Journal of Engineering Sciences Assiut University
Faculty of Engineering
Vol. 48, No. 6
November 2020
PP. 1024-1050

كلية الهندسة
جامعة أسيوط

AN INTEGRATED ANALYSIS WITH LIFE CYCLE ASSESSMENT, BUILDING INFORMATION MODELING, AND ENVIRONMENTAL PERFORMANCE FOR WINDOW MATERIALS: ASSIUT UNIVERSITY HOSPITAL CLINIC AS A CASE STUDY

Ahmed AbdelMonteleb Mohammed Ali

Assistant Professor, Department of Architecture, College of Architecture and Planning, Qassim University, Qassim, 52571, Saudi Arabia
Assistant Professor, Department of Architectural Engineering, Faculty of Engineering, Assiut University, Assiut, 71515, Egypt
Email: ahm.ali@qu.edu.sa, ahmed.abdelmonteleb@aun.edu.eg

Received: 7 September 2020; Revised: 3 October 2020; Accepted: 3 October 2020

ABSTRACT

The main goal of this study is to undertake the three methods of life cycle assessment (LCA), the environmental performance (EP), and the building information modeling (BIM) to determine the environmental performance and impacts of two window frame materials: aluminum and wood. This study has been carried out in a proposed project at the Assiut University campus. The LCA has been conducted by assessing materials and processes involved in manufacturing the two window frame types using the SimaPro. The LCA scope of this research covers from cradle to the gate with a designated system boundary. The network flow has been drawn to produce one kilogram of aluminum and wood; the quantities data were gathered from the BIM (using Autodesk Revit). Selecting the database is carefully picked from the Ecoinvent dataset to be closer to Egypt's manufacturing processes. Afterwards, the IMPACT 2002+ with midpoint and endpoint calculations has been used. Finally, the LCA results have been compared with the EP results (using DesignBuilder) to determine the best choice between the two materials.

The integration analysis shows that the aluminum industry has higher negative environmental impacts and environmental performance than the wood industry. The total midpoint results of the two materials are found to be 29.6 Pt for aluminum, and 7.57 Pt for the wood. Turning to the endpoint results, human health and resource depletion impacts are the most significant results. The human health scored the highest value, with 13.9 Pt for aluminum and 3.51 Pt for wood.
A novel framework for integrating LCA, BIM, and EP for a proposed building during the early phases of a project has been conducted in this study. The presented study can be used as a model for integrating comparative analysis on other proposed projects as the LCA applications in Egypt are scarce due to the absence of a reliable database. This study has introduced a value applying an approach to select the appropriate life cycle inventory database from the Ecoinvent dataset. The research findings contribute to choosing the most suitable window frame materials with the most energy-efficient effect and the least environmental burden. Moreover, it can help the concerned legislative bodies and the decision-makers.

KEYWORDS
Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Building information modeling (BIM), Environmental Performance

CONTENTS

Nomenclature

Chemical composition

CO_2	Carbon dioxide	SO_2	Sulfur dioxide

CH_4	Methane	NO_x	Nitrogen oxide
N_2O	Nitrous oxide	NH_3	Ammonia
PM	Particulate per matter	C_2H_4	Ethylene

Measurement units

Pt	Eco-points	kg	Kilogram
m^3	Cubic meter	kg/m^3	Density
m^2	Square meter	kg CO_2 eq	Kilogram carbon dioxide equivalent

Abbreviations

LCA	Life Cycle Assessment	LCI	Life cycle Inventory
BIM	Building Information Modeling	LCIA	Life cycle Impact Assessment
EP	Environmental performance	HH	Human Health
ISO	International Standards Organization	GHG	Greenhouse Gas
AUHC	Assiut University Hospital Clinic	GWP	Global Warming Potential
CED	cumulative energy demand	AU	Assiut University campus
DFP	Depletion-fossil fuel potential	PVC	Polyvinyl chloride

1. Introduction

Buildings play a significant role in the global energy and environmental strategies since they have a remarkable share of the world's energy consumed. This share is around 40 % and more than one-third of greenhouse gas (GHG) emissions [1]. According to Egypt's first BIENNIAL report [2], the building industries and materials have 23% of all fuel combustion activities and 22% of all GHG emissions, as shown in Figure 1.

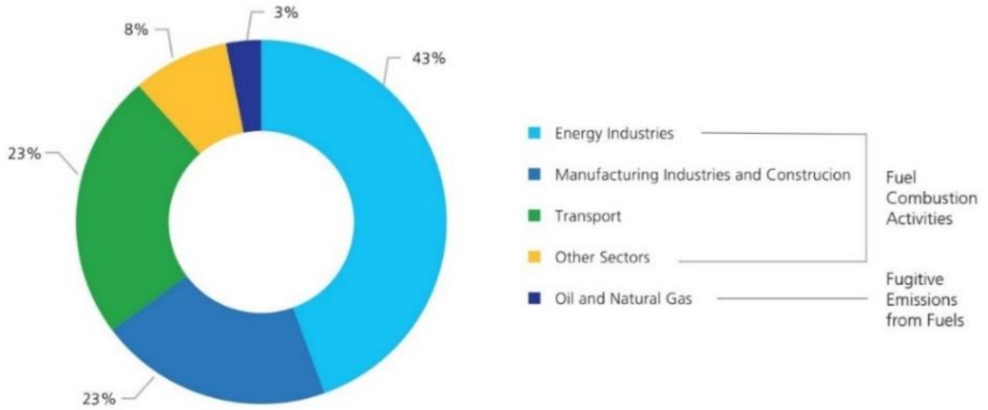


Figure 1 Emissions per category in the energy sector [3]

Previously, a brief was given regarding raw material extraction, energy emissions, and GHG emissions. As for emissions such as CO_2, CH_4, and N_2O,

Figure 2 shows the contribution of the main categories to the total emissions. Fuel combustion pursuits make up 97% of total emission with the CO_2 as the main contributor.

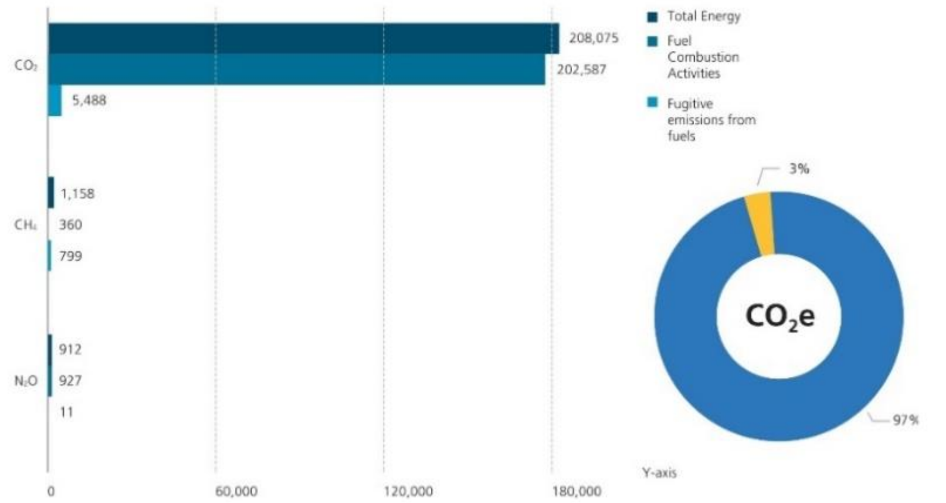


Figure 2 Main energy categories contributing to energy emissions [3]

Figure 3 describes the contribution of the fuel consumption subcategories to total CO_2, CH_4, and N_2O emissions. The CO_2 emissions are ranked third for the manufacturing industries and construction.

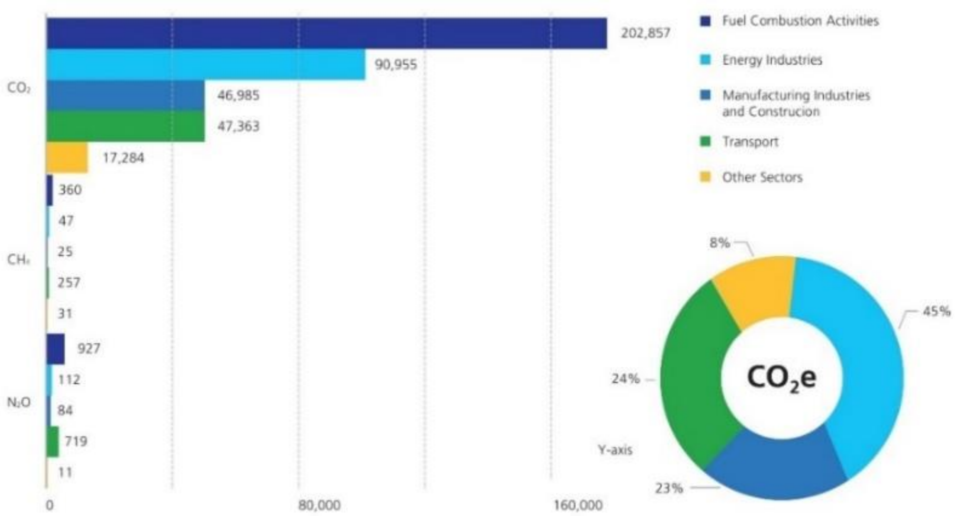


Figure 3 Fuel combustion activities contribution [3]

As shown in previous statistics, many natural raw materials are consumed by physical industries. Also, the fuel combustion used in manufacturing emits enormous hazardous emissions. On the other hand, the window opening has a considerable function in all buildings. Depending on the designers, there are enormous designs and various frame materials. The windows building has a prominent role in providing daylighting and preserving environmental performance inside the spaces/rooms.

