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ENVIRONMENTAL ANALYSIS OF A DAY-CARE BUILDING IN EGYPT BY LIFE CYCLE ASSESSMENT TOOL

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ABSTRACT

This paper aims to measure the footprint for construction materials and construction and demolition waste (CDW) environmental impacts for a case study building in Egypt through the complete Life Cycle Assessment (LCA) of the building 'from cradle to grave'. The LCA measures eight impact categories, including carbon emissions and energy demand. Our analysis demonstrates the relative importance of life cycle stages; construction processes and materials manufacturing that make the largest contributions to the buildings' environmental impacts. The results show that the material manufacturing stage is the most critical stage because of its high contribution (about 70%) of the total environmental impacts. On the other hand the disposal stage contributes (about -10%). The results can help engineers and construction industry stakeholders in Egypt to use more sustainable construction materials and change their CDW management practice.

1. Introduction

Life Cycle Assessment (LCA) is a universally recognised assessment tool which evaluates the environmental impacts for a product or an activity for all the stages of the product starting from raw materials extracting from the earth, energy consumption to the product disposal [1]. LCA assess the environmental impacts for the whole building life cycle by compiling an inventory of building raw resources (raw material extraction stage, transportation these materials to manufacturing sites), energy consumption (material manufacturing, materials transportation to construction site, on-site construction stage, and use/maintenance stage) to the building demolition and waste disposal, interpreting the results of the inventory analysis and impact assessment. Fig. 1 shows the whole life cycle of building products.

Fig. 1. The life cycle of building [2]

1.1. Resource extraction stage

The extraction of raw resources like iron, aggregates, wood, coal and gypsum is the first stage of most buildings' life cycle. This stage includes the energy used in the transportation of these resources to manufacturing site [2]

1.2. Manufacturing stage

Including the processes of production of materials and components used in the construction. This stage consumes energy and raw resources.

1.3. On-site construction

This is an important life cycle stage, including building product transportation, waste generation, and the energy used for machines like cranes and mixers, the on-site construction stage includes on site processes and materials transportation on site [3].

1.4. Use /Maintenance stage

The use /maintenance stage includes energy use, and the water used during its operation. It also takes into account the material replacing which happening in the building during its operation, which introduces new products or systems.

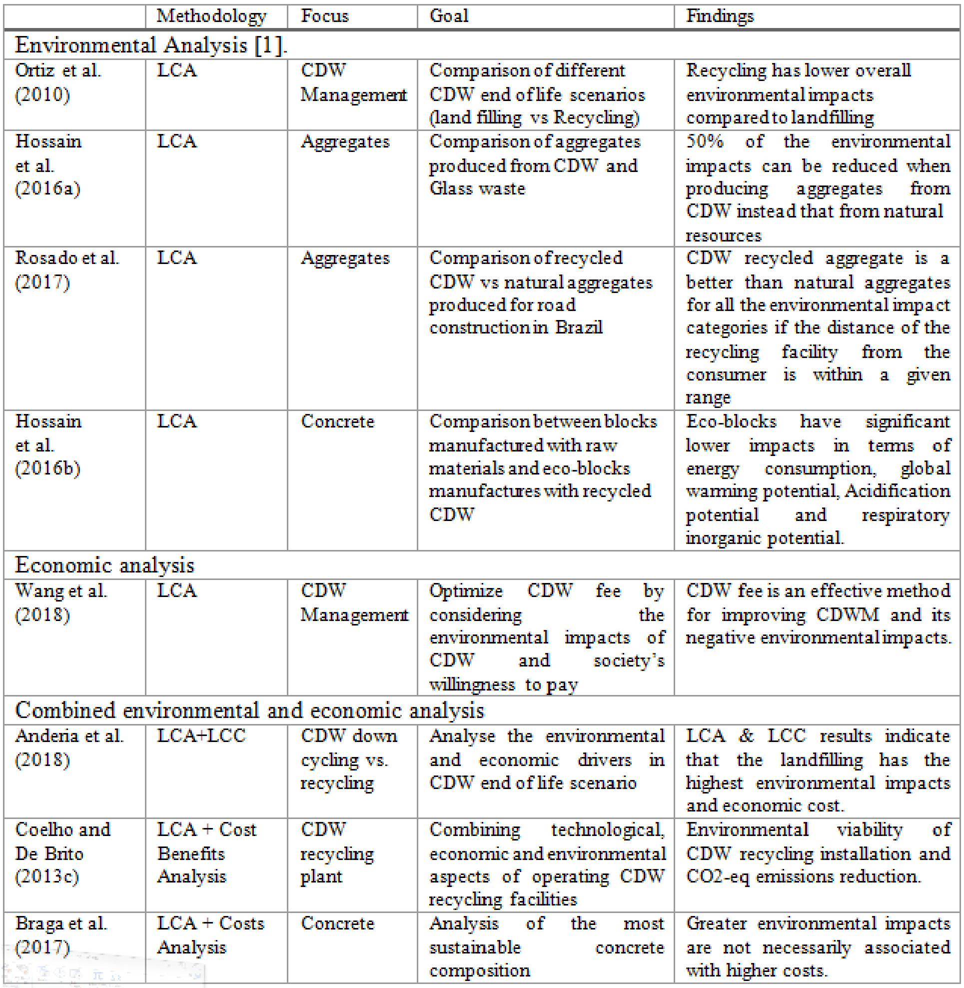
1.5. End of life and disposal stage

Demolition represents the end of a building's life cycle. This stage includes energy consumed in the building demolition and transportation of CDW to landfill or waste sorting site. It includes reusing and recycling for CDW as well.

