

Original Article

# Construction Quantities and Cost Estimation for Building Houses and Schools in a Proposed Smart City Using BIM Techniques

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**Abstract** - The concept of sustainable buildings is an important and fundamental feature of smart cities. In this research, four criteria were adopted for sustainable buildings: increasing the height of the building's ceiling, using highly insulating bricks in the walls, using glass bands on the tops of the exterior walls, and finally, using planar materials to cover the buildings. The work in this research was divided into four sequential phases. In the first phase, two-dimensional plans were obtained for the residential units and schools. In the second phase, the plans of the first phase were converted to three-dimensional plans according to the Revit software package. In the third phase, all detailed schedules of quantities for the building were entered, as for the school building in both its states (sustainable and non-sustainable), the secondary phases for representing the building are (foundation, ground and first floors, flattening and finishing). Finally, the fourth phase was allocated to calculating the estimated costs for all residential units and schools within the proposed innovative City. The study showed that the estimated cost of the housing and education sector (for sustainable buildings) increased by 55% compared to the cost of non-sustainable buildings.

**Keywords** - Smart City, Construction Project Management, Building Information Modeling, Sustainable Building.

## 1. Introduction

In the real estate investment market for urban development in general and smart city development in particular, estimating the projected costs of proposed smart city structures and facilities is a crucial issue [1, 2]. Because BIM technologies provide an accurate spatial representation of the various building components and their construction requirements, they have become widely used in this regard over the past 20 years, replacing traditional construction project management software like MS Project and Primavera [3-6]. One of the most well-known BIM programs used worldwide is the Revit software package [7, 8]. Architects and engineers who specialise in planning, constructing, and implementing smart cities have concentrated on the crucial and significant issue of building sustainability [9-11].

It is well recognised that cities contain a wide variety of land uses and buildings with different purposes [12, 13]. However, the current research summarises that the majority of buildings in small cities, which are located closer to residential complexes than cities, are used for residential purposes first, followed by educational uses like schools. In the construction

and building industry, project management refers to striking the optimal balance between the three factors of quality, or what are known as specifications, cost, and implementation time [14, 15].

The subject of construction and engineering project management is crucial for accurately estimating the quantities of construction materials needed in construction and their costs, but generally speaking, no one criterion is prioritised over the others [16]. Project management is the discipline that involves arranging, planning, acquiring, and managing resources to achieve specific goals within a set amount of time. It comprises applying techniques, tools, skills, and knowledge to successfully finish projects [17]. Planning and scheduling are essential in the building industry. Because of the absence of increasing complexity in this field [18]. To minimise overall cost, time, and resource efficiency, the construction industry requires incredibly accurate planning, scheduling, and project management [19]. In the realm of engineering and construction project management, the application of BIM technology constitutes a significant change [20-22].



Engineering standards. Every engineering project has unique constraints and conditions. Therefore, based on the estimated quantity schedules that are established beforehand, the beneficiary is the one who decides the construction project's form and life cycle [23-25]. Using a common digital representation, architects, engineers, contractors, and other professionals can design, build, and maintain buildings and infrastructure through the collaborative process of building information modelling, or BIM [26-28]. A smart, sustainable city is one that uses technology to optimise the use of limited resources and enhance its basic processes. It combines data management and 3D modelling, enabling better decision-making throughout a project's lifecycle. This knowledge-based system provides stakeholders with up-to-date information [29].

## 2. Literature Review

Many previous studies have been conducted in the field of BIM techniques in construction and building project management, as follows: It has been demonstrated that parametric modelling software for BIM may be used to carry out a number of standard GIS software tasks, such as feature extraction, geographic searches, DEM production, and reference system translation [30].

In [31], they conclude with a review of the advantages and disadvantages of visual programming languages in relation to BIM. The research on H-BIM and its practical use in the realm of cultural heritage is reviewed in this publication. Additionally, it looks at the effectiveness and usefulness of several modelling approaches developed to depict families of pertinent elements as illustrated in [32]. Two procedures have been performed using a BIM-integrated building asset management approach to schedule asset development [33]. A study investigates the state of practice for Airport BIM 7 (ABIM) and the use of ABIM procedures in digital airport operations and maintenance by tying together existing data sources and integrating smart airport technologies [34].

