Evaluation of Building's Life Cycle Carbon Emissions Based on BIM and LCA: A Case Study of Affordable Housing in Morocco

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Abstract

Morocco is undertaking tremendous actions toward reducing the impact of climate change especially in terms of energy efficiency and building sector adaptation. However, until now neither Building Information Modeling (BIM) has been used in this context nor an analysis of Building's Life Cycle Carbon Emissions (BLCCE) of affordable housing has been conducted in Morocco. This paper aims to propose an approach using BIM and Life Cycle Assessment (LCA) to calculate and analyze the carbon emissions in different stages of building lifecycle of affordable housing named 'social housing'. For this purpose, an affordable housing parcel containing full-residential and mixed-use buildings was considered as a case study. Consequently, beside emphasizing the BIM capability to facilitate Embodied Carbon (EC) emissions, this study revealed that, concrete, bricks, steel, ceramic tiles, and paint are the most contributing materials in emitted EC with an approximative share of 90%. Meantime, glass is an impactful material for mixed-use buildings as it contributes to 8% of the total EC. Furthermore, this paper discloses that for social housing, the operational stage contributes to 98% of the BLCCE where 73% among it is due only to fossil energy consumption (butane), and full-residential buildings produce 11.6% more BLCCE than mixed-use buildings.

Keywords

BIM, Carbon footprint; CO_2 emission; Life Cycle Assessment; Embodied carbon; Operational Carbon; Green building

1. Introduction and Local Context:

Reducing greenhouse gas (GHG) emissions is a worldwide concern for which several inter-countries agreements have been signed. For instance, Kyoto Protocol and Paris Agreement display the commitments of industrialized countries and economies to limit and lessen their GHG emissions in accordance with agreed individual targets (Martha Benduski, 2020). In 2009, Morocco announced its commitment to engage strategies toward adopting more ecological solutions namely enhancing the energy efficiency and producing at least 52% of national electricity based on renewal sources by 2030 (Habous, 2009). For this purpose, Morocco prepared the related legal context through several laws and codes, namely the law N°13.01 in 2010 that regulated the production and use of renewal energy. Meanwhile, they built Noor Ouarzazate platform, one of the biggest mega-power solar plants in the world with a production of 580 MW of Concentrated Solar Power (CSP), and launched Noor Midelt platform, in 2018, a mega-power solar plant that is expected to produce more than 1600 MW of CSP (Masen, 2019). In the same vein, the kingdom committed, in 2015 as part of Paris Agreement, to reduce its GHG emissions by a minimum of 17% by 2030 compared to the status quo and a maximum of 42% under the condition of obtaining foreign financial aids (UNFCCC, 2020).

Building sector is a significant economic sector in Morocco as it contributes to an average of 6.6% of the national gross domestic product and offers almost 1 million permanent jobs and annual 30000 temporary jobs. Yet, because building sector is one of the most contributing sectors in climate change, as it is responsible for 33% of global carbon emissions and 40% of worldwide energy consumption (Peng, 2016) Morocco engaged several actions toward reducing the impact of this sector. Indeed, Morocco mandated utilizing only solar water heaters for all construction projects that benefit from incentives given by the government including affordable housing. Moreover, in 2014, upheld by foreign investment funds, Morocco launched and mandated energy efficiency codes, mainly the "building energy efficiency code" and "thermal construction regulations in Morocco" that entered into force in 2015 (AMEE, 2014). Thus, to facilitate its implementation, a software, named BINAYATE, was developed based on the thermic characteristic of a large material database including local building materials, and made available for architects.

In 2015, Morocco adopted the "2030 agenda of the sustainable development goals" and joined the "global alliance for buildings and construction" working for efficient and resilient buildings to reach a Net-Zero buildings by 2050. In the same year, Morocco upgraded the law N°13.01 through the law N°58.15 to regulate the direct injection of low voltage in the cities' electrical network which will allow reducing the energy bill (Moroccan Government, 2016). However, its implementation remains dependent on the upgrading of the electrical network infrastructure and the standardization of electricity suppliers. Furthermore, in 2016, monumental actions were undertaken in the same vein, namely creation of the "Moroccan buildings alliance for the climate", where almost all key actors of the national Architecture, Engineering, and Construction (AEC) industry were signatories of the creation agreement, release of the climate change mitigation, and adaptation plan for housing sector, and submission of the project "Improving the energy performance of Moroccan housing" to the Nama Facility (DHPV, 2017). Likewise, the country launched the national strategy for sustainable development of eco-construction that synthetizes and addresses the actions to be undertaken and its timeline to meet the goals that Morocco committed to, either as a member of the aforementioned organizations or as a self-active country in this area (Meriem Houzir, 2016).

