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ORIGINAL ARTICLE

Cradle-to-gate life cycle assessment of interior floor material alternatives in Egypt

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Abstract
The building materials sector has a major environmental impact and is one of the main causes of environmental degradation in the construction industry. An Environmental Impact Assessment of several interior floor material options, such as ceramic, marble, and parquet tiles, is conducted in this study using a Life Cycle Assessment (LCA) methodology. Due to the shortage of LCA applications in Egypt and the unavailability of the inventory database for the materials industries, the study uses a case study of a new city in Egypt to assess the environmental effects of various floor materials. The LCA approach uses SimaPro software V9.50 and its integrated Ecoinvent database V3.0 to define the objective and scope, conduct an inventory analysis, evaluate the impact, and interpret the results. According to the LCA findings, ceramic tiles, followed by marble tiles and parquet tiles, have the lowest negative environmental impacts. Regarding the singles score, results (midpoint method) have revealed that the marble tiles have hit the highest adverse environmental impacts by 2.24 pt, followed by parquet by 1.21 pt, and finally, the ceramic tiles by 0.594 pt. The global warming potential of ceramic tiles is 0.539 kg CO_2, which is less than 74% of the global warming potential of marble tiles (2.01 kg CO_2). The non-renewable energy impact of the marble tiles is (38.70 Mj primary), which is higher by 78% of the non-renewable energy of ceramic (8.46 Mj primary). Finally, the human health impact has recorded the highest numbers in the marble industry by 1.12E−5 DALY, which means the marble industry needs a high amount of energy. Ultimately, the findings of this study can potentially improve the sustainability and energy efficiency of construction projects by assisting decision-makers in selecting and applying environmentally friendly building materials.

Keywords Life cycle impact assessment · Cradle-to-gate · BIM · Floor materials · New Assiut city

List of symbols

CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
PPM	Particulate per matter
SO_2	Sulfur dioxide
NO_x	Nitrogen oxide
NH_3	Ammonia
C_2H_4	Ethylene
Pt	Eco-points
m^3	Cubic meter
m^2	Square meter
Mj primary	Primary energy in mega-joules (MJ)
kg	Kilogram
kg/m^3	Density
kg CO_2 eq	Kilogram carbon dioxide equivalent

Abbreviations

LCA	Life cycle assessment
BIM	Building information modeling
EP	Environmental performance
ISO	International standards organization
EIA	Environmental impact assessments
NAC	New Assiut city
PDF	Potentially disappeared fraction of species
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
GHG	Greenhouse gas
IEA	International energy agency
DALY	Disability adjusted life years
eq	Equivalents

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1 Introduction

In Fig. 1, 40% of annual global CO_2 emission caused by the built environment. The buildings construction and infrastructure (also known as "embodied carbon") accounts for additional 13% of the total emissions annually, with building operations accounting for 27% of those emissions. [5, 19].

According to the International Energy Agency (IEA) [19], embedded carbon emissions are locked in place as soon as a structure is constructed, unlike operational carbon emissions, which can be decreased over time with building energy upgrades and using renewable energy. To achieve zero emissions by 2040, it must act today to control embodied carbon—Fig. 2.

As seen in Fig. 3, the building industry accounts for the most significant portion of worldwide CO_2 emissions. Concrete, steel, and aluminum account for 23% of total emissions (most of which are used in the built environment) [5, 19].

The lack of comprehensive Environmental Impact Assessments (EIAs) of interior floor material alternatives, including ceramic, marble, and parquet tiles, utilizing a Life Cycle Assessment (LCA) approach in the context of a new city is the research issue this study attempts to solve. The LCA methodology, which follows the "cradle to gate" principle, is a comprehensive strategy that considers how building materials will affect the environment throughout the course of their whole life cycle [13, 38].

These materials are widely used in building construction, although it is unclear how they may affect Egypt's environment throughout their lifetime. The goal of the study is to offer useful knowledge about how various floor materials affect the environment., assist in selecting suitable building materials for sustainable development, and apply the information to newly constructed buildings in Egypt's new cities. Numerous factors affect the cost, durability, aesthetic appeal, and performance of different interior floor material alternatives, like parquet, marble, and ceramic tiles.

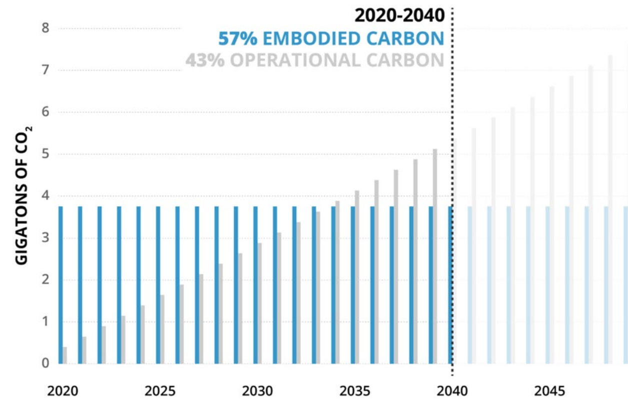


Fig. 2 Total carbon emissions of new structure [19]

The case study in this research is set a typical new city in a developing country, where selecting appropriate floor materials can significantly impact the city's environmental performance. Through raw material extraction, manufacturing, and transportation, the research seeks to assess the environmental impact of these flooring materials at each stage of their life cycle. The objective of this study aligns with the Sustainable Development Goals [35]. Specifically, Goal Nu. 9, “Industry, Innovation and Infrastructure,” and Goal Nu. 11, “Sustainable Cities and Communities.” Nevertheless, this study does not cover use and disposal at the end of life. The study will consider four impact categories by midpoint method, including global warming potential, non-renewable energy, and respiratory inorganic, and three impact categories by endpoint method, including human health, climate change, and resource depletion.

To sum up, utilizing an LCA approach to select interior floor materials require an EIA to promote sustainable growth in the building industry. The study aims to provide helpful

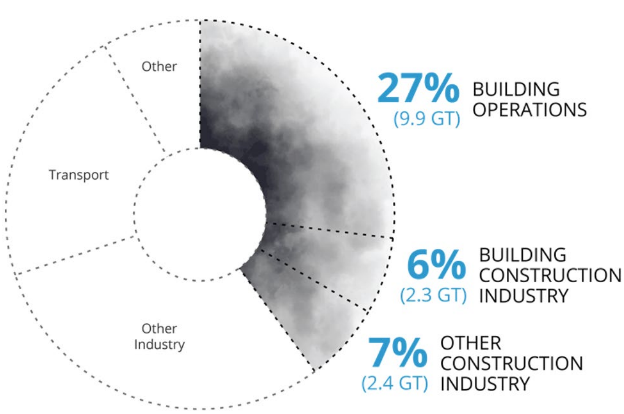


Fig. 1 Annual Global CO_2 emissions in 2022 [19]

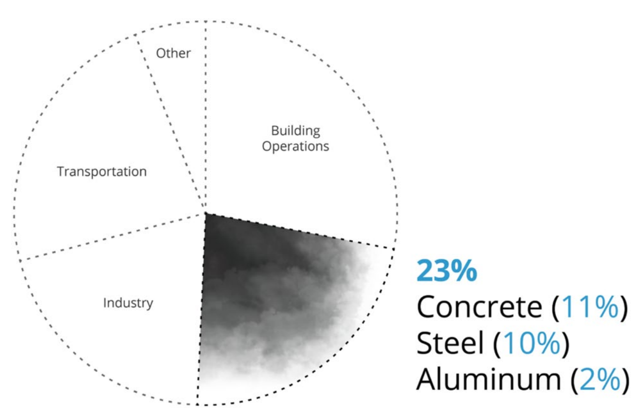


Fig. 3 Annual Global CO_2 emissions by industry type [19]

information on the environmental effects of different floor materials and assist in the decision-making process when choosing appropriate building materials for sustainable development. Decision-makers may find the findings helpful in selecting eco-friendly flooring solutions for subsequent development projects.