Another study provides techniques to assess the commonly used profiles of swept solids in order to convert the IFC into a shapefile. A bridge model is utilised to validate the proposed method, and a Web GIS-based bridge management system is developed to demonstrate potential applications of the updated shapefile model [35]. An article intends to investigate the definitions, characteristics, applications, and issues of digital twins as well as their interactions with other digital technologies used in the construction and maintenance of built assets [36]. And finally, for building projects, the Bill of Quantities (B.O.Q.) is an essential document that analyses labour, materials, and costs. Manual measuring and interpretation are part of traditional procedures, but 3D Building Information Modelling (BIM) provides a new method [37].

## 3. Problem Statement

When planning and designing proposed smart cities, project management engineers, especially in developing countries, often fall short in terms of not preparing detailed bills of quantities required to establish such a city. This is where the research problem begins. By using BIM techniques, it is possible to develop detailed schedules of quantities for all facilities and buildings within the proposed City before its implementation. This gives competing implementing companies a great opportunity to win the investment project through the large estimated value that they will specify in their detailed schedules of quantities required for the purpose of winning this investment opportunity. The current research is an attempt to bridge the research gap between traditional research related to engineering management of construction projects, which relies on well-known software packages (MS Project, Primavera), on the one hand, and research that relies on completing architectural and structural designs of buildings according to the BIM system, on the other hand. The research contribution of the current work lies in employing the BIM system in the requirements of engineering management work for construction projects.

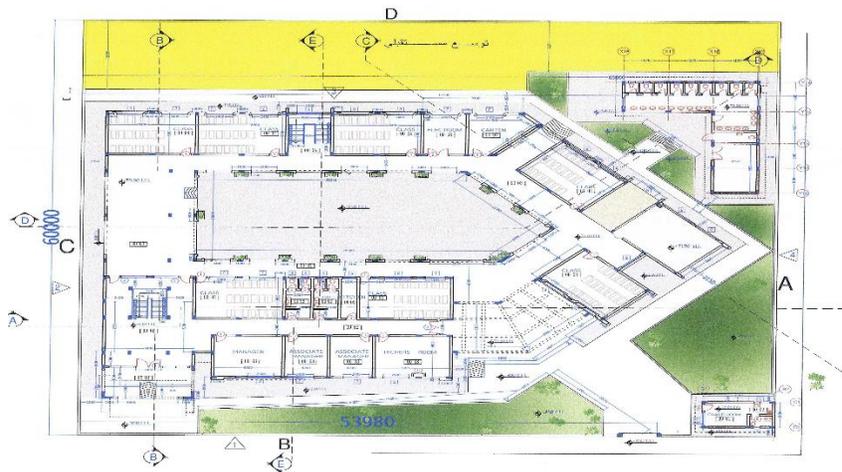


Fig. 1 Master plan of the school building in PDF format [17]

## 4. Methodology of the Work

### 4.1. Data

Detailed design maps of the basic construction stages for both horizontal housing units and schools.

(Figure 1) It is an example of this, showing the basic construction stages of a school building.

### 4.2. Specialized Software Packages include the following

- The AutoCAD software package was issued by Autodesk for the year 2022. [38]
- Revit software package issued by Autodesk for the year 2023. [39]

### 4.3. Sequence of Operations

Digital operations can be summarized in four stages as follows:

