Recycled Aggregate Concrete in Post Disaster Economic Construction

Hafeth I. Naji, Mohammed Sh. Mahmood and Zahraa A. Jalil

Abstract This paper aims at finding economic methods to reconstruct the destroyed cities post disasters and reduce the cost of reconstruction material in Iraq. One of these methods is to use of recycled fine aggregate (RFA) or fine recycled aggregate (FRA) instead of natural fine aggregate (NFA). Recycled aggregate concrete is resulting from many of the buildings destroyed as a result of natural or man-made disasters. The method of this research includes two parts, the first part includes theoretical aspect where data on RFA was collected, especially on the physical and mechanical properties, also on the information about cost of building material in Iraq, and the information about types and cost of stone crusher. Selected the best concrete mix containing RFA, that its physical and mechanical properties are better or closer to normal mix properties. The second part of the research is to conduct the practical side using the building information modeling (BIM) technique. A small destroyed city was modeled and it included various models of buildings. The amount of concrete used in ceiling and beams construction was calculated, extracting the volume of fine aggregate and its cost in the case of normal construction, and calculation of cost in the case of the use RFA instead of NFA, which is processed at the work site by a stone crusher can reduce the cost of building materials. The conclusions from this study is the total cost required for the purchase of building materials that used for the construction of ceilings and beams can be reduced by 18.38%.

Keywords Economic construction · Disaster · Reconstruction · Recycle · RFA · NFA · BIM

H. I. Naji (✉) · M. Sh.Mahmood · Z. A. Jalil
Department of Civil Engineering, University of Diyala, Baquba, Iraq
e-mail: Hafizibrahem1973@gmail.com

F. Mohamed Nazri (ed.), *Proceedings of AICCE'19*, Lecture Notes in Civil Engineering 53, https://doi.org/10.1007/978-3-030-32816-0_77

1 Introduction

In recent years, Iraq has been subjected to wars that have destroyed many cities. Due to the economic situation in the country, many researchers have sought to find the best and least costly ways to reconstruct these cities. The depletion of natural resources, on the one hand, and the increased cost of transporting and landfill waste, on the other, encouraged the use of recycled concrete in the workplace as a source of aggregates. The use of waste of destroying buildings as a source of new concrete production has become more common in the last decade [6].

After the second world war, for the first time demolished waste was recycled in Germany [7], since then, many research has been carried out in many countries and has shown an effort to develop the use of destroyed city waste. After reviewing the methodological literature in this regard and knowing many of the practical rules that predicted the thermal and mechanical performance related to RFA. BIM is a process that involves modeling a building with all its details and the ability to change its design throughout the life cycle of a building. After complete modeling of the building, all information can be extracted such as construction scheduling (4D BIM), cost estimating (5D BIM) and analyzing [4].

The core of this research selected the best alternatives that can be applied during this research and investigation of the results in order to reduce the cost of post-disaster reconstruction.

2 Literature Review

Many studies seek to develop engineering work and performance in the face of disasters and recovery in a way that is appropriate to the economy of the country. Natural or man-made disasters cause major destruction in cities, especially in densely populated areas, which have a negative impact on the social situation, the impacts of disasters on the environment in term of physical to socio-economic and include injuries, fatalities and wide-spread destruction of property [5].

The management of debris after disasters is a major concern because of the abundance of debris and the difficulty of transport to landfills, as well as the depletion of natural materials for reconstruction after disasters [8].

As a result, many studies have been directed towards the use of recycled concrete. On the one hand, the problems of destroyed concrete waste and environmental degradation can be addressed. On the other hand, as a substitute for natural debris, total recycled construction waste can save natural sand resources and reduce the ex-traction of natural sands, which is suited to sustainable development requirements [9].

It has been found that the use of recycled concrete has an impact on the environment and cost. When used in the construction of physical structures, it was found to reduce the cost of construction and also preserve the environment [2].

3 Methodology

The method of this paper includes two parts, theoretical and practical aspects.

The first part includes:

- Collection of data on the thermal and mechanical properties of concrete containing RFA.
- Investigate the cost of building materials in Iraq and crushers used to break down the destroyed concrete structures.

