APPLYING LCA-BIM INTEGRATION FOR A SUSTAINABLE MANAGEMENT PROCESS

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This work investigates the benefits of performing Life Cycle Assessment (LCA) using Building Information Modelling (BIM) techniques on a case study management process. This provides insights for reducing the environmental impacts of building materials and elements along the life cycle of a concrete residential project in Egypt. The study follows the LCA ISO 14040 and 14044 guidelines, local materials database, Revit modelling and One-Click LCA plugin. The result outlines that most of the environmental impacts occur during the operation and manufacturing phase. It also shows that slabs and beams result in most of the environmental loads. In terms of the material analysis, it was found the steel reinforcement had the largest impact. This study indicates the potentials and challenges of applying an LCA-BIM integration procedure towards achieving a sustainable management process in middle and low-income countries. This helps project team members to consider the use of different construction materials, elements and building life cycle phases that contribute fewer impacts.

Keywords: environmental impact assessment, Life Cycle Assessment (LCA)

INTRODUCTION

In 2018, the Global Status Report for Buildings and Construction reported that construction buildings alone were responsible for approximately 36% of the global energy and resource consumption, and around 39% of the global greenhouse gas emissions (GlobalABC, IEA and UNEP, 2019). It is noted that 60% of buildings in Egypt are residential and that makes the residential sector the main energy consumer, accounting for 42% of the total consumption (ElGohary and Khashaba, 2018). In this regard, the consumption of the residential sector has been increasing in the past few years; in 2016 and 2017, it reached 5514 and 5744 (ktoe), respectively. Moreover, carbon dioxide emissions were increasing (6% every two years) and expected to continue growing. In 2013, 2015, and 2017 the residential sector presented 15, 16, and 17 Metric tons of carbon dioxide equivalent ($MTCO_2eq$), respectively (US EIA, 2018).

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Any project can be seen as an input-output process; consuming raw materials, water and energy and emitting waste. Soust-Verdaguer, Llatas, and García-Martínez (2017) argued that there is a growing attention to adopt sustainable design approaches to reduce buildings environmental impacts. The term "Green BIM" has also emerged denoting the use of BIM techniques to account for buildings environmental loads. It may also enable better collaboration between project team members at various project stages and achieve interoperability and consistent standards in the construction industry. This allows systems and individuals to exchange information which is a pivotal concern for the construction industry in middle- and low-income countries. The underlying interoperability framework converts a software-specific data format into a global data format; thus, the tools enable the exchange, transfer, and process of data (Grilo and Jardim-Goncalves, 2010). The BIM currently provides project team members with required data to assess the building performance throughout its life-cycle (Najjar *et al.,* 2017; Santos *et al.,* 2019).

Life Cycle Assessment (LCA) encompasses for all physical exchanges with the environment through various phases of the building process, nevertheless, it cannot be considered a common process in middle and low-income countries due to several challenges associated with data availability, specialized software and practitioners competencies (Ismaeel and Elsayed, 2018). Hence, Anand and Amor (2017) argued that both the information for building materials and their environmental impacts assessment are harmonized by BIM. This facilitates the application of LCA in the building industry and considers the environment as one of the criteria for design decision-making. Hence, this study emphasizes the interoperability between LCA and BIM to allow the exchange of data and interaction between BIM Model, Revit Structure 2020, and One-Click LCA plugin as shown in Figure 1. This aims at evaluating the environmental impacts of building materials and elements for a residential building in Egypt during its life-cycle.

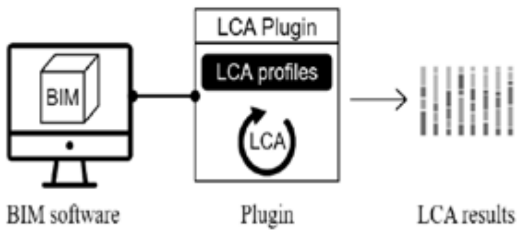


Figure 1: Workflow based on use of an LCA plugin for the BIM software source (Wastiels and Decuypere, 2019)

LITERATURE REVIEW

LCA is defined as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product or system throughout its life cycle" (ISO, 2006). It is the most universally type of validation used for environmental impact with broad international acceptance. Through LCA, The life cycle inventory (LCI) is an essential step, adding basic flows over time and space (Hauschild *et al.,* 2013). The functional unit is used to assure a comparable level of function or service. Moreover, the selection of impact categories is the main obligatory components of Life Cycle Impact Assessment (LCIA).