2 Literature review

This section will present the literature review based on the LCA application, integration of LCA and building information modeling (BIM), and recent applications of the (cement, marble, porcelain, and wood) industries.

First, in terms of LCA applications, Estokova et al. [13] have discussed using LCA to evaluate the environmental impact of sustainable building materials, such as wood, bamboo, straw, hemp, and recycled material. The authors have compared these materials to conventional building materials and examined the effects of these materials' manufacture, usage, and disposal on the environment. According to the paper, using sustainable building materials can significantly lessen the adverse effects of construction projects on the environment, especially regarding energy use and greenhouse gas emissions.

The environmental effects of several building floor systems, such as laminated timber beams, steel joists, wood joists, and reinforced concrete, were assessed by Valencia-Barba et al. [36]. The analysis has considered several phases, such as the acquisition of raw materials, manufacture, transportation, installation, use, and disposal. According to the findings, reinforced concrete has the most significant environmental impact, whereas laminated timber beams have the lowest, especially regarding energy consumption and ability to cause global warming.

When assessing the embodied energy of residential structures, Ghaemi et al. [15] considered several phases, including acquiring raw materials, production, transportation, construction, usage, and disposal. Silvestri et al. [33] have provided a comparative life cycle assessment to assess the production of face bricks and more environmentally friendly coating options. LCA's ability to thoroughly examine the environmental impact of buildings at every stage of their life cycle—manufacturing, construction, use, and end-of-life—has been emphasized by Ingrao et al. [20].

The previous literature study showed that incorporating the LCA into building design and construction methods can lower greenhouse gas emissions and encourage more environmentally friendly building practices.

Thirdly, concerning using LCA in the ceramics industry, Sappa et al. [32] produced ceramic tiles using the LCA approach and added municipal solid waste incinerator bottom ash as a raw material. The findings show that employing

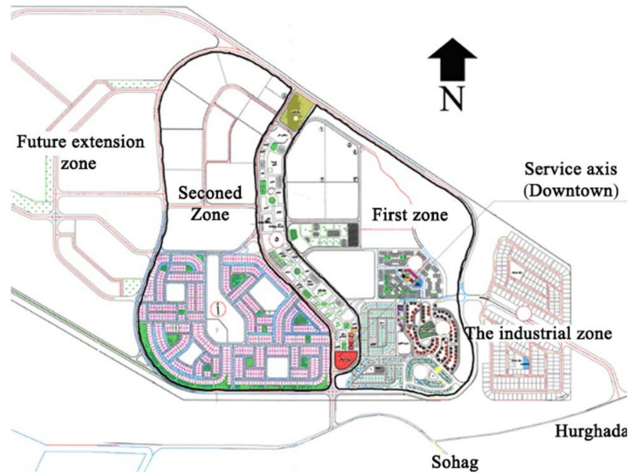


Fig. 4 NAC master plan (by visiting the New Assiut City Municipal in July 2023)

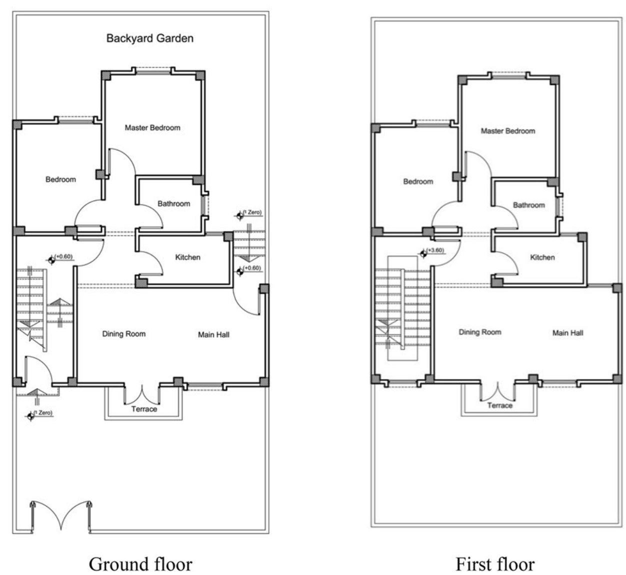


Fig. 5 Ibny Baitak project model (X)

this waste as a raw material in manufacturing ceramic tiles can significantly reduce the adverse environmental effects, especially energy consumption and greenhouse gas (GHG) emissions. A study on predicting GHG emissions and potential mitigation strategies for the ceramic tableware sector was presented in Thailand by Chuenwong et al. [11]. The findings demonstrate that these emissions can be significantly decreased by expanding renewable energy sources, enhancing production efficiency, and introducing greener production techniques. Atılgan Türkmen et al. [6] and Quinteiro et al. [30] assessed the environmental effect of ceramic tile production in Turkey by considering several phases, such

Fig. 6 Current structure problems of some Ibny Baitak buildings in NAC (pictured in July 2023) [1]

as procuring raw materials, manufacturing, transportation, usage, and disposal. According to the findings, the manufacture of ceramic tiles has a significant negative influence on the environment.

Ibáñez-Forés et al. [18] and Almeida et al. [4] evaluated the effects on the environment of several ceramic tile types, including glazed and unglazed tiles, and various manufacturing techniques, including wet and dry processing. The LCA was used on thin ceramic tiles with beneficial technological features by Pini et al. [28]. The results show that compared to other ceramic tiles, the large, thin ceramic tile has a lower environmental impact regarding energy consumption, GHG emissions, and resource depletion potential. Han et al. [16] have published an LCA of ceramic material and a comparative analysis with three others façade materials. According to the findings, producing ceramic material has less impact on the environment than producing the other three materials, especially regarding energy consumption and GHG emissions.

Monteiro et al. [25] have presented an integrated environmental and economic LCA of improvement strategies for the ceramic industry. These strategies aim to minimize the environmental impact, specifically energy consumption and greenhouse gas emissions, while yielding economic benefits like cost savings. The LCA and life cost analysis are integrated in their approach.

The LCA of ceramic materials combined with decorative stone wastes has been studied by Barbosa et al. [7]. The findings show that the environmental impact of ceramic material production can be significantly reduced by using ornamental stone wastes, especially when it comes to energy consumption and potential global warming. A cradle-to-gate analysis of red clay for applications in the ceramics industry has been presented by Bovea et al. [9]. The results show that red clay mining and transportation significantly negatively influence the environment, especially regarding energy use and greenhouse gas emissions.

Fourthly, regarding the application of LCA in the marble sector, Capitano et al. [10] have published an analysis of marble manufacturing facilities' energy and environmental impacts using the combined approaches of "by phases" and "by a single process together." Gazi et al. [14] have offered an assessment of the energy efficiency and environmental effects of a typical marble quarry and processing facility.

Ros-Dosdá et al. [31] have provided an environmental profile of Spanish porcelain stoneware tiles, considering multiple stages such as raw material procurement, manufacturing, transportation, usage, and disposal.

Tighnavard Balasbaneh et al. [34] have published an LCA and life cycle cost assessment of a glued laminated timber–concrete composite floor slab system, which pertains to implementing LCA in the wood industry. The findings show that the hybrid system has a more negligible life cycle cost and less environmental impact than conventional reinforced concrete slab systems. The LCA analysis that evaluates the carbon emissions related to using wood as a building material was presented by Lin et al. [22]. The results have shown that the use of wood in buildings has a lower carbon footprint than that of concrete and steel, primarily because wood can sequester carbon and requires less energy during manufacturing.

