PORT-SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 22 No. 1 March 2018 pp: 17:24

Quantifying CO_2 Emissions Released from the Materialization Stage of a Traditional Building in Egypt

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ABSTRACT

It is known that the construction industry is always playing an important role in social and economic development, which already pushed it to be considered as a primary source of carbon dioxide emissions. Consequently, carbon mitigation plans and energy conservation strategies of buildings had attracted the concentration of many developed countries. Many past studies have been conducted to assess carbon emissions associated with the operation, maintenance and disposal stage of buildings and to reduce it as CO_2 emissions must be assessed firstly in order to find the suitable mitigation plan. There is no any conducted study proposed to assess the initial carbon emissions released from traditional buildings in Egypt. In order to address that issue, the current study proposes a detailed framework for the buildings' initial emissions assessment; the study divides the life cycle of traditional buildings into three stages based on material flow: the materialization and on-site construction stage, operation and maintenance stage and disposal stage. The current study is only focusing the materialization and on-site construction stage as it represents the initial emissions of the building's life cycle. Finally, the carbon emissions debt of the case study is quantified. Results show that the materialization and on-site stage of a traditional residential building in Egypt (with a concrete structure) is contributing a large amount of CO_2 emissions which must be mitigated in the future by adding renewable energy alternatives (which can cut down an equivalent future emissions' debt of the traditional energies going to be consumed by the building).

KEYWORDS

Low carbon building - assessing carbon emissions - carbon mitigation strategies - renewable technology alternatives.

1. INTRODUCTION

Recently, since the start of the industrial evolution (1750), carbon dioxide (CO_2) emissions which caused by human activities had contributed to climate change forcing the global temperature to be increased [1]. Human activities already modified the chemical composition of the atmosphere by increasing the concentration of greenhouse gases (GHG) in the atmosphere, primarily carbon dioxide, methane, and nitrous oxide [2]. The largest known contributions were coming from burning the fossil fuels that release CO_2 emissions to the atmosphere [3]. Human impact on climate during that evolution greatly exceeds those who due to natural process (solar changes and volcanic eruptions) [4]. GHG have reached their highest levels and the greenhouse effect forced the Earth's surface temperature to be increased [5].In addition, various studies had shown that the future climate change could hit Africa hard, but with different degrees over different parts of the continent. Intergovernmental Panel on Climate Change (**IPCC**) had provided a broad assessment of changes expected to 2100 in Africa for all climate scenarios, and the main message is that the entire African continent is very likely to warm during this twenty-first century [6]. Therefore, every government around the world till now are seeking new reactions as a reply for climate changes, they have been studying the buildings' opportunities and possibilities to be turned into low or zero carbon in order to stop future emissions related to construction sectors. A life cycle assessment for carbon emissions released from a building life cycle must be conducted in order to quantify the carbon debt of the building. Life cycle must be divided into stages in order to facilitate calculation processes of materials flow and energy flow within a building life cycle; building life cycle division is considered as a critical step in past studies.

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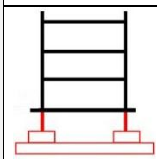
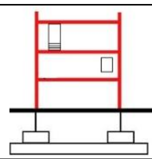
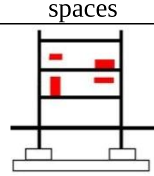
2. LIFE CYCLE ASSESSMENT

In order to understand why buildings consume energy and how, two factors must be recognized and defined as they may help determining the energy flow and material flow within the building life cycle, they are (buildings components and buildings types' classification). According to Electrical and Mechanical Services Department (**EMSD**), there are two types of the energy needs within buildings, one of them is essential (which reflects direct utilization such as lighting, air conditioning, escalators and lifts, and electrical power distribution within the building) and the other is complementary (which reflects indirect utilization of energy such as the building enclosure or envelope) [7].

2.1. Buildings' components

In 2015, according to (**Suryakanta**), building components were classified into sub-structure and super-structure components [8]. In the current study, furniture elements can be added as a third component to the classification of buildings as shown in (Table 2-1).

