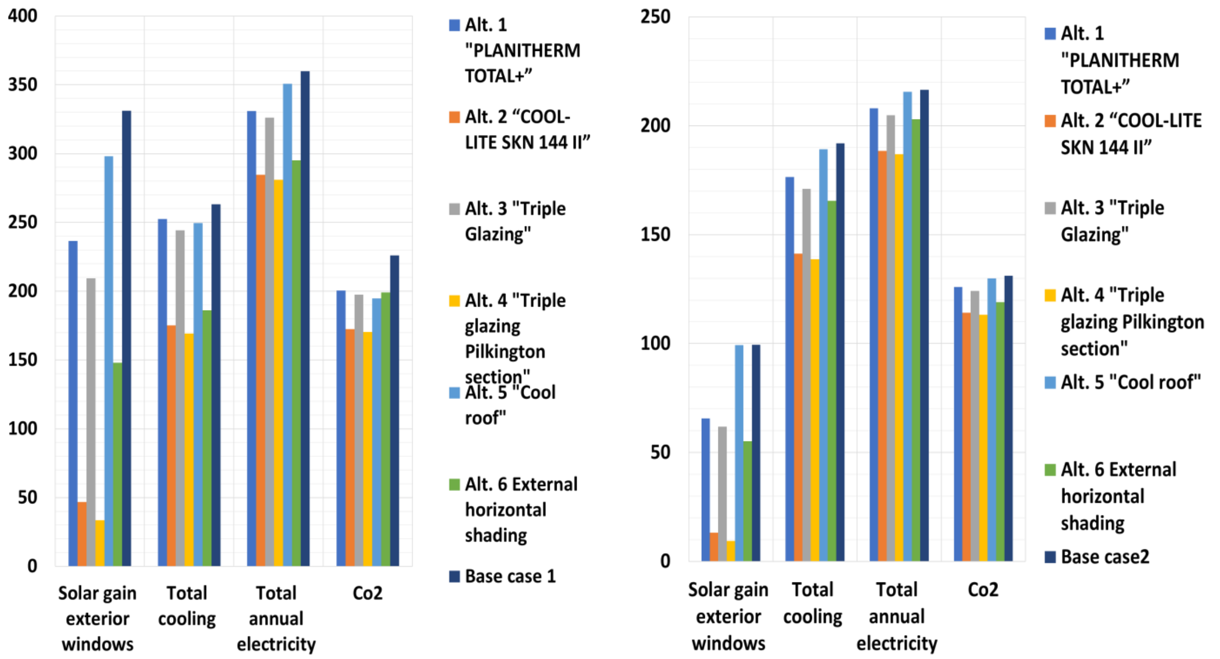


Fig. 7. Design builder constructed models for the case studies.

Optimum alternatives before and after applying the developed Model (before applying the model is based on the simulation results in which it indicates the alternative that is the most efficient in total energy consumption and cooling loads) are illustrated in Table 8 and Fig. 7. The final decision-making models for the case studies are elaborated in Tables 9 and 10. The optimum alternative in Table 10 selected for the case studies indicates different results between simulation tools' and the Model's; in which it is Alt. 6 in 238 office building, and Alt. 2 in the Nile tower. This assures that the selection is based on each case conditions of application, although Alt. 4 which is the best in energy savings (imported/not available in the Egyptian market) in both the cases is, not the optimum alternative to be applied in the Egyptian market.



238 office building The Nile tower

Fig. 8. Chart illustrating the 6 retrofit alternatives effect on [total cooling loads- Total annual electricity- CO_2 emissions – Solar gain in exterior windows) compared to base case using design-builder simulation tool.

Table 8. The different ranks of alternatives based on simulation results and the model application.

Optimum alternative before and after applying Model		Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
238 building	Simulation	Alt.4	Alt.2	Alt.6	Alt.3	Alt.1	Alt.5
	Model	Alt.6	Alt.5	Alt.2	Alt.1	Alt.4	Alt.3
The Nile tower	Simulation	Alt.4	Alt.2	Alt. 6	Alt.3	Alt.1	Alt.5
	Model	Alt.2	Alt.5	Alt.4	Alt.6	Alt.1	Alt.3

Table 9. Model application results to 238 office buildings.