2. Literature review

Table 1 shows the findings of some of the most recent LCA and economic studies implemented CDW management. LCA has been widely used to estimate and compare the environmental performances and impacts of different waste management practices. Regarding CDW management, some recent LCA studies focused on the comparison among the different end of life scenarios [1].

Table 1.
Environmental and Economic analysis on CDW: literature review.



	Methodology	Focus	Goal	Findings
Environmental Analysis [1].				
Ortiz et al. (2010)	LCA	CDW Management	Comparison of different CDW end of life scenarios (land filling vs Recycling)	Recycling has lower overall environmental impacts compared to landfilling
Hossain et al. (2016a)	LCA	Aggregates	Comparison of aggregates produced from CDW and Glass waste	50% of the environmental impacts can be reduced when producing aggregates from CDW instead that from natural resources
Rosado et al. (2017)	LCA	Aggregates	Comparison of recycled CDW vs natural aggregates produced for road construction in Brazil	CDW recycled aggregate is a better than natural aggregates for all the environmental impact categories if the distance of the recycling facility from the consumer is within a given range
Hossain et al. (2016b)	LCA	Concrete	Comparison between blocks manufactured with raw materials and eco-blocks manufactures with recycled CDW	Eco-blocks have significant lower impacts in terms of energy consumption, global warming potential, Acidification potential and respiratory inorganic potential.
Economic analysis				
Wang et al. (2018)	LCA	CDW Management	Optimize CDW fee by considering the environmental impacts of CDW and society's willingness to pay	CDW fee is an effective method for improving CDWM and its negative environmental impacts.
Combined environmental and economic analysis				
Anderia et al. (2018)	LCA+LCC	CDW down cycling vs. recycling	Analyse the environmental and economic drivers in CDW end of life scenario	LCA & LCC results indicate that the landfilling has the highest environmental impacts and economic cost.
Coelho and De Brito (2013c)	LCA + Cost Benefits Analysis	CDW recycling plant	Combining technological, economic and environmental aspects of operating CDW recycling facilities	Environmental viability of CDW recycling installation and CO2-eq emissions reduction.
Braga et al. (2017)	LCA + Costs Analysis	Concrete	Analysis of the most sustainable concrete composition	Greater environmental impacts are not necessarily associated with higher costs.

The work mentioned in the literature emphasizes that using CDW as a building materials has many environmental and economic benefits, it contributes in reducing air, land, and water emissions which released from waste incineration, or landfill dumping. In addition, it saves raw sources and the energy used in materials extraction and manufacturing. In this study, the environmental impacts is measured for a case study building in Egypt during its life cycle. From material manufacturing stage to the disposal stage with focusing on the end of life stage to provide an approach for reconsider the construction and demolition waste management practice in Egypt.

3. Methodology

The frame work of the environmental impacts for a Day-care building life-cycle in New Assiut City, Egypt. By Athena Impact Estimator for buildings (Athena Sustainable Material Institute) with focusing on the end of life stage.

3.1. Case study description

The case study is a day care building located in New Assiut city (NAC), Egypt. The building is a single level of about 568 m^2, with 5 m height, sees Fig. 2. The entire structure of the building is made of reinforced concrete. The building including 5 class rooms, multipurpose hall, 2 office rooms, court, kitchen, storage and 8 wash rooms.

(a) The building floor plan

(b) Main Building Façade

(c) Sec A-A

Fig. 2. Day care building in NAC, Egypt.

3.2. Steps of LCA process

ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study. An LCA study includes four main steps:

Step 1: Defining the goal and scope of the study.
Step 2: Making a model of the product life cycle with all the environmental inputs and outputs. This data collection effort is usually referred to as life cycle inventory (LCI). Step 3: Understanding the environmental relevance of all the inputs and outputs. This refers to as life cycle impact assessment (LCIA).
Step 4: The interpretation of the study [4]. Fig. 3 shows the steps of LCA according to the ISO standards.

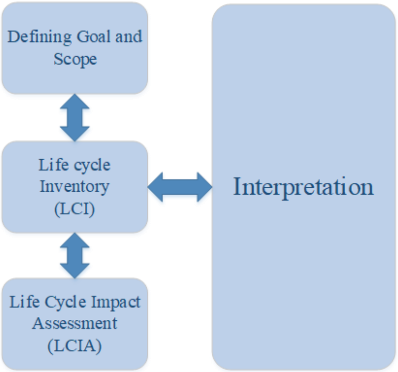


Fig. 3. LCA phases according to ISO 14040 [5]

3.2.1. Defining goal and scope

The Main aim of this study is to measure the environmental impacts for a Day care building as a case study in Egypt throughout its entire life cycle stages by Athena Impact Estimator for buildings as an LCA tool.