(Table 2-1) building components classification

Component type	Sub Structure	super structure	Furniture Elements
Place existing	Below bases level	Above bases level	Building spaces
			
Description and Function	Transmit the load of structure to ground and insulate the building super structure	It is the main load itself	Facilitate building's main function
Samples	Foundation, Plinth and insulations	Walls, floors, doors and windows, painting and water supply systems	HVAC and ventilation system devices, bulbs and water heaters

Source: Suryakanta (2017), adapted by the researcher

2.2. Building occupancy classification

There are many factors affecting energy efficiency in buildings such as location, climate, building type, user's behavior and awareness [9]. According to World Business Council for Sustainable Development (**WBCSD**), a building type is the dominant factor affecting energy within the building system [10], so buildings classification will always help understanding the energy demand of the different buildings. Buildings have internationally classified by the International Building Code (**IBC**) into eleven groups (A, B, E, F, H, I, M, R, S, U, and Others) [11]; only group (R) is focused in the current study as it is concerning with residential buildings which is representing the major percentage of the Egyptian region's buildings.

2.3. Building life cycle division

In 2009, the Royal Institute of British Architects (**RIBA**) has broken down the building's whole life cycle into three stages (construction stage, service life stage and disposal stage) [12]. Many other past studies adopted a three stages life cycle division in their calculations, for example, a study proposed by (**Zhang, X and his fellows**) in 2015 for a detailed carbon emission inventory for buildings, it has divided the life cycle of typical building into three stages and five sub-phases based on material and energy flow; main stages are (materialization, operation and disposal stage), and the five sub-phases are (material preparation phase, on-site construction phase, building operations phase, building demolition phase and material recycling phase) [13]. Therefore, the current study adopts the three stages division based on material flow within the building life cycle, which are (materialization and on-site construction stage, operation and maintenance stage and disposal or renovation stage).

2.4. Life cycle assessment model (LCA)

2.4.1.LCA traditional model

LCA model is widely used in many past studies to assess carbon emissions life cycle in a building system, it can be considered as a traditional model [14]. LCA model is following three phases to assess the potential environmental aspects (gathering an inventory of relevant inputs and outputs, evaluating environmental impacts potentials which are associated with those inputs and outputs, and discussing results of the inventory and impact phases in light of the assessment objectives) [15]. According to RIBA, when going to assess carbon emissions and carbon reduction options using LCA model, both energy and emissions need to be expressed as factors; these factors were given in many past scientific researches and studies [12].

Accordingly, RIBA also has discussed how the LCA works and concluded that there are four linked components must be involved with the LCA model [12] (scoping and goal definition, life cycle inventory, impact analysis, and improvement analysis), where:

1	**scoping and goal definition**
	-The purpose of LCA and expected products must be identified. -The boundaries of the study (what is and is not included) and assumptions (based on goal definition) must be determined also.
2	**Life cycle inventory**
	-Following past studies making benefits of its results and recommendations, the energy and raw material inputs and environmental releases associated with each stage of production must be Quantified using the model equations or using any certified software.
3	**Impact analysis**
	-The impacts on human health and the environment associated with energy and material inputs and environmental releases quantified by the inventory must be assessed.
4	**Improvement analysis**
	-Opportunities to reduce energy, material inputs, or environmental impacts for each stage of the life cycle of any product must be proposed and evaluated.

2.4.2.LCA modern models

There are many modern LCA models online which have been proposed by many leading authorities and organizations associated with the environmental impacts assessments, the potential environmental aspects and potential aspects associated with a product or a building system. For example (**GaBi software, OpenLCA, LEGEP, SBS, Oneclicklca, ELODIE, SimaPro, Umberto and others**). Unfortunately, all programs of them are requiring huge databases inputs which must be provided for every specific region. Till now, no of them has provided for the Egyptian region, so in light the comparison shown in (Table 2-2), the traditional LCA model is used for the purpose of the current study.

