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Comparative Life Cycle Assessment of Polymeric and Conventional Concrete for Sustainable Construction: A Case Study of a New Clinic at Assiut University Hospital in Egypt

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Ahmed AbdelMonteleb M. Ali [1]

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Abstract

The building material industry has the largest share in global environmental emissions. This research investigates the environmental impact of polymeric concrete compared to conventional concrete in the construction of a new clinic at Assiut University Hospital in Egypt. A life cycle assessment (LCA) was conducted from raw material extraction to production stage (cradle to gate stage) using SimaPro V9.5 software. All environmental impact has been investigated using the IMPACT2002+ method using the midpoint and endpoint results. The LCA results showed that polymeric concrete had a lower environmental impact than conventional concrete regarding global warming, acidification, and eutrophication potential. In terms of the single score outcomes, climate change had a significant impact on both ordinary and polymer concrete, with the former scoring 0.90 mPt and the latter recording a much lower 0.14 mPt, indicating a 75% reduction. Furthermore, when considering the weighting results (midpoint result), it was found that specific environmental impacts, such as global warming, respiratory inorganic, and non-renewable energy impacts, had a more significant effect overall. Specifically, the global warming potential was found to be 8.95 Kg CO_2 eq. and 1.38 Kg CO_2 eq. for polymer and ordinary concrete, respectively. Lastly, the endpoint result showed that human health was impacted the most, with a total reduction of 84.24%. The DALY recorded for ordinary concrete was 3.69E-06, whereas, for polymer concrete, it was 5.8E-07. The findings of this study suggest that polymeric concrete can be a more sustainable alternative to conventional concrete for specific applications. One of the main difficulties faced in applying polymer concrete in the construction industry is its higher cost compared to conventional concrete. The production process of polymer concrete requires specialized equipment and expertise, which can increase the overall cost of the material. Additionally, the use of polymer concrete may require changes in construction techniques and design specifications, which can be challenging for contractors and engineers who are used

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[1] Assoc. Prof., Department of Architecture, College of Architecture and Planning, Qassim University, Qassim, 52571, Saudi Arabia. ahm.ali@qu.edu.sa
Assoc. Prof., Department of Architectural Engineering, Faculty of Engineering, Assiut University, Assiut, 71515, Egypt. ahmed.abdelmonteleb@aun.edu.eg

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to working with conventional materials. Moreover, the durability and long-term performance of polymer concrete in certain applications have not been extensively studied and may require further research and testing. Finally, the availability of raw materials and the disposal of waste materials from the production process may also pose challenges in the widespread adoption of polymer concrete in the construction industry.

1. Introduction

According to the official statistics [1], Egypt is one of the top 14 cement-producing nations globally, with an annual production capacity of more than 82 million tons and an average sales volume of over 54 million tons. Huang et al. [2] have examined the environmental consequences of building material use, as it shown in Fig. 1. The study has shown that building materials, such as cement, steel, and glass, increased dramatically during this period, significantly increasing environmental impacts such as greenhouse gas emissions, energy consumption, water consumption, and solid waste generation.

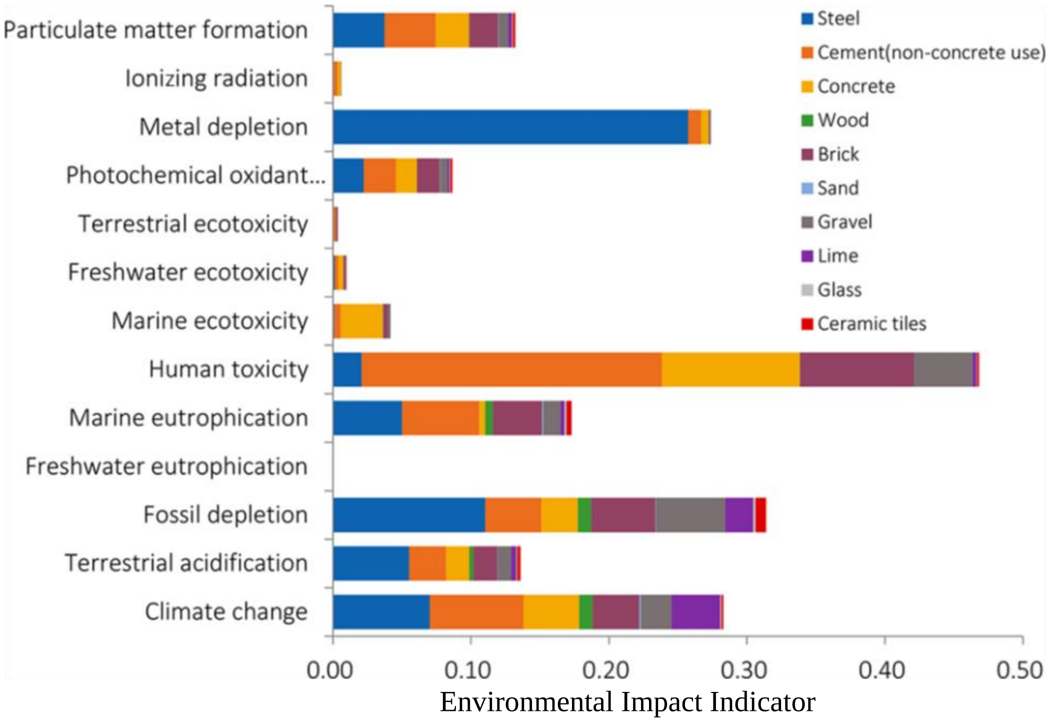


Fig. 1 Environmental impact indicators associated with the production of building material used [2]

These studies [3]– [5] focus on the use of innovative materials and techniques to enhance the performance of concrete and reduce its environmental impact. The first study, Manjunatha et al. have investigated the use of human hair as a fiber to reinforce concrete and reduce the challenges of hair disposal. The second study, Tangadagi et al. have explored the use of coconut shells as a sustainable alternative to traditional coarse aggregates in concrete. The third study, Srinath et al. have reviewed the potential of alccofine, a supplementary cementitious material, to improve the mechanical and durability properties of concrete. These studies have demonstrated a growing interest in sustainable and innovative approaches to concrete construction.

As for the sustainable alternatives, polymer concrete is a composite material from combining polymer resins and aggregates such as sand, rock, or gravel. It has become increasingly popular in the construction industry due to its high strength, durability, and resistance to environmental factors such as corrosion and weathering [6]. However, it has its environmental impact, which can be measured using the life cycle assessment approach (LCA). The LCA is a tool that evaluates the environmental impact of a product or service throughout its entire life cycle, from raw material extraction to the disposal phase [7].It provides valuable information about environmental impacts, including carbon footprint, energy consumption, and waste generation [8].

Several studies have been conducted to assess the environmental impact of polymer concrete using LCA. Studies such as Yang et al. [9], Turner and Collins [10], and Garbacz and Sokołowska [11] have compared the environmental impact of different types of concrete, including conventional Portland cement-based concrete and alternative materials such as geopolymer concrete and concrete with fly ash. The studies have found that alternative materials can significantly reduce the environmental impact of concrete production and contribute to sustainable development in the construction industry. Other studies, such as Panesar et al. [8], have investigated the impact of functional unit selection on the LCA of green concrete. Ferdous et al. [12] have focused on optimizing the design of epoxy polymer concrete for improved mechanical properties and durability. [13]

Moreover, the articles have highlighted the importance of LCA, as discussed in Chau et al. [14], in promoting sustainable development in the construction industry. Huntzinger and Eatmon [15] have compared conventional and alternative technologies for Portland cement manufacturing, while Cao et al. [16] have discussed the challenges in estimating CO_2 emissions from cement production in China. In the following points, from the studies mentioned above, the author has summarized the main points of the comparison between polymeric and conventional Concrete.

1. *Raw Materials*: Conventional concrete is made of Portland cement, aggregates, water, and admixtures, while polymeric concrete is made of polymer resins, aggregates, and sometimes fillers and additives.
2. *Strength and Durability*: Polymeric concrete has higher strength and durability than conventional concrete due to polymer resins and aggregates.
3. *Resistance to Environmental Factors*: Polymeric concrete is resistant to environmental factors such as corrosion, weathering, and chemical attack, making it suitable for applications in harsh environments. Conventional concrete is vulnerable to environmental factors, resulting in cracking and damage over time.
4. *Curing Time*: Polymeric concrete has a faster curing time than conventional concrete, reducing the time required for construction and allowing for quicker project completion. This can result in cost savings and improved productivity.
5. *Cost*: Polymeric concrete is generally more expensive than conventional concrete due to the cost of polymer resins and specialized equipment required for its production and installation.
6. *Availability*: Polymeric concrete is not widely available compared to conventional concrete, limiting its use in specific applications. However, the demand for sustainable construction materials is increasing, which may lead to greater availability of polymeric concrete.
7. *Design Flexibility*: Conventional concrete has greater design flexibility than polymeric concrete, making it suitable for applications requiring intricate designs or shapes.