Consequently, when the indoor thermal comfort is under control, energy consumption and environmental emissions will be reduced. Façade openings consist of two main parts: (1) glass and (2) window frames. This study will introduce an integrated comparative analysis of windows frame material, which are aluminum and wood. Three methods will be introduced and applied, Life Cycle Assessment (LCA), Building Information Modeling (BIM), and Environmental Performance (EP). The study's primary goal is to investigate the environmental emissions from the aluminum and wood manufacturing process (LCA method), afterwards, compared to the indoor environmental performance results (EP method). The two scenarios' quantities will be calculated using the BIM model and considered as inputs in the PRe SimaPro (LCA results) and DesignBuilder (EP results). This methodology will be applied to a proposed project at the Assiut University campus.

This study will carry value to the scientific research community. Moreover, the findings can help the building and construction industry choose the most suitable window frame materials that are more energy-efficient and less environmentally harmful and help the concerned legislative bodies and the decision-makers.

2. Literature review

Santos et al. [4] have introduced methods of integrating the LCA, BIM, and life cycle cost analysis for the high-rise projects. This research has introduced an analysis for a building in the design stage to conduct the LCA and LCC analysis. Also, in the design stage, Soust-Verdaguer et al. [5] have presented the LCA method to compare the timber and concrete family house. Their methods were the integration of BIM and LCA to assess the environmental impacts of the material industry. Using various environmental categories such as Global Warming Potential (GWP), Human Toxicity, and Resources Depletion, the study has presented its cradle-to-grave results.

Another study was carried out in Ghana by Ansah et al. [6], in which a comparative analysis has been done on four types of different façade materials, and an analysis integrating the BIM and LCA has been introduced. This study has measured the cumulative energy demand (CED) and GWP, as they are critical environmental parameters in this field, consistent with Owsianiak et al.

[7]. Ultimately, this study has offered useful guidelines for choosing façade systems. Santos et al. [4] have reported the integration of BIM and LCA; the outcome was mainly a developed model.
Xue et al. [8] selected the Campus buildings as a case study; this study has assessed abiotic depletion-fossil fuel potential (DFP) and GWP of the whole building materials. Finally, the research has introduced suggestions for future proposed buildings. DFP and GWP are the life cycle impact assessment (LCIA) results using the SimaPro and Ecoinvent database, focusing on the environmental assessment based on the input material and embodied emissions.
Adams and Pomada [9] have focused on the EP of windows materials with changing the thermal insulation. Also, the LCA of these materials has been carried out using the SimaPro and Ecoinvent database. The primary goal was decreasing ambient temperature and humidity. Souvirona et al. [10] have studied the indoor thermal comfort of window glazing and frame types regarding energy consumption.
The LCA of double-glazed aluminum-clad timber windows was carried out by Asif [1] to estimate the environmental impacts using the SimaPro and Ecoinvent databases. The study scope is a cradle-to-grave method by considering over a 30-year life span. Studying the production of window types and LCA of the manufacturing process have been implemented to calculate the embodied energy and the CO_2 emissions of the selected materials.
Applying the LCA, but for the renovation of existing buildings, Hasik et al. [11] have identified an approach to conduct whole building LCA on building renovation projects. This study has introduced an environmental impact assessment of the newly renovated building materials to reduce using new materials.
In Belgium, Eisazadeh et al. [12] have implemented numerous studies for advanced window systems for patient spaces in the hospitals. Using the MMG+_KU Leuven tool, this research has been conducted to address the environmental impacts for several modules, including glazing, coatings, window frame material, and window-to-wall ratio.
For windows retrofitting in heritage buildings to reduce the operating energy-saving, Litti et al. [13] have used the LCA method to discuss the difference between retrofitting alternatives for the windows to total replacement. For Italian residential windows, Intini et al. [14] have studied the LCA of the polyvinyl chloride (PVC) windows using the SimaPro software and Ecoinvent database. Another LCA for recycling PVC window frames has been conducted by Stichnothe et al. [15]. Using the SimaPro, the results have revealed that using PVC from recycled waste frames is the best environmental choice to reduce the GWP of the manufacturing process.

Using the Athena software, Salazar et al. [16] have compared the environmental impacts of different window framing materials to select the sustainable window based on the LCA method for optimizing window performance. For more sustainable choices, Kim et al. [17] have implemented the LCA study on a composite facade system and a glass curtain wall system to compare the environmental impacts, for mitigating the CO_2 emissions. Other international studies have been conducted such as [13], [18]–[21].
In August 2019, an investigation was conducted by Dalia Yacout [22]. During 2006 -2019, there were 39 LCA studies published in Egypt. It indicates the necessity to encourage LCA applications for assessing environmental impacts as a sustainable methodology in Egypt. Around 44% (17 case studies) of these studies have been applied to construction and building materials. Seven studies were on the cement and brick over the past 13 years, which clearly shows that there is an evident deficiency in the LCA applications. Only one study, Gihan Garas [23], studied some agricultural waste materials for building materials manufacturing in 2016.
Ultimately, many research types have globally introduced the LCA study and environmental performance individually, and others have applied the integration of the LCA and BIM. The case studies were different; one for an existing building, the other for a retrofitting building, and a few for the proposed projects. A novel framework for integrating LCA, BIM, and EP for a proposed building during the early phases of a project has been conducted in this study.

3. Material and Methods

This study will apply the LCA, BIM, and EP methods on one proposed building in Assiut, Egypt. The LCA will be used to assess the environmental impacts of aluminum and wood industries. The EP of the two window frame materials will be simulated. To collect information about the building construction components, the BIM comes to do that. Finally, the LCA results will be compared to the EP findings to specify the best choice. Regarding the study variants, this research has only focused on the cradle to gate scope for the aluminum and wood manufacturing process, as a designated system boundary. As shown in Figure 4, the integration analysis framework between the LCA, BIM, and EP.

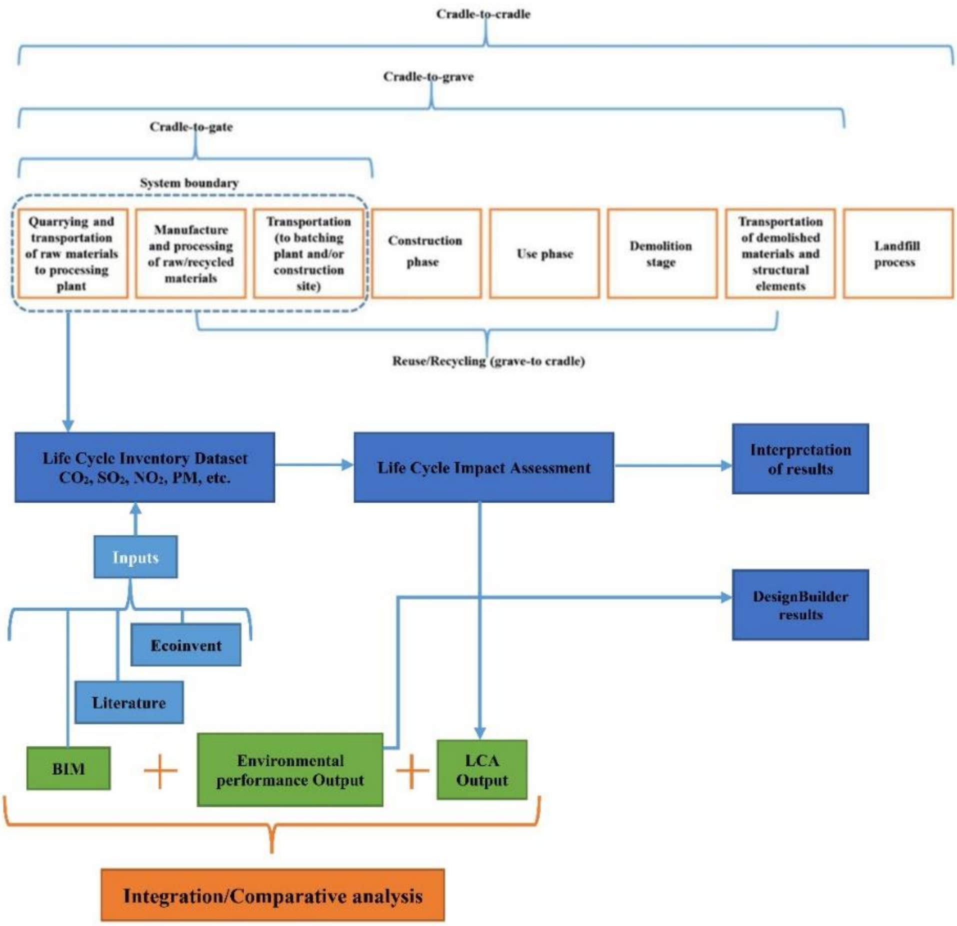


Figure 4 Framework of the integration analysis

3.1. Building Information Modeling method

According to Eleftheriadis et al. [24], BIM is defined as "a set of interacting policies, processes, and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle". The building model has been built in the BIM software, Autodesk Revit V2020, as a licensed version, as shown in Figure 5. The project consists of two floors and two underground levels (-3.20 level), the foundation level to -2.00 meter, and the drilling level to -3.20 meter. The total area of the building is around 442 m^2. Moreover, it contains eight different spaces: service rooms, clinics, waiting areas, and administrative space. The handicapped standards are considered in the building, as shown in Figure 5.