(Table 2-2) Comparison between LCA traditional and modern models

	LCA traditional models	**LCA modern models**
Databases needed	Needs less data such as material quantities, emissions factors and life time expectancies for the components	Needs huge databases on materials manufacturing systems, social indicators, product development, local legislations, products inputs/outputs and other data.
Time, effort and cost	Needs more time, effort and less costs	Needs less time, effort but may costs more
Data availability for Egypt	Data available except the materials' emissions factors	Not available
Scientific research	Engaged	Not engaged yet

Source: Adapted by the researcher

2.5. LCA model's equations

LCA is calculating material inputs using a number of equations in order to estimate the CO_2 emissions outputs. In order to get benefits of past studies that used the LCA model, a model equations adopted in 2015 by (**Xiaocun Zhang and Fenglai Wang**) was chosen as an example to follow in the quantification method for the current study. The quantification model proposed by (**Zhang, X. and Wang, F.**) has been gone through nine phases covering the whole life cycle emissions of the building [13]. In light of the purpose of the current study, only emissions released from materialization and on-site construction stage is focused using the following equations:

(Equation 2-1)

$$E_{MAT} = E_{PREP} + E_{TRANS} + E_{CONS}$$

Where, (E_{MAT}) represents the total and final emissions debt released from the materialization and on-site construction stage taking into account emissions released from the preparation phase of the different materials types (E_{PREP}), emissions released during the transportation of every material type to the construction site (E_{TRANS}) and emissions released during the implementation of the different material on-site (E_{CONS}).

- *Emissions released from the preparation phase*

(Equation 2-2)

$$E_{PREP} = \sum_{i=1}^{n} m_i \times \left(1 + \frac{w_i}{100}\right) \times EF_{mat,i}$$

Where, (n) is the total number of material types, (i) is the material type, (m_i) is the exact consumption of material (i), (w_i) is the loss rate of type (i) material during transportation and construction phases and ($EF_{mat,i}$) is the CO_2 emission factor of type (i) material which is given in many past researches and studies. Worth mentioning, that emission factor may be affected by the individual regions weather, economic states and other factors it is slightly differing from region to region; as such factors are not available for Egypt region, factors used by (**Zhang, X. and Wang, F.**) for China region is used in the current study as they also are very close to factors used by (**Chau, C. K. and his fellows**) in their study in 2012 in France [16].

- *Emissions released from the transportation phase for every material:*

(Equation 2-3)

$$E_{TRANS} = \sum_{i=1}^{n} m_i \times \left(1 + \frac{w_i}{100}\right) \times S_i \times EF_{trans,i}$$

Where, (S_i) is the transport distance of type (i) material and ($EF_{trans,i}$) is the CO_2 emissions for unit (i) material transported for unit distance which is given in many past studies such the study by (**Chau, C. K. and his fellows**) in 2012 [17], which adopted data from the Inter-Governmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories report [17].

- *Emissions released from the phase of on-site construction:*

(Equation 2-4)

$$E_{CONS} = E_{MAC} + E_{MEA}$$

Where, (E_{MAC}) is the emissions released from construction machinery operation, and (E_{MEA}) is the provisional measures on construction sites emissions Such as temporary lighting and power supply which can be estimated based on energy procurement records.

(Equation 2-5)

$$E_{MAC-1} = \sum_{i=1}^{m} (T_{mac,i} \times EF_{mac,i})$$

Where, ($T_{mac,i}$) is the working time for type (i) machinery, (m) is the total number of machinery types and ($EF_{mac,i}$) is the CO_2 emission factor for unit working time for type (i) machinery which is given in past studies such as the example study conducted by (**Zhang, X. and Wang, F.**).

(Equation 2-6)

$$E_{MAC-2} = \sum_{i=1}^{p} (Q_{sub,i} \times EF_{sub,i})$$

Where, (p) is the total number of sub-project types, ($Q_{sub,i}$) is the engineering quantity of type (i) sub-project, and ($EF_{sub,i}$) is the CO_2 emission factor for unit engineering quantity of type (i) sub-project.

In addition, (Zhang, X. and Wang, F.) also proposed (Equation 2-7) which represents the load index of the building which reflects the building life-cycle value taking into account three components (the product of building area, story height, and service life).