The literature review highlighted the potential of sustainable building practices and materials to lower construction costs and their environmental impact. The review emphasized how crucial it is to consider a building material or system's whole life cycle to completely comprehend its cost and environmental impact. In the end, incorporating sustainable building techniques will help achieve the objective of creating a constructed environment that is more sustainable for coming generations. As a result, this research aims to apply the LCA to Egypt, particularly newly developed cities. Specifically, the application will focus on a few carefully selected floor materials commonly used in Egypt [27].

3 Case study analysis

The New Assiut City (NAC) in Assiut, Egypt, has been selected as a case study since it is a new city and struggles to provide residents with the best structures and services. The location, city area, city planning, and finally, its constituent zones of the future city of Assiut will be briefly discussed below [1]. As a result, the presentation of the NAC is the main topic of this part. The NAC lies about 15 km from Assiut on the (Cairo–Sohag) desert route, close to its junction with the (Hurghada–Assiut) road. As seen in Fig. 4, the urban block of the city is composed of two residential neighborhoods separated by a primary service axis (city center), a third district (the future extension area), an industrial zone, and a regional area, as shown in Fig. 4.

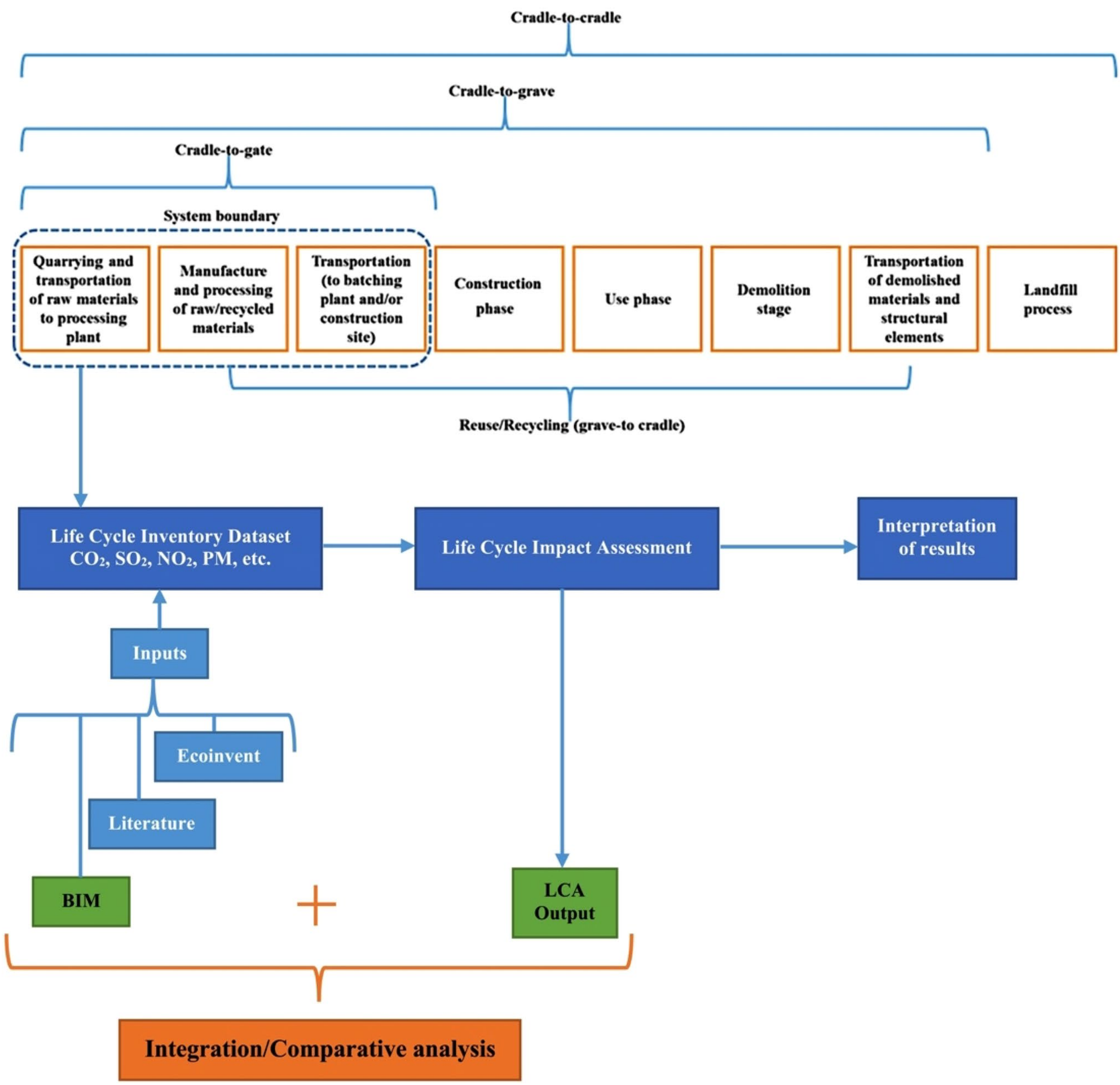


Fig. 7 System boundary of LCA application in this study

With a construction rate of 50% of the block, the beneficiary citizen constructs a housing (residential) unit. This residential unit has a floor area of (63 m^2) and comprises two bedrooms, a hall, a kitchen, and a bathroom. It also has a stairway with a floor area of (12 m^2) that leads to a flat floor of (75 m^2). There are three different models (X), (Y), and (Z), and this paper will use model (Y) as a case study, as shown in Fig. 5.

Figure 6 presents the justification for the author's choice to use the Ibny Baitak project in NAC as a case study for further investigation. Because the implementation depended on establishing themselves, significant problems

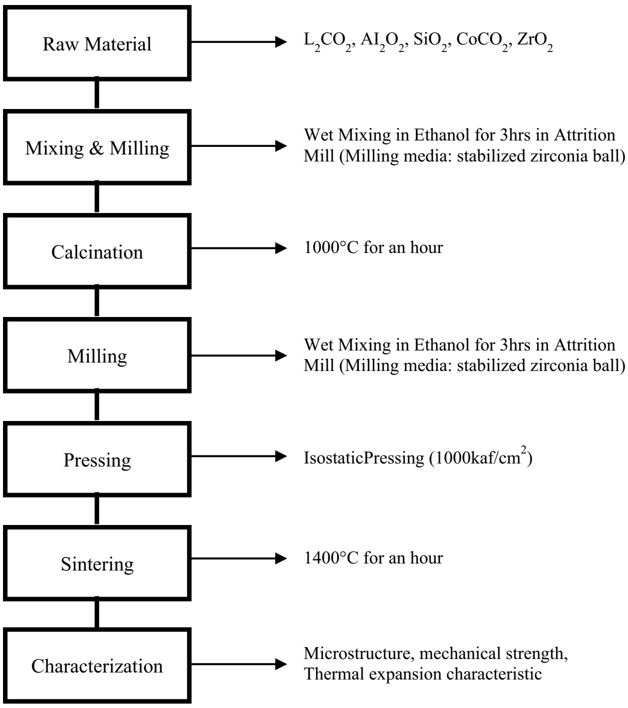


Fig. 8 Process flow diagrams of ceramic manufacturing [21]

have surfaced. These structures were constructed using materials without specifications and control, including foundation materials, brick and concrete kinds, coatings, and insulating materials (with heat and water resistance).