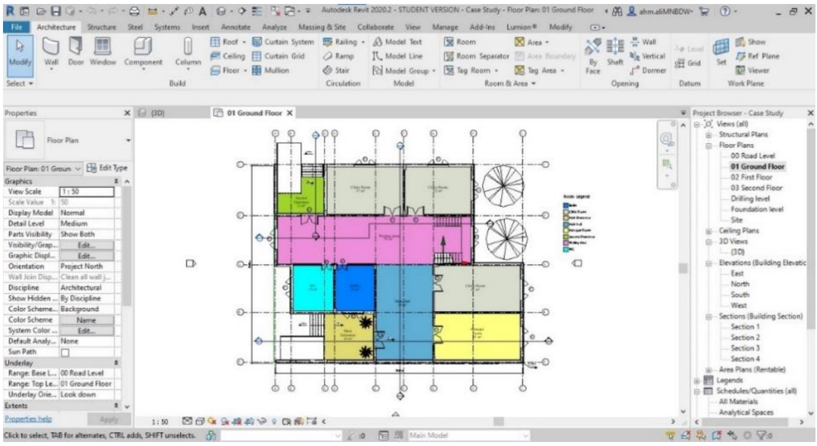


Figure 5 User interface of Autodesk Revit V2020 as a licensed version

3.2. DesignBuilder method

DesignBuilder is a simulation software that aids in assessing the EP of new and existing buildings. The author has used the licensed version 6.1.6.11 to simulate the case study's temperature and humidity for the aluminum and wood materials. The model has been exported as gbxML from Revit to the DesignBuilder with all BIM information. Figure 6 shows the case study model.

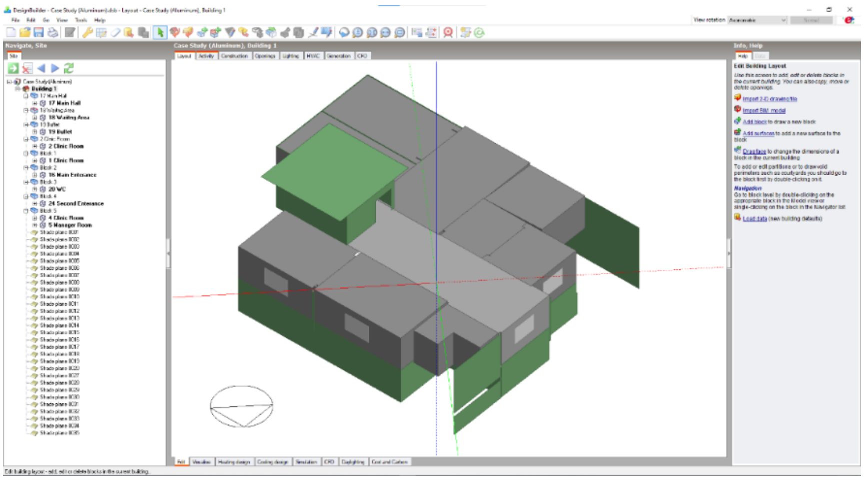


Figure 6 DesignBuilder model of AUHC

Figure 7 provides the thermophysical properties of the two window frame types: (a) aluminum and (b) wood. The author has depended on the Egyptian thermal material database from the literature and approved companies such as (Materials Database - Thermal Properties - Thermtest Inc.) [25], which introduce the thermal properties of different Egyptian materials, and then compared the same to the DesignBuilder library database to select the two materials from the software.

Inner surface	
Convective heat transfer coefficient (W/m2-K)	5.846
Radiative heat transfer coefficient (W/m2-K)	1.847
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	23.290
Radiative heat transfer coefficient (W/m2-K)	1.710
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	32000.002
R-Value (m2-K/W)	0.170
U-Value (W/m2-K)	**5.881**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0050
Km - Internal heat capacity (KJ/m2-K)	6.1600
Upper resistance limit (m2-K/W)	0.170
Lower resistance limit (m2-K/W)	0.170
U-Value surface to surface (W/m2-K)	31999.999
R-Value (m2-K/W)	0.170
U-Value (W/m2-K)	**5.881**

a) Thermophysical properties of aluminum

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	9.500
R-Value (m2-K/W)	0.275
U-Value (W/m2-K)	**3.633**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0200
Km - Internal heat capacity (KJ/m2-K)	16.7300
Upper resistance limit (m2-K/W)	0.275
Lower resistance limit (m2-K/W)	0.275
U-Value surface to surface (W/m2-K)	9.500
R-Value (m2-K/W)	0.275
U-Value (W/m2-K)	**3.633**

b) Thermophysical properties of wood

Figure 7 The thermophysical properties of the two window frame materials (DesignBuilder database)

3.3. Case study

Assiut University Hospital Clinic (AUHC) is a proposed project to be constructed inside the Assiut University (AU) campus. Figure 8 presents the google earth of the campus. Figure 9 shows the AUHC location inside the AU campus. This proposed building will undergo an integrated study to assess the LCA and EP using the BIM method.

Figure 8 Location of the Assiut University campus in Assiut city, Egypt (Google earth source)

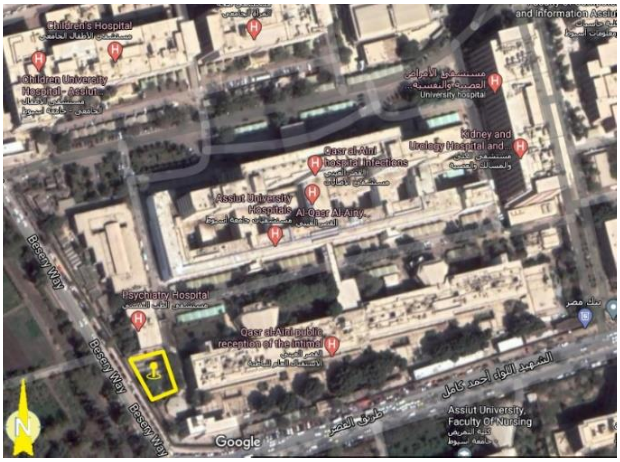


Figure 9 Location of the proposed new clinic (Google earth source)

Using the BIM model, the geographic location is determined by defining the internet mapping property, as presented in Figure 10. The longitude and latitude are designated with coordinators 27.1838397979736 and 31.1667556762695, respectively.

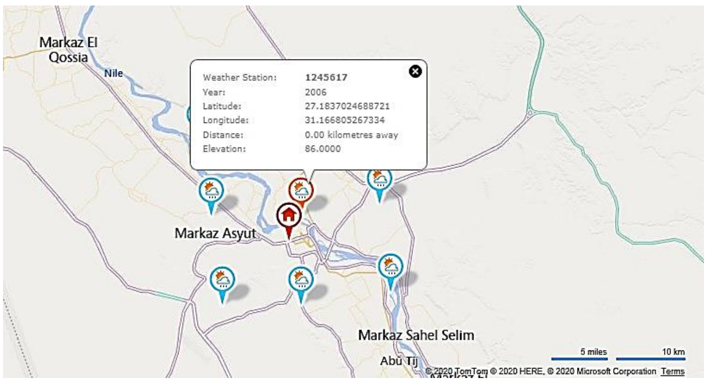
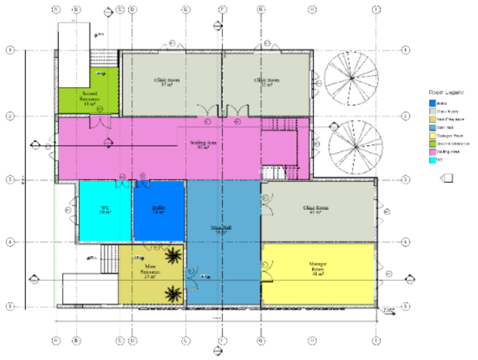
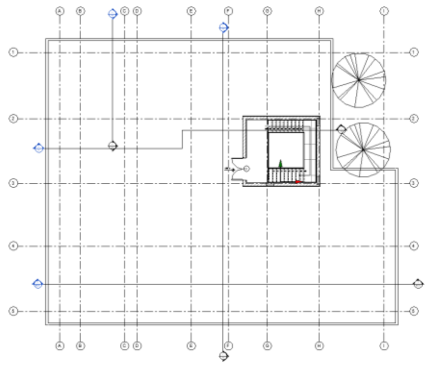


Figure 10 Location weather station of AUHC based on Autodesk Revit

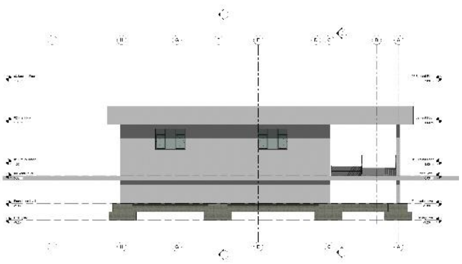
The weather file data is already embodied in the BIM model. Figure 11 documents the full BIM model drawings. It presents samples of drawings; the advantage of BIM is building all components together.