The second part of the methodology includes:

- Modeling a small city using BIM technique.
- Calculated the amount and cost of concrete used in the construction of roofs and beams.
- Replacement of NFA by using concrete containing RFA instead of NFA by ration 100%.

3.1 *Theoretical Aspect*

3.1.1 Collection of Data

The information about recycled fine aggregate concrete has been collected based on its physical and mechanical properties, provided that it is close to the normal concrete properties in order to be highly utilized. As shown below are some of the main properties of RFA (Table 1).

Alternative (4) is considered as the best alternative, this is because compressive strength is close to the normal compressive strength of the concrete (24.1 MPa), which can be used in the concrete of the roof and beams, as well as for the thermal conductivity and density in the ordinary concrete is (1.046 W/m K) (2407.31 kg/m^3). Alternative (4) was taken into account in this research and depending on the mixing percentages used for each alternative, the percentage of RFA concrete was the 100% replacement NFA concrete as shown in the Table 2.

Table 1 Properties of concrete containing RFA [1]

Alternatives	Density (kg/m^3)	Compressive strength (MPa)	Thermal conductivity (W/m K)
A.1	2339.4	47.5	2.06
A.2	2314.1	43.2	1.94
A.3	2306.1	37.6	1.68
A.4	2216.2	27.1	1.21

Table 2 Percentage of replacement of NFA with RFA [1]

Alternatives	Percentage of replacement of NA with RA (%)	w/c ratio
A.1	10	0.54
A.2	25	0.56
A.3	50	0.59
A.4	100	0.64

Recycled concrete is not always pure, it contains many impurities that may be remnants of crushed bricks, cement mortar, ceramics and glass, all these impurities are affected on concrete properties, but their presence in certain proportions preserves the physical and mechanical properties. The percentages allowed within the concrete mix are shown in the Table 3.

3.1.2 Cost of Building Materials and Crushers

The cost of building materials, it was calculated based on the cost of materials in Iraq during the years 2018–2019, especially the purchase cost of cement, sand and aggregate. Where the cost of 1000 kg of cement is 85,000 ID, the purchase cost of 8 m^3 of sand is 170,000 ID, and the purchase cost of 8 m^3 of gravel is 140,000 ID. By dividing the cost of the volume of the sand and gravel, find that the cost per cubic meter is 21,250 ID for sand and 17,500 ID for gravel, as shown in the Table 4.

Table 3 Composition of recycled aggregates [1]

Composition (%)	RFA
Concrete, mortar and natural stone	75.2
Masonry-clay materials	11.6
Glass	1.0
Bituminous materials	10.5
Others	1.7
Total	100

Table 4 Cost of material in Iraq

Material	Quantity	Cost (ID)
Cement	1000 (kg)	85,000
	1 (kg)	85
Sand	8 (m^3)	170,000
	1 (m^3)	21,250
Gravel	8 (m^3)	140,000
	1 (m^3)	17,500

One cubic meter of concrete contains specified percentages of cement, sand and gravel, and these percentages can be calculated by using the following equation for normal mix concrete (cement:sand:gravel) in the ratio of (1:2:4) [3].

$$1\ \text{m}^3 = 0.67\ (C + S + G). \tag{1}$$

where C is the volume of cement that required to construct 1 m^3 of concrete, S is the volume of sand and G is the volume of gravel, and 0.67 indicates a contraction in the volume of concrete components after the water addition, this contraction is about third of the volume or 0.33. By applying the equation, find that the value of) C), to find the amount of sand. Results of calculations are found by multiplying the amount of cement extracted (*2), and multiplying the amount of cement (*4) to find the amount of gravel. As for the cost of each item, the quantities extracted are multiplied by each price calculated in the previous table, when collecting the cost of all the materials, find that the cost per cubic meter of concrete and it is equal to 49,300 ID, as shown in the Table 5.

As for the price of crushers, the best crusher possible to be suitable for the production of large quantities of aggregate can be designed in a factory for crushers, where information was obtained for the crusher suitable for this work by a professional factory located in Turkey. The type of crusher is (JAW CRUSHERS MOBILE)-(R-90) and the purchase cost of crusher is $350,000 (Mert Makina Company, Turkey). Parts of the crusher are shown in the Fig. 1.