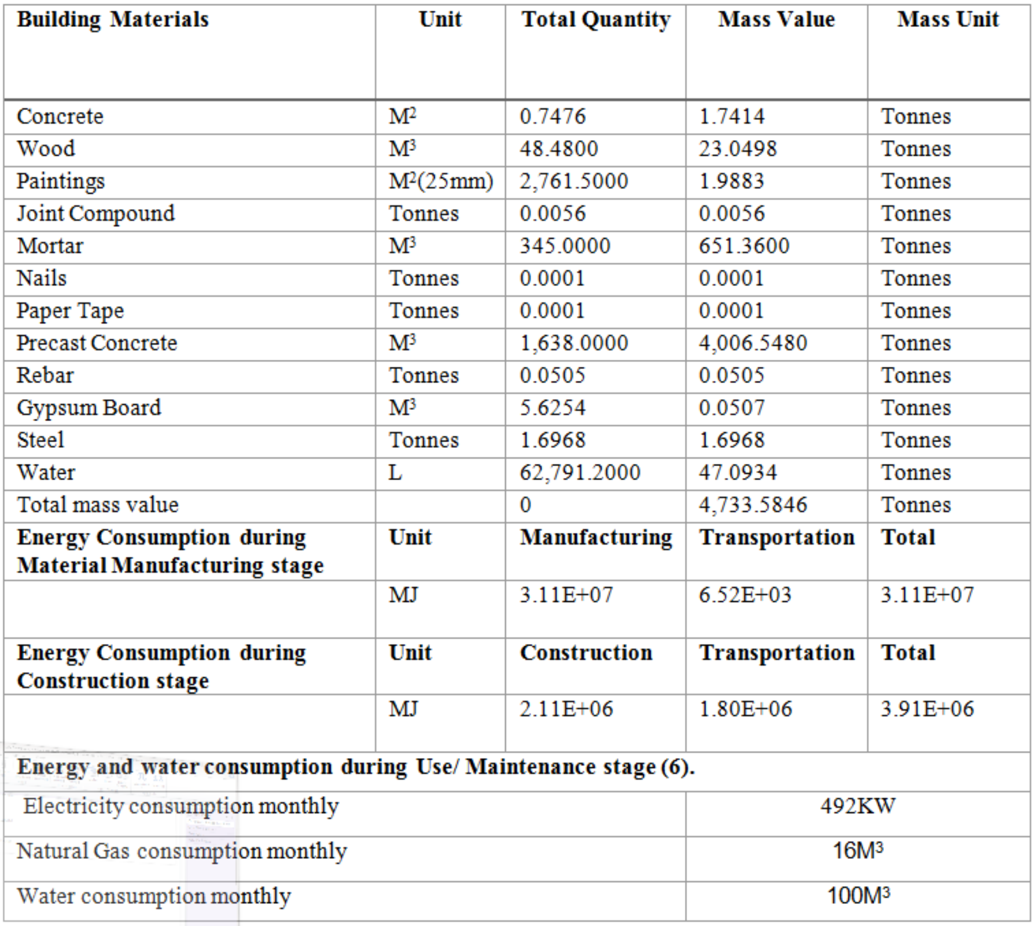
- System Boundaries: Complete LCA divided into 3 phases: preoperational (raw material extraction, material manufacturing and construction), operational (use and maintenance) and post-operational (end-of-life).
- Functional unit: The functional unit is the usable floor space (m^2) for the studied building. The building expectancy period is 60 years.

3.2.2. Life cycle inventory (LCI)

Inventory analysis is an essential part which uses LCA to recognize the environmental impacts for the construction materials from manufacturing, Construction, transportation to the end of life. In addition to resources and energy consumption [14]. From the literature review Egypt suffered from shortage of life cycle database, thus, the authors collected all the material quantities and specifications in Table 2 and any missing data will be taken from literature review and Athena Impact Estimator for buildings database [6].

- Pre-operational phase: This phase included the total quantity of the construction materials and the consumption of water and electric energy during the construction stage. In addition, the construction waste, the transportation of material from raw resources to manufacturing sites then to the construction sites and the waste transportation to the landfill.
- Operational phase: In this phase, the water, electric energy, and natural gas consumption used in lighting, air conditioners and heating and the construction materials required for building maintenance were considered. As in the construction, solid waste generated by the replacement of components in the maintenance process, the transportation of these materials and the generated waste were included.
- Post-operational phase: In this phase, the data for building demolition was calculated from construction industry stakeholders in Egypt. All the waste is sent to landfill without any processing.