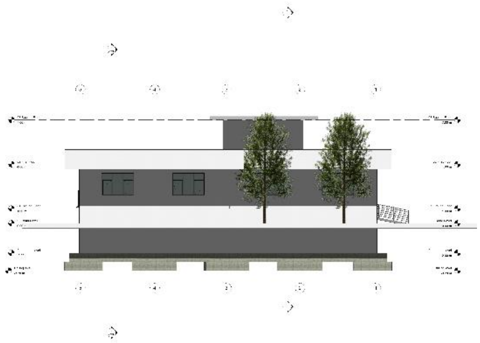
(a) The ground floor



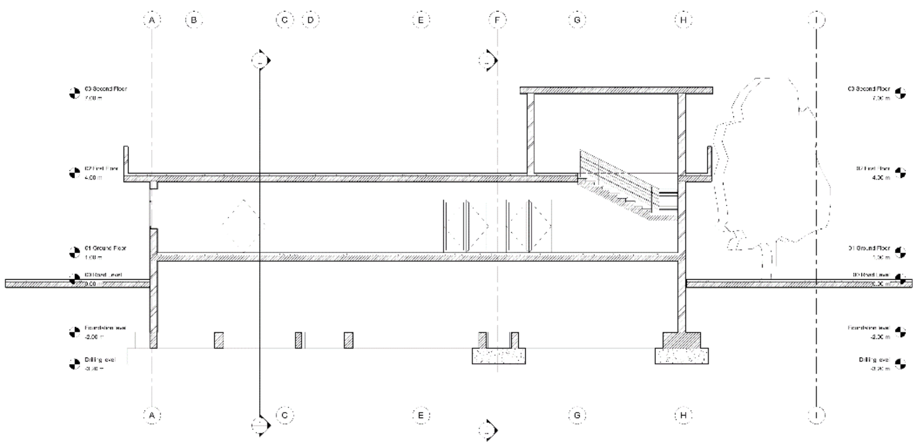
(b) The first floor



(c) The southern facade



(d) The western facade



(e) The building section

(f) Proposed perspectives

Figure 11 BIM model documents

4. Comparative LCA of window frame materials

4.1. Goal and scope definition

The International Standards Organization (ISO) has defined the most acknowledged standards with many series, shown in Figure 12.

- ISO 14040: Environmental management, LCA, Principles, and framework [26].
- ISO 14041: Environmental management, LCA, Goal definition and inventory analysis [27]
- ISO 14042: Environmental management, LCIA [28].
- ISO 14043: Environmental management, Life-cycle interpretation [29].

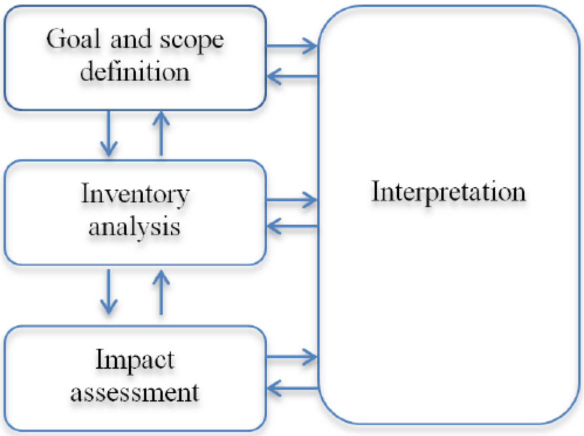


Figure 12 LCA framework defined by ISO [30]

Turning into the LCA study, Ali et al. [31] and Al-Ghamdi [32] have introduced a comparison between the LCA software. The two studies have mentioned that the PRe SimaPro is a complex analysis tool and an advanced skill level due to a comprehensive comparison. So, the PRe SimaPro version 9.1 has been used as a faculty licensed with all open-license Ecoinvent database. One of the essential phases of carrying out the LCA in SimaPro is to define the network flow of the manufacturing process for each material: aluminum and wood. Figure 13 displays the network flow of the wood industry. Also, Figure 14 presents the network flow of the aluminum industry for producing one kilogram (1 kg) of aluminium . There are raw materials, electricity, and fuel usage as inputs, and emissions as outputs. These data have been gathered from the literature reviews and Ecoinvent database. The study has introduced an approach for dealing with the lack of the Egyptian life cycle database, which will be discussed in a later section; *Life cycle inventory (Material inputs)*.

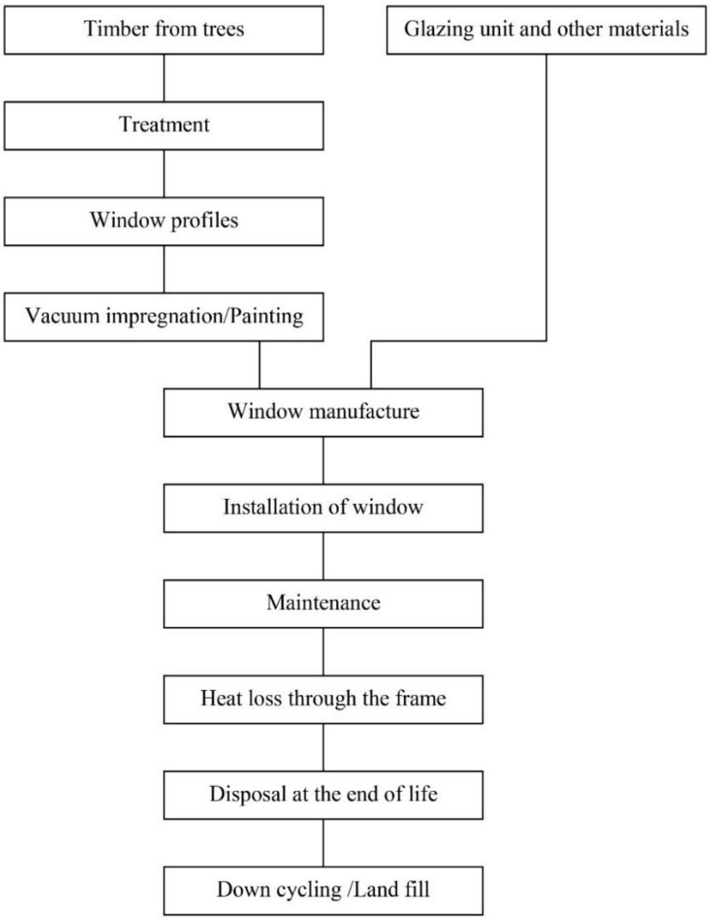


Figure 13 Network flow of the wood industry [33]

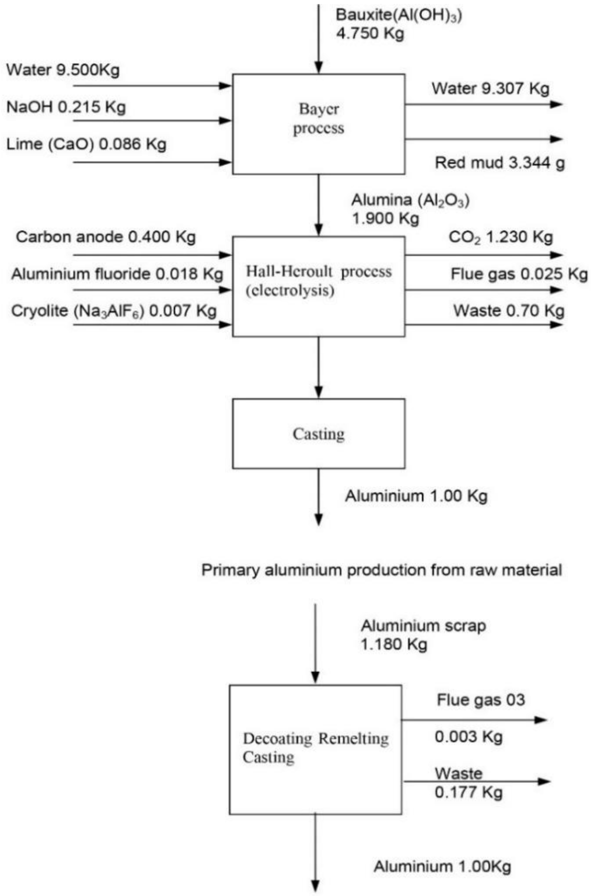


Figure 14 Network flow of the aluminum industry [33]

4.2. Life cycle inventory (Material inputs)

Based on the series ISO 14041: Environmental management, LCA, Goal definition, and inventory analysis, which was illustrated in section *4.1. Goal and scope definition*, as well as several previous scientific articles such as [34], [35], [44]–[46], [36]–[43], one kilogram (1 kg) has been defined to be the functional unit (FU). Table 1 lists the whole building material quantities from the BIM model. All these figures have been calculated according to the FU with one kilogram (1 kg) of wood and aluminum. The material quantities from BIM output are considered as inputs in SimaPro software.