4 Life cycle assessment methodology

The LCA method provides a thorough understanding of the environmental effects of various interior floor materials, enabling the selection of suitable building materials for sustainable development. The LCA methodology of different interior floor materials, including ceramic, marble, and parquet tiles, typically involves the following steps:

1. Goal and scope definition: The goals and limitations of the LCA study are determined at this step. It contains the limits of the product system, the analysis's functional unit, and the effect categories that will be evaluated.
2. Inventory analysis: This step collects data on the inputs and outputs of the product system under inquiry, including raw materials, energy consumption, transportation, and waste generation. Primary data sources, like surveys and interviews, and secondary data sources, such as databases and literature, may be used in the data collection process.
3. Impact assessment: This step uses the information collected from the inventory analysis (previous step) to assess the possible environmental impacts of the product system under investigation. Impact categories, including the potential for human toxicity, acidification, eutrophication, and global warming, are used in the impact assessment.

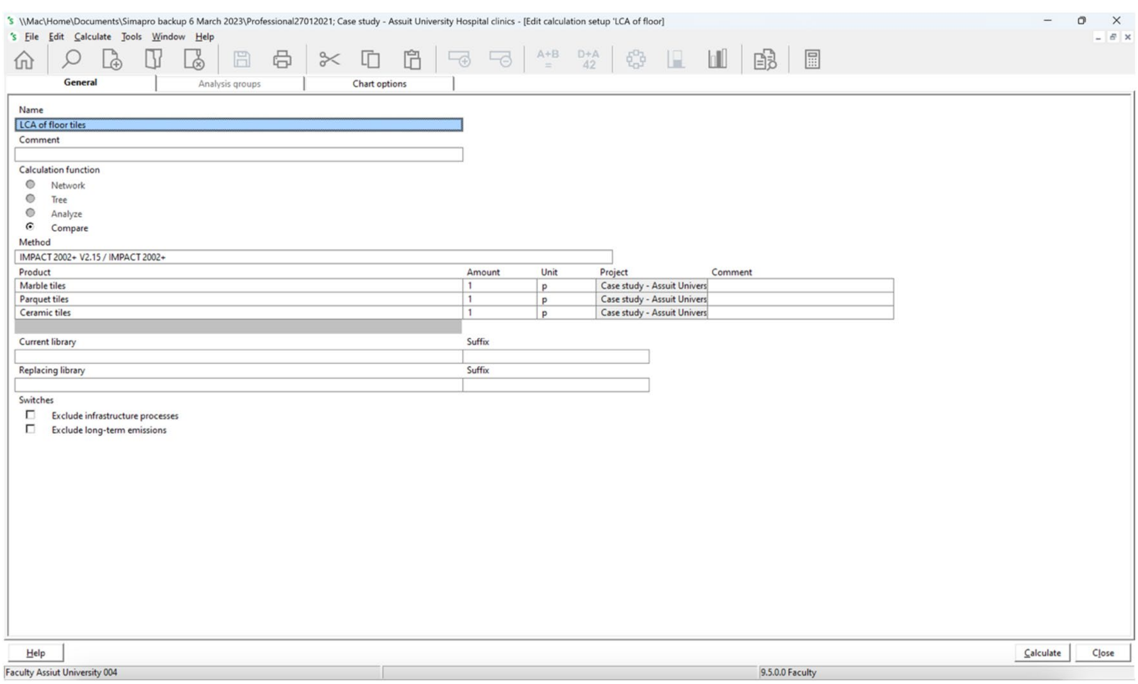
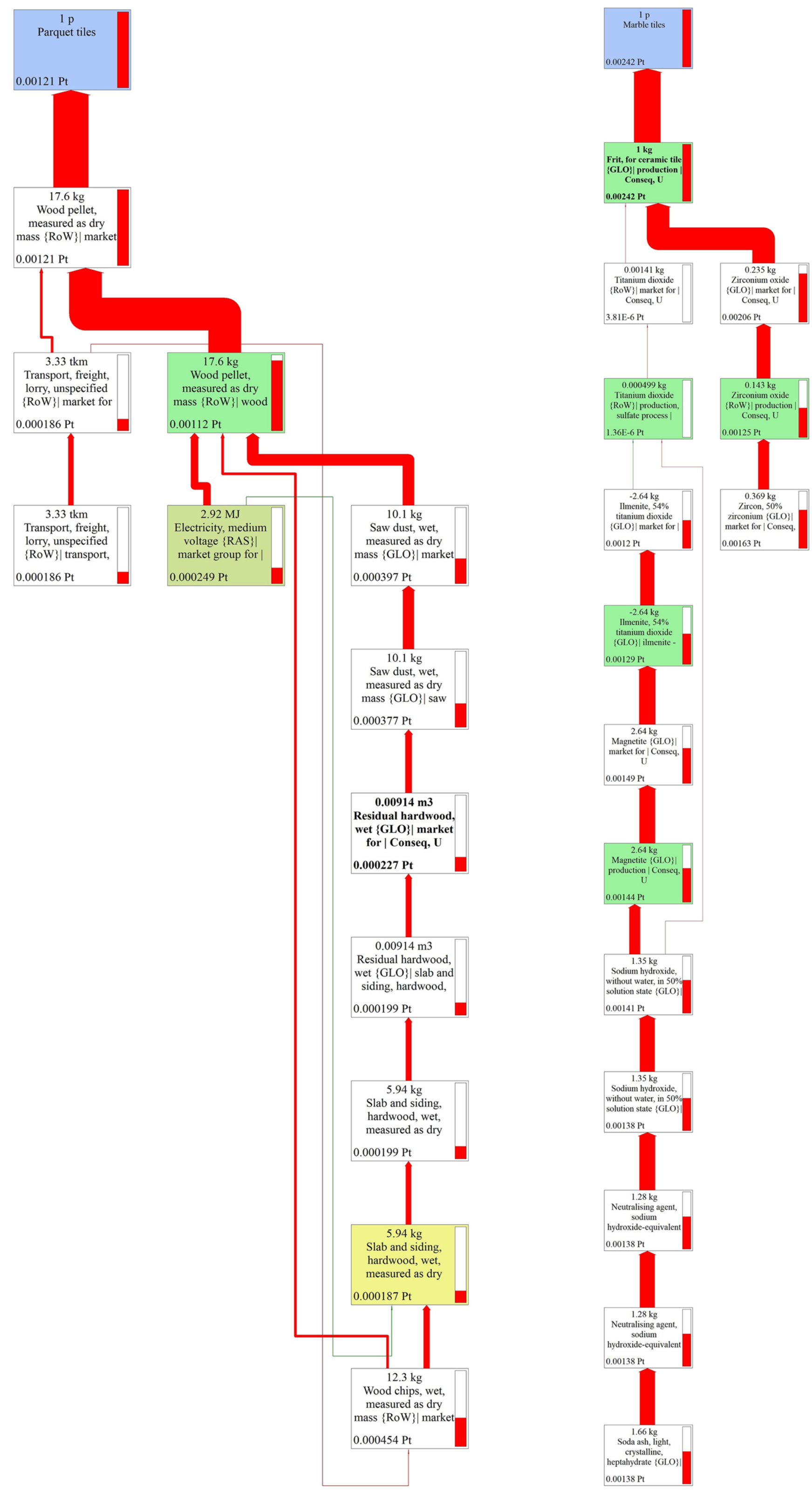
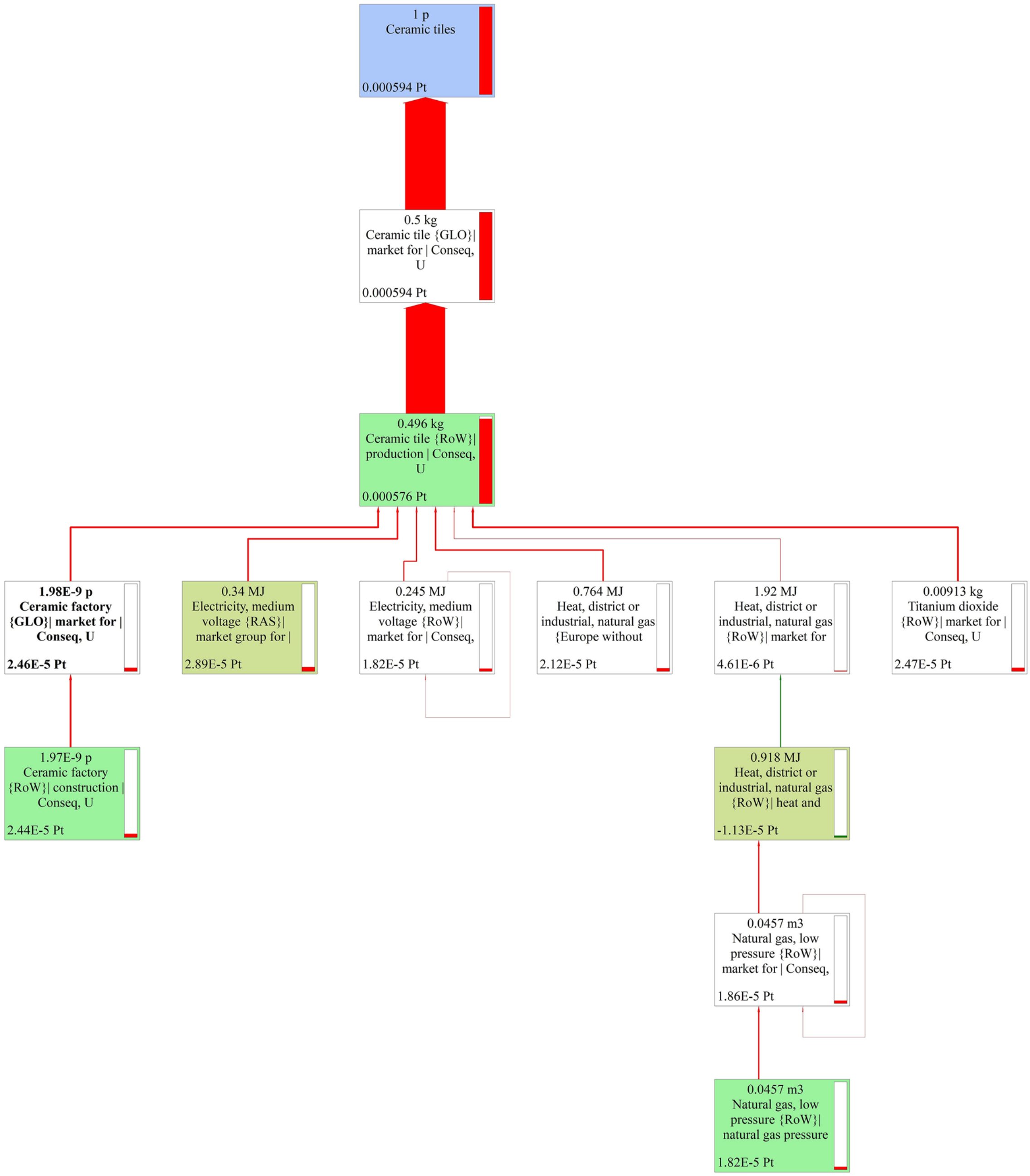