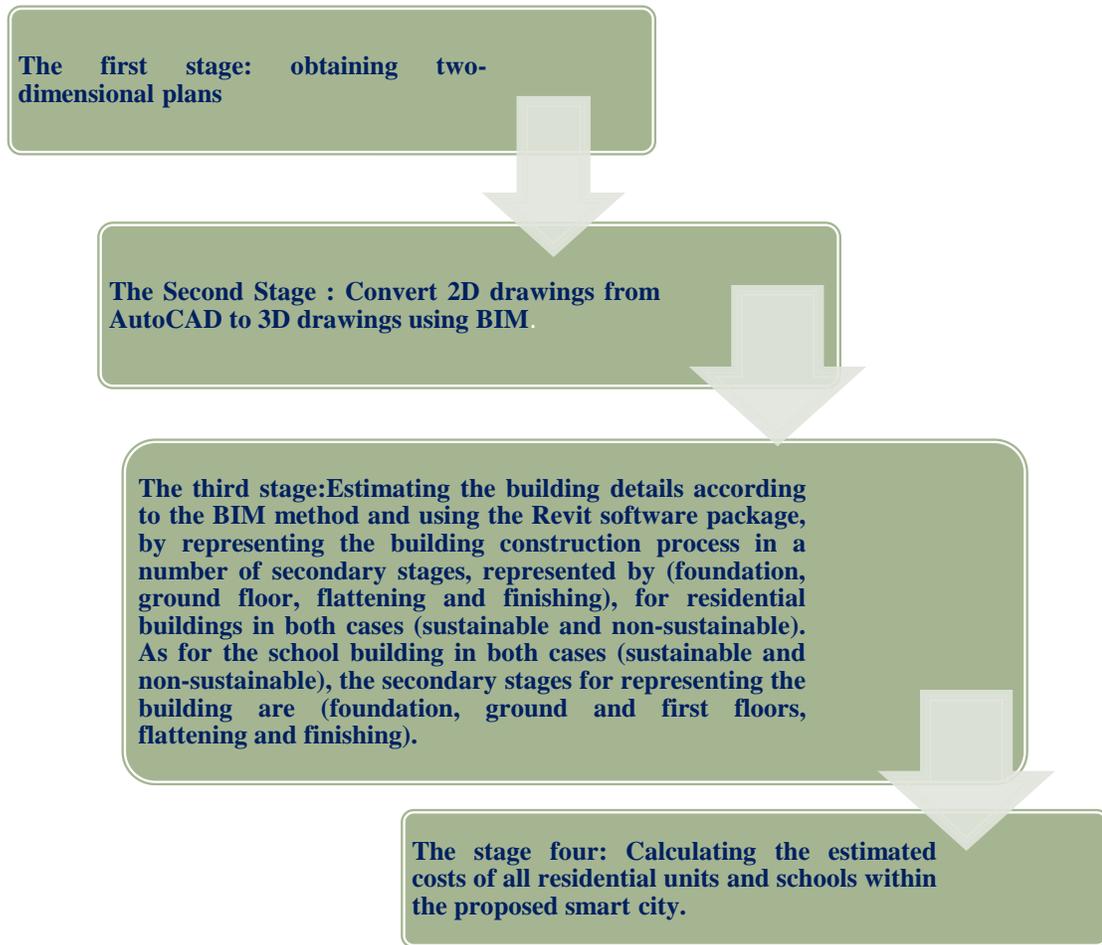


Fig. 2 Block diagram of the sequence of operations

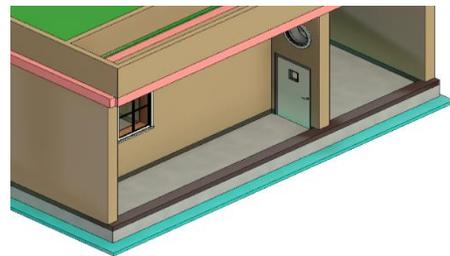
## 5. Results

### 5.1. Stages of Building Construction using the BIM Techniques

#### 5.1.1. The stages of Horizontal Housing Unit Using BIM Techniques

##### Building Foundation

The foundation of the horizontal residential unit, which has an area of 200 m<sup>2</sup>, consists of three layers (Blinding, base, damp proofing course), as shown in Figure 3.