(Equation 2-7)

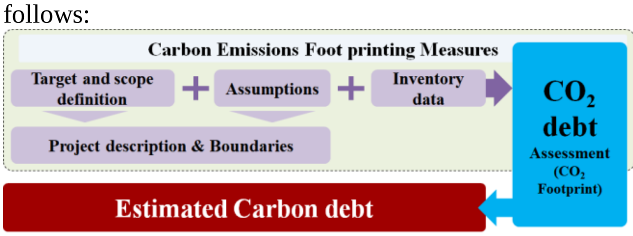
$$LI_j = \frac{E_J}{(A \times H \times T)}$$

Where, (LI_j) is the load index, (E_J) is the quantified carbon emissions of any life cycle stage, (A) is thebuilding area, (H) is the average story/floor height and (T) is the service life of the building.

3. CASE STUDY

3.1. Methodology

In order to quantify the carbon emissions amounts released from a building's life cycle, it is recommended to recognize the methodology shown in **(Figure 3-1)** as follows:



(Figure 3-1) Carbon emissions quantification methedology by the researcher

3.1.1.Target and Scope Definition

- **Purpose**

The target or the purpose of the CO_2 assessment is to quantify the impact of the materialization and on-site construction stage of a (new-constructed) traditional building in Egypt. The study aims to identify the highest impact material types in order to make a futuristic attention for the construction industry within the Egyptian region. It is expected to monitor the exact CO_2 emissions quantities released from the materialization and on-site construction stage of a traditional building as an indirect emissions or embodied emissions debt.

- **Scope**

✓ **Building type**

As the selected building would act as representatives of the current local building market, it should be from a list of buildings which selected based on the criteria proposed by (**Zhang, X. and Wang, F.**) [16], which contains the following aspects:

-Information and details related to the building should be ready, completed, available and accessible.

-The sample should represent a wide range of built forms, scale, designs and specifications within the region of the study.

-The sample can be constructed with modern building materials in recent decades.

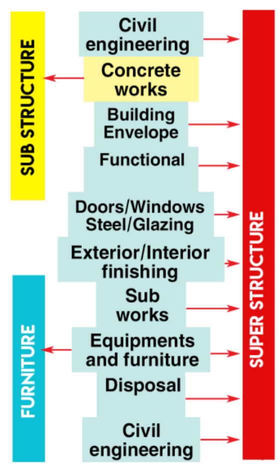
So, the most suitable building type which follows the criteria is the residential building.

✓ **Why indirect emissions?**

Firstly, **direct emissions** are emissions that associated with operation stage equipment, devices, and daily uses of electricity involved with cooling, heating or ventilating building spaces, they can be mitigated easily by choosing efficient appliances and devices that must be identified by an authorized agency.

Otherwise, **indirect emissions** are already emitted in the early materialization and on-site construction stage which have no chances to be mitigated once the building is already constructed; it is always considered as embodied energies, so **embodied energies which cause the indirect emissions are only focused in the current study.**

Additionally, in light of previous studies, based on data observed from a number of similar projects and based on the material flow within a building life cycle which associated with the project implementation processes, the current study has divided the implementation phase of a building into ten steps as shown in (Figure 3-2), and the only focused materials based on data accessibility are materials who associated with the construction and finishes.

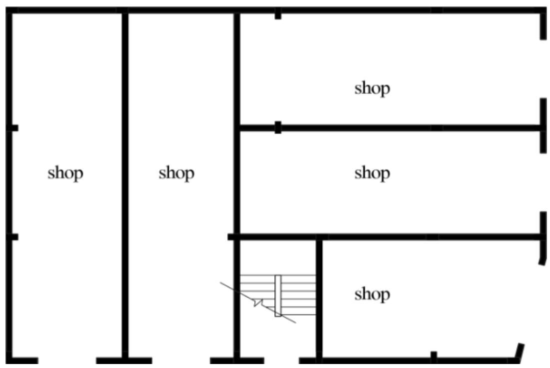


(Figure 3-2) building implementation phases
Source: Adapted by the researcher based many observation for implemented projects in Egypt