Table 1 Material quantities from the BIM model

Name	Area (m^2)	Volume (m^3)
Brick	861	164.16
Concrete	4382	0.88
Steel	---	17.00

Name	Area (m^2)	Volume (m^3)
Mortar	3089	29.70
Tiles	1556	62.29
Glass	132	0.41
Plaster	3358	32.31
Wood/Aluminum (window frames opening)	88	1.20

Concerning the assumption and limitation of this study, the shortage of LCA applications and inventory datasets in Egypt is the main barrier. Therefore, the study has tried to get an appropriate method of selecting the building materials' database. Martínez-Rocamora et al. [47] have reviewed many studies; only those were dealing with the construction material industry. One of the study results is that the Ecoinvent and GaBi Database are the most comprehensive LCA databases. On paying the full SimaPro license, Ecoinvent is perfectly suited for construction purposes, since every category of construction material is included and developed with a wide variety of products. That is why this study has relied on the Ecoinvent V3 dataset [48]. Selecting the database is carefully conducted by picking the global market and the global industry of aluminum and wood from the Ecoinvent (SimaPro-based) to be closer to Egypt's manufacturing processes.

4.3. Life cycle impact assessment

The LCIA phase helps us differentiate among the environmental impacts of the materials. There are many methods for converting the life cycle inventory (LCI) database to the LCIA; this study will use the single score to present the midpoint and endpoint methods. Global warming, aquatic ecotoxicity, respiratory and non-renewable energy have been covered in the midpoint impact category. The second method involves the Human Health (HH) damage, Ecosystem Quality (EQ), and Resource Depletion (RD), which is involved in the endpoint impact category. Concerning the calculations of the environmental impact, the life cycle impact category should be designated. So, based on the literature review, there are many life cycle impact categories; for instance, articles [31], [32], [49], [50] have used the IMPACT 2002+ to analyze the impact categories that this study will investigate. Table 2 displays the IMPACT 2002+ category properties with the two methods: the midpoint and endpoint methods.

Table 2 IMPACT 2002+ characterization as life cycle impact category (version Q2.2) [51]

[source]	Midpoint category	Midpoint reference substance	Damage category (Endpoint)	Damage unit	Normalized damage unit
[a]	Human toxicity (carcinogens + non-carcinogens)	kg Chloroethylene into air-eq	Human health		
[b]	Respiratory (inorganics)	kg PM2.5 into air-eq	Human health	DALY	Point
[b]	Ionizing radiations	Bq Carbon-14 into air-eq	Human health		
[b]	Ozone layer depletion	kg CFC-11 into air-eq	Human health		
[b]	Photochemical oxidation (= Respiratory (organics) for human health)	kg Ethylene into air-eq	Human health Ecosystem quality	n/a	n/a
[a]	Aquatic ecotoxicity	kg Triethylene glycol into water-eq	Ecosystem quality		
[a]	Terrestrial ecotoxicity	kg Triethylene glycol into soil-eq	Ecosystem quality		
[b]	Terrestrial acidification/nutrification	kg SO_2 into air-eq	Ecosystem quality	PDF·m^2·y	Point
[c]	Aquatic acidification	kg SO_2 into air-eq	Ecosystem quality		
[c]	Aquatic eutrophication	kg PO- into the water -eq	Ecosystem quality		
[b]	Land occupation	m^2 Organic arable land-eq · y	Ecosystem quality		
	Water turbine	inventory in m3	Ecosystem quality		
[IPCC]	Global warming	kg CO_2 into air-eq	Climate change (life support system)	kg CO_2 into air-eq	Point
[d]	Non-renewable energy	MJ or kg Crude oil-eq (860 kg/m^3)	Resources	MJ	Point
[b]	Mineral extraction	MJ or kg Iron-eq (in ore)	Resources		

[a]IMPACT 2002, [b]Eco-indicator 99, [c]CML 2002, [d] Ecoinvent, [IPCC] (IPCC AR5 Report), and [USEPA] (EPA). DALY= Disability-Adjusted Life Years; PDF= Potentially Disappeared Fraction of species; -eq= equivalents; y= year.

5. Results and Interpretation

In this section, the results will be divided into two subsections: (1) LCA results using the IMPACT 2002+, and (2) DesignBuilder results. Then, a comparative analysis will be conducted.

5.1. Life cycle assessment results

Based on the network flow of each material, the single score method results, as an LCIA finding, are shown in Figure 15. As an apparent result, the aluminum scored the highest environmental impact—the single score presents its findings, with point (Pt) unit. So, overall, the aluminum had 29.6 Pt and the wood had 7.57 Pt: declining the impact by 75% approximately. These results are in agreement with Carlisleet al. [52]. Turning to the impact categories, the respiratory inorganics and GWP are the highest harmful impacts for each industry, in consonance with Owsianiak et al. [7]. As for the GWP, with equivalent emissions, the aluminum and wood industries' results are (7.57E4 kg CO_2 eq) and (1.57E5 kg CO_2 eq), respectively. It can be attributed to the fact that the fuel used in the aluminum industry is more than the wood industry, consistent with Wang et al. [53].

The non-renewable energy comes in the third rank of the aluminum industry with 6.15 Pt and 1.4 Pt for the wood industry. On the other hand, there are some ignored impacts, such as aquatic acidification, aquatic eutrophication, and aquatic ecotoxicity. These are below 1.00 Pt for the aluminum industry, and below 0.05 Pt for the wood industry. Another ignored environmental impact is the ozone layer depletion. The ozone is affected by chlorofluorocarbons (CFCs), halons, and bromides emissions, and both industries do not emit these emissions in the manufacturing process, as Hundy et al. [54] reported. The land occupation is one of the wood industry's ecological damages because of logging the trees and its effect on the ecosystem [55]. Therefore, the wood industry takes 0.519 Pt, compared to 0.0621 Pt for the aluminum industry. Turning to the terrestrial ecotoxicity impact, conforming to Hong et al. [56], there is a minimal environmental degradation from the aluminum industry; 1.67 Pt and a neglected impact of 0.508 Pt for the wood industry. Based on Segovia et al. and Nunez et al. [57], [58], the carcinogens category represented 66-78% of the total contributing emissions for the wood industry and 100% of the aluminum industry contributions. It could explain why the aluminum industry scored 1.14 Pt and the wood industry scored 0.178 Pt.

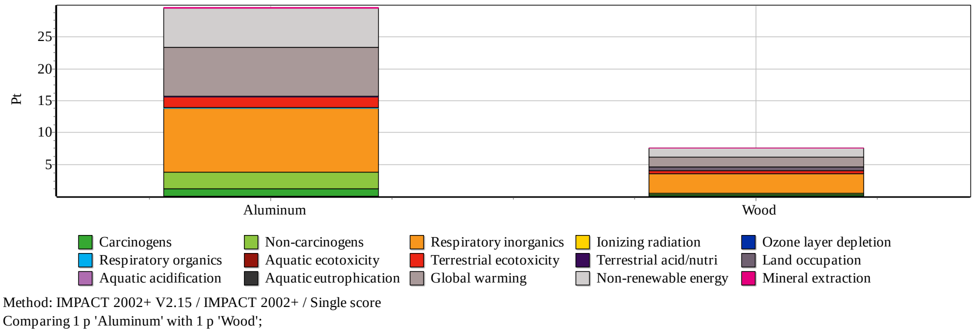


Figure 15 Single score results per impact category (Midpoint method)

Figure 16 presents the endpoint results. As the author pointed out, in the *Life cycle impact assessment* section, that HH and RD are the most significant in the results, the next column chart shows that the HH has recorded the highest value: 13.9 Pt for aluminium and 3.51 Pt for wood, in agreement with Babaizadeh et al. [59] results. Also, the RD was 6.22 Pt for aluminium and 1.44 Pt for wood, in agreement with Invidiata et al. [60] results. To investigate the endpoint method in-deep, Table 2 needs to be returned to. This table demonstrates the midpoint impacts that lead to the endpoint impacts. The respiratory inorganics, aquatic acidification, aquatic eutrophication, aquatic ecotoxicity, land occupation, and terrestrial ecotoxicity affect the ecosystem quality as an endpoint impact. These scored have recorded the lowest values by eco-points. So, Figure 16 supports this result, ranked last among the environmental impacts. The ecosystem quality impact has scored 1.89 Pt and 1.06 Pt for the aluminium and wood industry, respectively. On the other hand, for the effect of the GWP, land occupation and ozone layer depletion on the HH as an endpoint method, however, the GWP is the primary factor that increases the HH impact. The main contributor to the resources depletion is the non-renewable energy environmental impact. Consequently, the total environmental impacts of the resources depletion of the aluminium industry are higher than those of wood.