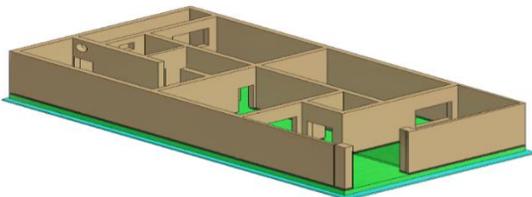
**Table 1. Layers of building foundation**

Layers	Thickness cm	Colors
Damp Proofing Course	15	
Base	40	
Blinding	10	

*Ground Floor*

1. Walls of Ground Floor

Depending on the building's sustainability status, the ground floor wall construction work will be (using thermal insulating bricks in the case of a sustainable building with a height of 3.5 m and using regular bricks in the case of a non-sustainable building with a height of 3 m), as shown in Figure 4.

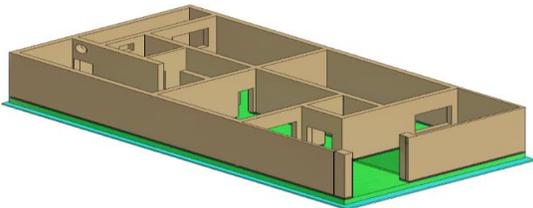


**Fig. 3 Layers of Building Foundation**

*Ground Floor*

1. Walls of Ground Floor

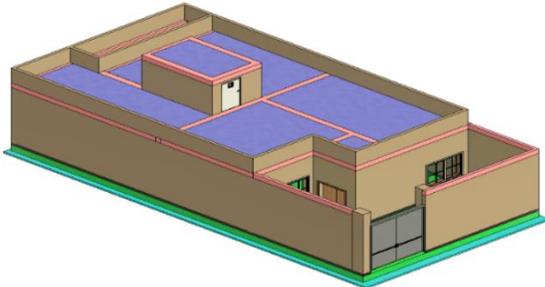
Depending on the building's sustainability status, the ground floor wall construction work will be (using thermal insulating bricks in the case of a sustainable building with a height of 3.5 m and using regular bricks in the case of a non-sustainable building with a height of 3 m), as shown in Figure 4.



**Fig. 4 Building walls using bricks**

2. Construction works

For the purpose of completing the construction work in the residential unit, the reinforced concrete work (ceiling, beams, and stairs) is shown in Figure 5.

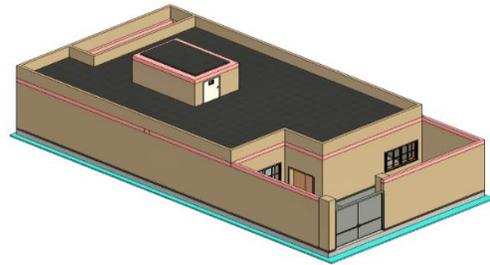


**Fig. 5 Construction works**

Flattering works and overall building works

Roofing

In order to complete the levelling and adjustment of the surfaces to achieve a certain horizontal level or slope, the building's levelling works were completed. These works are very important for the purpose of draining rainwater, and depending on the type of building, whether it is sustainable or non-sustainable, as shown in Figure 6.

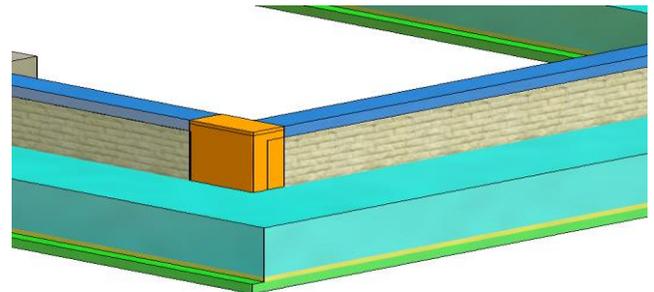


**Fig. 6 Finishing works in the residential unit**

5.1.2. The stages of school building using BIM Techniques

A. Building foundation

The building's foundation consists of six layers (Blinding, Screed, Base, Column necks, Wall adjacent to soil, Damp Proofing course), as shown in Figure 7.