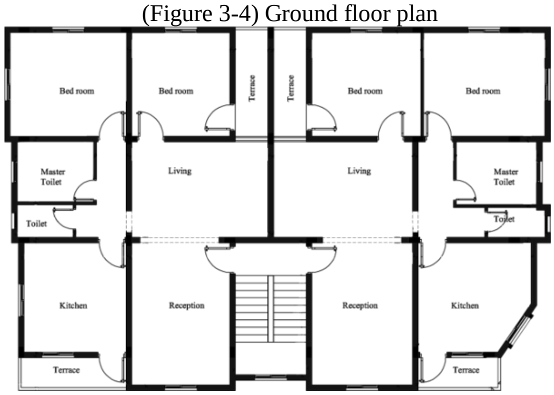
- Project **description**

Project type	Small residential building
Location	Egypt, PortSaid, Adel El-sherpiny street  (Figure 3-3) The site location captured by the researcher using Google earth at (15 Feb, 2017)
Site Area	480 m^2 , (Constructed area = 221 m^2)

Floors/stories	Two Floors (Ground level and 1st level)
Floors area	Ground floor (221 m^2), 1st Floor (255 m^2)
Structure	Concrete structure with flat slabs
Current Status	The materialization and on-site construction stage was finished



(Figure 3-4) Ground floor plan



(Figure 3-5) First floor plan

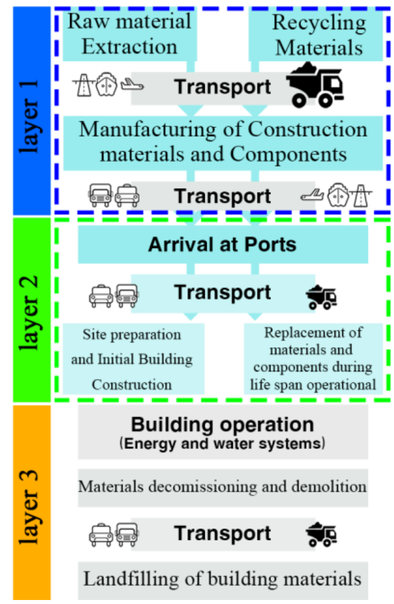
(Figure 3-6) the case study building
Modeled and visualized by the researcher

3.1.1.Assumptions

1	**Emissions factor** values for each material (preparation, transportation and machinery processes) were extracted from past studies
2	The building's **life span** extends **seventy** years
3	Laborers have no any on-site accommodation during the whole implementation period

3.1.2.Inventory data and Material life cycle

According to the ease-acquisition of data from different sources, not all materialization sub-phases will be included in the framework of the current study, as shown in (Figure 3-7), layer one and layer two has only chosen to be focused within carbon assessment of the case study building.



(Figure 3-7) Materials life cycle figure
Source: proposed by Chau C.K. and his fellows (2006)

3.2. Carbon emissions quantification

In light of the LCA model's equations and in order to easy quantify the carbon dioxide emissions caused by the materialization and on-site construction stage, that stage has divided into three sub-phases (material preparation phase, material transportation to site phase and material implementation or construction phase) and each phase is responsible for a specific quantity of the released carbon dioxide emissions. In addition, based on data extracted, here is the list of materials used in the case study building, vehicle used to transport each material type to site and machineries included to finish the construction phase:

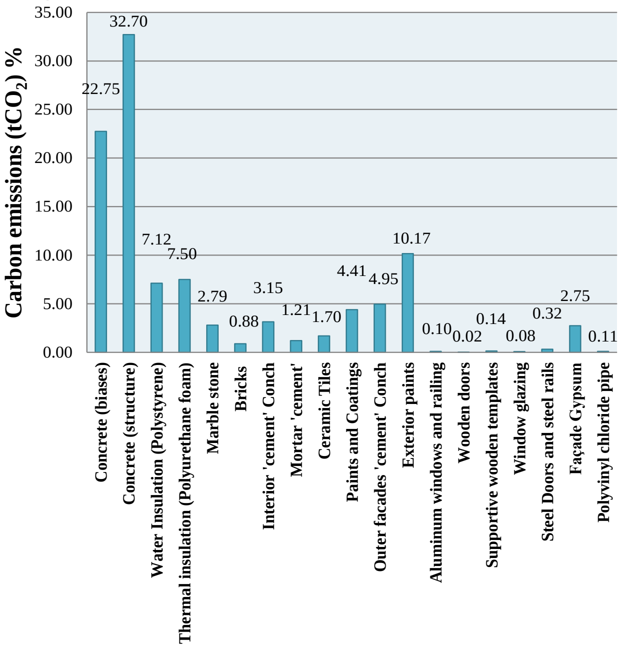
Materials list	
Concrete (biases)	
Concrete (structure)	
Water Insulation (Polystyrene)	
Thermal insulation (Polyurethane foam)	
Marble stone	
Bricks	
Interior (cement) conch, mortar (cement), outer facades (cement) conch	
Ceramic Tiles	
Interior and exterior paints and coatings	
Aluminum windows and railing	
Wooden doors, steel Doors and steel rails	
Supportive wooden templates	
Window glazing	
Façade Gypsum	
Polyvinyl chloride pipe	
Vehicles and Machineries list	
Concrete's Vehicle	Crawler crane (20 tons)
(Six tons) Truck	Excavator (PC228)
komatsu loader (WA180)	Electric hoist (5 tons)
Bar straightener (Φ 14)	Bar cutter (Φ 40)
Angle bending machine(Φ 40)	Drum concrete mixer (400 L)
Mortar mixer (200 L)	Concrete vibrator

