Application of comparative life cycle assessment to a proposed build-ing for reduced environmental impacts: Assiut University Hospital Clinic as a case study

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Abstract

Although buildings have many benefits, the construction industry represents a big barrier to implement the strategic environmental plans. Specifically, in Egypt as one of the developing countries, the building construction sector consumes around 40% of the global raw material extraction, according to (World Resources Institute, 2015). Furthermore, the manufacturing industries and construction processes have 23% of all fuel combustion activities and have 22% of all GHG emissions according to the BIENNIAL update report (Ministry of Environment, 2018). This paper is one of a set of scientific papers that will be introduced to apply the integration methodology of Life Cycle Assessment (LCA) and Building Information Modeling (BIM) on a health clinic as a proposed building in Assiut University Hospital. The results have revealed that that the main harmful environmental impacts are the respiratory inorganics, global warming potential, and non-renewable energy as the midpoint method, additionally the human health and resource depletion as endpoint method. In particular, the GWP results of the steel, concrete, brick, and tiles are (3.4E5), (2.55E5), (9.67E4), and (4.31E4) kg CO_2 equivalent respectively as a midpoint result. For the endpoint method, the weighting results conducted that the human health and resources depletion have recorded the largest figures, as well as the steel, concrete, brick, and tiles industries have massive environmental burdens. Additionally, the paper has summarized that there is an urgent need to introduce sustainable alternatives of building materials particularly since these industries emit many of emissions such as CO_2, P. M2.5, SO_2 and C_2H_4. Ultimately, the paper has introduced future recommendations for both proposed and existing buildings.

Keywords

Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Building information modelling (BIM), Energy efficiency

الملخص

على الرغم من أن المباني لها فوائد عديدة، إلا أن صناعة البناء تمثل حاجزًا كبيرًا أمام تنفيذ الخطط البيئية الإستراتيجية. على وجه التحديد، في مصر باعتبارها واحدة من البلدان النامية، يستهلك قطاع تشييد المباني حوالي ٤٠٪ من المواد الخام العالمية المستخرجة، طبقا لتقرير معهد الموارد العالمية لعام ٢٠١٥. علاوة على ذلك، تمتلك الصناعات التحويلية وعمليات البناء ٢٣٪ من جميع أنشطة احتراق الوقود ولديها ٢٢ من جميع انبعاثات غازات الدفيئة (غازات الاحتباس الحراري) وفقًا

لتحديث تقرير BIENNIAL، طبقا لوزارة البيئة المصرية لعام ٢٠١٨. هذه الورقة هي واحدة من مجموعة الأوراق العلمية التي سيتم تقديمها لتطبيق منهجية تكامل تقييم دورة الحياة (Life Cycle Assessment) ونمذجة معلومات البناء (Building Information Modelling) على عيادة صحية كمبنى مقترح في مستشفى جامعة أسيوط بمدينة أسيوط - مصر. أظهرت النتائج أن الآثار البيئية الضارة الرئيسية هي المواد غير العضوية في الجهاز التنفسي، بالإضافة إلى ظاهرة الاحتباس الحراري، والطاقة غير المتجددة كطريقة نصفية بيئية (Midpoint method)، بالإضافة إلى صحة الإنسان واستنفاد الموارد كطريقة نهائية بيئية (Endpoint method). على وجه الخصوص، فإن نتائج غازات الاحتباس الحراري لصناعة الحديد والخرسانة والطوب والبلاط هي (3.4E5) و(2.55E5) و(9.67E4) و(4.31E4) كيلو جرام من ثاني أكسيد الكربون المكافئ (kg CO_2 equivalent) على التوالي كنتيجة نصفية بيئية. بالنسبة للطريقة نهائية بيئية، أظهرت نتائج الترجيح أن صحة الإنسان واستنفاد الموارد سجلت أكبر الأرقام، بالإضافة إلى أن صناعات الحديد والخرسانة والطوب والبلاط لها أعباء بيئية هائلة. بالإضافة إلى ذلك، لخصت الورقة أن هناك حاجة ملحة لإدخال بدائل مستدامة من مواد البناء خاصة وأن هذه الصناعات تنبعث منها العديد من الانبعاثات مثل ثاني أكسيد الكربون والجسيمات الدقيقة وثاني أكسيد الكبريت وغاز الايثلين. في النهاية، قدمت الورقة توصيات مستقبلية لكل من المباني المقترحة والمباني القائمة.

الكلمات المفتاحية

تقييم دورة الحياة (LCA)، تقييم الأثر البيئي (EIA)، نمذجة معلومات البناء (BIM)، كفاءة الطاقة

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

EEAA	Egyptian Environmental Affairs Agency	LCI	Life cycle Inventory
GHG	Greenhouse Gas	LCIA	Life cycle Impact Assessment
LCA	Life Cycle Assessment	HH	Human Health
ISO	International Standards Organization	EQ	Ecosystem Quality
AUHC	Assiut University Hospital Clinic	GWP	Global Warming Potential
AUH	Assiut Hospital University		

Introduction

Even though the buildings offer many benefits to society, they can have significant environmental and human health impacts. According to the Egyptian Environmental Affairs Agency (EEAA) of the Egyptian Ministry of Environment, the building construction sector consumes around 40% of the global raw material acquisition. On the other hand, carbon dioxide (CO_2) emissions account for 99% of total greenhouse gas (GHG) emissions of the energy division, as demonstrated in Figure 1.