The framework for LCA according to ISO 14040:2006 consists of four iterative steps: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation (ISO, 2006). There are three LCI methods with significant differences, pros and cons;

the Process Analysis shall be used in this study which operates according to a bottom-up approach starting from the small material scale to the whole building.

It is noted that the Ecoinvent database is the world's leading LCI database which convey both in terms of transparency and consistency (Anand and Amor, 2017; Azari and Abbasabadi, 2018).

Bionova Ltd. developed One-Click LCA as an automated tool in Helsinki, 2011. It operates based on a web-based interface, which can be incorporated into compatible open standard software, and as a plug-in tool in the Revit software. This tool complies with the international standards for the LCA study. One-Click LCA is independently approved for EN 15978, EN 15804, ISO 21931-1, ISO 21929-1 and ISO 14040. Furthermore, it has been created over an international Environmental Product Declarations database which addressed the European market (Bionova, 2015). Also, it makes it possible to select, change and simulate the performance of building materials. It has been used by scholars who studied the integration of LCA and BIM by using different tools such as the One-Click LCA and Tally. The results for both tools were compatible and showed that the manufacturing phase had the highest environmental impact and that the concrete slabs had the major contribution to CO_2 emissions (Petrovic *et al.,* 2019). Table (1) shows the life cycle stages as defined by EN 15978 divided into pre- operational phases, operational phase and post-operational phase (Bionova, 2015).

Table 1: Life-Cycle Stages as defined by EN 15978, elaborated after (Bionova, 2015)

Building life cycle																
Module A					Module B							Module C				Module D
Product / Manufacture Stage [A1-A3]			Construction Process Stage [A4-A5]		Use stage [B1-B7]							End-of-life Stage				
					Building Fabric					Operation of the Building						
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw materials supply	*Transport*	Manufacturing	Transport	Construction	*Use*	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Demolition	Transport (to disposal)	Waste processing	Disposal	Reuse Recycling Energy recovery
Pre- Operational phases					Operational phase							Post operational phase				

RESEARCH METHOD

Figure 2 shows a flowchart for a LCA-BIM based decision support analysis for a residential building in Egypt composed of a ground floor and 5 upper floors, 8 apartments with a total floor area of 1446 m^2. The case study was selected because it represents the best practices in designing and constructing a residential building in Egypt; the floor plans and 3D model are shown in Figure 3. The case study is a reinforced concrete (RC) solid slab system consisting of cast-in-place RC slabs with various thickness (12-25) cm and several cross-sections for the beams and columns as well as combined and isolated footings.

The LCA framework follows ISO 14040 and 14044. The steps can be described as follows;

- Goal and scope definition: investigating the environmental impact of different building materials, elements and construction phases.

- Scope: covering six impact categories along the building life cycle.
- Functional unit: square meters of building floor plan
- Service life: The average life of most structural buildings is 50 years.
- System boundary: cradle to cradle covering the projects life cycle stages; extraction of raw materials, manufacturing, transportation, operation as well as end-of-life scenarios (reuse, recover and recycle) of the building
- Impact categories: this covers midpoint impact categories as shown in Table (2) (Hauschild *et al.,* 2013).
- Life cycle inventory (LCI): this accounts for all the inputs and outputs for the three defined phases of the projects life cycle according to (Bionova, 2015). This includes Pre- Operational phases: [A1-A5], Operational phase: [B6 and B7], it is noted that [B1- B5] are excluded from the scope of this study and Post operational phase: [C1- C4] and [D] module.