3.2 Practical Aspect

The type of buildings that modeled are residential buildings with different designs (building A, building B), primary school (school 1), intermediate school (school 2), medical clinic, market and mosque. The number of buildings (A) included in the small city was 30 residential buildings, the number of buildings (B) was 36 and The number of high school is 2. The software used in the work is Revit, which is one of the important programs used in the calculation of quantities and costs accurately and prevents mistakes, so that any change in the design change results directly (Figs. 2 and 3).

Table 5 Cost and quantity of cement, sand and gravel in (1 m^3) of concrete

Material	Apply the equation	Volume (m^3)	Cost (ID)
Cement	C	0.21 = 300 kg	300 * 85 = 25,500
Sand	2C	0.42	0.42 * 21,250 = 8925
Gravel	4C	0.85	0.85 * 17,500 = 14,875
Total			49,300

Fig. 1 Crusher parts, **a** first crusher, **b** second stage crusher, **c** vibrator, **d** belt conveyor, **e** control room (Mert Makina Company, Turkey)

Type A and B are three-storey residential buildings with an area of approximately (600 m^2) for building A and (750 m^2) for building B. The area of school 1 is (1404 m^2), and the area of school 2 is (1048 m^2) (Figs. 4 and 5).

The area of the market is (863 m^2), it is consisting from two-storey. The area of medical clinic is 251 m^2 and the area of the mosque is 372 m^2 (Figs. 6, 7 and 8).

In each of these modelled the concrete structure of each building, from these structures calculates the amount and cost of concrete used in the ceilings and beams.

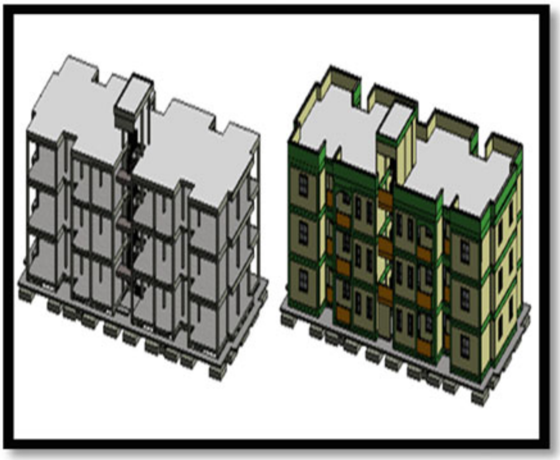

Fig. 2 Modelling of building A

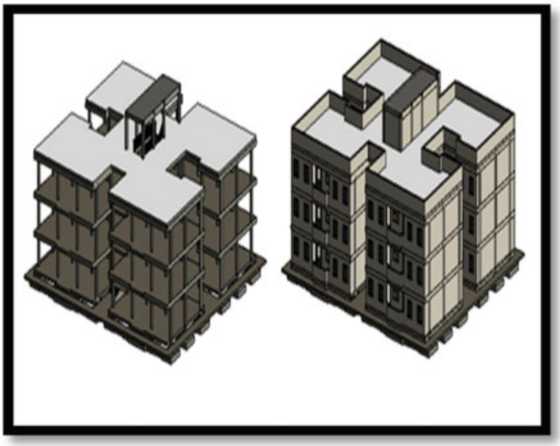

Fig. 3 Modelling of building B

4 Result and Discussion

All models implemented within the BIM technology, the amount and cost of concrete used in the ceilings and beams was calculated and the results were as shown in Tables 6 and 7.

After calculating the amount and cost of concrete used in ceiling and beams, the total amount of concrete was calculated, as shown in Table 8.