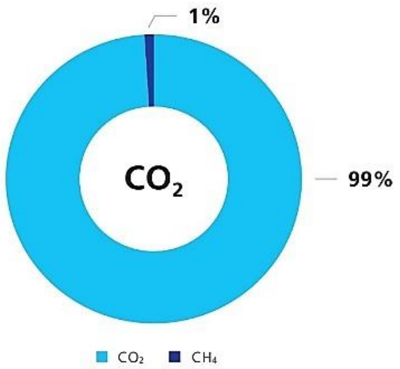


FIGURE 1 ENERGY EMISSIONS PER GAS (WORLD RESOURCES INSTITUTE, 2015)

Meanwhile, corresponding to Egypt's first BIENNIAL update report to the united nations framework convention on climate change (Ministry of Environment, 2018), the manufacturing industries and construction have 23% of all fuel combustion activities, 22% all GHG emissions. In 2015, it was 17% according to (World Resources Institute, 2015).

The author has previously introduced the statistics from global raw material extraction, Energy emissions, and GHG emissions. Now the author will turn to specific emissions such as CO_2, CH_4, and N_2O. Based on (Egyptian Ministry of Environment, 2017), fuel combustion pursuits make up 97% of total emissions, and CO_2 is the main contributor.

Literature review

Life cycle assessment (LCA) is a tool to measure any manufactured stuff's environmental impacts. LCA methods applications in Egypt are still minimal. Here, the author will present the latest case studies published in international journals to prove the importance of applying the LCA in Egypt to construct and build industries.

(Khasreen et al., 2009) introduced a brief history of LCA and the need for LCA in buildings and recapped up future research and recommended to apply it in all developing countries for the whole building.

There were many LCA standards; in 1994. The Canadian Standards Association released the first global LCA standard. However, the International Standards Organization ISO was the most acknowledged standards with many series, shown in Figure 2.

- ISO 14040: Environmental management, LCA, Principles, and framework (International Organization For Standardization (ISO), 2006).
- ISO 14041: Environmental management, LCA, Goal definition and inventory analysis (International Organization For Standardization (ISO), 1998)

- ISO 14042: Environmental management, LCA, Life-cycle impact assessment (International Organization For Standardization (ISO), 2000a).
- ISO 14043: Environmental management, LCA, Life-cycle interpretation (International Organization For Standardization (ISO), 2000b).

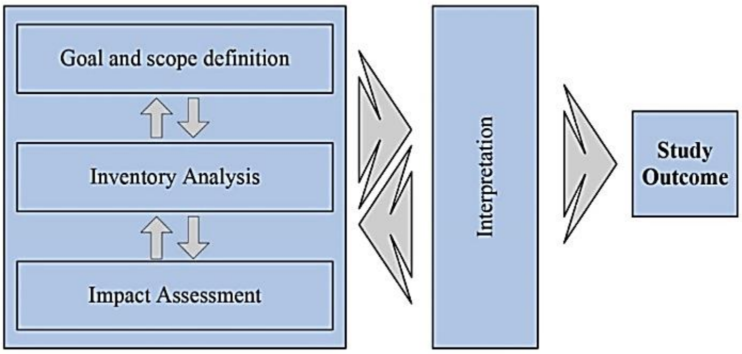


FIGURE 2 LIFE-CYCLE ASSESSMENT FRAMEWORK (KHASREEN ET AL., 2009)

(Al-Ghamdi & Bilec, 2017) reported that many green building rating systems use a comparative LCA study. In their paper, a comparative study was done to assess the LCA software tools available to designers. PRe SimaPro is the result of the comparison in Table (1) - in their paper - as a complex analysis tool and an advanced skill level.
Various researches have been conducted in many building sectors; for instance (Mannan & Al-Ghamdi, 2020) proposed a review of all studies in constructional and operational water use and associated environmental impacts to apply the latest developments from the LCA perspective. Also, the applications have been accomplished not only to the new building but also to the retrofit buildings (Tokede et al., 2018). There are many scientific papers that have applied the LCA on the building, such as (Collinge et al., 2013; Janjua et al., 2020; Kamali et al., 2018; Marique & Rossi, 2018; Martinopoulos, 2020; Najjar et al., 2019; Oquendo-Di Cosola et al., 2020). Unfortunately, only tens of studies have been carried out in Egypt. The international research has tried to introduce a new application to prove LCA's essential to measure the energy efficiency and environmental impacts for all construction building sectors.
Based on those mentioned earlier, this paper will apply the LCA and building information modelling (BIM) methodology on one of the proposed buildings in Assiut, Egypt. This paper is one of a series of scientific papers. The first one is the LCA of the whole building, and the second one will be the comparison between the material of building openings, the third is the comparison among specific of glass windows type, the last but not the least is to introduce one of the newest promising sustainable brick types.

Methodology

This paper will introduce the LCA and BIM methodologies on one proposed building in Assiut, Egypt. The LCA will be used to assess the environmental impacts and energy efficiency of the building construction materials. To collect the building construction components, the BIM comes to do that. The LCA-BIM integration in the construction material can help evaluate and deliver the sustainability features. Both methodologies will be applied to reduce the energy consumed and mitigate environmental emissions from the manufacturing and construction sectors.