Overall, the articles highlighted the significance of considering the effects of concrete production on the environment and the possibility of alternative materials and technologies to support sustainable development in the building sector. The literature review also emphasizes the need for additional studies to enhance production procedures and raise the reliability of life cycle evaluation techniques.

As well as there is a need to investigate the environmental impact of polymer concrete made from alternative sources of aggregates, such as recycled waste materials.

Therefore, this study aims to conduct an LCA of polymer concrete in a specific proposed building, Assiut University Hospital Clinic (AUHC) in Egypt, to assess the environmental impact of the polymer concrete as an alternative to conventional concrete to evaluate its potential for enhancing the material's sustainability. Since choosing the polymer concrete composite falls outside the author's area of expertise, the paper has utilized the Ecoinvent V3 database embodied in SimaPro V9.5 to obtain the polymer concrete data. The novelty of this study is the application of LCA on the building materials using SimaPro as there is a clear shortage of LCA studies in Egypt, also another contribution is building the life cycle inventory database to be more suitable for future studies. The findings of this study can provide valuable insights into the environmental impact of polymer concrete in different applications and contexts and inform the development of sustainable practices in the construction industry.

2. Literature review

Many researchers have studied alternatives to conventional concrete to improve the environmental impacts of material manufacturing. One concrete alternative research, Yang et al. [5], have discussed the potential of alkali-activated concrete as a sustainable alternative to traditional Portland cement-based concrete. Conventional concrete production significantly contributes to global greenhouse gas emissions; therefore, finding options to reduce carbon footprint is crucial. The article has found that alkali-activated concrete has a lower carbon footprint and can reduce CO_2 emissions by up to 60% compared to traditional concrete.

Juenger et al. [17] have investigated the role of supplementary cementitious materials (SCMs) in concrete production. SCMs are materials that are added to concrete in addition to cement to improve its properties and sustainability. Examples of SCMs include fly ash, slag, silica fume, and metakaolin. Using SCMs in concrete production can reduce the amount of cement required, reducing the material's carbon footprint and promoting sustainable construction practices.

Garbacz et al. [11] have presented a comparative study of concrete-like polymer composites with fly ash. Fly ash is a byproduct of coal combustion and is commonly used as a supplementary cementitious material in concrete production. The study has found that adding fly ash to polymer composites improves their mechanical properties, including their compressive and flexural strength.

Aldred et al. [18] have evaluated the potential of geopolymer concrete as an alternative to traditional Portland cement-based concrete. Geopolymer concrete uses aluminosilicate materials, such as fly ash and slag, combined with an alkaline activator to produce a binder. The authors have noted that geopolymer concrete has a lower carbon footprint than traditional concrete due to its use of waste materials and the lower amount of CO_2 it emitted during production.

Salas et al. [19] have evaluated the environmental impact of geopolymer concrete using LCA. The study has found that using geopolymer concrete can reduce greenhouse gas emissions, energy consumption, and waste generation in the construction industry.

Gursel et al. [7] have explored the potential of rice husk ash (RHA) as a sustainable alternative material in concrete production. The study found that using RHA reduced the carbon footprint of concrete production and had a lower environmental impact in all life cycle stages, from raw material acquisition to end-of-life disposal. The study has concluded that RHA can be a sustainable alternative material in concrete production, and its use can reduce the construction industry's environmental impact.

Duxson et al. [21] have revealed the potential of inorganic polymer technology to develop 'green concrete.' The production of traditional Portland cement-based concrete is associated with significant carbon emissions; therefore, finding alternatives to reduce carbon footprint is necessary. Inorganic polymer technology is a sustainable alternative to traditional cement-based concrete.

Crossin [22] has investigated the use of ground granulated blast furnace slag (GGBFS) as a cement substitute in concrete production and its potential to reduce greenhouse gas (GHG) emissions. The study has found that the production of GGBFS generates significantly lower GHG emissions than Portland cement, primarily due to reduced energy consumption and lower carbon content. Manjunatha et al. [23] have presents a life cycle assessment (LCA) of concrete prepared with sustainable cement-based materials. The study has evaluated the environmental impact of the concrete production process and its potential to reduce carbon emissions. While Manjunatha et al. [24] have investigated the engineering properties and environmental impact assessment of green concrete prepared with PVC waste powder. The study has evaluated the mechanical and durability properties of concrete and its potential to reduce plastic waste while also being a sustainable building material.

On the other hand, the literature review has revealed the importance of LCA application to assess the environmental impacts of alternative materials. Asadollahfardi et al. [13] have presented an environmental LCA of concrete with different mixed designs. The study has evaluated the environmental impact of concrete production using different mix designs, including traditional Portland cement-based concrete, high-performance concrete, and concrete with SCMs such as fly ash and slag. The study has found that using SCMs in concrete production can significantly reduce its environmental impact, particularly regarding greenhouse gas emissions.

Chau et al. [14] have provided a comprehensive overview of LCA methods and their applications to the building industry. The study has discussed the importance of LCA in promoting sustainable development in the construction industry and highlights the need for further research to optimize the assessment methods.

Cao et al. [16] have examined the challenges in estimating CO_2 emissions from cement production in China. The authors conclude that accurate estimation of CO_2 emissions from cement production are crucial for developing effective climate change policies and promoting sustainable development in the construction industry. Also, Chen et al. [25] have examined the environmental impact of cement production in China. The study has found that cement production is a significant source of air pollution in China, contributing to high levels of particulate matter, sulfur dioxide, and nitrogen oxide emissions. Huntzinger et al. [15] have compared the traditional process of Portland cement manufacturing with alternative technologies and evaluated their environmental impact using LCA. The authors conclude that using alternative technologies can contribute to sustainable development in the construction industry.

Conducting an LCA of polymer concrete can provide several benefits, such as identifying areas for improvement, improving the design and manufacturing of the material, and providing valuable information to stakeholders. Therefore, the novelty of this paper is applying the LCA and conducting this approach on the polymer concrete to achieve a more sustainable future in one of the buildings in Assiut, Egypt, to suggest an alternative to ordinary concrete.

3. Methods and tools

The LCA of polymer concrete as a substitute material for conventional concrete has been examined. The dataset for building construction quantities will be collected using BIM. This paper will focus on the cradle to gate scope of the polymer and conventional manufacturing process as an LCA system boundary, as one of ISO standards steps of LCA application. As the main aim of this study to compare between both concrete types, only raw material extraction to production concrete stage will be included, all upcoming stages are not subject to evaluation. The proposed building in Assiut, Egypt, will undergo LCA and BIM analyses in this study.

3.1. Building information modelling

LCA is a technique that enables estimating energy consumption and environmental emissions, which can be computed using an LCA tool [26]. Building Information Modeling (BIM) is the most efficient approach for obtaining construction quantities, making the process more straightforward. The combination of LCA with BIM can significantly evaluate the environmental costs of material manufacturing, as demonstrated in prior research by Senem Seyis and Shu Su et al. [27], [28], which have been summarized. This comprehensive approach will be employed in this study, where LCA will analyze the environmental impacts of different scenarios, and BIM will provide information on the building materials for LCA input. Autodesk Revit is the most frequently used BIM software, and the 2020 student-licensed version will be utilized in this study, as shown in Fig. 2.