Circular sawing machine

3.2.1. Material production emissions (E_{PREP})

This phase is concerned with data on materials types' inventory, final material inputs, emissions factors (emissions released from the unit material prepared) and the final emissions caused by the preparation of each material type. There are two factors associated with the final material inputs which can't be neglected as they may affect the final emissions of the materialization stage replacement factor for each material which defines how many time will a material be replaced during the whole life cycle of the building, wastage percentage as every material type may has a wastage during its transportation journey and implementation).

In 2007 according to (**Chau, C. K., and hos fellows**), the replacement factor for any material type can be estimated dividing the life span of the building by the material expected life time [18]. Finally, data extracted, final material input quantity was multiplied by its emission factor, put into (Equation 2-2) and results are shown in (Figure 3-8).

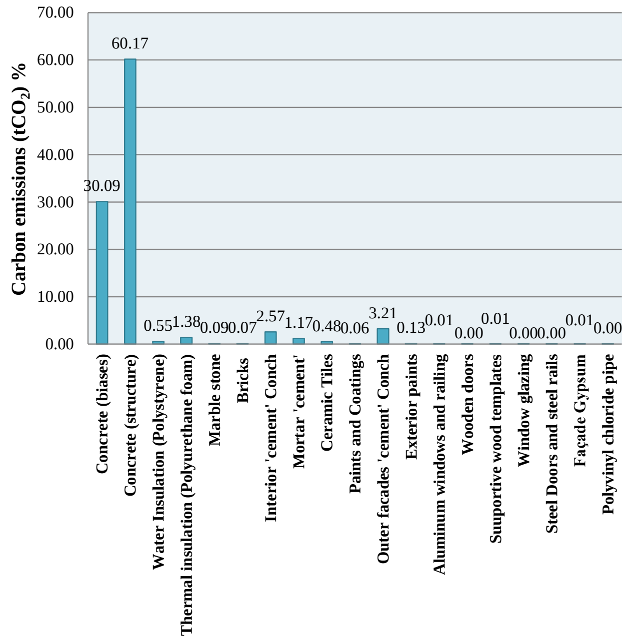


(Figure 3-8) CO_2 emissions resulted from every material type during its preparation phase

3.2.2. Material transportation emissions (E_{TRANS})

This phase is concerned with data on transportation vehicles types, fuel type and energy consumed by every vehicle to transport every material from factory to the construction site and the final emissions caused by the transportation of each material type.

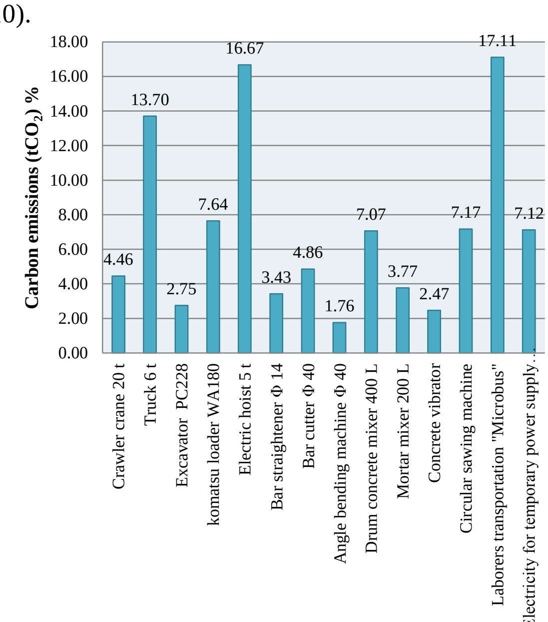
Data on the final material input quantities, vehicles used to transport materials from factory to the construction site, distance for every material transported and emissions factor data for every transportation vehicle who used to transport the different materials were extracted, put into (Equation 2-3) and results are shown in (Figure 3-9).