Building information modelling and LCA trends

Over twenty years ago, LCA was widely used as a sustainable tool to measure and reduce the environmental impacts and the energy consumed. As well, BIM is described 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" (Stathis Eleftheriadis et al., 2017) reported. Many of the articles adopt the integration tool between the BIM and LCA for their application, for example, but not limited (S. Eleftheriadis et al., 2018; Hasik et al., 2019; Janjua et al., 2020; Lee et al., 2017; Llatas et al., 2020; Najjar et al., 2019; Seyis, 2020; Su et al., 2020; Weißenberger et al., 2014).

This article will bring together the application of LCA and BIM capabilities to assess the environmental impacts and the energy consumed for one of the proposed buildings in Assiut city, Egypt. Corresponding to the BIM software, Autodesk Revit is the most common one; this research has used the 2020 (licensed version), as presented in Figure 3.

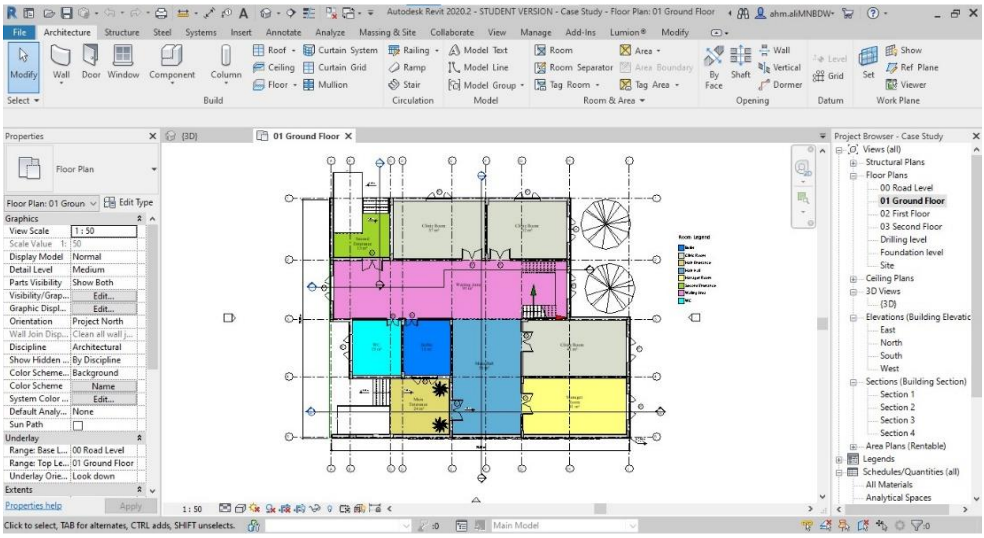


FIGURE 3 AUTODESK REVIT USER INTERFACE VERSION 2020 (LICENSED VERSION)

As for the LCA, the PRe SimaPro is the best LCA tool according to a comparison conducted by (Ali et al., 2016); version 9.1 has been used as a faculty licensed, as shown in Figure 4.

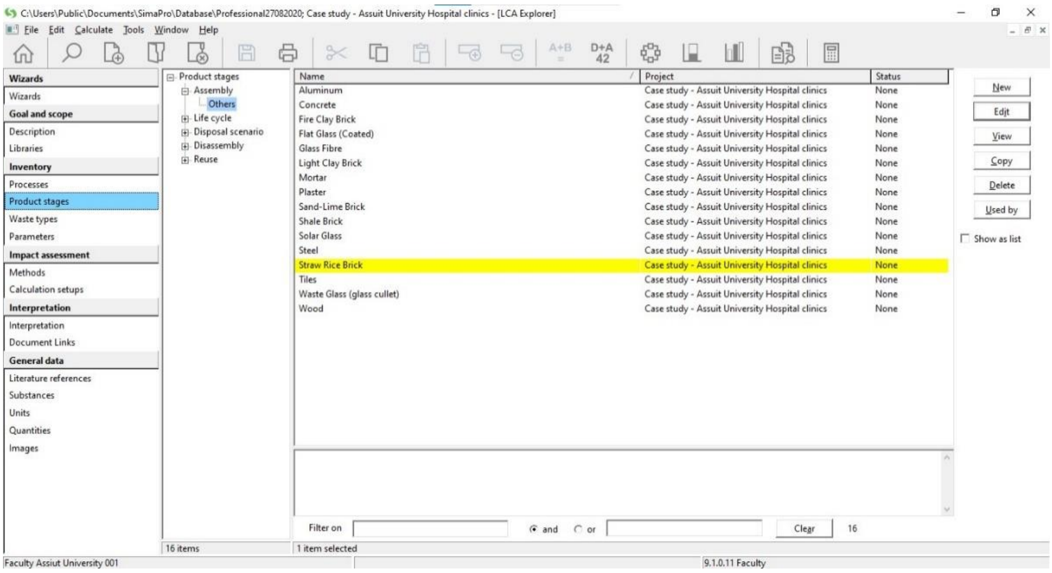


FIGURE 4 PRE SIMAPRO USER INTERFACE VERSION 9.1

Case study

This part will take the Assiut University Hospital Clinic (AUHC) as a case study to investigate the building's environmental impact and energy consumed. The aim is to pinpoint the most significant building materials in its construction phase from the environmental emissions point of view and consider recommendations to apply the LCA and BIM methodologies for all forward projects and research. AUHC is one of the proposed projects inside the campus of Assiut Hospital University (AUH). Figure 5 shows the campus of Assiut University and the location of the proposed new clinic.