Layer	Thickness cm	Color
Damp Proofing Course	15	Blue
Wall adjacent to soil	40	Yellow
Column necks	40	Orange
Base	52	Light Blue
Screed	5	Yellow
Blinding	10	Green

**Fig. 7 Layers of building foundation**

*Ground Floor*

1. Columns and Beams of the Ground Floor

Reinforced concrete columns and beams are constructed on the ground floor. These columns are among the most

important structural elements responsible for transferring loads from the roof and beams to the foundations and from there to the soil. The dimensions and measurements of these columns depend on the loads placed on them and their structural design, as shown in Figure 8.

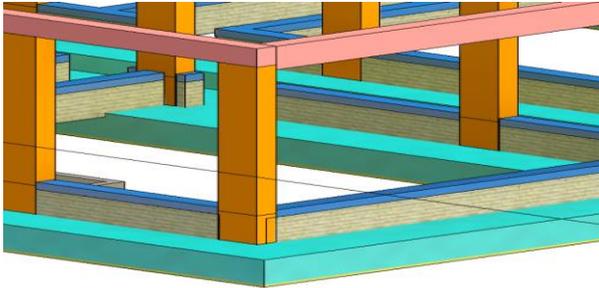


Fig. 8 Columns and beams on the ground floor

2. Slab of Ground Floor

The reinforced concrete ceiling of the ground floor is characterised by its strength, durability, and ability to withstand heavy loads, as shown in Figure 9.

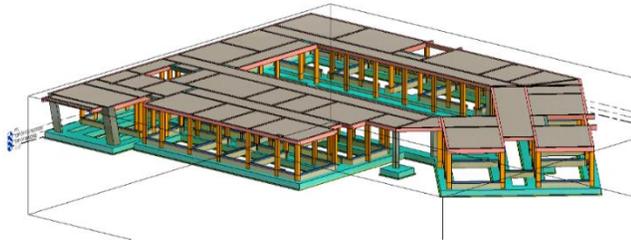


Fig. 9 Reinforced concrete ceiling of the ground floor

3. Stairs of the Ground Floor

A set of reinforced concrete stairs is used to move from the ground floor to the first floor, as shown in Figure 10.

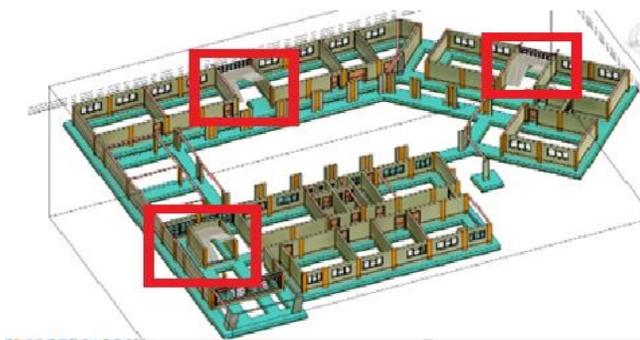


Fig. 10 Set of concrete stairs

4. Walls of Ground Floor

Depending on the building's sustainability status, the ground floor wall construction will be (using thermal insulating bricks in the case of a sustainable building and using regular bricks in the case of a non-sustainable building), as shown in Figure 11.

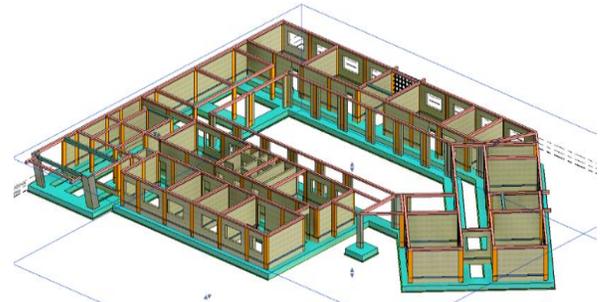


Fig. 11 Construction of ground floor walls (sustainable or unsustainable)

5. Added - Upper-exterior Walls glass belt of Ground Floor

For the sustainable building, a glass belt was created at the top of the ground floor wall, which allows more natural light to enter the building, reducing the need for artificial lighting during the day, as shown in Figure 12.