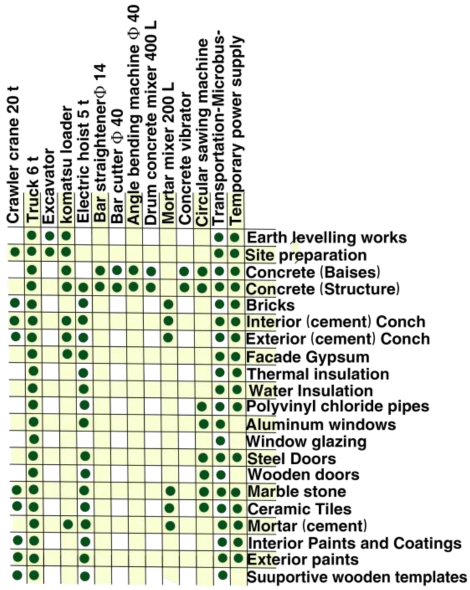
(Figure 3-9) CO_2 emissions resulted from every material type during its transportation phase

3.2.3. On-site construction emissions (E_{CONS})

This phase is concerned with data on machinery used in the construction process, fuel type and energy consumed by every machinery, laborers transportation, temporary power supply for sub-services needed during this phase and the final emissions caused by machineries worked on this phase. Data on machineries used to implement every material type was extracted and concluded in (Figure 3-11). Data on machinery types, working days, fuel type, fuels' hourly consumption rates, and emission factors for a unit working time for a machinery type were extracted and put into (Equation 2-5) and results are shown in (Figure 3-10).



(Figure 3-10) CO_2 emissions resulted from every material type during its constrcution phase



(Figure 3-11) releationship between every material type and machinery used within the process of its construction

4. CARBON DEBT RESULTS DISCUSSION

Finally and in light of CO_2 emissions' debt resulted from the three phases of the materialization and on-site construction stage which shown in (Table 4-1), the CO_2 debt of the stages can be calculated putting carbon emission results into (Equation 2-1) and the final CO_2 debt of this stage is about (**419.9564 ton CO_2**) which represents a high environmental impact compared with the building size.

Consequently, it is very essential to show the resulted emissions weight by the unit value of the building taking building area, story height, and service life into account, so it can be used as a standard for the other building that have the same specification of the studied case. So, resulted CO_2 debt, building area, story height and service life values was put into (Equation 2-7) and the final Load index value for the traditional building case study (emissions of unit building value) is (**0.003878** TonCO_2).

(Table 4-1) CO_2 emissions debt of the materialization and on-site construction stage

CO_2 emissions (TonCO_2)		Percentage %
E_{PREP}	324.411	77.2
E_{TRANS}	74.43	17.7
E_{CONS}	21.116	5.0
Total	**419.9564**	**100.0**

Accordingly, by observing the calculated debt results, it can be found that the Egyptian traditional buildings' materials can be divided into three types from the point emissions impact strength as follows:

- **High impact materials**: which contribute a very high amount of carbon emissions compared to other materials **such as:**
  - ✓ Insulation products, contributing with (49.04 TCO_2).
  - ✓ Polyvinyl chloride, contributing with (0.44 TCO_2).
  - ✓ Facade gypsum, contributing with (9.01 TCO_2).
  - ✓ Traditional concrete products, contributing with (205.097 TCO_2).
  - ✓ Paints, coatings and conch, contributing with (80.78 TCO_2).
- **Medium impact materials**: which impact slightly lower but still has an **impressive** great influence **such as:**
  - ✓ Aluminum products
  - ✓ Marble stones
  - ✓ Ceramic tiles
  - ✓ Glazing products
- **Low impact materials**: which have lower quantities and lower emissions **such as:**
  - ✓ Clay brick
  - ✓ wood products