FIGURE 5 LOCATION OF THE CAMPUS OF ASSIUT UNIVERSITY AND PROPOSED NEW CLINIC IN AUH IN ASSIUT CITY

The project's geographic location is set on the BIM model by defining the internet mapping service, as shown in Figure 6. The longitude and latitude are defined with coordinators 27.1838397979736 and 31.1667556762695, respectively. Furthermore, Figure 7 documents a sample of BIM model drawings.

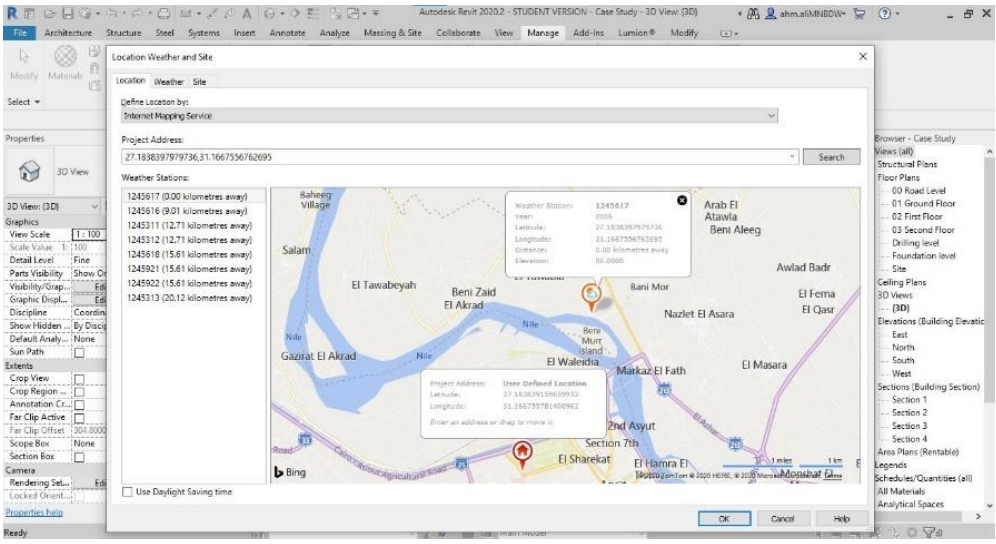
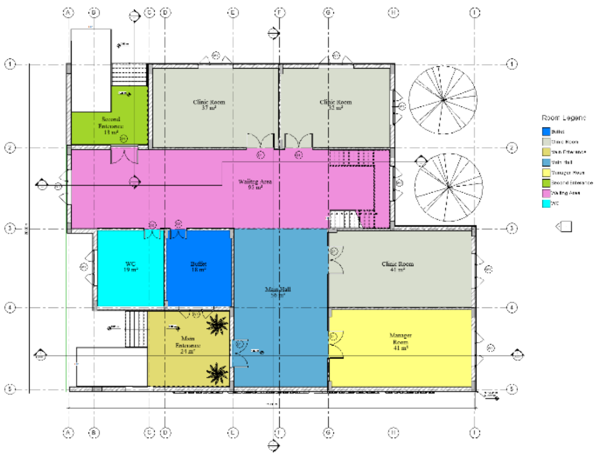
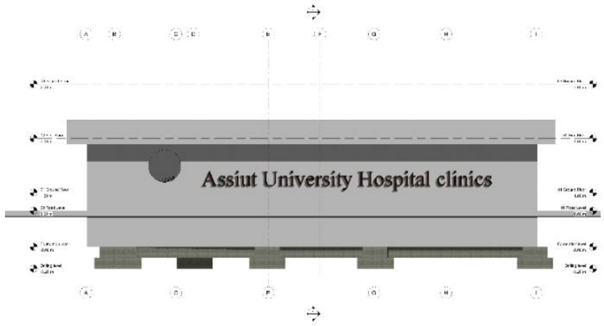


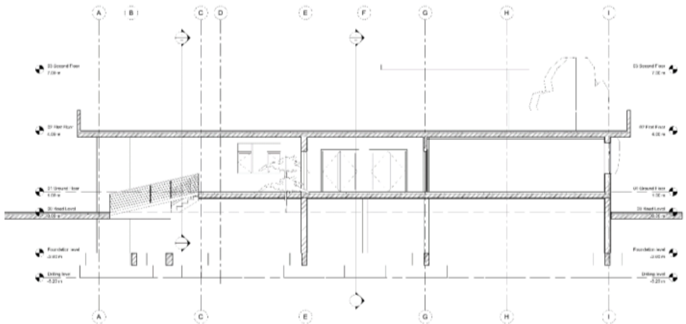
FIGURE 6 LOCATION WEATHER AND SITE OF AUHC



a) The ground floor



b) The southern facade



c) The building section

d) Proposed perspectives

FIGURE 7 BIM MODEL DOCUMENTS

Establishment of LCA Model for Assiut University Hospital Clinic

As we have previously discussed, based on the flowchart of decision support analysis designed by (Najjar et al., 2019), as shown in Figure 8, the case study methodology of this article has been built. The LCA methodology contains four phases: Goal and Scope Definition, Life cycle Inventory (LCI), Life cycle Impact Assessment (LCIA), and finally, Interpretation.