Fig. 12 For the sustainable building, a glass belt was created at the top of the Wall

First Floor

The stages of constructing the first floor are carried out in the same manner as mentioned above in the stages of constructing the ground floor.

Flattening Works and Overall Building Works

1. Parapet -Columns-Beams of Penthouse

In order to complete the construction work in the building, the reinforced concrete works for the concrete (columns, beams, and ceilings) were completed, as shown in Figure 13.

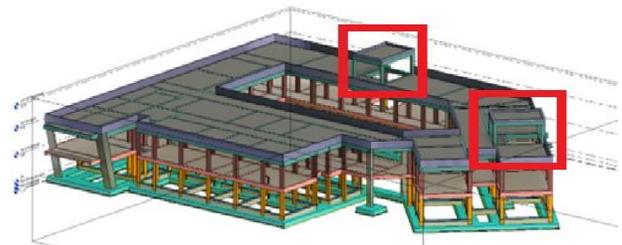


Fig. 13 Construction finishing works

2. Roofing

In order to complete the leveling and adjustment of the surfaces to achieve a certain horizontal level or slope, the building's leveling works were completed. These works are

very important for the purpose of draining rainwater, and depending on the type of building, whether it is sustainable or non-sustainable, as shown in Figure 14.

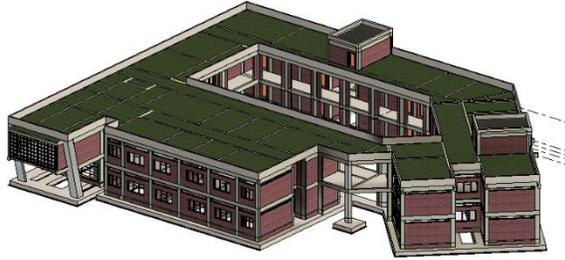


Fig. 14 Flattening works in the building

### 3. Curtain Walls

Glass facades are a common architectural element in modern buildings. A large glass facade has been used as a major part of the building's exterior structure to take advantage of natural sunlight, reducing artificial lighting during the day, as shown in Figure 15.



Fig. 15 Glass facades in the building

## 6. Estimated Quantity Tables for Building Construction Stages

### 6.1. Costing Quantities for Horizontal Residential Unit Building

Table 2. Overall quantities for constructing a horizontal housing unit with an area of 200 m<sup>2</sup>

I-Building Foundation					
Construction stage	Discription	Unit	Quantity	Price \$	Total \$
1-Blinding	Pouring the cleaning layer using regular concrete, thickness (10) cm	m <sup>3</sup>	21.42	100	2142
2-Base	Pouring the foundation layer using reinforced concrete with a thickness of 40 cm	m <sup>3</sup>	80	300	24000
3-Damp proofing course	Pouring a moisture-proof layer using regular concrete, with a thickness of 15 cm.	m <sup>3</sup>	4.18	150	627
Total cost of building the foundation: 26769 \$					
II-Ground Floor					
1-A-walls of the non-sustainable building	Building walls using regular bricks	m <sup>3</sup>	120.24	150	18036
1-B-walls of the sustainable building	Building walls using thermal insulating bricks	m <sup>3</sup>	122.72	300	36816
2-Slab -Beams -Stair	Reinforced concrete works (ceiling, beams, stairs)	m <sup>3</sup>	30.14	003	9042
Total cost of ground floor non-sustainable			27078	\$	
Total cost of ground floor sustainable			45858	\$	
III- Flattening works and overall building works					
1- Penthouse	Penthouse works	m <sup>3</sup>	2.47	300	741
2- Windows	Windows	m <sup>2</sup>	20	200	4000
3- Doors	Doors	number	9	400	3600
4-A- roofing of the non-sustainable	Surface paving works (non-sustainable construction)	m <sup>2</sup>	129.059	50	6452.95
4-B- roofing of the sustainable	Sustainable roof paving works (roof planting) to enhance insulating layers, rainwater drainage, and irrigation	m <sup>2</sup>	129.059	200	25811.8

	systems				
Total cost flattening works and overall building works are non-sustainable				14793.95 \$	
Total cost flattening works and overall building works are sustainable				34152.8 \$	
The total cost of building a horizontal housing unit is 68640.95 \$					
The total cost of building a horizontal housing unit sustainable				106779.8 \$	

**6.2. Costing Quantities for School Building**

The quantities of materials required for the school Construction phases are summarized with their estimated costs as shown in Tables 3, 4, and 5.