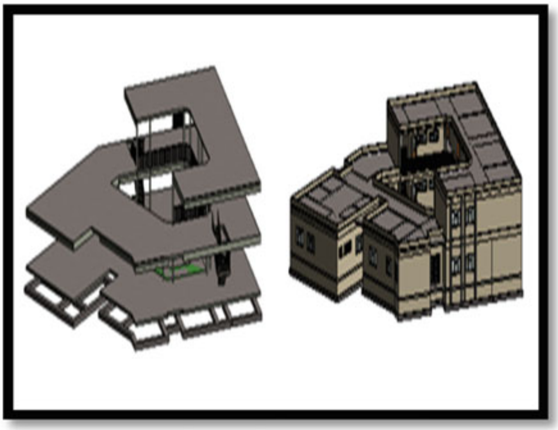

Fig. 4 Modelling of school 1

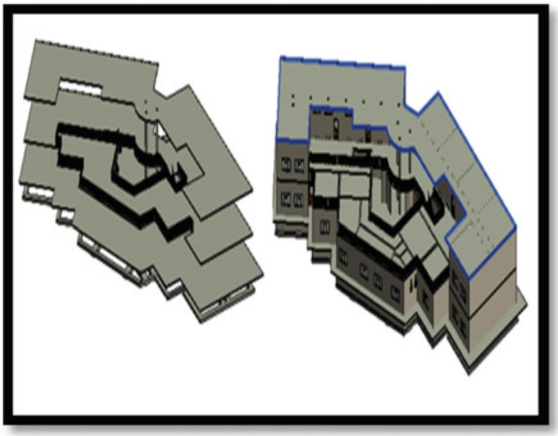

Fig. 5 Modelling of school 2

$$\begin{aligned}\text{Total volume of ceiling and beams} &= \text{total volume of the ceiling} \\ &\quad + \text{total volume of beams} \\ &= 32{,}315.22 + 5039.41 \\ &= 37{,}354.63\ \text{m}^3\end{aligned}$$

This amount of concrete is sufficient to construct roofs and beams of a small city, consisting of a group of residential units and some service units, and through this result can extract the amount of sand that must be supplied to produce this large quantity of concrete and needed to provide on-site.

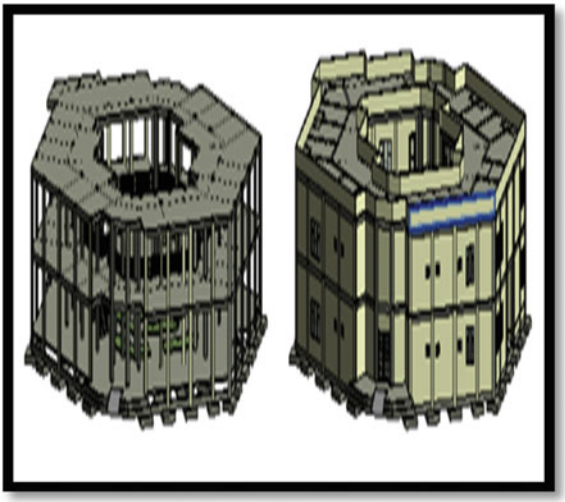

Fig. 6 Modelling of market

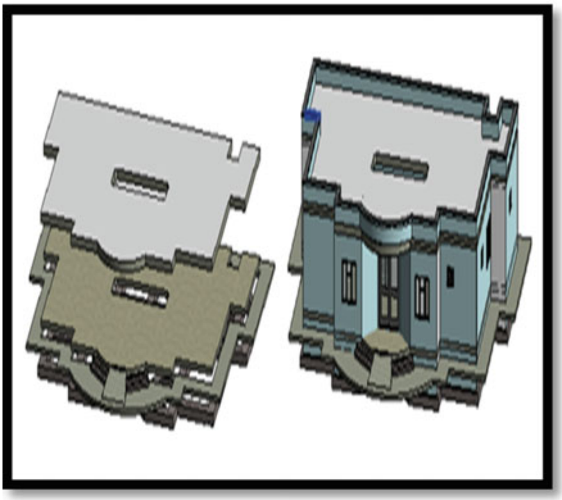

Fig. 7 Modelling of medical clinic

- Volume of sand: apply Eq. (1)