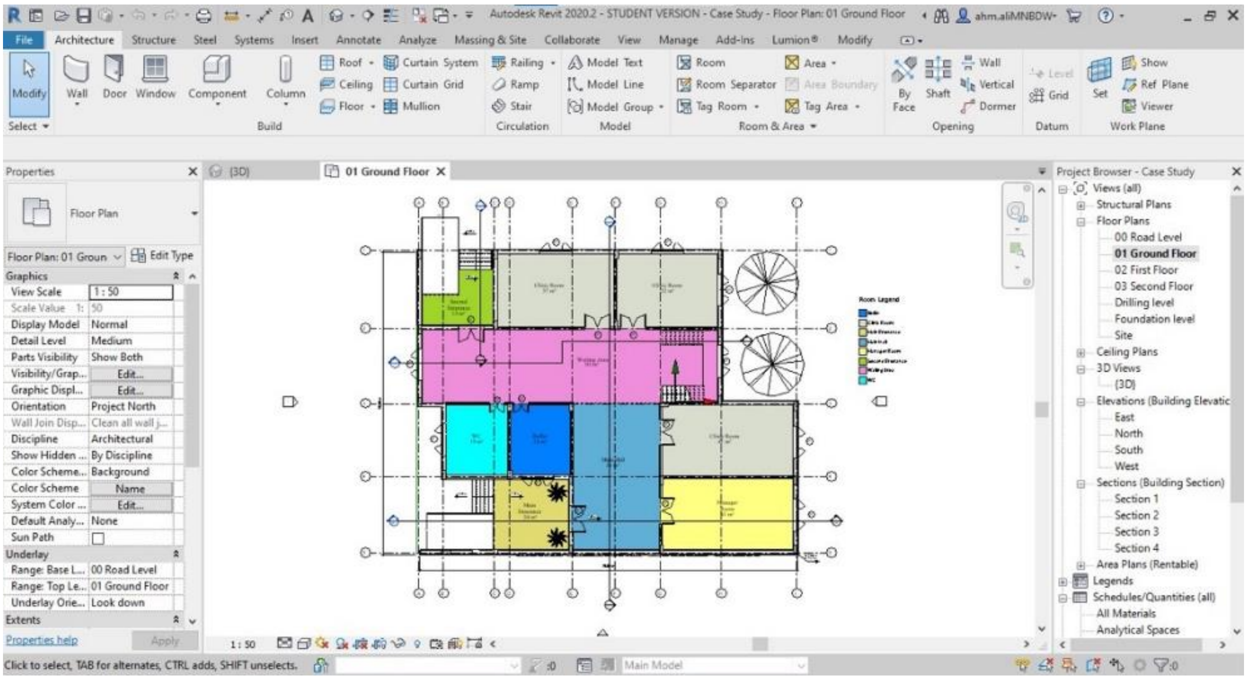


Fig. 2 Modelling the case study on Autodesk Revit

3.2. Life Cycle Assessment approach

The International Standards Organization (ISO) is the widely recognized principles body, offering numerous parts, as illustrated in Fig. **3**.

- ISO 14040: Principles and framework [29].
- ISO 14041: Goal definition and inventory analysis [30]
- ISO 14042: Life-cycle impact assessment [31].
- ISO 14043: Life-cycle interpretation [32].

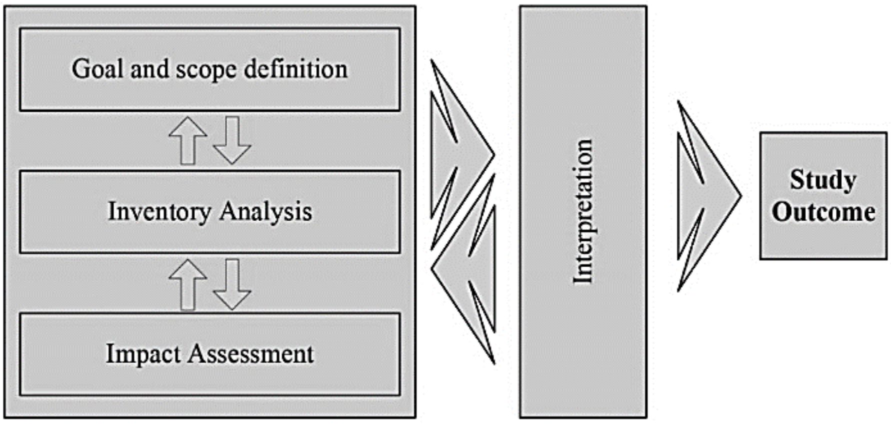


Fig. 3 Life-cycle assessment framework [33]

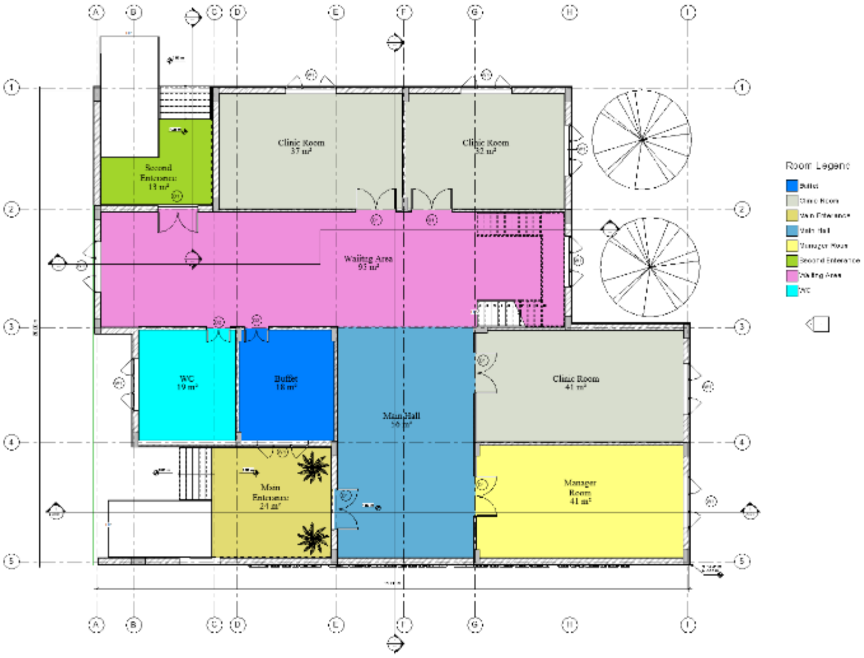
After conducting a comprehensive comparison, Ali et al. [28] and Al-Ghamdi [29] reported. It was concluded that the most widely used LCA tool is PRe SimaPro. Therefore, all open-license Ecoinvent databases were employed with the PRe SimaPro V9.5 academic license.

4. Case study

In this section, the study will use the AUHC as a case study to analyze its environmental impact and energy usage. The aim is to determine the necessary building materials used during construction that significantly impact the environment. Additionally, the study will suggest using LCA and BIM approaches for future research and projects. The proposed AUHC project will be built within the Assiut Hospital University (AUH) campus, and its location is shown in Fig. **4**, which also presents the Assiut University campus.

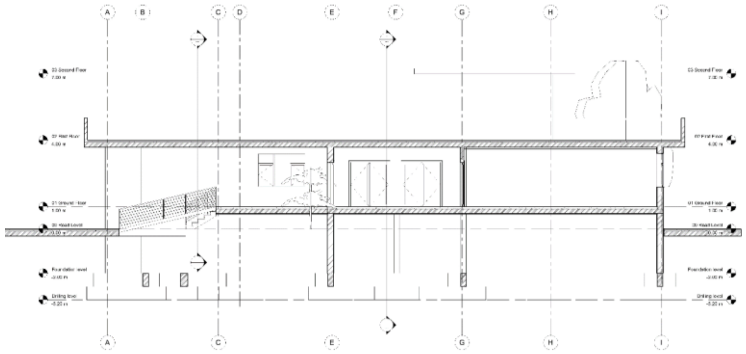
Fig. 4 Assiut University Campus Location

The BIM model defines the project's geographical location by specifying the internet mapping service. Fig. **5** displays a sample of BIM model drawings.



a) Ground floor plan

b) AUHC clinic facade



c) AUHC clinic section

d) AUHC clinic proposed perspectives

Fig. 5 AUHC clinic modeling in Revit (BIM interface)

5. Life Cycle Assessment Application

In this section, the LCA parts based on the ISO standards will be discussed, which are, (1) Goal and Scope Definition, (2) Life Cycle Inventory (LCI), (3) Life Cycle Impact Assessment (LCIA), and (4) Interpretation step.

5.1. Goal and scope definition

Panesar et al. [8] have examined the impact of selecting different functional units on the LCA of green concrete. Functional units are the quantified description of the function of a product or service and are used as a basis for comparison when conducting an LCA. The study has revealed that the selection of functional units significantly affects the LCA results of green concrete. The study has highlighted that choosing functional units should be carefully considered when conducting an LCA of green concrete to ensure that the assessment accurately reflects the product's environmental impact. Therefore, the functional unit of this study is (1 kg) for the polymer and conventional concrete from c to gate, as shown in Fig. **6**.