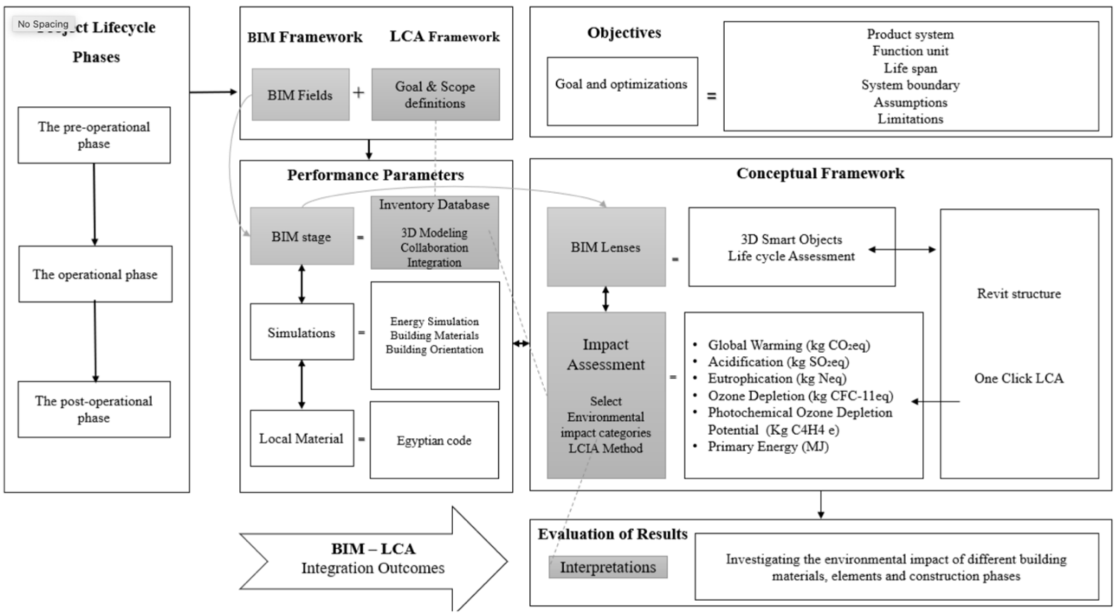


Figure 2: Detailed BIM and LCA integration flowchart for a residential building in Egypt

Table 2: Selected impact categories

Impact category	Abbreviation	Measurement unit
Global warming potential	GWP	kg CO_2eq
Acidification potential	AP	kg SO_2eq
Eutrophication potential	EP	kg PO_4eq
Ozone depletion potential	ODP	kg CFC-11eq
Photochemical ozone creation potential	POCP	kgC_2H_4 eq
Primary energy demand	PED	MJ

The initial plans and modelling of the solid slab concrete structural systems are modelled using the Autodesk Revit software, nevertheless, it is noted that some material environmental properties are not specified and needed to be manually entered.

The Pre-Operational Phase

This phase accounts for the total mass of the main building materials, electricity consumption and water use. The direct material losses (solid waste) and material transportation are also considered.

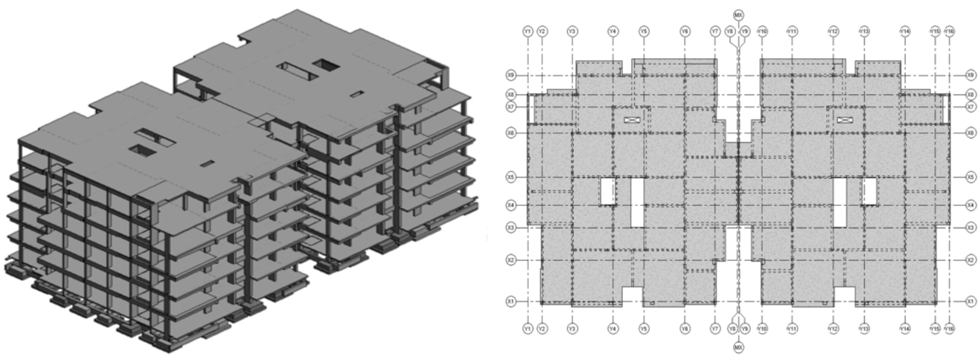


Figure 3: The residential case study building (3D model and structural floor plan)