Table 2.
The total construction material quantities and specifications for the case study



Building Materials	**Unit**	**Total Quantity**	**Mass Value**	**Mass Unit**
Concrete	M^2	0.7476	1.7414	Tonnes
Wood	M^3	48.4800	23.0498	Tonnes
Paintings	M^2(25mm)	2,761.5000	1.9883	Tonnes
Joint Compound	Tonnes	0.0056	0.0056	Tonnes
Mortar	M^3	345.0000	651.3600	Tonnes
Nails	Tonnes	0.0001	0.0001	Tonnes
Paper Tape	Tonnes	0.0001	0.0001	Tonnes
Precast Concrete	M^3	1,638.0000	4,006.5480	Tonnes
Rebar	Tonnes	0.0505	0.0505	Tonnes
Gypsum Board	M^3	5.6254	0.0507	Tonnes
Steel	Tonnes	1.6968	1.6968	Tonnes
Water	L	62,791.2000	47.0934	Tonnes
Total mass value		0	4,733.5846	Tonnes
Energy Consumption during Material Manufacturing stage	**Unit**	**Manufacturing**	**Transportation**	**Total**
	MJ	3.11E+07	6.52E+03	3.11E+07
Energy Consumption during Construction stage	**Unit**	**Construction**	**Transportation**	**Total**
	MJ	2.11E+06	1.80E+06	3.91E+06
Energy and water consumption during Use/ Maintenance stage (6).				
Electricity consumption monthly			492KW	
Natural Gas consumption monthly			$16M^3$	
Water consumption monthly			$100M^3$	

3.2.3. Life cycle of construction and demolition waste (CDW)

Construction waste in NAC transported to landfill. The environmental impacts for construction waste should be taken in the account of the whole life-cycle impacts. The life-cycle of construction waste includes: material manufacturing stage, transportation stage, on-site construction stage, and end of life stage.

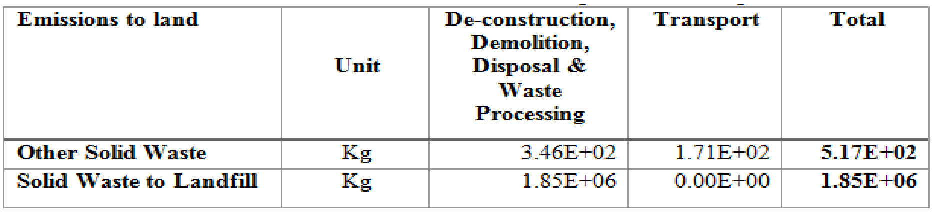
- Material manufacturing stage: This stage refers to the production of building materials in factory. For example, concrete is made by mixing aggregates, sand, water, and cement. This process consumes raw materials, energy and release emissions [3].
- Transportation stage: This stage indicates transporting building materials from factory to construction site.
- On-site construction stage: This stage called waste generation stage. In this stage building materials transfer to construction waste for many reasons: 1) Design changes during construction stage, 2) Design and construction detail error, 3) Materials damage during transportation, 4) Difficulties accessing vehicles that reach construction sites. 5) Inadequate protection during unloading, 6) Improper methods of unloading, 7) Lack of on-site waste management plans, 8) Insufficient planning for required quantities, 9)

Material damage due to material handling. Therefore, the construction stage is a very important part of life-cycle of construction waste [7], [8], [9], [13].

- End of life stage: This stage causes many environmental impacts, because the construction waste is sent to the landfill without reusing or recycling. This stage releasing lots of land emissions [10].

Table 3 shows the land emissions that released during the end of life stage according to Athena Impact Estimator for buildings. Solid waste releases the biggest amount of emissions during demolition, disposal and waste processing. In addition to the released emission during its transportation to landfill.

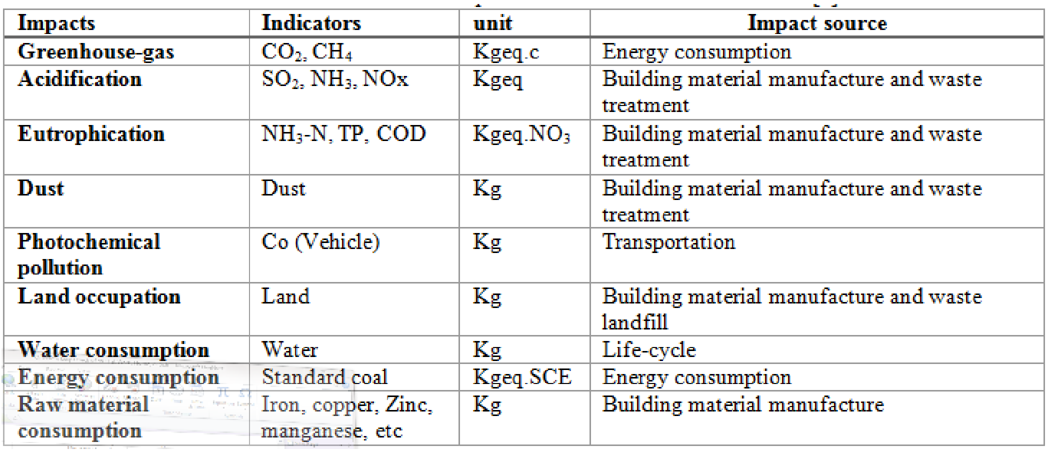
Table 3.
The total emissions to land during End of life stage.