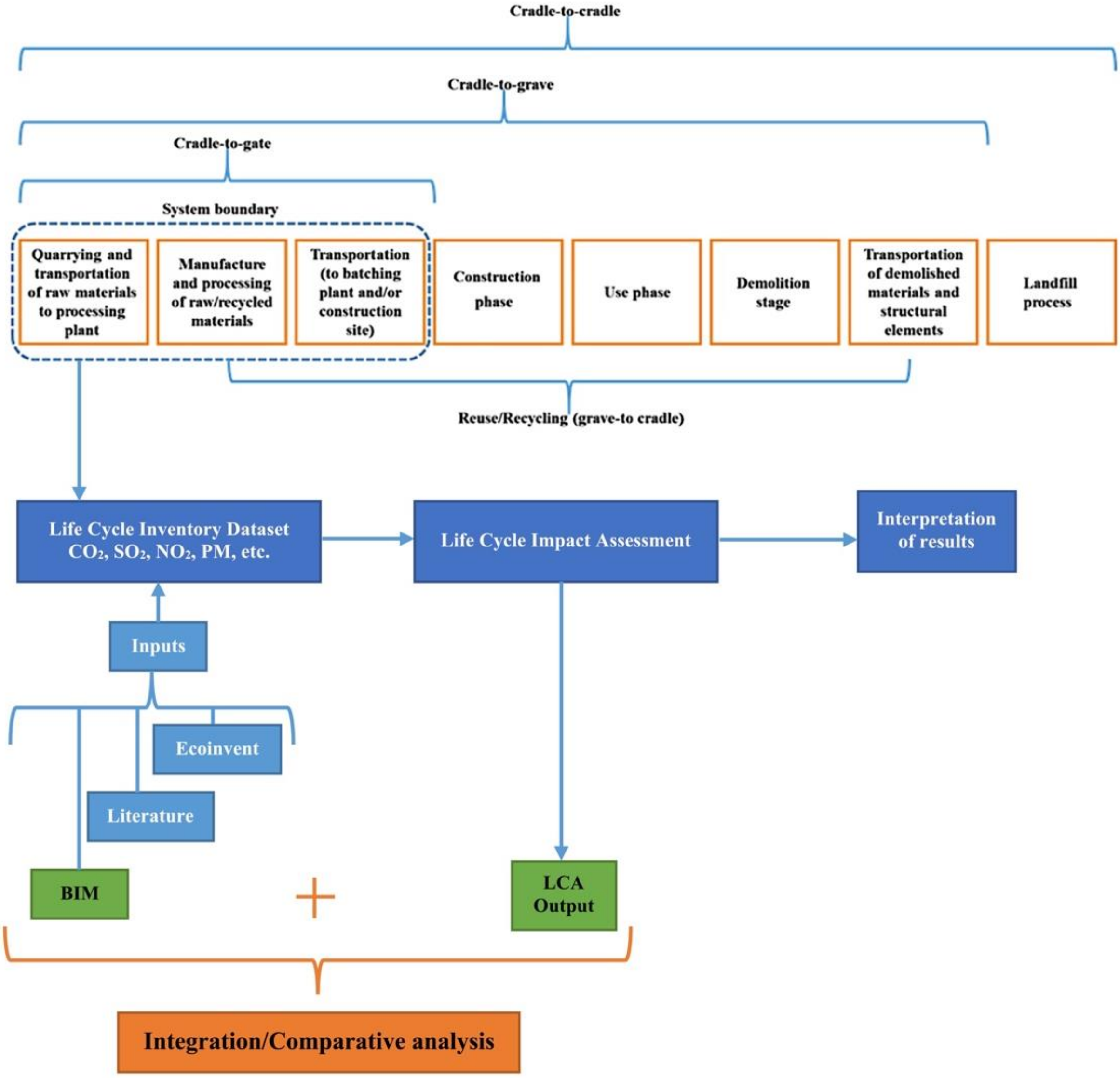


Fig. 6 System boundary of LCA application in this study

This study will assess the environmental impacts of polymers and conventional concrete. The two concrete types have been constructed in SimaPro. Then, the network flows of the two concrete types' manufacturing process have been built in SimaPro, as shown in Fig. **7**

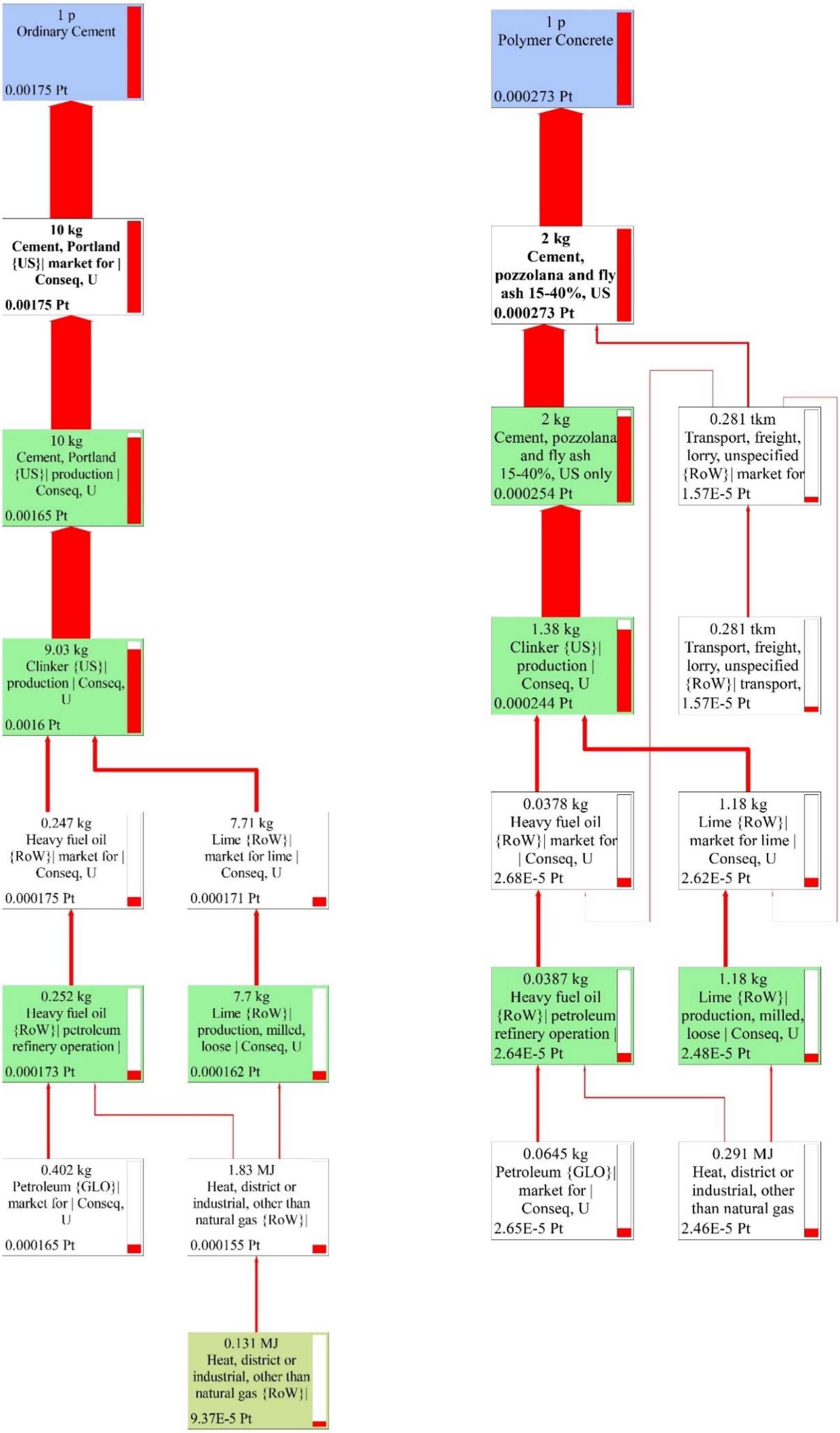


Fig. 7 Network flow of the ordinary and polymer concrete in SimaPro

5.2. Life cycle inventory

The previous section has outlined the LCA approach's initial phase (based on ISO 14041). The Revit program determines the quantities of building materials, as indicated in Table 1.

Table 1 Bill of quantities extracted from the BIM model.