In this regard, it is noted that the transportation of waste from the supplier to the construction site was reported. The material flows and the unit processes chosen by the Ecoinvent database were determined. During the construction period, the consumption of water and electricity was obtained from the supplier bills and provided by the construction companies. Concerning the solid waste, the usual theoretical loss was estimated as 2-5% for RC, 6% for RC rebar and 8% for Soil waste (sand) (El-Desouky, Ibrahim and ElDieb, 2018). The overall values of inventoried construction materials for the quantification of construction waste are applied. Table (3) shows authors estimation to the consolidated transportation distance using Google maps as a result of the lack of supplier data in this regard. This was done for 1) transporting building materials to the building sites and 2) transporting solid waste to the destination. Then the distance was doubled to account for the empty trucks arrival distance to the construction site and its return to the building site.

Table 3: Transportation calculations

Life cycle phase	Material	Distance supplier/ Construction site	Distance construction site/ landfill
Construction	Cast-in-place concrete, structural concrete	29 km	7km*2=14km
Construction	The sand soil	--	7km*2=14km
Construction	Steel reinforcing rod, galvanized steel and rolled section	31 km	31km*2=62km

The Operational Phase

This phase includes the domestic water and electricity use, artificial lighting, energy used for cooking, as well as building maintenance requirements. The solid waste generated during the maintenance process and its transportation are also included. The consumption of electricity and water was calculated according to the average use and number of occupants. For the annual electric energy consumption, it was estimated as 387,072 kWh /building/year- according to the Egyptian Electricity Holding Company (Desoki, 2018). Also, the energy use was calculated according to Egypts mean voltage matrix available in the Ecoinvent database. Similarly, the values used by the Central Agency for Public Mobilization and Statistics state that water use is 328 m^3/building /year. Nevertheless, the impact resulting from the maintenance stage was excluded because the assumed lifespans of the used materials were equal to or greater than 50 years.

The Post-Operational Phase

In this phase, reusing, recovering energy, and recycling materials were considered as end of life scenarios. Table (4) shows the inventory data for the project case study.

Table 4: The inventory data for the solid slab concrete structural system

Description	Solid slab structural system	
I-Pre-operational phase		
Construction process	Total for the building	
	Input materials	Output (waste)
Foundation and sub structures	614 m^3	27016 kg
Steel rebar for foundation and sub structures	35,948 kg	2157 kg
RC-Columns	308 m^3	13552 kg
Steel rebar for columns	32340 kg	1940 kg
Shear walls	137 m^3	6028 kg
Steel rebar for shear walls	16440 kg	986 kg
Solid slab with beams	2003 m^3	88132 kg
Steel rebar for solid slab and beams	159460 kg	9568 kg
Soil waste	-	1,289,232 Kg
Consumption during the construction phase		
Water (m^3)	100 m^3	-
Electricity, 2 Generator, diesel-driven (100 Kilo-volt-amperes), (operation per hour)	1320 h	-
Equipment used during the construction phase		
Crane, diesel-driven, (operation per hour)	800 h	-
Vibrators operation, diesel-driven, (operation per hour)	120 h	-
Excavator, crawler and wheel loaders diesel-driven, (operation per hour)	48 h	-
Compactors, diesel-driven (operation per hour)	8 h	-
II- Operational phase		
Electric energy	387,072 kWh/ building /year	
Water	328 m^3/ building /year	
III- Post operational phase		
Total incorporated mass (kg)	-	1,438,083 kg

Then the LCIA was carried out on the following levels to pinpoint the highest contribution of environmental impact:

- Materials: steel reinforcement and RC
- Construction elements: foundation and substructures, columns, shear walls, as well as slabs and beams
- Life cycle phases of the whole building: pre-operational, operational and post-operational).

RESULTS

This paper presents a LCA-BIM based decision support analysis for a residential building in Egypt that tackles the material, construction element and life cycle stage.

For different impact categories, the Primary energy demand (PED) is the highest environmental impacts during the building's life cycle. It is followed with the GWP with value 1.57E7 kg CO_2eq then AP with value 4.40E4 kg SO_2eq, EP, POCP and the least value was for ODP.