**Table 3. Quantities and Costs for Constructing the Building Foundation of the School Building**

<b>I- Building Foundation</b>					
<b>Construction stage</b>	<b>Description</b>	<b>Unit</b>	<b>Quantity</b>	<b>Price \$</b>	<b>Total \$</b>
1-Blinding	Pour a clean layer of regular concrete, 10 cm thick.	m <sup>3</sup>	89.93	150	13489.5
2-Screed	Pouring a protective layer of insulating material over regular concrete, with a thickness of 5 cm	m <sup>3</sup>	80.65	100	8065
3-Base	Pouring the foundation layer using reinforced concrete with a thickness of 52 cm	m <sup>3</sup>	419.39	350	146786.5
4-Column necks	Pouring column necks using reinforced concrete	m <sup>3</sup>	7.54	350	2639
5-walls adjacent to soil	Building walls using regular bricks at a low height at the level of all column necks.	m <sup>3</sup>	59.96	150	8994
6-Damp Proofing Course	Pouring a moisture-proof layer using regular concrete, with a thickness of 15 cm	m <sup>3</sup>	13.47	150	2020.5
Total cost of building foundation			181994.5	\$	

**Table 4. Quantities and Costs for Constructing the Ground Floor and First Floors of the School Building**

<b>II-Ground Floor</b>					
<b>Construction stage</b>	<b>Description</b>	<b>Unit</b>	<b>Quantity</b>	<b>Price \$</b>	<b>Total \$</b>
1. A- columns of ground floor (non-sustainable)	Casting columns using reinforced concrete (non-sustainable construction)	m <sup>3</sup>	42.65	500	21325
1-B- columns of ground floor (sustainable)	Casting columns using reinforced concrete (sustainable construction)	m <sup>3</sup>	48.22	500	24110
2-Beams of the ground floor	Connecting columns using reinforced concrete beams	m <sup>3</sup>	90.82	500	45410
3-A- stairs-ground floor (non-sustainable)	Casting stairs using reinforced concrete (non-sustainable construction)	m <sup>3</sup>	11.22	500	5610
3-B- stairs-ground floor (sustainable)	Staircase casting using reinforced concrete (sustainable construction)	m <sup>3</sup>	11.34	500	5670
4. Slab of the ground floor	Pouring the ground floor ceiling using reinforced concrete with a thickness of 18	m <sup>3</sup>	208.27	500	104135

	cm				
5-A- walls of the non-sustainable building on the ground floor	Building walls using regular bricks (non-sustainable construction)	m <sup>3</sup>	262.01	150	39301.5
5-B- walls of the sustainable building on the ground floor	Building walls using thermal insulating bricks (sustainable construction)	m <sup>3</sup>	284.28	300	85284
6-Doors of ground	Doors	number	32	400	12800
7 - windows of the ground floor	Windows	m <sup>2</sup>	465.5	200	93100
8- Added-Upper-exterior walls, glass belt of ground floor	Glass belt at the top of the walls (sustainable construction)	m <sup>2</sup>	95	200	19000
Total cost of ground floor non-sustainable			321681.5 \$		
Total cost of ground floor sustainable			389509 \$		
The First Floor is very similar to the ground floor, so that its total cost for non-sustainable					339217.5 \$
The First Floor is very similar to the ground floor, so that its total cost for sustainable					411236 \$

Table 5. Quantities and Costs for Constructing the Flattening Works and Overall Building Works of the School Building