Emissions to land	Unit	De-construction, Demolition, Disposal & Waste Processing	Transport	Total
Other Solid Waste	Kg	3.46E+02	1.71E+02	**5.17E+02**
Solid Waste to Landfill	Kg	1.85E+06	0.00E+00	**1.85E+06**

Environmental impacts mainly include energy consumption, resource consumption and greenhouse gas emissions, which include greenhouse gas, acidification, etc. The environmental impact indicator for construction waste has been identified in [1], as shown in Table 4.

Table 4.
Environmental impact indicator of construction waste [1].



Impacts	Indicators	unit	Impact source
Greenhouse-gas	CO_2, CH_4	Kgeq.c	Energy consumption
Acidification	SO_2, NH_3, NOx	Kgeq	Building material manufacture and waste treatment
Eutrophication	NH_3-N, TP, COD	Kgeq.NO_3	Building material manufacture and waste treatment
Dust	Dust	Kg	Building material manufacture and waste treatment
Photochemical pollution	Co (Vehicle)	Kg	Transportation
Land occupation	Land	Kg	Building material manufacture and waste landfill
Water consumption	Water	Kg	Life-cycle
Energy consumption	Standard coal	Kgeq.SCE	Energy consumption
Raw material consumption	Iron, copper, Zinc, manganese, etc	Kg	Building material manufacture

This study identified the energy consumption at the end of life stage. Fig. 4 shows the demolition and disposal stage consumes Gasoline and Non-Hydro renewable. The end of life stage (Demolition & disposal, and waste transportation) consumes 11 sources of energy i.e., Hydro, coal, Diesel, Heavy fuel oil, LPG, Natural Gas, Nuclear, Renewable energy, Primary energy, Non-renewable energy, and Fossil Fuel. Fig. 5 shows the environmental impacts for the end of life stage. Then the most influencing impacts are shown in Table 5, which shows greenhouse gases emissions, acidification and resource consumption.

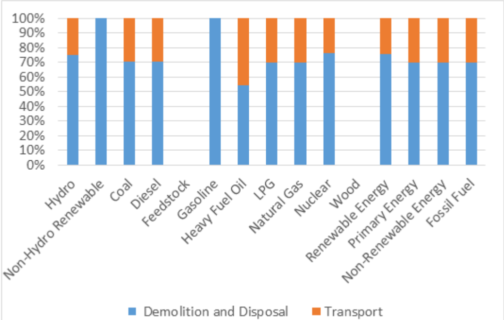


Fig. 4. Energy consumption during the end of life stage

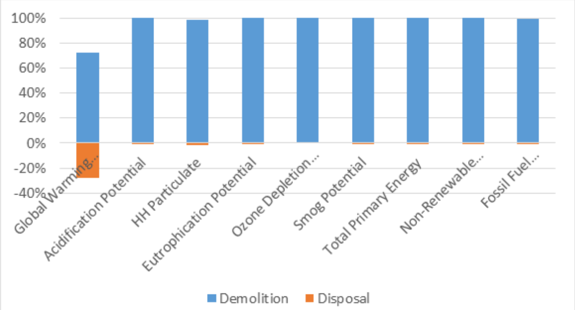
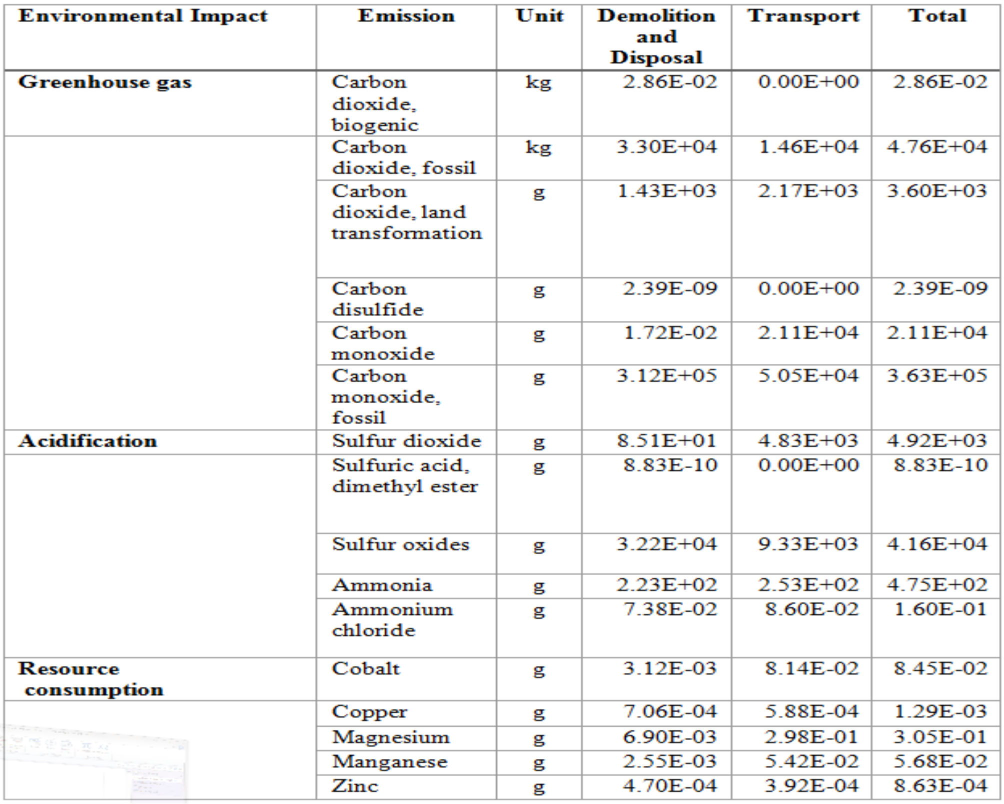