Worth mentioning, the resulted emissions from the different machineries used can't be neglected. Evidences are clear whether for on-site construction phase or the transportation phase. So, vehicles must be reviewed urgently in terms of fuel consumption rates and fuel type as in the current study the machineries altogether have contributed with (95.33 TCO_2) presenting (22.7 percentages) of the total emissions of both transportation and on-site construction phases. Machineries also have shown varieties in their associated emissions, some can considered a high impact such the microbuses used to transport laborers, the electric hoist, the six tons truck, the comatsu loader, the circular sawing machine and the drum concrete mixer.

Finally, it can be concluded that a traditional building in Egypt that has a (0.25m of clay bricks), covered with conch and paints from the inside, covered with conch and exterior coatings from the outside, its floors are covered with ceramic tiles, its stairs covered with marble stone, can release about (**0.003878** TCO_2) for its unit value. That emissions' debt can be mitigated by applying renewable energy systems to the buildings, as they may help cutting an equivalent future debt of the traditional energies going to be used which represents a great chance to impose restrictions on traditional buildings. Renewable energy systems must be applied to the building system following the steps:

- Renewable technologies alternatives must be proposed to be added on-site or off-site in order to provide clean power for the building.
- Based on the equivalent emissions' annual savings measures and the estimated carbon debt, every renewable technology alternative can have a period to pay-back the building's emissions debt.
- The shortest pay-back period must be chosen as it must not exceed the building service life.
- A deep comparison must be conducted between the **different** renewable alternatives for an accurate preference (based on the size of the project, total costs per technology, benefits expected, added

value of the alternative and the plenty of the renewable resource for the site).

- One or more alternatives can be chosen to be applied to the project.

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"حساب الإنبعاثات الكربونية الناتجة عن مرحلة تصنيع المواد لمبني تقليدي في مصر"

الملخص:

من المعروف أن صناعة التشييد دائما ما تلعب دورا هاما في التنمية الإقتصادية والمجتمعية، الأمر الذي يجعلها مصدر رئيسي لإنبعاثات غاز ثاني أكسيد الكربون. من ثم، و بسبب التغيرات المناخية، فإن تطوير خطط وإستراتيجيات لتخفيض انبعاثات الكربون للمباني أصبح أمرا حرجا بالنسبة للدول المتقدمة.تم اجراء العديد من الدراسات السابقة لحساب وتخفيض انبعاثات الكربون المتعلقة بمرحلة تشغيل المبني والصيانة ومرحلة الهدم. و مع ذلك، فلابد اولا من حساب وتعيين إنبعاثات الكربون لتحديد الخطة الملائمة لتخفيض تلك الإنبعاثات. لسوء الحظ فإنه لم يتم اجراء أي دراسة مسبقا لتعيين الانبعاثات الاولية الناتجة عن المباني التقليدية في مصر. ولمواجهة تلك المشكلة، تقدم الدراسة الحالية إطار مفصل لتعيين الانبعاثات الاولية للمبني التقليدي في مصر، تقوم الدراسة علي تقسيم دورة حياة المبني إلي ثلاث مراحل رئيسية بناءا علي تدفق مواد الإنشاء خلال دورة حياة المبني وهي: مرحلة تصنيع المواد والانشاء في الموقع، مرحلة التشغيل والصيانة ، ومرحلة الهدم. تركز الدراسة الحالية فقط علي مرحلة تصنيع المواد والانشاء في الموقع بإعتبارها المسؤولة عن الانبعاثات الاولية لدورة حياة المبني. تشير نتائج الدراسة إلي ان مرحلة تصنيع المواد والانشاء في الموقع لمبني تقليدي من الهيكل الخرساني قد تنتج قدر كبير جدا من الانبعاثات الكربونية والتي يتحتم تخفيضها ووقفها في المستقبل القريب عن طريق إضافة مصادر للطاقة المتجددة للمباني لوقف قدر مكافئ من الدين الكربوني المستقبلي للطاقات التقليدية المتوقع إستهلاكها من قبل المبني.