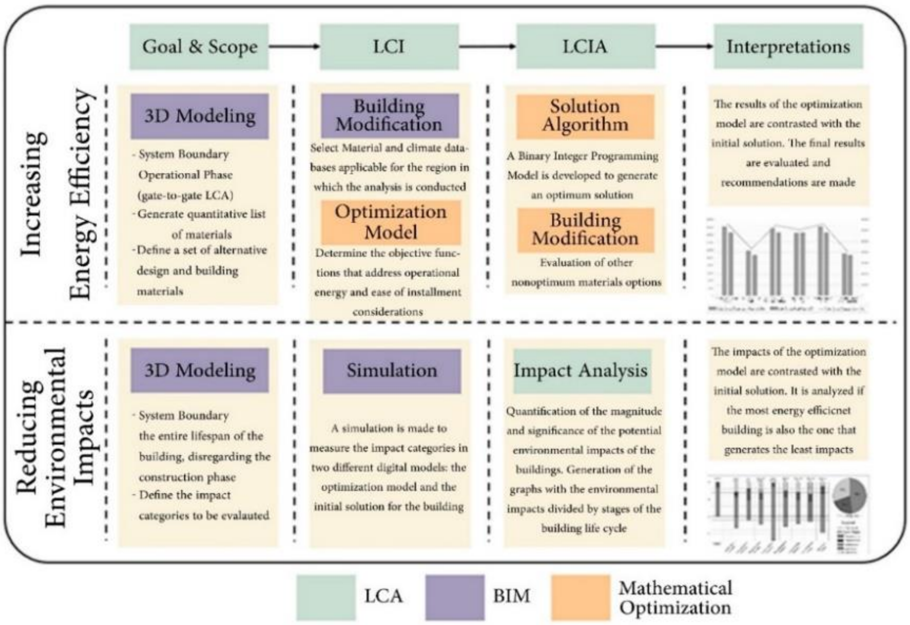


FIGURE 8 FLOWCHART OF DECISION SUPPORT ANALYSIS

Goal and Scope Definition

This study's primary goal is to contribute to assessing the environmental impacts of all building materials by adopting the LCA and BIM methodological process. It helps decision-makers, building designers, and building material manufacturers with environmental impacts caused by these industries. One kilogram (1 kg) has been designated as a functional unit for each building material.

Inventory Analysis

As one of the BIM model findings as was designed, Table 1 lists the building material quantities. These figures have been calculated according to the standard density kg/m^3 of all materials. As the quantities of the materials are mandatory (from BIM study), the life cycle inventory (LCI) (from LCA study) also is required. The material quantities from BIM are considered as inputs in SimaPro. The LCI databases, in SimaPro, depend on the Ecoinvent V3 dataset, which is a European data. Because of gathering the LCI of Egyptian materials is one of the difficulties of the LCA application in Egypt, this paper has based on the Ecoinvent database by considering a minimal error in the results. Selecting the database from the Ecoinvent (SimaPro-based) is carefully done by picking the same manufacturing process of the building materials in Egypt.

TABLE 1 BILL OF QUANTITIES EXTRACTED FROM THE BIM MODEL

Name	Area (m^2)	Volume (m^3)
Brick	861	164.16
Concrete	4382	0.88
Steel		17.00
Mortar	3089	29.70
Tiles	1556	62.29
Glass	132	0.41
Plaster	3358	32.31
Wood/Aluminum openings	88	1.20

Impact Assessment

The Life Cycle Assessment (LCIA) process helps us distinguish among the various choices of environmental impacts. Many factors convert the LCI to the LCIA, such as the characterization, normalization, weight, and single score. Based on the literature review (Al-Ghamdi & Bilec, 2017; Ali et al., 2016; Hossain & Thomas Ng, 2019; Ingrao et al., 2018), there are two approaches proposed; the midpoint and endpoint methods. The first method covers Global warming, Aquatic Eco toxicity, Respiratory and Non-renewable energy; all of them are calculated with equivalent via equations embedded in the SimaPro calculations. The second one covers Human health damage, Ecosystem quality, and Resources; all of them are shown in (Ali et al., 2016).

(Ali et al., 2016).

Result and interpretation

As we have discussed before regarding the IMPACT 2002+ method in the previous section (Impact Assessment), the author will present the characterization, single score, and weighting results.

Single score per impact category

As Figure 9 shown, the steel has the worst environmental impacts, and the plaster has less one; this corresponds to (Ansah et al., 2020; Llantoy et al., 2020; Sedláková et al., 2020). Steel manufacturing records 111 points (Pt), then concrete with 58.4 Pt. The tiles and the brick industry come in the third and fourth ranks with (47.5 Pt) and (30.1 Pt). The first contributor to the environmental impacts is respiratory organics (42.8 Pt) in the steel industry and (36.6 Pt) in the tiles industry. The second contributor is the global warming potential (GWP), recorded (34.3 Pt) and (4.35 Pt) for steel and tiles industries, respectively. However, the GWP is the first contributor to concrete (25.8 Pt) and brick (9.76 Pt) because of the fossil fuels combustion, the electrical energy usage, and the coal usage as it is reported by (Janjua et al., 2020; Ministry of Environment, 2018; World Resources Institute, 2015; Wu et al., 2020).