Fig. 5. The environmental impacts for the demolition and disposal

Table 5.
Emissions to air and resource consumption during end of life stage



Environmental Impact	Emission	Unit	Demolition and Disposal	Transport	Total
Greenhouse gas	Carbon dioxide, biogenic	kg	2.86E-02	0.00E+00	2.86E-02
	Carbon dioxide, fossil	kg	3.30E+04	1.46E+04	4.76E+04
	Carbon dioxide, land transformation	g	1.43E+03	2.17E+03	3.60E+03
	Carbon disulfide	g	2.39E-09	0.00E+00	2.39E-09
	Carbon monoxide	g	1.72E-02	2.11E+04	2.11E+04
	Carbon monoxide, fossil	g	3.12E+05	5.05E+04	3.63E+05
Acidification	Sulfur dioxide	g	8.51E+01	4.83E+03	4.92E+03
	Sulfuric acid, dimethyl ester	g	8.83E-10	0.00E+00	8.83E-10
	Sulfur oxides	g	3.22E+04	9.33E+03	4.16E+04
	Ammonia	g	2.23E+02	2.53E+02	4.75E+02
	Ammonium chloride	g	7.38E-02	8.60E-02	1.60E-01
Resource consumption	Cobalt	g	3.12E-03	8.14E-02	8.45E-02
	Copper	g	7.06E-04	5.88E-04	1.29E-03
	Magnesium	g	6.90E-03	2.98E-01	3.05E-01
	Manganese	g	2.55E-03	5.42E-02	5.68E-02
	Zinc	g	4.70E-04	3.92E-04	8.63E-04

3.2.4. Life cycle impact assessment (LCIA)

LCIA is the process which identify the environmental impacts such the global warming potential, acidification potential, eutrophication potential, Ozone layer depletion, emissions to (air, land, and water), resource and energy consumption. The entire building life cycle steps for the case study building are shown in Fig. 6.

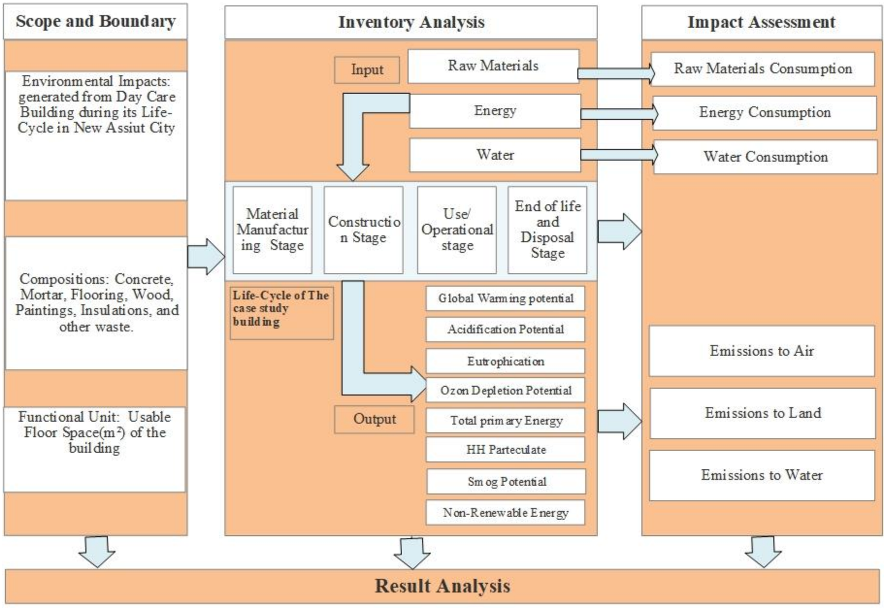


Fig. 6. The life cycle Impact Assessment for Day Care Project in Egypt.

4. Results, Interpretation and discussion

Fig. 7 indicates the total environmental impacts during the BLC. It shows that the most impactful stage is the material manufacturing stage, the highest environmental impact for this stage is the Ozone depletion potential with (8.87×10^{-3}) Kg CFC-11eq. The second impactful stage is the use/maintenance stage; the highest environmental impact for this stage is the Human Health particulate with (9.84×10^{2}) kg PM2.5eq.