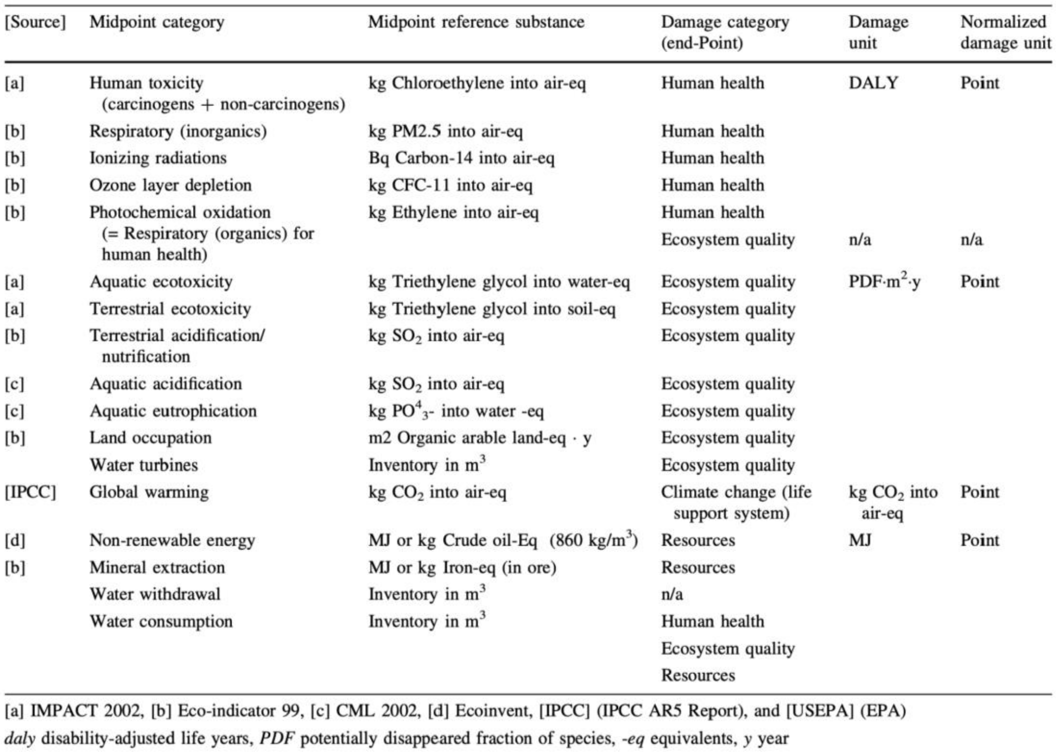
Name	Area (m^2)	Volume (m^3)
Brick	861	164.16
Concrete	4382	0.88
Steel		17.00
Mortar	3089	29.70
Tiles	1556	62.29
Glass	132	0.41
Plaster	3358	32.31
Wood/Aluminum openings	88	1.20

This study has relied on a few hypotheses from the literature review to fill in the data shortage for the input materials because there are few LCA applications and LCI in Egypt. Rocamora et al. [34] compared many LCA applications of construction materials. The database version used for this investigation is Ecoinvent V3 [35]. The Ecoinvent (SimaPro-based) database's global market and concrete-related sectors were specifically picked to be more compatible with Egyptian production methods.

5.3. Life cycle impact assessment

Based on the ISO standard, it differentiates the environmental impacts between the two concrete types. This paper will calculate the environmental effects using the midpoint and endpoint methods. This study will use the IMPACT 2002+ method, as listed in Table 2 to investigate the environmental effects based on the literature review [36]– [39].

Table 2 IMPACT 2002+ characterization version Q2.2 [40]



[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 $PO^4{}_3$- into water -eq	Ecosystem quality		
[b]	Land occupation	m2 Organic arable land-eq · y	Ecosystem quality		
	Water turbines	Inventory in m^3	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)

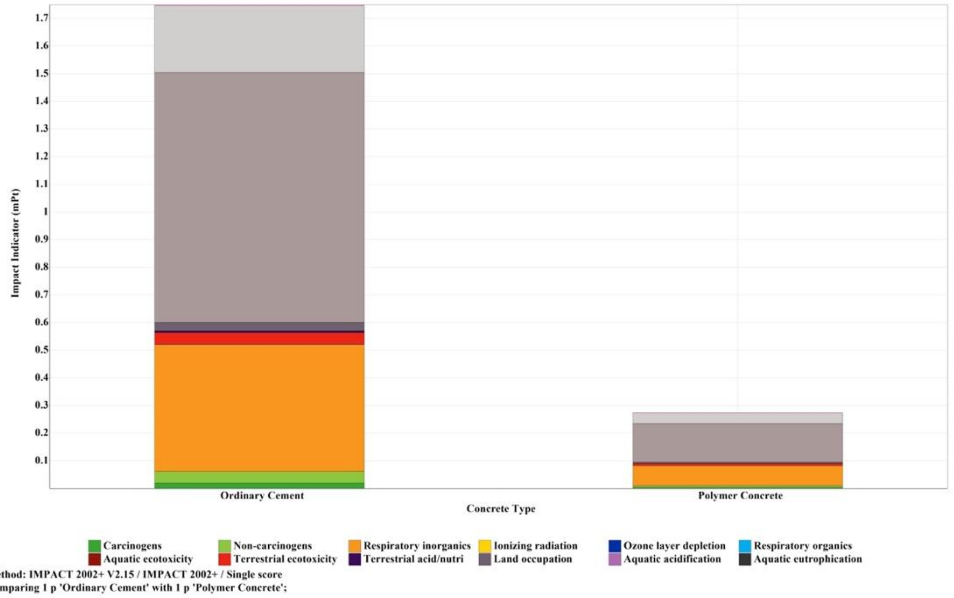
daly disability-adjusted life years, *PDF* potentially disappeared fraction of species, *-eq* equivalents, *y* year

6. Result and discussion

This section will present the LCA results using a single score and weighting per impact category.

6.1. Single score per material

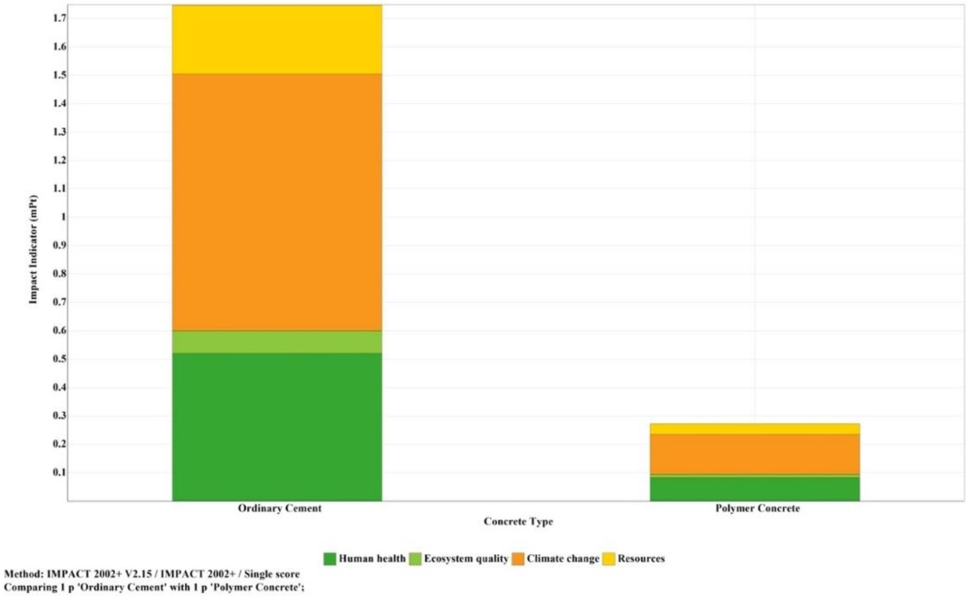
The next Fig. 8 presents the single score results by midpoint approach of IMPACT2002+ methodology by points (Pt). Ordinary cement has recorded the highest adverse environmental impacts (1.75 Pt). However, the polymer concrete recorded (0.27 Pt) a reduction of 84.57% of the destructive effect.



Method: IMPACT 2002+ V2.15 / IMPACT 2002+ / Single score
Comparing 1 p 'Ordinary Cement' with 1 p 'Polymer Concrete';

Fig. 8 Single Score results per environmental impact type with midpoint method

Fig. 9 highlights the single Score results per material type with endpoint method by points (mPt). Climate change has pointed to 0.90 mPt for ordinary concrete; however, the polymer concrete of 0.14 mPt with a 75% reduction, which is the most crucial factor affecting the cement industry consistent with Smith [41]. The second environmental impact is the human health effects, with 0.52 mPt for ordinary concrete and 0.08 mPt for polymer concrete, with 84.60% reduction. The third adverse impact is the effects of the resources, with 0.24 mPt for conventional concrete and 0.04 mPt for polymer concrete, with 83.33% reduction. The ecosystem quality has a negligible impact, corresponding to Shi et al. [42].