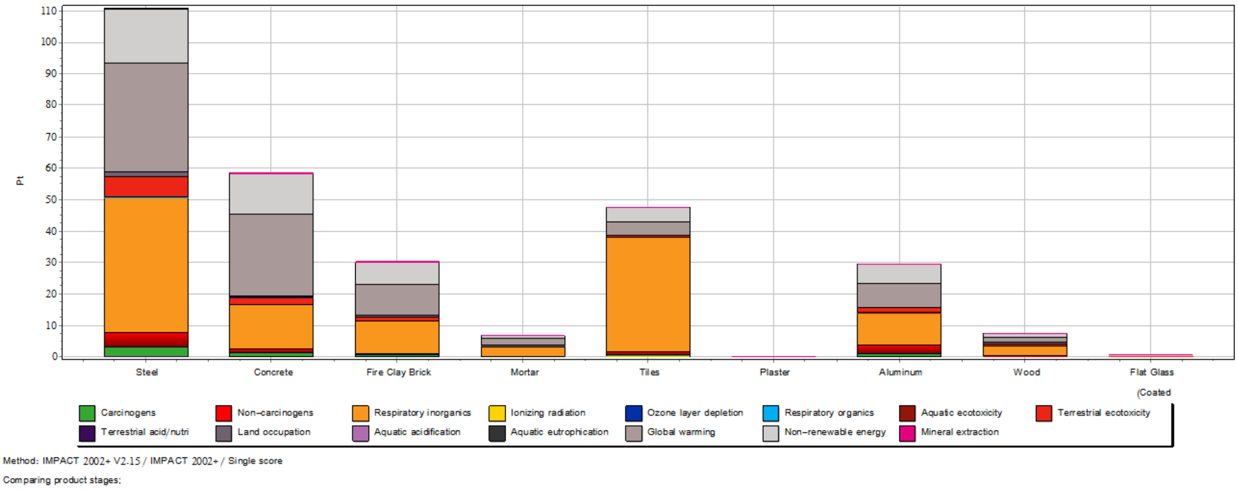


Figure 9 Single score results per impact category (Midpoint method)

Figure 10 presents the single score results with the endpoint method. In this section, the author will point out the other method, including Human Health (HH). Ecosystem Quality (EQ) and resource depletion. Regarding the HH results, the steel recorded the highest points with (50.7 Pt) then the tiles with (38.1 Pt). The resources impact ranked the second contributor, steel (17.8 Pt), concrete (13.2 Pt), and finally, the brick (7.29 Pt), respectively. These industries need a massive amount of raw materials and emit many of CO_2, P. M2. 5, SO_2 and C_2H_4 emissions, in line with (Hu, 2019; Oquendo-Di Cosola et al., 2020) results.

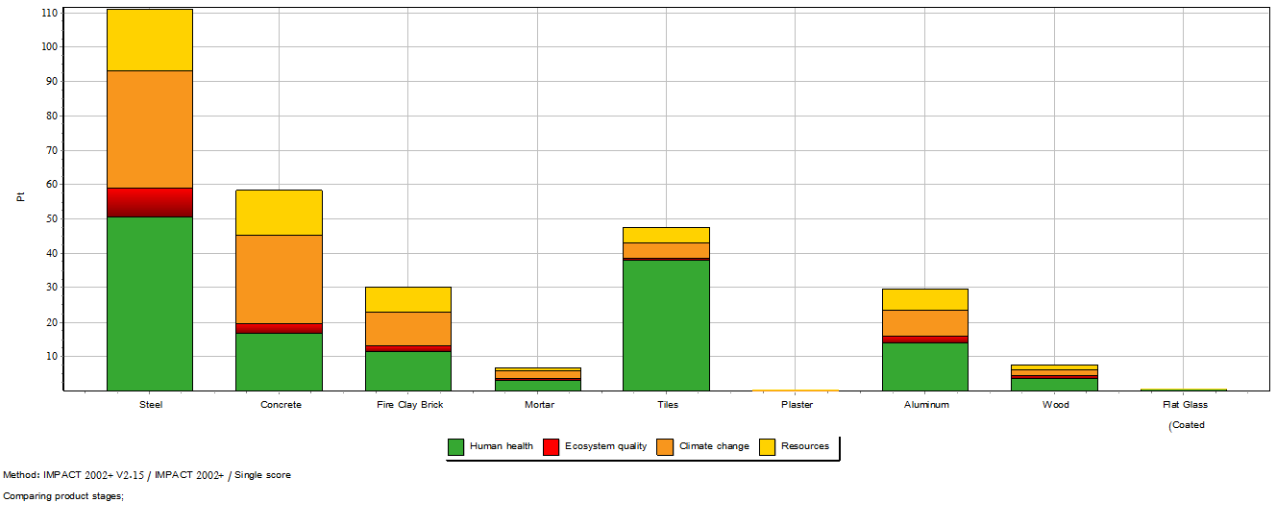


Figure 10 Single score results per building material (endpoint method)

To demonstrate the results with equivalent life cycle impact categories, Table 2 shows the characterization results. Many of studies, such as (Ansah et al., 2020; Bahramian & Yetilmezsoy, 2020; Hu, 2019; Najjar et al., 2019; Sedláková et al., 2020; Thibodeau et al., 2019; Wu et al., 2020; Xue et al., 2020), have focused on the GWP as it is the first challenges on the environmental impacts overall the world. Therefore, the GWP results of the steel, concrete, brick, and tiles are (3.4E5 kg CO_2 eq), (2.55E5 kg CO_2 eq), (9.67E4 kg CO_2 eq) and (4.31E4 kg CO_2 eq) respectively.