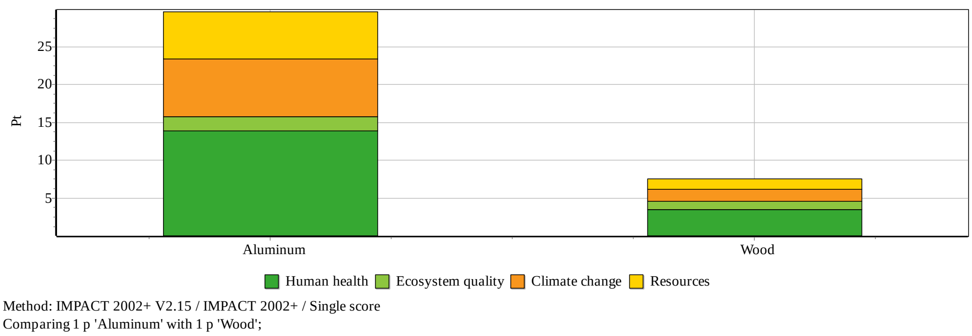


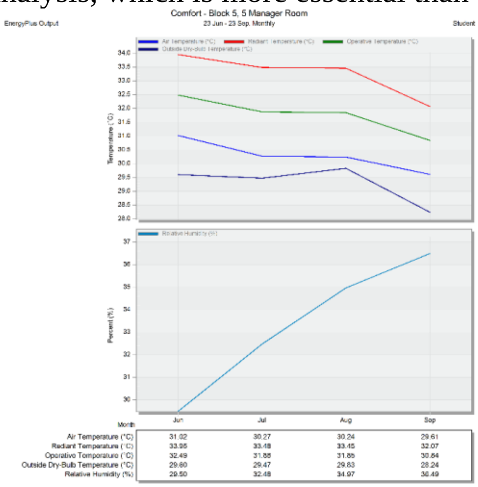
Figure 16 Single score results per window material (Endpoint method)

5.2. DesignBuilder findings

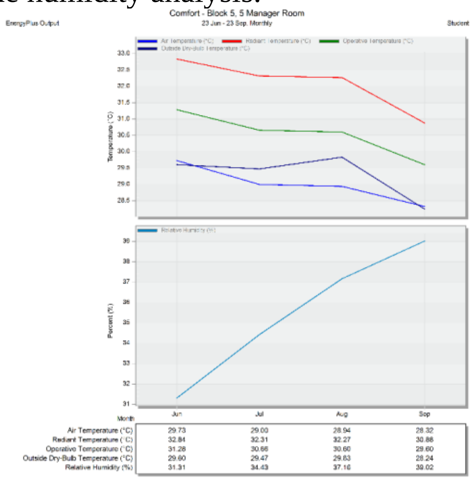
It is the last part of the analysis, after presenting the LCA and BIM methods, the EP results will be addressed in this section. Furthermore, the simulation measures have been calculated during the summer period from Jun. 23 to Sep. 23. Also, to unify the variants, the glazing type has been fixed for two scenarios. As Figure 17 displays, the ambient temperature difference for the aluminum and wood windows has fluctuated between 1.00 - 1.30 °C with a slight change. Using the metal windows frames, it causes a slight rise in indoor temperatures.

With the fundamentals of EP, the humidity is inversely proportional to the temperature, as reported in Mbithi et al. [61]. In aluminum windows, the relative humidity is higher than the wood window case by 1.81-2.53%.

As an overall EP result, there is a small difference between the two cases' results, even though the aluminum windows are the highest in the temperature analysis, which is more essential than the humidity analysis.



a) Aluminum window frame case



b) Wood window frame case

Figure 17 Environmental performance results with DesignBuilder simulation

6. Discussion

As a holistic result of the integration analysis, the aluminum industry has recorded higher negative environmental impacts, and environmental performance, than the wood industry. Significantly, the GWP and non-renewable energy sources impacts have scored high numbers because the carbon dioxide and methane are released into the atmosphere from the fuel used in the building materials industry. To interpret this increment, the Annual Report of the Union of Concerned Scientists [62] has revealed that fossil fuels coal, oil, and natural gas will increase greenhouse gases. Consequently, the

GWP will negatively increase, as using such fuels for the aluminum industry is mandatory, as shown in Figure 14 and agreement with [63]–[66].
Regarding the aquatic acidification, aquatic eutrophication, and aquatic ecotoxicity, results were below 1.00 Pt for the aluminum industry, and below 0.05 Pt for the wood industry. Because they are water emissions, and the wood and the aluminum get rid of its waste into municipal landfills, which reduces the aquatic impacts [67]. The HH and RD have recorded the most massive numbers; specifically, the aluminum industry has a remarkable environmental burden, consistent with Salazar et al. [67] and Babaizadeh et al. [68]. In particular, the HH has recorded the highest impacts in the aluminum industry since the CO_2, CH_4, and N_2O are emitted much more than by the wood.
As a comprehensive outcome, selecting the building materials is very important to achieve the maximum environmental and energy optimization. Additionally, in this millennium, introducing sustainable building materials becomes necessary and vital for implementing strategic environmental plans. To summarize, the aluminum is not the best option for the window frames; this result is drawn from the integration analysis of the LCA and EP, aided by the BIM. Regarding the industry improvements, sustainable alternative materials and substitutional fuels should be introduced by the stakeholders: designers, policymakers, and building owners. The presented study can be used as a model for consistent LCAs on other proposed projects. Also, as future extended work, the life cycle cost analysis is suggested to be investigated.

7. Limitation and recommendations

The main obstacles and challenges indicate that three important points should be considered. First, designers should use the BIM application on the newly designed building. Second, the lack of an Egyptian LCI database should be addressed. Third, the LCA applications in Egypt are scarce, as there is an absence of the Egyptian LCI database. So, such applications should be encouraged. The author recommends using the European dataset to apply the LCA in Egyptian case studies by selecting the global industry and market data from the Ecoinvent database. This study has presented a method of selecting the building materials' database from the Ecoinvent to apply the LCA application in Egypt. Therefore, the life cycle inventory dataset and analysis outcomes provided in this research are anticipated to help designers better understand building material selection and system improvement from the whole life cycle perspective.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have influenced the work reported in this research.

References

[1] M. Asif, "An empirical study on life cycle assessment of double-glazed aluminium-clad timber windows," *Int. J. Build. Pathol. Adapt.*, vol. 37, no. 5, pp. 547–564, 2019, doi: 10.1108/IJBPA-01-2019-0001.
[2] E. E. A. A. Ministry of Environment, *Egypt's first Biennial Update Report to the United Nations Framework Convenstion on Climate Change*. 2018.
[3] Egyptian Ministry of Environment, *State of the Environment Report 2017 Arab Republic of Egypt*. 2017.
[4] R. Santos, A. Aguiar Costa, J. D. Silvestre, and L. Pyl, "Development of a BIM-based Environmental and Economic Life Cycle Assessment tool," *J. Clean. Prod.*, vol. 265, 2020, doi: 10.1016/j.jclepro.2020.121705.
[5] B. Soust-Verdaguer, C. Llatas, and L. Moya, "Comparative BIM-based Life Cycle Assessment of Uruguayan timber and concrete-masonry single-family houses in design stage," *J. Clean. Prod.*, vol. 277, p. 121958, 2020, doi: 10.1016/j.jclepro.2020.121958.
[6] M. K. Ansah, X. Chen, H. Yang, L. Lu, and P. T. I. Lam, "An integrated life cycle assessment of different façade systems for a typical residential building in Ghana," *Sustain. Cities Soc.*, vol. 53, no. November 2019, p. 101974, 2020, doi: 10.1016/j.scs.2019.101974.
[7] M. Owsianiak, A. Laurent, A. Bjørn, and M. Z. Hauschild, "IMPACT 2002+, ReCiPe 2008 and ILCD's recommended practice for characterisation modelling in life cycle impact assessment: A case study-based comparison," *Int. J. Life Cycle Assess.*, vol. 19, no. 5, pp. 1007–1021, 2014, doi: 10.1007/s11367-014-0708-3.
[8] Z. Xue, H. Liu, Q. Zhang, J. Wang, J. Fan, and X. Zhou, "The impact assessment of campus buildings based on a life cycle assessment-life cycle cost integrated model," *Sustain.*, vol. 12, no. 1, pp. 1–24, 2020, doi: 10.3390/su12010294.
[9] J. Adamus and M. Pomada, "Selected issues of choosing composite materials for window supporting beams," *J. Build. Eng.*, vol. 32, no. February, p. 101542, 2020, doi: 10.1016/j.jobe.2020.101542.
[10] J. Souviron, G. van Moeseke, and A. Z. Khan, "Analysing the environmental impact of windows: A review," *Build. Environ.*, vol. 161, no. April, 2019, doi: 10.1016/j.buildenv.2019.106268.
[11] V. Hasik, E. Escott, R. Bates, S. Carlisle, B. Faircloth, and M. M. Bilec, "Comparative whole-building life cycle assessment of renovation and new construction," *Build. Environ.*, vol. 161, no. May, p. 106218, 2019, doi: 10.1016/j.buildenv.2019.106218.
[12] N. Eisazadeh and K. Allacker, "Environmental Performance of Advanced Window Systems in Patient Rooms," *Procedia CIRP*, vol. 69, no. May, pp. 166–171, 2018, doi: 10.1016/j.procir.2017.11.032.
[13] G. Litti, A. Audenaert, and M. Lavagna, "Life cycle operating energy saving from windows retrofitting in heritage buildings accounting for technical performance decay," *J. Build. Eng.*, vol. 17, no. December 2017, pp. 135–153, 2018, doi: 10.1016/j.jobe.2018.02.006.