For life cycle phase: Figure 4 shows that the largest part of the environmental impacts occurs during the operational phase. The energy consumption during the operation phase was approximately (78.4%-90.2), while the manufacturing stage was approximately (3.6%-18.7%), the transportation stage accounted for approximately (2.1%-4.4), the construction stage represented about (0.6%-1.2%) and the end of life was about (0.3%-1.2%). Nevertheless, the water consumption during the operation phase had a less impact of (0.1%-0.3%).

For the construction materials: Figure 5 shows that the reinforcement steel rebar dominates four out of six impact categories: AP, EP, POCP, and PED but otherwise, the reinforcement concrete dominates two out of the six impacts. This is due to the large amount of energy required for manufacturing the steel elements and transporting the steel waste to the landfill area.

For the construction elements: Figure 6 shows that the slabs and beams had a higher value than the other construction elements followed by the foundations and substructures, columns, and shear walls. This is due to the large material quantities (RC and Reinforcement rebar of 2,003 m^3 and 154,460kg, respectively) included in their manufacturing process which required more energy input and lead to more output emissions. Similarly, for the transportation to the site stage (the steel reinforcement for slabs required 4 trailers/ 40-ton capacity). The RC is delivered to the site by a pump with capacity of 140 m^3/hour, hence, for the slabs, 2 pumps working 8 hours/day are needed. Thirdly, during construction stage, it depends on the required equipment and operational hours as well as the buildings floor number. The construction waste included concrete and steel, as well as soil waste (resulting from cut and fill)- noting that the soils swell factor is equivalent to 1,289,232 kg. Finally, the end of life scenarios (reuse, recycle and energy recovery), are the highest for slabs and beam according to EN-15978. This is because the RC in this stage are 55% recycled into coarse aggregate and 45% landfilled, but the reinforcement steel rebars are 95% recovered and 5% landfilled.

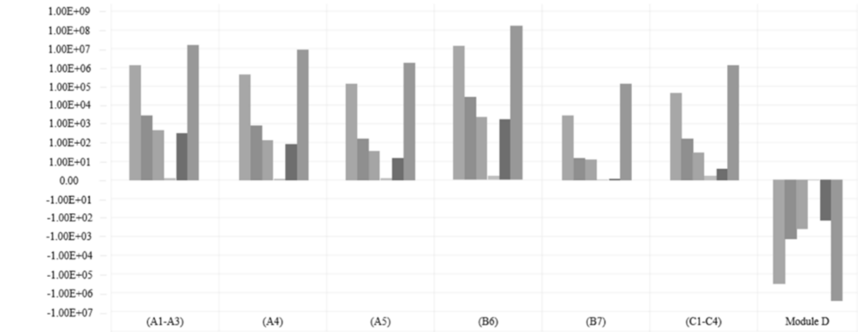
DISCUSSION

The results of the current study (in Egypt) correspond to international findings in terms of the impact of concrete structures, building elements and materials (Anand and Amor, 2017; Azari and Abbasabadi, 2018; Petrovic *et al.,* 2019). Furthermore, the study shows that applying LCA in a developing country like Egypt includes several challenges. This includes data availability, time limitations, users’ skills and guiding principles, this is in addition to considering the variations arising from building types. This calls for the need to integrate it with BIM techniques to ensure transparency, coherency and consistency of the assessment and promote its endorsement in the building industry (Najjar *et al.,* 2017; Soust-Verdaguer, Llatas and García-Martínez, 2017; Wastiels and Decuypere, 2019). On the other hand, some challenges exist for the use of the software itself and the comprehensiveness of imbedded database and its compatibility with the project type and local context. Hence, in this study, practitioners had to perform manual entry for some materials according to the Egyptian code of practice.