$$37{,}354.63 = 0.67\,(C + 2C + 4C)$$
$$C = 7964.73\ m^3$$
$$2C\ (SAND) = 2 * 7964.73 = 15{,}929.46\ m^3$$

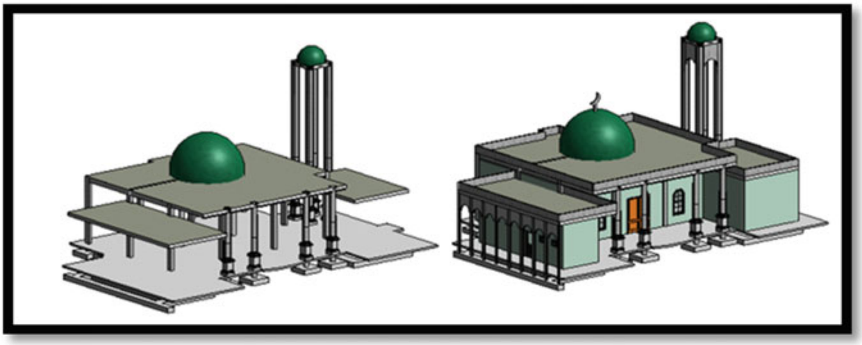

Fig. 8 Modelling of the mosque

Table 6 Volume and cost of ceiling and floor structure

Type of building	No.	Cost (ID)/(m^3)	Volume (m^3)	Cost (ID)
Building A	30	49,300	12,431.4	612,868,020
Building B	36	49,300	18,237.24	899,095,932
School 1	1	49,300	456.16	22,488,688
School 2	2	49,300	694.25	34,226,525
Market	1	49,300	310.71	15,318,003
Medical clinic	1	49,300	75.34	3,714,262
Mosque	1	49,300	110.12	5,428,916
Total			32,315.22	1,593,140,346

Table 7 Volume and cost of beam structure

Type of building	No.	Cost (ID)/(m^3)	Volume (m^3)	Cost (ID)
Building A	30	49,300	2220	109,446,000
Building B	36	49,300	2664	131,335,200
School 1	1	49,300	3.64	179,452
School 2	2	49,300	101.64	5,010,852
Market	1	49,300	42.62	2,101,166
Medical clinic	1	49,300	0.7	34,510
Mosque	1	49,300	6.81	335,733
Total			5039.41	248,442,913

Table 8 The total cost and volume of concrete for floor and beam

Type of building	No.	Volume (m^3)	Cost of each building (ID)
Building A	30	14,651.4	722,314,020
Building B	36	20,901.24	1,030,431,132
School 1	1	459.8	22,668,140
School 2	2	795.89	39,237,377
Market	1	353.33	17,419,169
Medical clinic	1	76.04	3,748,772
Mosque	1	116.93	5,764,649
Total		37,354.63	1,841,583,259

- Cost of sand:

$$\begin{aligned}\text{Cost} &= 15{,}929.46\ \left(\text{m}^3\right) * 21{,}250\ \left(\text{ID/m}^3\right)\\ &= 338{,}501{,}025\ \text{ID}\end{aligned}$$

This amount represents the cost of buying the sand necessary for the manufacture of concrete for the ceilings and beams of the small city, where the use of recycled concrete in the workplace instead of natural sand, this saves the cost of purchasing materials and can be used in other work stages.

- $$\begin{aligned}\text{Savings ratio of cost} &= \frac{\text{cost of sand}}{\text{total cost of materail for roofs and beams}} * 100\%\ \text{(researcher)}\\ &= \frac{338{,}501{,}025}{1{,}841{,}583{,}259} * 100\% = 18.38\%\end{aligned}$$

Through this result, it was noted that the percentage that can be retained and not included in the expenditure of building materials is estimated at 18.38%, which is a high percentage where it can be used by buying materials to supplement the parts of other buildings.

5 Conclusion

After studying the results, it can conclude the following.

- The amount of sand required to reconstruct a small destroyed city was very large.
- Providing this quantity of NFA needs high cost and great effort to deliver it to the work site.

- When using alternative instead of natural sand, it is possible to save the cost of natural sand by using the destroyed concrete after crushing it with special crushers inside the site.
- Provide the cost of transporting natural sand from the source to the site, as the alternative is produced at the work site in the center of the destroyed city.

Acknowledgements The researcher would like to acknowledge the team of engineers working in the department of civil engineering, University of Diyala.

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