[14] F. Intini, G. Rospi, N. Cardinale, S. Köhtz, and M. Dassisti, "Life cycle assessment of Italian residential windows: Sensitivity of analysis," *Int. J. Heat Technol.*, vol. 34, no. Special Issue 2, pp. S235–S241, 2016, doi: 10.18280/ijht.34S207.

[15] H. Stichnothe and A. Azapagic, "Life cycle assessment of recycling PVC window frames," *Resour. Conserv. Recycl.*, vol. 71, pp. 40–47, 2013, doi: 10.1016/j.resconrec.2012.12.005.

[16] J. Salazar, "Life cycle assessment (LCA) of windows and window materials," *Eco-Efficient Constr. Build. Mater. Life Cycle Assess. (LCA), Eco-Labelling Case Stud.*, pp. 502–527, 2013, doi: 10.1533/9780857097729.3.502.

[17] K. H. Kim, "A comparative life cycle assessment of a transparent composite façade system and a glass curtain wall system," *Energy Build.*, vol. 43, no. 12, pp. 3436–3445, 2011, doi: 10.1016/j.enbuild.2011.09.006.

[18] A. Pierucci, A. Cannavale, F. Martellotta, and F. Fiorito, "Smart windows for carbon neutral buildings: A life cycle approach," *Energy Build.*, vol. 165, pp. 160–171, 2018, doi: 10.1016/j.enbuild.2018.01.021.

[19] T. Bruce-Hyrkäs, P. Pasanen, and R. Castro, "Overview of Whole Building Life-Cycle Assessment for Green Building Certification and Ecodesign through Industry Surveys and Interviews," *Procedia CIRP*, vol. 69, no. May, pp. 178–183, 2018, doi: 10.1016/j.procir.2017.11.127.

[20] Carbon Leadership Forum, "Life Cycle Assessment of Buildings : Technical Guidance," no. June, p. 12, 2018, [Online]. Available: http://carbonleadershipforum.org/projects/lca-practice-guide/.

[21] H. Gervasio and S. Dimova, *Model for Life Cycle Assessment (LCA) of buildings*. 2018.

[22] D. M. M. Yacout, "Assessing Status of Life Cycle Assessment Studies in Egypt," vol. 2, no. August, pp. 177–189, 2019, doi: 10.14456/cast.2019.15.

[23] G. Garas, E. Bakhoum, and M. Allam, "Optimal use of selected waste materials in buildings," *Ecol. Environ. Conserv.*, vol. 22, no. 3, pp. 1129–1136, 2016.

[24] S. Eleftheriadis, D. Mumovic, and P. Greening, "Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 811–825, 2017, doi: 10.1016/j.rser.2016.09.028.

[25] "Materials Database - Thermal Properties - Thermtest Inc.," 2020. https://thermtest.com/materials-database (accessed Sep. 28, 2020).

[26] International Organization For Standardization (ISO), "ISO - ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework," 2006. https://www.iso.org/standard/37456.html (accessed Sep. 04, 2020).

[27] International Organization For Standardization (ISO), "ISO - ISO 14041:1998 - Environmental management — Life cycle assessment — Goal and scope definition and inventory analysis," 1998. https://www.iso.org/standard/23152.html (accessed Sep. 04, 2020).

[28] International Organization For Standardization (ISO), "ISO - ISO 14042:2000 - Environmental management — Life cycle assessment — Life cycle impact

assessment," 2000. https://www.iso.org/standard/23153.html (accessed Sep. 04, 2020).
[29] International Organization For Standardization (ISO), "ISO - ISO 14043:2000 - Environmental management — Life cycle assessment — Life cycle interpretation," 2000. https://www.iso.org/standard/23154.html (accessed Sep. 04, 2020).
[30] M. M. Khasreen, P. F. G. Banfill, and G. F. Menzies, "Life-Cycle Assessment and the Environmental Impact of Buildings: A Review," *Sustainability*, vol. 1, no. 3, pp. 674–701, Sep. 2009, doi: 10.3390/su1030674.
[31] A. A. M. M. Ali, A. M. Negm, M. F. Bady, M. G. E. Ibrahim, and M. Suzuki, "Environmental impact assessment of the Egyptian cement industry based on a life-cycle assessment approach: a comparative study between Egyptian and Swiss plants," *Clean Technol. Environ. Policy*, vol. 18, no. 4, 2016, doi: 10.1007/s10098-016-1096-0.
[32] S. G. Al-Ghamdi and M. M. Bilec, "Green Building Rating Systems and Whole-Building Life Cycle Assessment: Comparative Study of the Existing Assessment Tools," *J. Archit. Eng.*, vol. 23, no. 1, pp. 1–9, 2017, doi: 10.1061/(ASCE)AE.1943-5568.0000222.
[33] T. M. M. Asif, A. Davidson, "Life Cycle of Window Materials - a Comparative Assessment," *Chart. Inst. Build. Serv. Eng. CIBSE*, pp. 1–13, 2002.
[34] A. Ghose, S. J. McLaren, and D. Dowdell, "Upgrading New Zealand's existing office buildings – An assessment of life cycle impacts and its influence on 2050 climate change mitigation target," *Sustain. Cities Soc.*, vol. 57, no. March, p. 102134, 2020, doi: 10.1016/j.scs.2020.102134.
[35] A. D. La Rosa *et al.*, "Life cycle assessment of a novel hybrid glass-hemp/thermoset composite," *J. Clean. Prod.*, vol. 44, pp. 69–76, 2013, doi: 10.1016/j.jclepro.2012.11.038.
[36] Chin How Ong, "Life Cycle Assessment of Cement in Malaysia," 2007.
[37] R. Azari, "Integrated energy and environmental life cycle assessment of office building envelopes," *Energy Build.*, vol. 82, pp. 156–162, 2014, doi: 10.1016/j.enbuild.2014.06.041.
[38] A. Mastrucci, A. Marvuglia, U. Leopold, and E. Benetto, "Life Cycle Assessment of building stocks from urban to transnational scales: A review," *Renew. Sustain. Energy Rev.*, vol. 74, no. February, pp. 316–332, 2017, doi: 10.1016/j.rser.2017.02.060.
[39] V. Oquendo-Di Cosola, F. Olivieri, L. Ruiz-García, and J. Bacenetti, "An environmental Life Cycle Assessment of Living Wall Systems," *J. Environ. Manage.*, vol. 254, no. November 2019, p. 109743, 2020, doi: 10.1016/j.jenvman.2019.109743.
[40] P. Hewlett, *Lea" s Chemistry of Cement and Concrete*, vol. 58, no. 10. 2004.
[41] A. A. M. Ali, A. M. Negm, M. F. Bady, M. G. E. Ibrahim, and M. Suzuki, "Environmental impact assessment of the Egyptian cement industry based on a life-cycle assessment approach: a comparative study between Egyptian and Swiss plants," *Clean Technol. Environ. Policy*, vol. 18, no. 4, pp. 1053–1068, 2016, doi: 10.1007/s10098-016-1096-0.
[42] M. Dabaieh, J. Heinonen, D. El-Mahdy, and D. M. Hassan, "A comparative

study of life cycle carbon emissions and embodied energy between sun-dried bricks and fired clay bricks," *J. Clean. Prod.*, vol. 275, p. 122998, 2020, doi: 10.1016/j.jclepro.2020.122998.

[43] E. Jamieson, B. McLellan, A. van Riessen, and H. Nikraz, "Comparison of embodied energies of Ordinary Portland Cement with Bayer-derived geopolymer products," *J. Clean. Prod.*, vol. 99, pp. 112–118, 2015, doi: 10.1016/j.jclepro.2015.03.008.

[44] B. Cai, J. Wang, J. He, and Y. Geng, "Evaluating CO2 emission performance in China's cement industry: An enterprise perspective," *Appl. Energy*, vol. 166, pp. 191–200, 2015, doi: 10.1016/j.apenergy.2015.11.006.

[45] D. Song, J. Yang, B. Chen, T. Hayat, and A. Alsaedi, "Life-cycle environmental impact analysis of a typical cement production chain," *Appl. Energy*, vol. 164, pp. 916–923, 2016, doi: 10.1016/j.apenergy.2015.09.003.

[46] S. Eleftheriadis, P. Duffour, and D. Mumovic, "BIM-embedded life cycle carbon assessment of RC buildings using optimised structural design alternatives," *Energy Build.*, vol. 173, pp. 587–600, 2018, doi: 10.1016/j.enbuild.2018.05.042.

[47] A. Martínez-Rocamora, J. Solís-Guzmán, and M. Marrero, "LCA databases focused on construction materials: A review," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 565–573, 2016, doi: 10.1016/j.rser.2015.12.243.

[48] Ecoinvent Centre, "Ecoinvent data v3.2," *Switzerland.: Swiss Centre for Life Cycle Inventories*, 2016. http://www.ecoinvent.org/home.html (accessed Mar. 28, 2016).