Fig. 9 Calculation setup of the three-floor materials in SimaPro

Fig. 10 Network flow of the three interior floor materials studied in SimaPro



(a) Network flow of parquet tiles *(b) Network flow of marble tiles*



(c) Network flow of ceramic tiles

Fig. 10 (continued)

4. Interpretation: At this step, the results of the inventory analysis and impact assessment must be combined and analyzed to reach conclusions and offer suggestions for enhancing the sustainability of the product system under consideration.

4.1 Goal and scope

At this step, the objectives and scope of the LCA research are set. The study will examine the environmental impact of

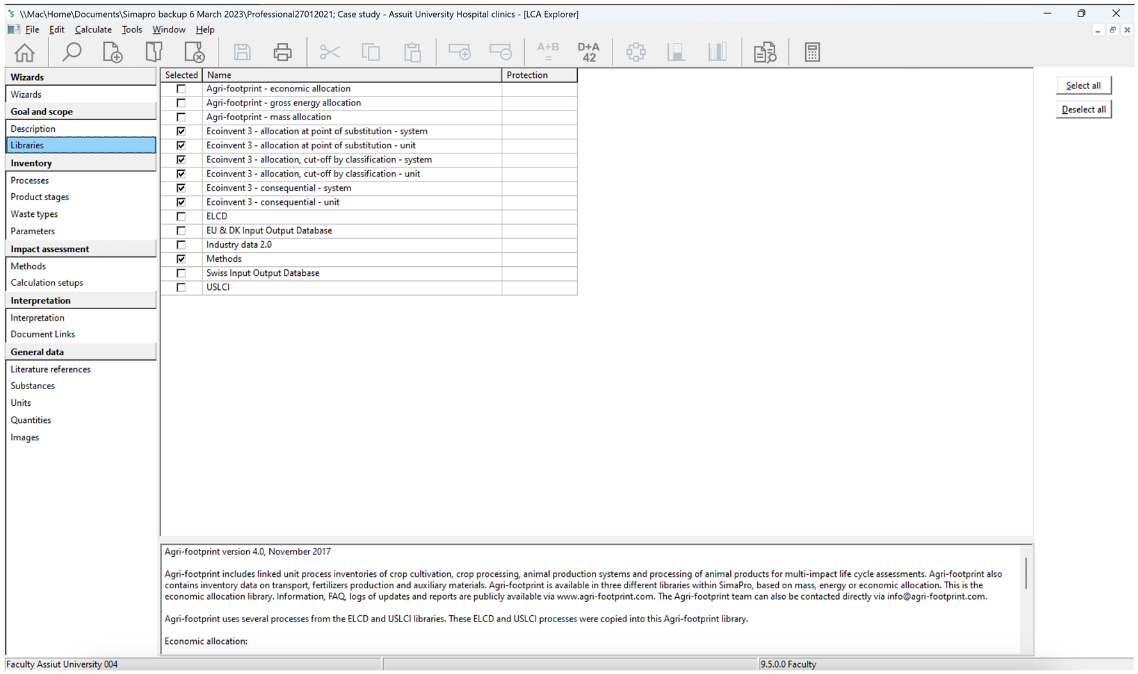


Fig. 11 Ecoinvent V3.2 database in SimaPro V9.50

three floor materials: marble, parquet, and ceramic. These materials have been selected based on the bills of quantities and specifications of the Ibny Baitak (x) model used in the current state. The environmental impact has been defined using the midpoint and endpoint approach in Sect. 4.3. Life cycle impact assessment (LCIA), both methods have been highlighted. The study's scope establishes the functional unit, system constraints, and data requirements. The study recommends applying carefully chosen functional units in an LCA of various floor materials to guarantee that the assessment appropriately reflects the product's environmental impact. The declared functional unit for this investigation of the various forms of insulation is 1 kg.

Figure 7 the system boundaries. The focus of this study will be the (cradle to gate) border, which comprises the following: (1) extraction of raw materials; (2) transportation and storage of raw materials; and (3) production and packing. Figure 8 depicts the complete ceramic manufacturing process.