Method: IMPACT 2002+ V2.15 / IMPACT 2002+ / Single score
Comparing 1 p 'Ordinary Cement' with 1 p 'Polymer Concrete';

Fig. 9 Single Score results per material type with endpoint method

6.2. Weighting per environment impact category

Fig. 10 presents the weighting results; the global warming, respiratory inorganic, and non-renewable energy impacts have recorded the highest environmental impacts, consistent with ASEC [43]. (1) The global warming potential was recorded at 8.95 $Kg\ CO_2\ eq.$ and 1.38 $Kg\ CO_2\ eq.$ For polymer and ordinary concrete, respectively. Due to the production of Portland cement, the main component of conventional concrete is a significant source of greenhouse gas emissions, based on Marceau et al. [44]. However, the production of polymer resins used in the production of polymeric concrete significantly impacts the material's environmental performance, consistent with Alhazmi et al. [45]. (2) The respiratory inorganic has 0.004 $Kg\ PM_{2.5}\ eq$ and 0.0007 $Kg\ PM_{2.5}\ eq$ for polymer and ordinary concrete, respectively. (3) The non-renewable energy reached 36.77 $MJ\ primary$ and 5.84 $MJ\ primary$ for polymer and ordinary concrete respectively.

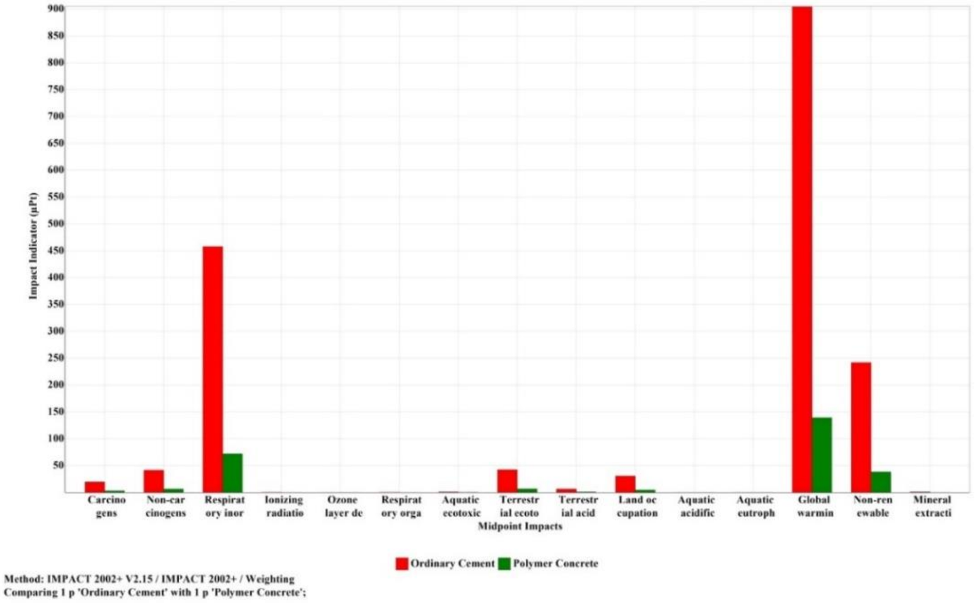


Fig. 10 Weighting results per environmental impact type with midpoint method

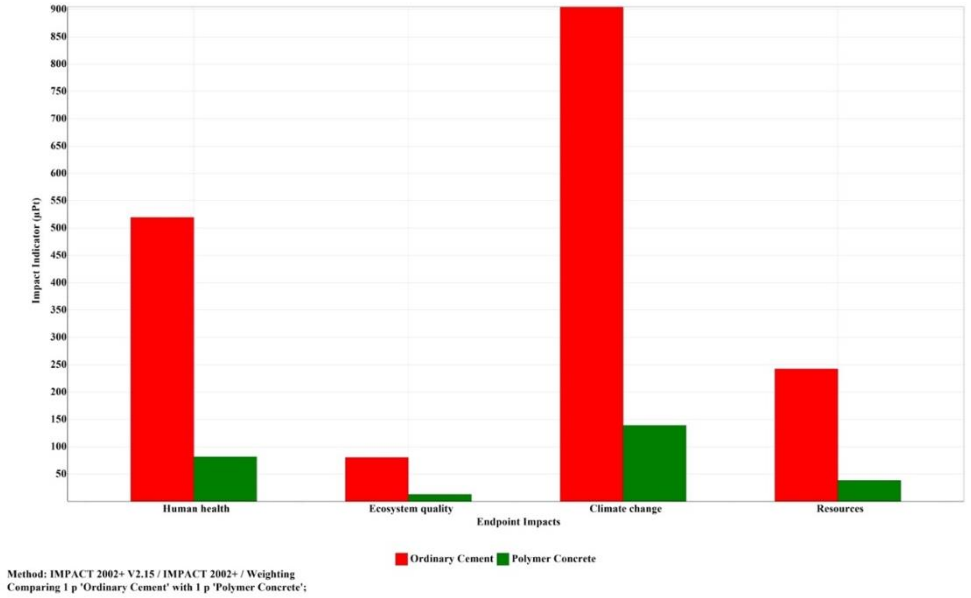


Fig. 11 Weighting results per impact type with endpoint method

Some LCIA techniques have embraced Disability Adjusted Life Years (DALY) as a measure of human health environmental impact to incorporate varied-points into linked to damages to human health, as it is mentioned by Dastjerdi et al., Li et al., Shi et al. and Hu et al. [46]– [49]. As a result of the following Fig. 11, the human health recorded 3.69E-06 $DALY$ for ordinary concrete and 5.8E-07 $DALY$, with a total reduction of 84.24%.

7. Conclusions

One of the main benefits of conducting an LCA of polymer concrete is the ability to identify environmental hotspots. These are areas of the life cycle where the material significantly impacts the environment. For example, producing polymer resins requires significant energy and generates greenhouse gas emissions. By identifying these hotspots, manufacturers of polymer concrete can focus on reducing their environmental impact and improving their sustainability. Polymeric concrete and conventional concrete production have different environmental impacts. Here is a conclusion and comparison of the environmental effects of the two materials based on the article's findings:

1. *Carbon Footprint*: The production of Portland cement, the main component of conventional concrete, is a significant source of greenhouse gas emissions, as it is mentioned by Marceau et al. [44]. Polymeric concrete has a lower carbon footprint than conventional concrete due to recycled aggregates and a longer curing time.
2. *Energy Consumption*: Polymeric concrete has lower energy consumption than conventional concrete due to the lower curing time and the use of recycled aggregates, as reported by Alhazmi et al. [45].
3. *Waste Generation*: Polymeric concrete production generates less waste than conventional concrete production due to recycled aggregates and cement's absence, as documented by Alhazmi et al. [45].
4. *Water Consumption*: Polymeric concrete production generally requires less water than conventional concrete production. It is due to the lower curing time and the absence of cement, which reduces the need for water in production.
5. *Environmental Toxicity*: The production of conventional concrete can result in the release of pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, which can have harmful effects on human health and the environment, as it is mentioned by Turner et al., Cao et al. and Chau et al. [10], [14], [16]. Polymeric concrete production, on the other hand, does not result in the release of these pollutants. However, the production of polymer resins used in concrete polymeric output can have environmental toxicity concerns due to the use of petrochemicals based on Salas et al. [19]

Overall, this article has revealed that polymeric concrete production has lower environmental impacts than conventional concrete production. Using recycled materials in polymeric concrete production can reduce its environmental impact and promote using more sustainable materials in the construction industry.

8. Limitation and recommendation

While the present study provides valuable insights into the environmental impact of polymeric concrete and its potential as a sustainable alternative to conventional concrete, several limitations should be considered. First, the study was conducted from a cradle-to-gate perspective, which means that the environmental impact of the use phase of the materials was not considered. Future studies should consider the use phase of the material to provide a more comprehensive assessment of its overall environmental impact.

Second, the study focused on comparing polymeric concrete to conventional concrete and did not consider other alternative materials that may have lower environmental impacts. Future studies should compare polymeric concrete to other alternative materials, such as geopolymer concrete, to identify the most sustainable option for construction applications.

Third, the study did not consider the economic or social impacts of using polymeric concrete compared to conventional concrete. Future studies should consider the economic and social factors associated with using polymeric concrete to assess its sustainability comprehensively.