	Fundamental Objectives	Variables	Wt %	SDVF value Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Total Value	Model Values Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6
Retrofit Variables Model	Resources efficiency	Saving Rate	17	0.23	0.54	0.21	0.32	1	1	$V1 * W1$	0.0391	0.0918	0.0357	0.0544	0.17	0.17
		Durability	15	0.8	0.85	0.85	1	1	1	$V2 * W2$	0.12	0.1275	0.1275	0.15	0.15	0.15
		Availability in the Egyptian market	9	1	1	1	0.25	1	1	$V3 * W3$	0.09	0.09	0.09	0.0225	0.09	0.09
		Existing envelope elements/component life span remaining	6	0.3	0.3	0.3	0.3	0.03	0	$V4 * W4$	0.018	0.018	0.018	0.018	0.0018	0
		Life span of the new applied technology	8	0.18	0.21	0.29	0.43	1	0.29	$V5 * W5$	0.0144	0.0168	0.0232	0.0344	0.08	0.0232
	Implementation	Duration of the implementation	14	0.85	0.85	0.5	0.5	1	1	$V6 * W6$	0.119	0.119	0.07	0.07	0.14	0.14
		Installation process (Difficulty)	12	1	1	0.2	0.2	1	1	$V7 * W7$	0.12	0.12	0.024	0.024	0.12	0.12
	Design impact	Aesthetics	11	0.66	0.66	0.66	0.66	0.33	1	$V8 * W8$	0.0726	0.0726	0.0726	0.0726	0.0363	0.11
		Special features	3	1	1	0	1	0	0	$V9 * W9$	0.03	0.03	0	0.03	0	0
	Certifications	Compatibility with GPRS	1	1	1	1	1	1	1	$V10 * W10$	0.01	0.01	0.01	0.01	0.01	0.01
		If the new applied product is certified EPD's (LEED)	4	1	1	0	1	0	0	$V11 * W11$	0.04	0.04	0	0.04	0	0
	Retrofit Alternatives (n) values		100 %	8.02	8.41	5.01	6.66	7.36	7.29	Total	0.673	0.735	0.471	0.525	0.798	0.813
				Total sum before applying weights						Total values for each Alternative after applying weights						

Table 10. Model Application Results to the Nile tower office building.

	Fundamental Objectives	Variables	Wt %	SDVF value						Total Value	Model Values					
				Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6		Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6
Retrofit Variables Model	Resources efficiency	Saving Rate	17	0.3	1	0.41	0.67	1	1	V1 ∗ W1	0.051	0.17	0.0697	0.1139	0.17	0.17
		Durability	15	0.8	0.85	0.85	1	1	1	V2 ∗ W2	0.12	0.1275	0.1275	0.15	0.15	0.15
		Availability in the Egyptian market	9	1	1	1	0.25	1	1	V3 ∗ W3	0.09	0.09	0.09	0.0225	0.09	0.09
		Existing envelope elements/componen t life span remaining	6	1	1	1	1	0.37	0	V4 ∗ W4	0.06	0.06	0.06	0.06	0.0222	0
		Life span of the new applied technology	8	0.36	0.55	0.7	0.83	1	0.55	V5 ∗ W5	0.0288	0.044	0.056	0.0664	0.08	0.044
	Implementation	Duration of the implementation	14	0.5	0.5	0.5	0.5	1	0.85	V6 ∗ W6	0.07	0.07	0.07	0.07	0.14	0.119
		Installation process (Difficulty)	12	0.9	0.9	0.85	0.85	1	1	V7 ∗ W7	0.108	0.108	0.102	0.102	0.12	0.12
	Design impact	Aesthetics	11	0.66	0.66	0.66	0.66	0.33	0	V8 ∗ W8	0.0726	0.0726	0.0726	0.0726	0.0363	0
		Special features	3	1	1	0	1	0	0	V9 ∗ W9	0.03	0.03	0	0.03	0	0
	Certifications	Compatibility with GPRS	1	1	1	1	1	1	1	V10 ∗ W10	0.01	0.01	0.01	0.01	0.01	0.01
		If the new applied product is certified EPD's (LEED)	4	1	1	0	1	0	0	V11 ∗ W11	0.04	0.04	0	0.04	0	0
	Retrofit Alternatives (n) values		100 %	8.52		6.97	8.76	7.7	6.4	Total	0.680		0.657	0.737	0.818	0.703
				Total sum before applying weights						Total values for each Alternative after applying weights						