This study will assess the environmental impacts of the three-floor materials. All materials have been built in SimaPro V9.50 [29], as seen in Fig. 9. The network flows of the production processes for ceramic, marble, and parquet tiles are illustrated in Fig. 10.

4.2 Life cycle inventory database

Information regarding the raw materials used to produce the materials, such as wood for parquet tiles, natural stone for marble tiles, and clay and sand for ceramic tiles, would be gathered as part of the LCA process. Energy will be used in the manufacturing, shipping, and installation of the items from cradle to gate. Because there are few LCA and LCI applications in Egypt, the study will rely on a few hypotheses from the literature review to make up for the lack of data for the input materials. Construction material LCA applications were evaluated by Rocamora et al. [23]. The Ecoinvent V3 database [12] utilized for this study is depicted in Fig. 11. The global market sector of the Ecoinvent (SimaPro-based) database was selected because it was more in line with Egyptian industrial practices.

4.3 Life cycle impact assessment (LCIA)

Using the inputs and outputs in the LCI stage, the environmental impacts of the floor materials will be calculated using both methods, which are the midpoint and endpoint. It includes evaluating the effect of numerous environmental indicators, such as four impact categories by midpoint method, including global warming potential, non-renewable energy, and respiratory inorganic, and three impact categories by endpoint method, including human health, climate change, and resource depletion. Based on the four series of ISO, the environmental impact of each floor material will be distinguished. IMPACT 2002 + technique, as listed in Table 1, will be used to calculate the environmental impacts by converting the LCI to LCIA on the literature review

Table 1 IMPACT 2002 + characterization version Q2.2 [8]

[Source]	Midpoint category	Midpoint reference substance	Damage category (end-point)	Damage unit	Normalized damage unit
[a]	Human toxicity (carcinogens + non-carcinogens)	kg Chloroethylene into air-eq	Human health	DALY	Point
[b]	Respiratory (inorganics)	kg PM2.5 into air-eq	Human health		
[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	PDF·m^2·y	Point
[a]	Terrestrial ecotoxicity	kg Triethylene glycol into soil-eq	Ecosystem quality		
[b]	Terrestrial acidification/nutrification	kg SO_2 into air-eq	Ecosystem quality		
[c]	Aquatic acidification	kg SO_2 into air-eq	Ecosystem quality		
[c]	Aquatic eutrophication	kg PO43- into water -eq	Ecosystem quality		
[b]	Land occupation	m_2 Organic arable land-eq · y	Ecosystem quality		
	Water turbined	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		
	Water withdrawal	inventory in m^3	n/a		
	Water consumption	inventory in m^3	Human health		
			Ecosystem quality		
			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

[2, 3, 17, 20], which can be interpreted in the fourth stage of International Standards Organization (ISO) [2, 3, 17, 20].

5 Building information modeling (BIM)

The BIM methodology of different interior floor materials, including ceramic, marble, and parquet tiles, typically involves the following steps:

1. Using BIM software to create a digital building model that includes sections, floor plans, elevations, and building features. The model can be generated using 3D modeling techniques. In this work, Autodesk Revit 2020 will be utilized (student license) to create a precise and comprehensive depiction of the building.
2. Accurate estimation of material costs and quantities can be achieved by obtaining the Ibny Baitak model's data from the BIM software, which can provide information on the number of materials.
3. The data extracted from the BIM software will be the inputs in SimaPro software for all floor material types.
4. Running the LCA software, the interpretation stage will then take place.

The BIM technique can offer a thorough and cohesive approach when choosing, defining, and overseeing interior floor materials during building design and construction. The building's overall performance and sustainability can be enhanced, material waste and expenses can be decreased, and material selection can be optimized using sustainability criteria with the aid of the BIM approach.

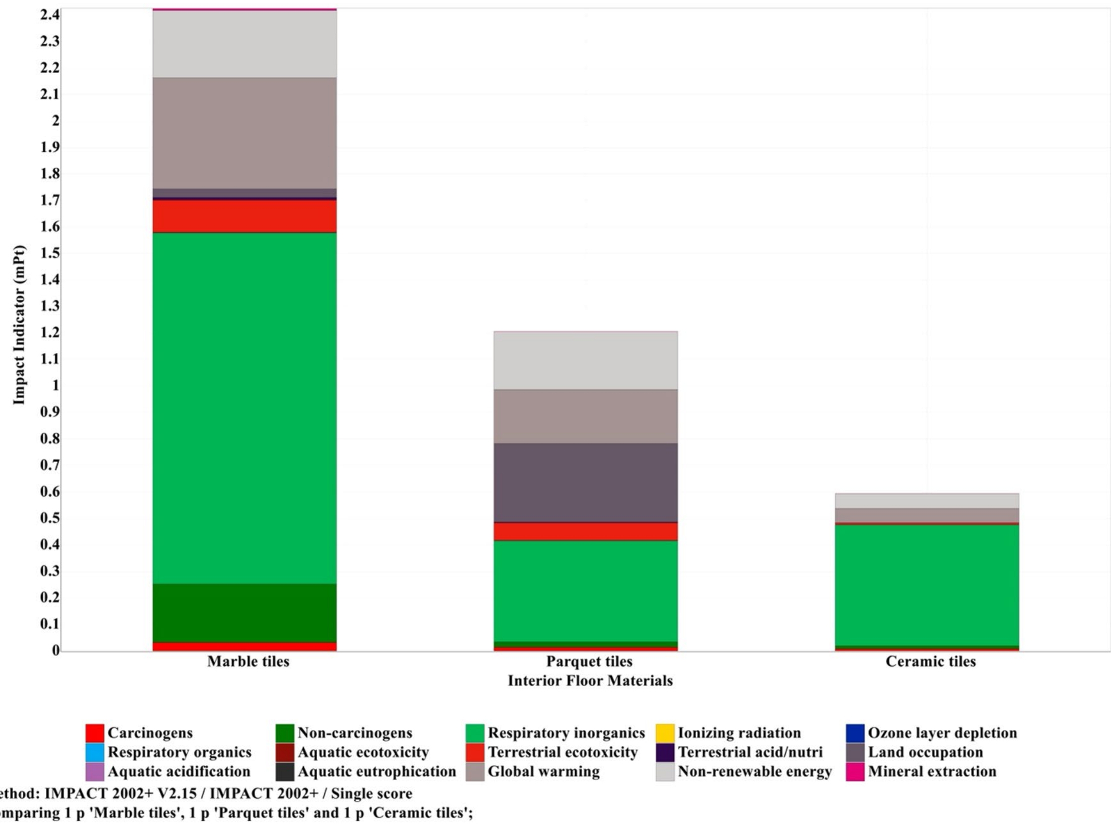


Fig. 12 Single score result of LCA scenarios by midpoint method

6 Results and interpretation

In this stage, the results of the LCA study are interpreted. The interpretation includes identifying the study's key environmental impacts and limitations and identifying areas for improvement.

6.1 EIA midpoint results

In this section, the results of all scenarios will be presented by the midpoint method for single score and weighting results.

6.1.1 Single score results

In Fig. 12, the singles score results by the midpoint method have revealed that the marble floor tiles have hit the highest adverse environmental impacts by 2.24 pt, followed by parquet by 1.21 pt and finally, the ceramic tiles by 0.594 pt. Marble is a naturally occurring stone cut and polished to create tiles [14]. According to the LCA findings, marble tiles have a more significant environmental impact than ceramic and parquet tiles. Compared to ceramic production, marble tile manufacture uses more energy and produces more greenhouse gas emissions owing to processing and transportation [10]. Furthermore, ceramic tile production and use stages consume less energy and emit fewer greenhouse gases [16, 24]. Due to processing and shipping, parquet tiles demand more energy during production [22].