Based on the findings of this study, the author recommends the following actions to enhance the sustainability of polymeric concrete in the construction industry:

1. Promote using recycled aggregates in producing polymeric concrete to reduce its environmental impact.
2. Further research should be conducted to develop more sustainable production methods for polymer resins used in the production of polymeric concrete.
3. Develop guidelines and standards for using polymeric concrete in construction to ensure its proper application and reduce the risk of adverse environmental impacts.
4. Conduct further research to assess the use phase of polymeric concrete and its overall environmental impact over the entire life cycle.
5. Compare polymeric concrete to other alternative materials, including geopolymer concrete, to identify the most sustainable option for construction applications.
6. Consider the economic and social factors associated with using polymeric concrete to assess its sustainability comprehensively.

Overall, while polymeric concrete has the potential to be a sustainable alternative to conventional concrete in the construction industry, further research and development are needed to enhance its sustainability and reduce its environmental impact. The findings of this study can inform future research and development efforts and promote the use of more sustainable materials in the construction industry.

References

[1] “Home - Egyptian Cement.” https://www.egyptian-cement.com/# (accessed May 31, 2023).

[2] B. Huang, F. Zhao, T. Fishman, W. Q. Chen, N. Heeren, and E. G. Hertwich, “Building Material Use and Associated Environmental Impacts in China 2000-2015,” *Environ Sci Technol*, vol. 52, no. 23, pp. 14006–14014, Dec. 2018, doi: 10.1021/ACS.EST.8B04104/SUPPL_FILE/ES8B04104_SI_004.XLSX.

[3] M. Manjunatha, B. Kvgd, J. Vengala, L. R. Manjunatha, K. Shankara, and C. Kumar Patnaikuni, “Experimental study on the use of human hair as fiber to enhance the performance of concrete: A novel use to reduce the disposal challenges,” *Mater Today Proc*, vol. 47, pp. 3966–3972, Jan. 2021, doi: 10.1016/J.MATPR.2021.04.039.

[4] R. B. Tangadagi, M. Manjunatha, S. Preethi, A. Bharath, and T. V. Reshma, “Strength characteristics of concrete using coconut shell as a coarse aggregate – A sustainable approach,” *Mater Today Proc*, vol. 47, pp. 3845–3851, Jan. 2021, doi: 10.1016/J.MATPR.2021.03.265.

[5] B. L. N. S. Srinath, C. K. Patnaikuni, K. V. G. D. Balaji, B. S. Kumar, and M. Manjunatha, “A prospective review of alccofine as supplementary cementitious material,” *Mater Today Proc*, vol. 47, pp. 3953–3959, Jan. 2021, doi: 10.1016/J.MATPR.2021.03.719.

[6] W. Lokuge and T. Aravinthan, “Effect of fly ash on the behaviour of polymer concrete with different types of resin,” *Mater Des*, vol. 51, pp. 175–181, Oct. 2013, doi: 10.1016/J.MATDES.2013.03.078.

[7] A. P. Gursel, H. Maryman, and C. Ostertag, “A life-cycle approach to environmental, mechanical, and durability properties of ‘green’ concrete mixes with rice husk ash,” *J Clean Prod*, vol. 112, pp. 823–836, Jan. 2016, doi: 10.1016/J.JCLEPRO.2015.06.029.

[8] D. K. Panesar, K. E. Seto, and C. J. Churchill, “Impact of the selection of functional unit on the life cycle assessment of green concrete,” *International Journal of Life Cycle Assessment*, vol. 22, no. 12, pp. 1969–1986, Dec. 2017, doi: 10.1007/S11367-017-1284-0/METRICS.

[9] K. H. Yang, J. K. Song, and K. Il Song, “Assessment of CO2 reduction of alkali-activated concrete,” *J Clean Prod*, vol. 39, pp. 265–272, Jan. 2013, doi: 10.1016/J.JCLEPRO.2012.08.001.

[10] L. K. Turner and F. G. Collins, “Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete,” *Constr Build Mater*, vol. 43, pp. 125–130, Jun. 2013, doi: 10.1016/J.CONBUILDMAT.2013.01.023.

[11] A. Garbacz and J. J. Sokołowska, “Concrete-like polymer composites with fly ashes – Comparative study,” *Constr Build Mater*, vol. 38, pp. 689–699, Jan. 2013, doi: 10.1016/J.CONBUILDMAT.2012.08.052.

[12] W. Ferdous *et al.*, “Optimal design for epoxy polymer concrete based on mechanical properties and durability aspects,” *Constr Build Mater*, vol. 232, p. 117229, Jan. 2020, doi: 10.1016/J.CONBUILDMAT.2019.117229.

[13] G. Asadollahfardi, A. Katebi, P. Taherian, and A. Panahandeh, “Environmental life cycle assessment of concrete with different mixed designs,” *https://doi.org/10.1080/15623599.2019.1579015*, vol. 21, no. 7, pp. 665–676, 2019, doi: 10.1080/15623599.2019.1579015.

[14] C. K. Chau, T. M. Leung, and W. Y. Ng, “A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings,” *Appl Energy*, vol. 143, no. 1, pp. 395–413, 2015, doi: 10.1016/J.APENERGY.2015.01.023.

[15] D. N. Huntzinger and T. D. Eatmon, “A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies,” *J Clean Prod*, vol. 17, no. 7, pp. 668–675, May 2009, doi: 10.1016/J.JCLEPRO.2008.04.007.

[16] Z. Cao *et al.*, “Toward a better practice for estimating the CO2 emission factors of cement production: An experience from China,” *J Clean Prod*, vol. 139, pp. 527–539, Dec. 2016, doi: 10.1016/J.JCLEPRO.2016.08.070.

[17] M. C. G. Juenger and R. Siddique, “Recent advances in understanding the role of supplementary cementitious materials in concrete,” *Cem Concr Res*, vol. 78, pp. 71–80, Dec. 2015, doi: 10.1016/J.CEMCONRES.2015.03.018.

[18] J. Aldred and J. Day, “IS GEOPOLYMER CONCRETE A SUITABLE ALTERNATIVE TO TRADITIONAL CONCRETE?” in *37th Conference on Our World in Concrete & Structures*, Singapore, 2012, pp. 29–31.

[19] D. A. Salas, A. D. Ramirez, N. Ulloa, H. Baykara, and A. J. Boero, “Life cycle assessment of geopolymer concrete,” *Constr Build Mater*, vol. 190, pp. 170–177, Nov. 2018, doi: 10.1016/J.CONBUILDMAT.2018.09.123.

[20] M. M. Farid, A. M. Khudhair, S. A. K. Razack, and S. Al-Hallaj, “A review on phase change energy storage: materials and applications,” *Energy Convers Manag*, vol. 45, no. 9–10, pp. 1597–1615, Jun. 2004, doi: 10.1016/J.ENCONMAN.2003.09.015.

[21] P. Duxson, J. L. Provis, G. C. Lukey, and J. S. J. van Deventer, “The role of inorganic polymer technology in the development of ‘green concrete,’” *Cem Concr Res*, vol. 37, no. 12, pp. 1590–1597, Dec. 2007, doi: 10.1016/J.CEMCONRES.2007.08.018.

[22] E. Crossin, “The greenhouse gas implications of using ground granulated blast furnace slag as a cement substitute,” *J Clean Prod*, vol. 95, pp. 101–108, May 2015, doi: 10.1016/J.JCLEPRO.2015.02.082.

[23] M. Manjunatha, S. Preethi, Malingaraya, H. G. Mounika, K. N. Niveditha, and Ravi, “Life cycle assessment (LCA) of concrete prepared with sustainable cement-based materials,” *Mater Today Proc*, vol. 47, pp. 3637–3644, Jan. 2021, doi: 10.1016/J.MATPR.2021.01.248.

[24] M. Manjunatha, D. Seth, B. KVGD, and B. A, “Engineering properties and environmental impact assessment of green concrete prepared with PVC waste powder: A step towards sustainable approach,” *Case Studies in Construction Materials*, vol. 17, p. e01404, Dec. 2022, doi: 10.1016/J.CSCM.2022.E01404.

[25] W. Chen, J. Hong, and C. Xu, “Pollutants generated by cement production in China, their impacts, and the potential for environmental improvement,” *J Clean Prod*, vol. 103, pp. 61–69, 2015, doi: 10.1016/J.JCLEPRO.2014.04.048.

[26] A. A. M. Ali, “Environmental Impacts Assessment of Rice Straw Brick as a Substitutional Sustainable Building Material in Assiut University Hospital Clinic,” *Journal of Advanced Engineering Trends*, vol. 41, no. 2, pp. 247–259, 2022, Accessed: May 26, 2023. [Online]. Available: http://jaet.journals.ekb.eg

[27] S. Seyis, “Mixed method review for integrating building information modeling and life-cycle assessments,” *Build Environ*, vol. 173, no. January, p. 106703, 2020, doi: 10.1016/j.buildenv.2020.106703.