8. RESULTS AND DISCUSSIONS

The retrofit alternatives are assumed to be a constant factor for testing the model, while the office buildings case studies are considered variable factors of the test; to show if the optimum selected alternative using the model will remain the same or may change according to the conditions of each case study.

Notifications about the Model:

The model's optimum alternatives are different from the optimum alternatives to the energy simulation tool. Which indicates its effect on the decision-making process as a decision-making tool for retrofits' selection for application to existing office buildings.

The evaluation of alternatives is performed based on the existing conditions of the building, i.e. the replacement or the installation of new elements i.e. shading device to the building and its construction difficulty. When assigning durability SDVF values, alternatives can be compared to each other, i.e. case of double or triple glazing; as the latest have a stronger cross-section although they are made out of the same material. Duration of the implementation will include installation and dissociation time of replaced elements.

The optimum alternative based on the sum of SDVF values before assigning the weights of the retrofit application variables may be the same after assigning the weights, as illustrated in the Nile tower case study. But in some in other cases it may affect in the final alternative selection after assigning the weights, this is clear in 238 building case study. This indicates how the decision makers' and stakeholders' concerns have a great effect on the selection process of the Alternative to be applied.

The model can only be applied to single alternatives selection; it is not tested if multiple alternatives are to be selected and applied at the same time – Deep Retrofits-.

9. CONCLUSION

The simulation tools especially the retrofit analysis ones can be used in retrofit measures selection to identify energy savings, the opportunity for conservation measures, and primary cost. It is not however, enough to rely only on these tools during the decision-making process for appropriate retrofits selection.

The decision model was derived from the analytical methods, decision analysis methods, and analyzing the retrofit analysis simulation tools to conclude the main considerations and outputs. It involves choosing the most preferred and the most appropriate alternative based on the decision-makers' values and objectives. The model is meant to fill the gaps found in the retrofit simulation tools output analysis by identifying new considerations and variables that affect in the selection of the retrofit technologies to be applied to office buildings' envelope in Egypt. It is a quantitative model to assess different alternatives and rank them according to these variables in total summation. The building owner cannot use this tool on his own without the aid of an architect or a designer. The owner can however, easily understand the final results of the model and the optimum alternative weakness and strength points.

The model enhances retrofit applications to office buildings envelope in Cairo through supporting decision makers in alternatives selection and target identification.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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نموذج لتطبيق التعديلات التحديثية على الغلاف الخارجي لمباني المكاتب القائمة كأداة لصنع القرار في القاهرة

يهدف البحث لتطوير نموذج لصنع القرار الأمثل لتطبيق التعديلات التحديثية على الغلاف الخارجي لمباني المكاتب القائمة في القاهرة مراعياً لظروف السوق المصرية لدعم اختيار صناع القرار وفقًا لأهدافهم والمعايير الهامة بالنسبة لهم وتم تطبيق النموذج على دراستين حالة تمثل غالبية مباني المكاتب في القاهرة، لدراسة مدى قابليته للتطبيق ومقارنة نتائجه بنتائج أدوات المحاكاة المتخصصة في تحليل التعديلات التحديثية. وتظهر نتائج الدراسة اختلاف نتائج أدوات المحاكاة عن النموذج المقترح مما يؤكد وجوب عدم الاعتماد كلياً على نتائج أدوات المحاكاة لتطبيق التعديلات لغياب معايير ومتغيرات تم مراعاتها في النموذج مثل مدة الفك والتركيب، وتوافر التعديلات التحديثية بالسوق المصرية.