CONCLUSION

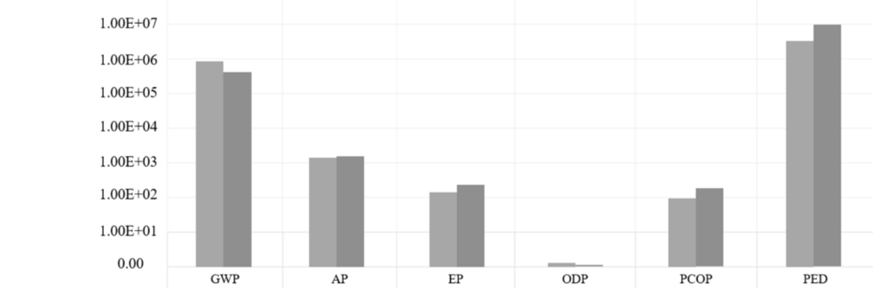
The study presents a LCA-BIM based decision support analysis for a residential building in Egypt that tackles the material, construction element and life cycle stage. This guides practitioners for a sustainable management process along the full building life cycle. The results show that the operational phase has the greatest environmental impact (76% in many impact categories); the pre-operational phase contributes to less than 23% while the post-operational phase has the least impact, with contributions of less than 1%.

On the construction element-level, the floors and beams as well as the foundation and substructures have the highest environmental impact.



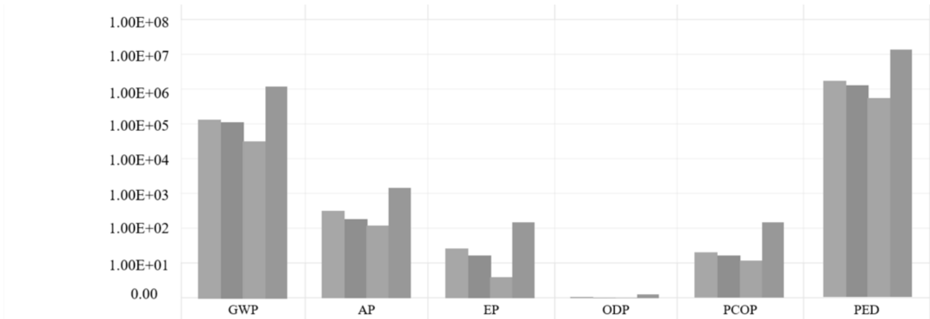
	(A1-A3)	(A4)	(A5)	(B6)	(B7)	(C1-C4)	Module D
	Pre-operational phase			Operational phase		Post-operational phase	
GWP	1.58E+06	6.29E+05	1.75E+05	1.38E+07	4.92E+03	7.66E+04	-5.28E+05
AP	4.70E+03	9.57E+02	2.96E+02	3.97E+04	2.66E+01	2.48E+02	-1.91E+03
EP	7.30E+02	1.96E+02	6.10E+01	3.86E+03	1.35E+01	5.94E+01	-6.41E+02
ODP	8.82E-02	1.06E-01	3.01E-02	2.20E+00	5.37E-04	1.43E-02	-2.24E-02
POCP	5.13E+02	9.32E+01	2.66E+01	2.10E+03	1.20E+00	6.96E+00	-2.90E+02
PED	1.49E+07	9.74E+06	2.91E+06	2.41E+08	1.04E+05	1.88E+06	-4.85E+06

Figure 4: The environmental impacts of the three defined life cycle phases



	GWP	AP	EP	ODP	PCOP	PED
Reinforcement concrete	9.75E+05	2.05E+03	2.82E+02	7.12E-02	9.26E+01	7.14E+06
Reinforcement steel rebar	6.78E+05	2.75E+03	4.87E+02	4.08E-02	4.07E+02	1.00E+07

Figure 5: The environmental impacts for building materials



	GWP	AP	EP	ODP	PCOP	PED
Foundation and substructures	2.63E+05	6.17E+02	4.61E+01	2.41E-02	4.55E+01	2.89E+06
Columns	1.53E+05	3.92E+02	2.34E+01	1.37E-02	3.27E+01	1.85E+06
Shear walls	5.97E+04	1.69E+02	6.98E+00	4.36E-03	1.42E+01	7.04E+05
Slabs and beams	1.27E+06	2.76E+03	2.55E+02	1.42E-01	2.29E+02	1.59E+07

Figure 6: The environmental impact of different building elements

While, on the material-level, the steel reinforcement dominates 4 out of 6 environmental impacts more than the RC. Hence, it is noted that the more construction materials used, the greatest impact therein, hence, the primary recommendations for team members is to reduce material quantities through adopting a material and resources efficiency approach and consider end of life scenarios during material selection; prioritising reuse and recycling materials.

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