TABLE 2 CHARACTERIZATION RESULTS

SimaPro 9.0.0.35	Impact assessment Date:		9/1/2020 Time:		9:45					
Project	Case study – Assuit University Hospital clinics									
Calculation:	Compare									
Results:	Impact assessment									
Method:	IMPACT 2002+ V2.15 / IMPACT 2002+									
Indicator:	Characterization									
Sorted on item:	Impact category									
Sort order:	Ascending									
Impact category	**Unit**	**Steel**	**Concrete**	**Brick**	**Mortar**	**Tiles**	**Plaster**	**Aluminum**	**Wood**	**Glass**
Carcinogens	kg C2H3Cl eq	7855.69	3048.56	1689.60	202.96	1438.92	8.50	2879.17	450.41	23.96
Non-carcinogens	kg C2H3Cl eq	11792.19	3250.61	1213.86	340.54	2359.06	8.76	6719.36	894.19	24.63
Respiratory inorganics	kg PM2.5 eq	433.99	142.49	104.02	28.29	370.38	0.46	102.01	30.09	2.97
Ionizing radiation	Bq C-14 eq	249709.02	133252.70	232664.71	38473.33	-257726.89	100.47	137414.58	78189.15	951.97
Ozone layer depletion	kg CFC-11 eq	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Respiratory organics	kg C2H4 eq	271.80	51.91	43.55	4.73	15.76	0.49	23.84	7.80	0.28
Aquatic ecotoxicity	kg TEG water	42190969.86	14485444.54	5746454.57	2877835.33	6565380.30	332566.76	14890586.12	4490739.02	162291.58
Terrestrial ecotoxicity	kg TEG soil	10986107.52	3734911.93	2221543.63	851831.14	959172.76	8758.24	2893830.27	879065.25	47184.76
Terrestrial acid/nutri	kg SO2 eq	-94.31	2287.53	1355.45	288.25	419.13	8.18	1303.81	279.04	41.70
Land occupation	m2org.arable	21193.65	6021.54	2869.03	1246.41	391.03	55.99	780.46	6523.75	55.89
Aquatic acidification	kg SO2 eq	-581.16	505.33	311.19	65.52	129.79	5.98	407.33	81.88	11.26
Aquatic eutrophication	kg PO4 P-lim	36.31	18.83	14.40	3.40	9.57	0.09	10.11	3.67	0.44
Global warming	kg CO2 eq	339709.05	255461.09	96667.76	20942.68	43093.44	460.06	75740.10	15688.55	1261.29
Non-renewable energy	MJ primary	2655805.73	2000104.79	1104526.87	146915.30	676455.75	6359.54	934267.71	212499.91	15040.00
Mineral extraction	MJ surplus	49991.09	5653.81	3273.68	342.67	5991.35	11.78	10793.78	2196.79	181.92

Weighting per impact category

Figure 11 exhibits the results of the weighting method per the impact categories. Regarding the impact categories, respiratory inorganics, GWP, and non-renewable energy have the worst environmental impacts. There are minimal impacts that are ignored in confirm with (Hasik et al., 2019; Hu, 2019; Kylili et al., 2017; Mannan & Al-Ghamdi, 2020; Marique & Rossi, 2018; Wu et al., 2020).

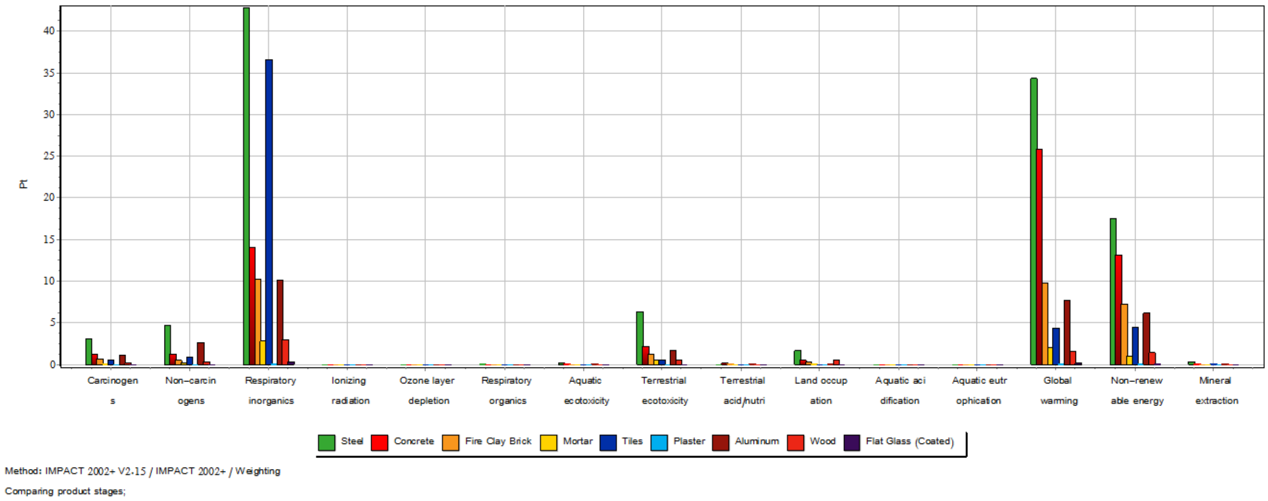


FIGURE 11 WEIGHTING RESULTS PER IMPACT CATEGORY (MIDPOINT METHOD)