[49] C. Ingrao, A. Messineo, R. Beltramo, T. Yigitcanlar, and G. Ioppolo, "How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance," *J. Clean. Prod.*, vol. 201, pp. 556–569, 2018, doi: 10.1016/j.jclepro.2018.08.080.

[50] M. U. Hossain and S. Thomas Ng, "Influence of waste materials on buildings' life cycle environmental impacts: Adopting resource recovery principle," *Resour. Conserv. Recycl.*, vol. 142, no. October 2018, pp. 10–23, 2019, doi: 10.1016/j.resconrec.2018.11.010.

[51] X. Bengoa and M. Margni, "IMPACT 2002 + : User Guide," 2012.

[52] H. Babaizadeh, N. Haghighi, S. Asadi, R. Broun, and D. Riley, "Life cycle assessment of exterior window shadings in residential buildings in different climate zones," *Build. Environ.*, vol. 90, pp. 168–177, 2015, doi: 10.1016/j.buildenv.2015.03.038.

[53] J. Wang, H. Wu, H. Duan, G. Zillante, J. Zuo, and H. Yuan, "Combining life cycle assessment and Building Information Modelling to account for carbon emission of building demolition waste: A case study," *J. Clean. Prod.*, vol. 172, pp. 3154–3166, 2016, doi: 10.1016/j.jclepro.2017.11.087.

[54] G. F. Hundy, A. R. Trott, and T. C. Welch, "Refrigerants," in *Refrigeration, Air Conditioning and Heat Pumps*, Elsevier, 2016, pp. 41–58.

[55] G. Doka *et al.*, "The Assessment of Environmental Impacts caused by Land Use in the Life Cycle Assessment of Forestry and Forest Products," 2016.

[56] J. Hong, J. Hong, J. Zhou, and X. Xu, "Environmental and economic life cycle

assessment of aluminium-silicon alloys production: A case study in China," *J. Clean. Prod.*, vol. 24, pp. 11–19, 2012, doi: 10.1016/j.jclepro.2011.11.003.

[57] F. Segovia, P. Blanchet, B. Amor, C. Barbuta, and R. Beauregard, "Life cycle assessment contribution in the product development process: Case study of wood aluminium-laminated panel," *Sustain.*, vol. 11, no. 8, 2019, doi: 10.3390/su11082258.

[58] P. Nunez and S. Jones, "Cradle to gate: life cycle impact of primary aluminium production," *Int. J. Life Cycle Assess.*, vol. 21, no. 11, pp. 1594–1604, Nov. 2016, doi: 10.1007/s11367-015-1003-7.

[59] H. Babaizadeh and M. Hassan, "Life cycle assessment of nano-sized titanium dioxide coating on residential windows," *Constr. Build. Mater.*, vol. 40, pp. 314–321, 2013, doi: 10.1016/j.conbuildmat.2012.09.083.

[60] A. Invidiata and E. Ghisi, "Life-cycle energy and cost analyses of window shading used to improve the thermal performance of houses," *J. Clean. Prod.*, vol. 133, pp. 1371–1383, 2016, doi: 10.1016/j.jclepro.2016.06.072.

[61] J. N. Mbithi, V. S. Springthorpe, and S. A. Sattar, "Effect of relative humidity and air temperature on survival of hepatitis A virus on environmental surfaces," *Appl. Environ. Microbiol.*, vol. 57, no. 5, pp. 1394–1399, 1991, doi: 10.1128/aem.57.5.1394-1399.1991.

[62] D. C. on W. in the S. Advisory, "2019 Annual Report," *2019 Annu. Rep.*, vol. 61, no. January, p. 26, 2019, doi: 10.1017/CBO9781107415324.004.

[63] G. Athira, A. Bahurudeen, and S. Appari, "Sustainable alternatives to carbon intensive paddy field burning in India: A framework for cleaner production in agriculture, energy, and construction industries," *J. Clean. Prod.*, vol. 236, p. 117598, 2019, doi: 10.1016/j.jclepro.2019.07.073.

[64] N. Said, S. A. El-Shatoury, L. F. Díaz, and M. Zamorano, "Quantitative appraisal of biomass resources and their energy potential in Egypt," *Renew. Sustain. Energy Rev.*, vol. 24, pp. 84–91, 2013, doi: 10.1016/j.rser.2013.03.014.

[65] M. M. Abdel Daiem, N. Said, and A. M. Negm, "Potential energy from residual biomass of rice straw and sewage sludge in Egypt," *Procedia Manuf.*, vol. 22, pp. 818–825, 2018, doi: 10.1016/j.promfg.2018.03.116.

[66] N. N Atta and A. A El Baz, "Anaerobic Co-Digestion of Wastewater Activated Sludge and Rice Straw in Batch and Semi Continuous Modes," *J. Fundam. Renew. Energy Appl.*, vol. 06, no. 02, 2016, doi: 10.4172/2090-4541.1000204.

[67] J. Salazar and T. Sowlati, "Life cycle assessment of windows for the North American residential market: Case study," *Scand. J. For. Res.*, vol. 23, no. 2, pp. 121–132, 2008, doi: 10.1080/02827580801906981.

[68] H. Babaizadeh, N. Haghighi, R. Broun, and S. Asadi, "Life Cycle Assessment of Common Materials Used for Exterior Window Shadings in Residential Buildings," *Procedia Eng.*, vol. 118, pp. 794–801, 2015, doi: 10.1016/j.proeng.2015.08.516.

JES, Assiut University, Faculty of Engineering, Vol. 48, No. 6, November 2020, pp. 1024-1050

تحليل متكامل مع تقييم دورة الحياة ونمذجة معلومات البناء والأداء البيئي لمواد النوافذ: عيادة مستشفى جامعة أسيوط كدراسة حالة

أحمد عبد المنطلب محمد علي

أستاذ مساعد بقسم العمارة، كلية العمارة والتخطيط، جامعة القصيم، القصيم ٥٢٥٧١، المملكة العربية السعودية
مدرس بقسم الهندسة المعمارية، كلية الهندسة، جامعة أسيوط، أسيوط ٧١٥١٥، مصر
البريد الالكتروني: ahm.ali@qu.edu.sa ، ahmed.abdelmonteleb@aun.edu.eg

الملخص

الهدف من الدراسة هو إجراء ثلاث طرق وهم تقييم دورة الحياة(LCA) ، والأداء البيئي(EP) ، ونمذجة معلومات البناء (BIM) لتحديد الأداء البيئي والتأثيرات البيئية الناتجة من تصنيع مادتي إطار النافذة: الألومنيوم والخشب. نُفذت هذه الدراسة بمشروع مقترح بحرم جامعة أسيوط كدراسة حالة. تم إجراء تقييم دورة الحياة من خلال تقييم المواد والعمليات المتضمنة في تصنيع نوعي إطارات النوافذ باستخدام برنامج. PRe SimaProيغطي نطاق دراسة تقييم دورة الحياة من بداية تجميع مواد البناء إلى تصنيع مواد البناء مع تحديد نظام معين للدراسة. تم رسم تدفق الشبكة لإنتاج واحد كيلوغرام من الألومنيوم والخشب بمساعدة المعلومات الواردة من) BIM باستخدام برنامج Autodesk Revit. يتم اختيار قاعدة البيانات بعناية من مجموعة بيانات Ecoinvent لتكون قريبة من عمليات التصنيع في مصر. بعد ذلك، تم استخدام IMPACT 2002+ مع حسابات نقطة المنتصف Midpoint results ونقطة النهاية.Endpoint results أخيرًا، تمت مقارنة نتائج LCA بنتائج EP باستخدام برنامج DesignBuilderلتحديد الخيار الأفضل بين المادتين.

كنتيجة شاملة لتحليل التكامل، سجلت صناعة الألمنيوم تأثيرات بيئية سلبية وأداء بيئي أعلى من صناعة الأخشاب. إجمالي نتائج المادتين كانت ٢٩,٦ وحدة للألمنيوم، والخشب ٧,٥٧ وحدة. بالانتقال إلى نتائج نقطة النهاية، فإن صحة الإنسان واستنفاد الموارد هي الأكثر أهمية في النتائج. سجلت صحة الإنسان أعلى قيمة، حيث سجلت ١٣,٩ وحدة للألمنيوم و ٣,٥١ وحدة للخشب .تم إجراء إطار جديد لدمج LCA وBIM وEP لمبنى مقترح خلال المراحل الأولى من المشروع في هذه الدراسة. يمكن استخدام الدراسة المقدمة كنموذج لتكامل التحليل المقارن في المشروعات المقترحة الأخرى حيث إن تطبيقات LCA في مصر تقريبًا نادرة نظرًا لعدم وجود قاعدة بيانات مصرية. قدمت هذه الدراسة قيمة جديدة ليتم تطبيق نهجًا لتحديد قاعدة البيانات المناسبة من مجموعة بيانات Ecoinvent .تساهم نتائج البحث في اختيار أنسب مواد إطارات النوافذ ذات التأثير الأكثر كفاءة في استخدام الطاقة وأقل عبء بيئي. علاوة على ذلك، يمكن أن تساعد الهيئات التشريعية المعنية ومتخذي القرار.

الكلمات المفتاحية :تقييم دورة الحياة، تقييم الأثر البيئي، نمذجة معلومات المباني، الأداء البيئي