6.1.2 Weighting results

In Fig. 13, the study's results have indicated that ceramic tiles have the lowest environmental impact, followed by parquet tiles and marble tiles. The global warming potential of ceramic tiles is 0.539 kg CO_2, which is less than 74% of the global warming potential of marble tiles (2.01 kg CO_2). The non-renewable energy impact of the marble tiles is 38.70 Mj primary, which is higher by 78% of the non-renewable energy of ceramic (8.46 Mj primary). To interpret this, ceramic tiles' production requires less energy and generates fewer greenhouse gas emissions than marble tiles and parquet tiles [25]. The respiratory inorganic has the third highest environmental impact in the three-floor type, and the ceramic tiles are similar to parquet tiles and lower than marble tiles.

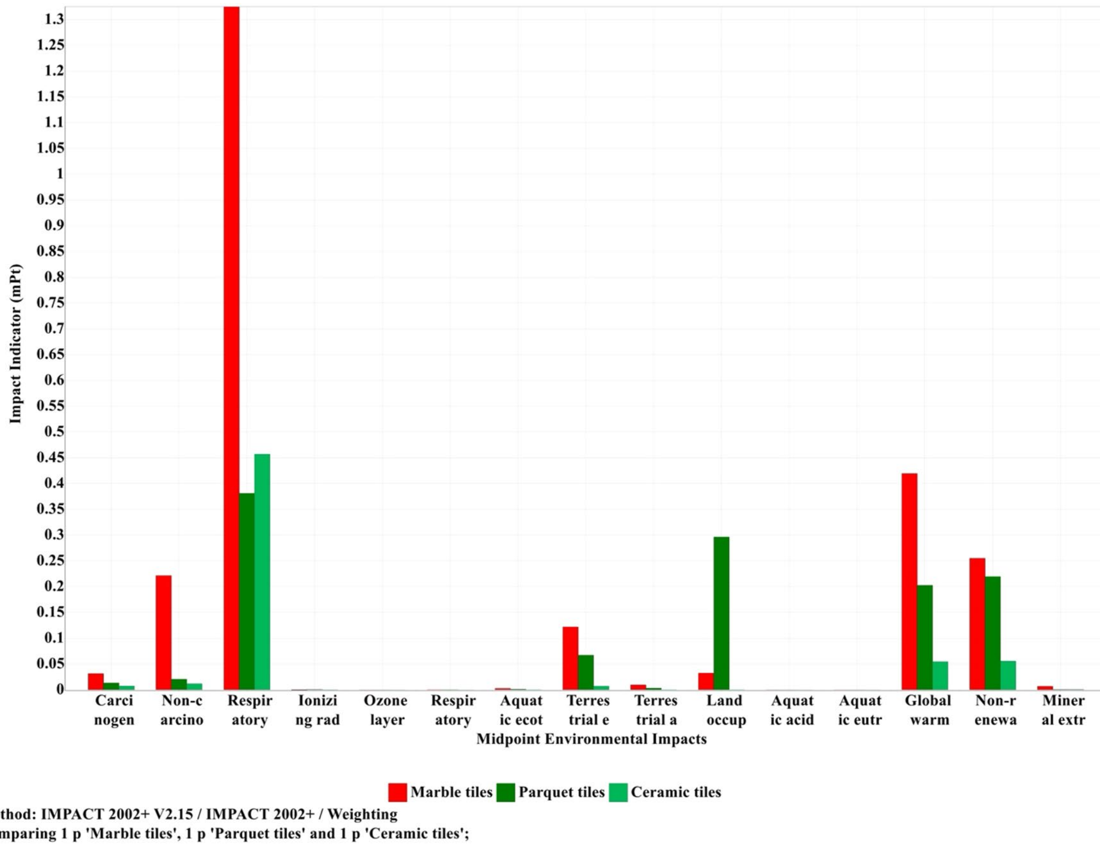


Fig. 13 Weighting result of LCA scenarios by midpoint method

6.2 EIA endpoint results

In this section, the results of all scenarios will be presented by the endpoint method for single score and weighting results.

6.2.1 Single score results

The endpoint method contains four impacts: (1) human health, (2) climate change, (3) resource depletion, and (4) ecosystem quality. The marble tile has pointed to the highest environmental impacts compared to the parquet and ceramic tiles. The endpoint results are consistent with the midpoint results in Fig. 14. The LCA results indicate that parquet tiles have a higher environmental impact than ceramic tiles but a lower impact than marble tiles. The production of parquet tiles requires more energy than ceramic tiles due to the need for processing and transportation.

6.2.2 Weighting results

Figure 15 presents the endpoint method by the weighting result. The human health impact has recorded the highest numbers in the marble industry by 1.12E−5 Disability Adjusted Life Years (DALY), which means the marble industry needs a high amount of energy [10]. The ceramic tiles have recorded values higher than parquet in the human health impact due to the emission of particulate per matter (ppm) during the sanding stage of the ceramic manufacturing. Regarding the climate change category, marble has the highest environmental footprint (0.419 pt) due to the emission of fossil CO_2 to the air during the extraction and production of the stone used.

7 Conclusion and discussions

Using the LCA methodology, the EIA of interior floor material alternatives, including ceramic tiles, marble tiles, and parquet tiles, provides valuable insights into the environmental impact of different materials throughout their life cycle. The study has focused on a case study of a new city (New Assiut City). It has evaluated the environmental impact of different floor materials based on four impact categories by midpoint method, including global warming potential, non-renewable energy, and respiratory inorganic and three impact categories by endpoint method,

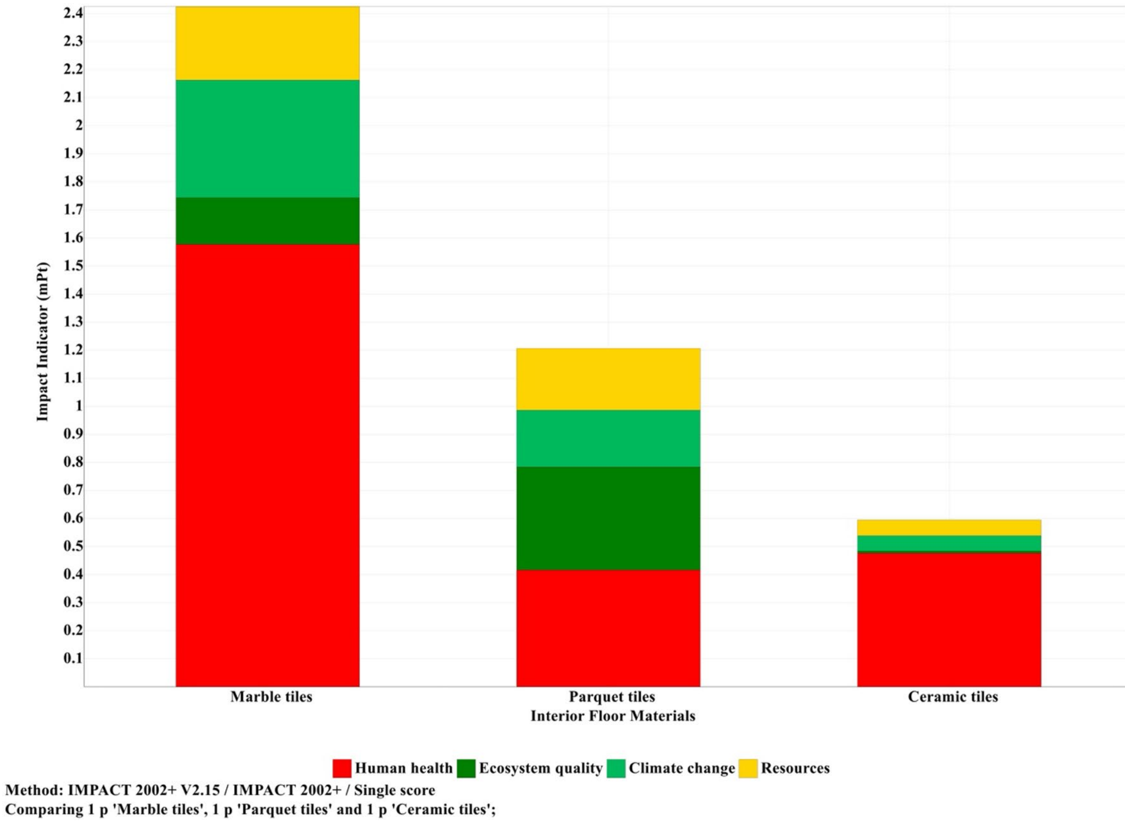


Fig. 14 Single score result of LCA scenarios by endpoint method

including human health, climate change, and resource depletion.