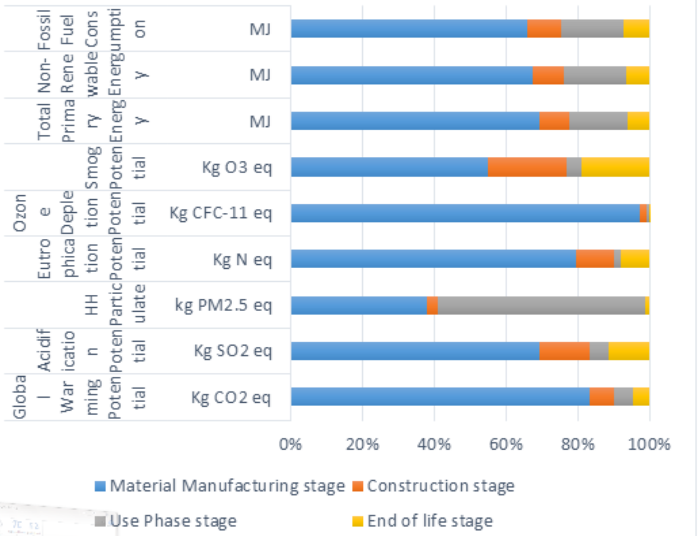
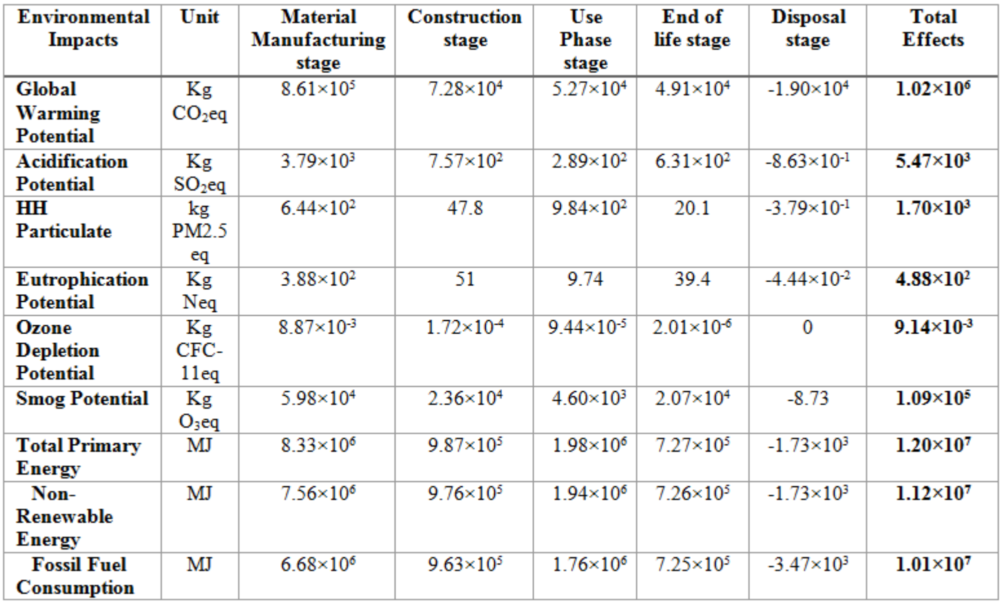


Fig. 7. The Environmental Impacts during BLC

The environmental impacts are Global warming potential Kg CO_2eq, Acidification Potential Kg SO_2eq, Human Health Particulate Kg PM2.5eq, Eutrophication (air & water) Kg Neq, Ozone Depletion Kg CFC-11eq, Smog (air) Potential Kg O_3eq, Total Primary Energy MJ, Non-Renewable Energy MJ, and Fossil Fuel Consumption MJ. Table 6 shows the total environmental impacts for every stage in the BLC. The highest negative effect for the whole BLC is the total primary energy as measured in this case study (1.20×10^7) MJ/m^2, [11] confirmed this result and mentioned that the total primary energy for a prefabricated building module in Italy is 29.2 GJ/m^2. While, the non-renewable energy is (1.12×10^7) MJ/m^2, and fossil fuel energy is (1.01×10^7) MJ/m^2, then the global warming potential measured as (1.02×10^6) Kg CO_2eq.

Table 6.
Total environmental impacts for building materials during BLC



Environmental Impacts	Unit	Material Manufacturing stage	Construction stage	Use Phase stage	End of life stage	Disposal stage	Total Effects
Global Warming Potential	Kg CO_2eq	8.61×10^5	7.28×10^4	5.27×10^4	4.91×10^4	-1.90×10^4	**1.02×10^6**
Acidification Potential	Kg SO_2eq	3.79×10^3	7.57×10^2	2.89×10^2	6.31×10^2	-8.63×10^{-1}	**5.47×10^3**
HH Particulate	kg PM2.5 eq	6.44×10^2	47.8	9.84×10^2	20.1	-3.79×10^{-1}	**1.70×10^3**
Eutrophication Potential	Kg Neq	3.88×10^2	51	9.74	39.4	-4.44×10^{-2}	**4.88×10^2**
Ozone Depletion Potential	Kg CFC-11eq	8.87×10^{-3}	1.72×10^{-4}	9.44×10^{-5}	2.01×10^{-6}	0	**9.14×10^{-3}**
Smog Potential	Kg O_3eq	5.98×10^4	2.36×10^4	4.60×10^3	2.07×10^4	-8.73	**1.09×10^5**
Total Primary Energy	MJ	8.33×10^6	9.87×10^5	1.98×10^6	7.27×10^5	-1.73×10^3	**1.20×10^7**
Non-Renewable Energy	MJ	7.56×10^6	9.76×10^5	1.94×10^6	7.26×10^5	-1.73×10^3	**1.12×10^7**
Fossil Fuel Consumption	MJ	6.68×10^6	9.63×10^5	1.76×10^6	7.25×10^5	-3.47×10^3	**1.01×10^7**