III- The Flattening works and overall building works					
Construction Stage	Description	Unit	Quantity	Price \$	Total \$
1-Parapet - Columns-Beam-Slab of Penthouse	The building roof works include concrete blocks (columns, beams, reinforced concrete ceilings) and the building curtain	m <sup>3</sup>	64.63	500	32315
2-A- roofing of the non-sustainable	Surface paving works (non-sustainable)	m <sup>2</sup>	1197.79	50	59889.5
2-B- roofing of the sustainable	Sustainable roof paving works (roof planting) to enhance insulating layers, rainwater drainage, and irrigation systems	m <sup>2</sup>	1197.79	200	239558
3- Curtain Walls	The building's glass facades	m <sup>2</sup>	105.80	300	31740
Total costs for the Flattening works and overall building works are non-sustainable					123944.5 \$
Total costs for the Flattening works and overall building works are sustainable					303613 \$
The total cost of the school building is unsustainable					966838 \$
The total cost of the school building is sustainable					1286352.5 \$

6.3. Estimated Quantity Tables for The Housing and School Sectors Within a Proposed Smart City

For a proposed smart city consisting of 20,000 horizontal housing units and 50 schools, the estimated construction cost is calculated (in both sustainable and non-sustainable construction cases) as follows:

1. Sustainable construction

The cost of the horizontal housing sector plus the cost of sustainable schools = the number of sustainable housing units \* the cost of one sustainable housing unit + the number of sustainable schools \* the cost of one sustainable school

$$TCSC = TCSH + TCSS$$

$$= NSH * CSH + NSS * CSS$$

$$= 20000 * 106779.8 \$ + 50 * 1286352.5 \$$$

$$= 2,199,913,625 \$$$

TCSC Total Cost Sustainable City

TCSH Total Cost Sustainable Housing

TCSS Total Cost Sustainable School

NSH=Number of Sustainable Housing

CSH=Cost Sustainable Housing

NSS=Number Sustainable School

CSS=Cost Sustainable School

Housing and Education Sector \*100%

$$SCVNSC = \frac{TCSC - TCNSC}{TCNSC} * 100\%$$

$$SCVNSC = \frac{2199913625\$ - 1421160900\$}{1421160900\$} = 55\%$$

## 2. Unsustainable Construction

The cost of the horizontal housing sector plus the cost of unsustainable schools = the number of unsustainable housing units \* the cost of one unsustainable housing unit + the number of unsustainable schools \* the cost of one unsustainable school

$$\begin{aligned} TCNSC &= TCNSH + TCNSS \\ &= NNSH * CNSH + NNSS * CNSS \\ &= 20000 * 68640.95 \$ + 50 * 966838 \$ \\ &= 1,421,160,900 \$ \end{aligned}$$

TCNSC Total Cost Non-Sustainable City

TCNSH Total Cost Non-Sustainable Housing

TCNSS Total Cost Non-Sustainable School

NNSH=Number non-Sustainable Housing

CNSH Cost non-Sustainable Housing

NNSS=Number non-Sustainable School

CNSS= Cost non- Sustainable School

## 3. Comparison of estimated costs for sustainable and non-sustainable housing and education sector buildings

Sustainable Housing and Education Sector - Unsustainable Housing and Education Sector / Unsustainable

SCVNSC= Sustainable Cost Versus Non-Sustainable Cost

TCSC Total Cost Sustainable City

TCNSC Total Cost Non-Sustainable City

## 7. Conclusion

1. The level of construction project management with high details LOD5, LOD6 for specifications and costs of complementary matters in the building (water and sewage network installations, cooling and air conditioning systems, electrical installation networks) requires a lot of effort and time, in addition to the need for mechanical and electrical engineering cadres, so they were not included in our project.

2. BIM technologies have provided a good method for managing the construction project (at the level of a single building) in terms of determining the specifications and estimated costs for the various construction stages included in a single building.

3. The practical results showed that it is possible to prepare a detailed and accurate bill of quantities for all stages of establishing the proposed smart City (planning, design, implementation).

4. The requirements for sustainable construction and its cost are approximately 55% higher than non-sustainable construction (for the same building specifications), which greatly increases the financial costs required to establish a smart city.

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