In line with the conclusions of the study and the findings of Vieira et al. and Quinteiro et al. [30, 38], ceramic tiles have the most minor adverse effects on the environment, followed by parquet and marble tiles. When it comes to manufacture and use, marble tiles use more energy and emit more emissions [10, 14], whereas ceramic tiles use less energy and emit fewer emissions [7, 26]. Because of processing and shipping, parquet tiles require more energy [22]. Ceramic tiles are an affordable and environmentally responsible option for interior flooring due to their low maintenance requirements and long lifespan [37].

In conclusion, the LCA methodology-based EIA of interior floor choices provides a comprehensive understanding of the environmental impact of different materials throughout their life cycles. The study concludes that ceramic tiles, instead of parquet and marble tiles, are the most cost-effective and environmentally friendly option for interior flooring. By overcoming the study's constraints and improving data uniformity and accessibility, it is possible to promote sustainable construction practices and reduce the detrimental environmental effects of building construction operations.

8 Limitation and recommendation

This topic's limitations and future work are discussed below [27].

1. Limited scope:

The case study of a new city was the main emphasis of the research, which may not accurately reflect the effects of various floor materials on the environment in other settings. Future research could broaden the scope to cover additional geographical areas, building kinds, and construction techniques to understand better how various floor materials affect the environment.

2. Data availability:

The LCA method requires a great deal of information (LCI), which includes data on transportation, energy consumption, and material composition. Especially for new or evolving materials, such data might not always be easily accessible. In order to provide a more accurate assessment of the environmental impact of different floor materials, future studies may focus on improving data accessibility.

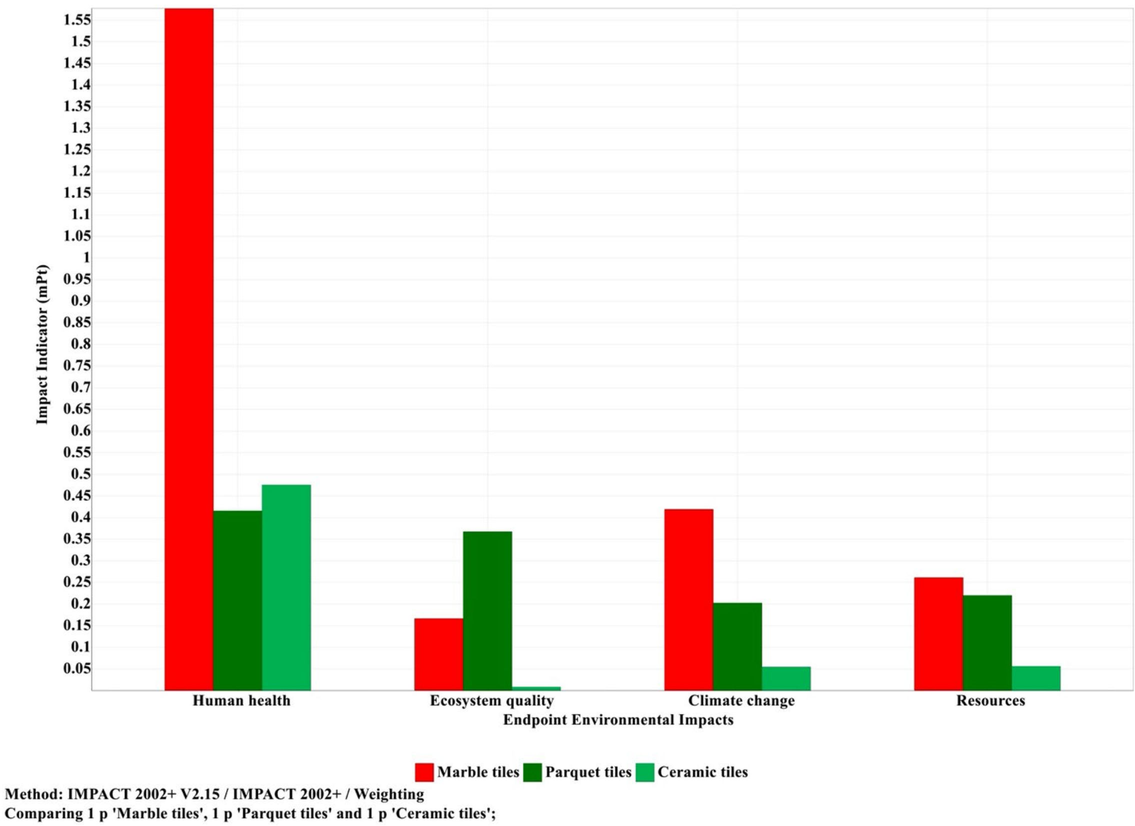


Fig. 15 Weighting result of LCA scenarios by endpoint method

3. Simplified impact categories:

Four impact categories—global warming potential, acidification potential, eutrophication potential, and human toxicity potential—were the focus of the study. These categories offer insightful information about how various floor materials affect the environment. However, they do not fully account for other environmental effects, including biodiversity loss, water consumption, and land usage. Future research could broaden the scope of the effect categories to offer a more thorough comprehension of how various floor materials affect the environment.

4. Case studies scope:

Future research could focus on the environmental effects of different floor materials at different life cycle stages, including the end of life. The study might be broadened to include substitute materials such as recycled or renewable materials to offer a more environmentally friendly option for interior floor materials. Subsequent studies could evaluate the expenses, potential health hazards, and safety implications of selecting different floor materials from an economic and social standpoint.

5. Standardized the protocols:

The lack of established standardized protocols in Egypt might result in inconsistent data gathering, processing, and interpretation, which can affect the dependability and accuracy of EIA findings. Furthermore, building laws and regulations may restrict the usage of specific materials.

6. Communication with the stakeholders:

Difficulties may arise in interpreting and communicating the EIA's results to stakeholders, including building owners, designers, and legislators. Because of its complexity and the technical language used in the assessment, stakeholders may find it challenging to understand and implement the LCA technique to make informed judgments.

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Data availability All materials and data in the paper are works of the authors. Any referred text has been rightfully acknowledged and cited. No copyright issues exist or have been flouted. The work is original, not published elsewhere or forwarded to any other avenue. The data and materials used to support the findings and conclusions of this manuscript are available upon request from the corresponding author. Restrictions may apply to the availability of these data and materials due to ethical or privacy considerations. The data used in this study is available upon request from the authors, subject to compliance with ethical and legal requirements.

Declarations

Conflict of interest The author of this paper declares he has no financial interests. The author affirms that the publication of this work does not include any conflict of interest. The authors have no relevant financial or non-financial interests to disclose.

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