According to the previous results, and as shown in Table 7 this study confirm that the materials production stage alone accounted for more than 70% of the total environmental impacts caused by a building, [11] supported this result. The second influential stage is the use stage which contributes by 15% of the total impacts, then the construction stage contributes by 10%. Finally, the disposal stage contributes by -10%, and that shows the importance of the waste treatment that the authors consumed for the case study building in Egypt. However, from other available literature review [6], [12] the most influential stage in the environment is the operational use stage it contributes more than 70-80%.

Table 7.
Total Environmental Impacts percentage during BLC

BLC stages	Total Environmental Impacts	Percentage
Material Manufacturing Stage	2.35E+07	70%
Construction Stage	3.02E+06	10%
Use Stage	5.73E+06	15%
End of life Stage	2.25E+06	5%
Disposal stage	-2.59E+04	-10%

Fig. 8 shows the building life cycle emissions to air, land and water. The Material manufacturing stage release the biggest emissions to water, air, and land. Then the end of life stage releases the most emissions to land it releases about 60% of the total land emissions.

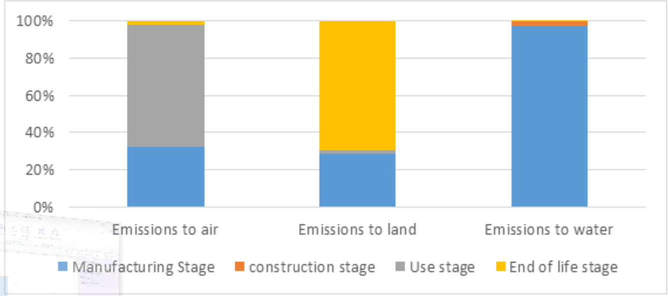


Fig. 8. Building material emissions during BLC

5. Conclusion

This paper measures the environmental impacts for a day care building in Egypt as a case study during its life cycle from the material manufacturing stage to the disposal stage with focusing on the end of life stage to help the construction industry stakeholders, engineers, and policy makers to reconsider the CDW management practice in Egypt. The results show that the material manufacturing stage is the most impactful stage which contributes 70%, which consumes raw materials, energy and fossil fuel energy. Then the use/maintenance stage is the second impactful stage. However, the end of life stage contributes by -10% of the total environmental impacts. As for the emissions to air, land and water; the material manufacturing stage is the main contributor to the water emissions. The use/maintenance stage is the main contributor to the air emissions. Moreover, the end of life stage has the role in the emissions to land; this stage produces the construction and demolition waste.

The findings of the research pointed out the relevance of LCA in the assessment of the building environmental performances. The aforementioned results indicate the opportunities to reduce the environmental impacts during BLC by using sustainable building materials in Egypt, using recycled building materials instead of building with new materials. Motivate applying 3Rs principle (Reduce, Reuse & Recycling) during BLC. Fees impose on contractors for illegal waste dumping.

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التحليل البيئى لمبنى حضانة بمصر من خلال أداة تقييم دورة حياة المبنى

الملخص العربى

يهدف هذا البحث إلى قياس التأثير البيئى لمواد البناء ومخلفات البناء والهدم عن طريق دراسة حالة لمبنى حضانة بمصر خلال دورة حياة المبنى. أداة تقييم دورة حياة المبنى تقيس ثمانية مؤشرات بيئية تؤثر سلبا على البيئة؛ وتتضمن انبعاثات غاز الكربون واستهلاك الطاقة. توضح هذه الدراسة الأهمية النسبية لمراحل دورة حياة المبنى؛ مرحلة عمليات البناء ومرحلة تصنيع المواد والتى تعتبر أكبر مساهم في الآثار البيئية للمباني. أظهرت النتائج أن مرحلة تصنيع مواد البناء تعد المساهم الأكبر فى الآثارالبيئية فهى تساهم بنسبة 70% من إجمالى الآثار البيئية للمبنى ككل أثناء دورة حياة المبنى. وعلى الجانب الآخر فإن مرحلة نهاية حياة المبنى تساهم بنسبة -10%. هذه النتائج تساعد المهندسين والقائمين على صناعة البناء والتشييد بمصر على تغيير ممارساتهم تجاه عملية إدارة مخلفات البناء والهدم.