For the endpoint method, Figure 12 presents the weighting results according to the overall impacts. The HH and resource depletion have recorded the most massive figures, and the steel, concrete, brick, and tiles industries have massive environmental burdens consistent with (Collinge et al., 2013; Hu, 2019).

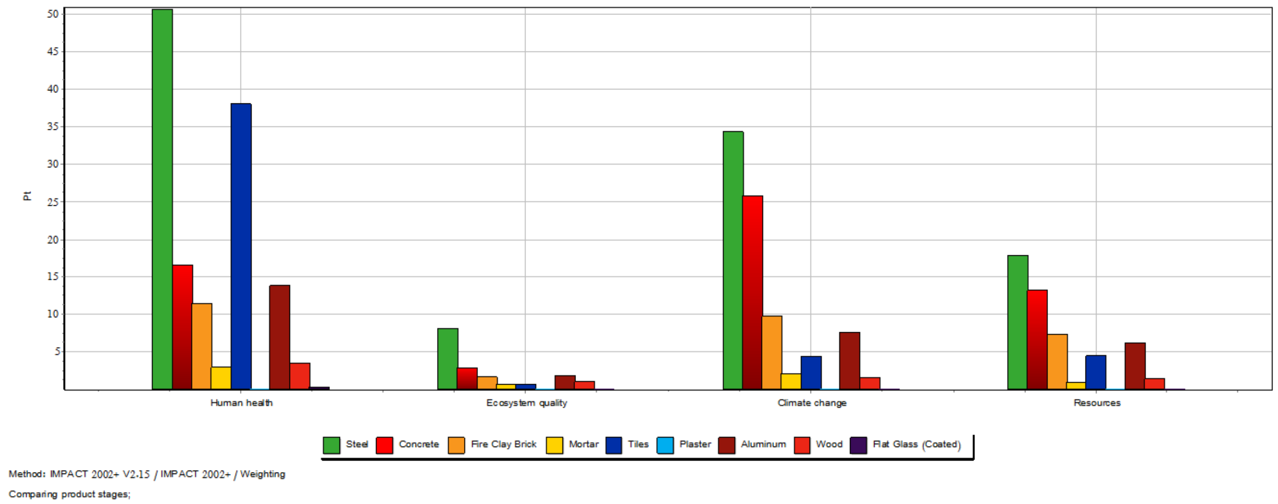


FIGURE 12 WEIGHTING RESULTS PER BUILDING MATERIAL (ENDPOINT METHOD)

Conclusions

This research's main idea is that the building materials cannot be chosen without investigating the environmental impacts of their manufacturing process. The sustainable building materials should be introduced nowadays. The results have proved an urgent need to introduce sustainable alternatives of steel, concrete, and brick particularly. According to the (Bahramian & Yetilmezsoy, 2020; Hossain & Thomas Ng, 2019; Janjua et al., 2020; Llantoy et al., 2020; Seyis, 2020), all of these industries need many of raw material acquisition in which effects on the depletion of the resources as an endpoint result. As well as these industries emit many of emissions such as CO_2, P. M2.5, SO_2 and C_2H_4 with mainly related to the respiratory inorganics, GWP and non-renewable energy. The consumed electricity and fuel to manufacture the building materials are the leading causes of these environmental impacts.

Future Recommendations

Based on the previous analysis, it can be realized that the significant harmful environmental impacts are the respiratory inorganics, GWP, and non-renewable energy as the midpoint method, additionally the human health and resource depletion as the endpoint method. In this part and based on the results, improvement proposals will be introduced regarding the new proposed buildings and the existing buildings.

Suggestions for the proposed buildings

Designers and decision-makers should consider selecting the building material, not only from the cost point of view but also from the environmental burdens. Meanwhile, this article revealed that the LCA applications should be approved to be the main mandatories to get the new building license.

Suggestions for existing buildings

For the existing buildings, the issue will be more complicated; however, another methodology should be applied in which is the LCA of the operational phase. That stage is concerned with electricity and water consumption and how to introduce more sustainable options, such as reusing or recycling the greywater and reducing the electricity bills. All of these solutions simultaneously will reduce the CO_2, P.M2.5, SO_2 and C_2H_4 Furthermore, it ultimately will mitigate respiratory inorganics, global warming potential, and non-renewable energy.

Limitations and recommendations

The main barriers indicate two important points, (1) the BIM application on the designed building in Assiut to take the advantages of the BIM modelling, and (2) the shortage of LCI database, that is why the LCA applications in Egypt are little or almost rare, so the researchers cannot build their applications without the Egyptian database. In that case, using the European dataset will be the most beneficial way to apply the LCA in Egyptian case studies. Considering the choice of convergent technology for the Egyptian industries, with the calculation of an error factor in the results.

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