[28] S. Su, Q. Wang, L. Han, J. Hong, and Z. Liu, “BIM-DLCA: An integrated dynamic environmental impact assessment model for buildings,” *Build Environ*, vol. 183, no. May, p. 107218, 2020, doi: 10.1016/j.buildenv.2020.107218.

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

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

[31] International Organization For Standardization (ISO), “ISO - ISO 14042:2000 - Environmental management — Life cycle assessment — Life cycle impact assessment,” 2000. https://www.iso.org/standard/23153.html (accessed Sep. 04, 2020).

[32] International Organization For Standardization (ISO), “ISO - ISO 14043:2000 - Environmental management — Life cycle assessment — Life cycle interpretation,” 2000. https://www.iso.org/standard/23154.html (accessed Sep. 04, 2020).

[33] A. A. M. Ali, “Application of comparative life cycle assessment to a proposed building for reduced environmental impacts: Assiut University Hospital Clinic as a case study,” *Journal of Architecture, Arts and Humanities Sciences*, vol. 7, no. 31, 2021, doi: 10.21608/mjaf.2020.41904.1847.

[34] A. Martínez-Rocamora, J. Solís-Guzmán, and M. Marrero, “LCA databases focused on construction materials: A review,” *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 565–573, 2016, doi: 10.1016/j.rser.2015.12.243.

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

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

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

[38] A. A. M. M. Ali, A. M. Negm, M. F. Bady, M. G. E. Ibrahim, and M. Suzuki, “Environmental impact assessment of the Egyptian cement industry based on a life-cycle assessment approach: a comparative study between Egyptian and Swiss plants,” *Clean Technol Environ Policy*, vol. 18, no. 4, 2016, doi: 10.1007/s10098-016-1096-0.

[39] S. G. Al-Ghamdi and M. M. Bilec, “Green Building Rating Systems and Whole-Building Life Cycle Assessment: Comparative Study of the Existing Assessment Tools,” *Journal of*

Architectural Engineering, vol. 23, no. 1, pp. 1–9, 2017, doi: 10.1061/(ASCE)AE.1943-5568.0000222.

[40] X. Bengoa and M. Margni, “IMPACT 2002 + : User Guide,” 2012.

[41] J. Smith, “Environment directorate working party on global and structural policies working party on development co-operation and environment development and climate change in egypt: focus on coastal resources,” 2004.

[42] C. Shi, a. F. Jiménez, and A. Palomo, “New cements for the 21st century: The pursuit of an alternative to Portland cement,” *Cem Concr Res*, vol. 41, no. 7, pp. 750–763, 2011, doi: 10.1016/j.cemconres.2011.03.016.

[43] ASEC, “ASEC Cement: Annual Report 2013,” 2013.

[44] M. L. Marceau, M. a Nisbet, and M. G. VanGeem, “Life cycle inventory of Portland cement concrete,” no. 3007, 2007.

[45] H. Alhazmi, S. A. R. Shah, M. K. Anwar, A. Raza, M. K. Ullah, and F. Iqbal, “Utilization of Polymer Concrete Composites for a Circular Economy: A Comparative Review for Assessment of Recycling and Waste Utilization,” *Polymers 2021, Vol. 13, Page 2135*, vol. 13, no. 13, p. 2135, Jun. 2021, doi: 10.3390/POLYM13132135.

[46] B. Dastjerdi, V. Strezov, M. A. Rajaeifar, R. Kumar, and M. Behnia, “Waste to Energy Technologies,” *Reference Module in Earth Systems and Environmental Sciences*, 2022, doi: 10.1016/B978-0-323-90386-8.00012-7.

[47] X. Li, Y. Zhu, and Z. Zhang, “An LCA-based environmental impact assessment model for construction processes,” *Build Environ*, vol. 45, no. 3, pp. 766–775, Mar. 2010, doi: 10.1016/J.BUILDENV.2009.08.010.

[48] S. Shi *et al.*, “Life cycle assessment of embodied human health effects of building materials in China,” *J Clean Prod*, vol. 350, p. 131484, May 2022, doi: 10.1016/J.JCLEPRO.2022.131484.

[49] G. Hu *et al.*, “Human health risk-based life cycle assessment of drinking water treatment for heavy metal(loids) removal,” *J Clean Prod*, vol. 267, p. 121980, Sep. 2020, doi: 10.1016/J.JCLEPRO.2020.121980.

تقييم مقارن لدورة الحياة للخرسانة البوليمرية والتقليدية من أجل البناء المستدام: دراسة حالة لعيادة جديدة في مستشفى جامعة أسيوط بمصر

الملخص:

تمتلك صناعة مواد البناء الحصة الأكبر من الانبعاثات البيئية العالمية. لذا يتناول هذا البحث دراسة التأثير البيئي للخرسانة البوليمرية مقارنة بالخرسانة التقليدية في إنشاء عيادة جديدة بمستشفى جامعة أسيوط في مصر. حيث إنه تم إجراء تقييم دورة الحياة (*LCA*) بدءًا من استخراج المواد الخام وحتى مرحلة الإنتاج (مرحلة المهد إلى البوابة) باستخدام برنامج *SimaPro V9.5*. في هذا البحث، تمت دراسة جميع التأثيرات البيئية باستخدام طريقة *IMPACT2002+* باستخدام نتائج نقطة المنتصف ونقطة النهاية *(Midpoint and Endpoint results)*.

أظهرت نتائج *LCA* أن الخرسانة البوليمرية لها تأثير بيئي أقل من الخرسانة التقليدية فيما يتعلق بالاحتباس الحراري و*Acidification and Eutrophication Potential*. أما عن نتائج النتيجة الفردية *(single score)*، كان لتغير المناخ تأثير كبير على كل من الخرسانة العادية والخرسانة البوليمرية، حيث سجلت الأولى ٠,٩٠ *mPt* وسجلت الأخيرة أقل بكثير من ٠,١٤ *mPt*، مما يشير إلى انخفاض بنسبة ٧٥٪. علاوة على ذلك، عند النظر في نتائج الترجيح (نتيجة النقطة المتوسطة) *(Midpoint results)*، فقد وجد أن تأثيرات بيئية محددة، مثل الاحتباس الحراري، وتأثيرات الطاقة غير العضوية التنفسية *(Respiratory Inorganic)*، والطاقة غير المتجددة، كان لها تأثير أكثر أهمية بشكل عام. على وجه التحديد، وجد أن احتمالية الاحتباس الحراري تبلغ ٨,٩٥ كجم من مكافئ ثاني أكسيد الكربون *(Kg CO_2 eq.)* و١,٣٨ كجم من مكافئ ثاني أكسيد الكربون *(Kg CO_2 eq.)* للبوليمر والخرسانة العادية على التوالي. وأخيرًا، أظهرت نتيجة نقطة النهاية *(Endpoint results)* أن صحة الإنسان هي الأكثر تأثراً، مع انخفاض إجمالي قدره ٨٤,٢٤٪. كان معدل *DALY* المسجل للخرسانة العادية هو ٣,٦٩*E-06*، بينما كان للخرسانة البوليمرية ٥,٨*E-07*.

في النهاية، تشير نتائج هذه الدراسة إلى أن الخرسانة البوليمرية يمكن أن تكون بديلاً أكثر استدامة للخرسانة التقليدية لتطبيقات محددة. ومن جانب آخر، إحدى الصعوبات الرئيسية التي تواجه تطبيق الخرسانة البوليمرية في صناعة البناء والتشييد هي تكلفتها المرتفعة مقارنة بالخرسانة التقليدية. لذا تتطلب عملية إنتاج الخرسانة البوليمرية معدات وخبرات متخصصة، مما قد يزيد من التكلفة الإجمالية للمادة. بالإضافة إلى ذلك، قد يتطلب استخدام الخرسانة البوليمرية تغييرات في تقنيات البناء ومواصفات التصميم، الأمر الذي قد يمثل تحديًا للمقاولين والمهندسين الذين اعتادوا العمل مع المواد التقليدية. علاوة على ذلك، فإن المتانة والأداء طويل المدى للخرسانة البوليمرية في بعض التطبيقات لم يتم دراستها على نطاق واسع وقد تتطلب المزيد من البحث والاختبار. وأخيرا، فإن توفر المواد الخام والتخلص من النفايات من عملية الإنتاج قد يشكل أيضا تحديات في اعتماد الخرسانة البوليمرية على نطاق واسع في صناعة البناء والتشييد.