However, despite the approved benefits of Building Information Modeling (BIM) in enhancing buildings sustainability, Building's Life Cycle Carbon Emissions (BLCCE) evaluation (Banteli & Stevenson, 2017), and decision making (Chen & Pan, 2016), it has not been considered in any of the undertaken actions by Morocco toward reducing building sector impact on climate change. Therefore, this study aims to address following objectives:

1. Highlight the capability of BIM to fasten and facilitate calculating carbon emissions in different stages of a building lifecycle in early stage of design phase, and help reducing building sector impact on climate change,
2. Provide a reference of carbon emissions and footprint of the most common types of affordable housing adopted in Morocco (full-residential buildings, mixed-use buildings, and parceling),
3. Reveal the top impactful building materials on the environment in terms of EC emissions,
4. Disclose the most contributing components in operational carbon emissions,
5. Access BLCCE of considered affordable housing types based on Life Cycle Assessment (LCA) approach.

The remaining of this paper is structured into 5 sections. The following section lays out a literature review of similar studies, existing BIM-based practices, and BIM added-value related to building carbon emission assessment. Next section describes the adopted research methodology. The 3rd section provides a description of the chosen case study and the reason behind this choice. In the 4th section, this paper outlines the case study results that are discussed in the following section. Finally, the related conclusions and recommendations are stated.

2. Literature Review

Several studies have emphasized BIM potential on validating hypothetic approaches and enhancing the efficiency of designing, assessing and decision making regarding the best solutions for sustainable buildings. For instance, Li et al. (2021) pointed out the capacity of BIM in performing many assessment and simulation works of a facility without having to construct it physically, and showed through a BIM-based approach that prefabrication helps in reducing EC emissions. Wang et al. (2018) used BIM technology to validate that using onsite-recycled materials diminish buildings carbon footprint. Abanda et al. (2017) developed a BIM-based framework that automates integration of the UK new rules of measurement in building design stage. Mousa et al. (2016) used BIM to create an automated tool that enables both assessment of Operational Carbon (OC) and real-time detection of carbon emission problems. Raza et al. (2019) reviewed the BIM benefits exposed in the literature and affirmed that BIM allows achieving energy efficiency and saving operational cost at design stage as it helps in testing the best sustainable solutions such as putting occupancy sensors, adapting the orientation of the building, and using different types of insulation on walls and windows. As shown in Table 1, several scholars used integrated BIM models to evaluate the amount of BLCCE generated by different categories of buildings in construction stage (EC), operational stage (OC) which is assumed to last 50 years, and demolition stage (Demolition Carbon – DO). However, no study has been undertaken in any African country.

Table 25: Literature review of similar studies

Reference	Building type	Building description	Country	Findings
(Lu et al., 2019)	Hospital	4-storey building with reinforced concrete structure and 6367 m^2 as Gross Floor Area (GFA)	China	Reinforced Concrete (RC) and Heating Ventilation and Air Conditioning (HVAC) are top carbon emitter, where RC emits 50% of EC and HVAC emits 54% of OC. Among the BLCCE, EC represents 8% and OC 91%.
(Gardezi et al., 2014)	Residential building	1-storey low-cost building	Malaysia	Brick, steel (all types included), and RC are the top contributors in EC emission, with respectively 37%, 26%, and 22%
		Apartment unit	Korea	More than 82% of the total EC was emitted by steel and concrete, with respectively 424.2 and 584.2 kg-CO_2/m^2 as footprint
(Khan et al., 2019)	Commercial building	4-storey building	Pakistan	Top contributing materials in EC emission are steel, concrete, brick, and aluminum with respectively 34%, 20%, 15%, and 12% of the sum of EC
(Shah et al., 2019)	Educational building	4-storey building with a framed structure and 2362 m^2 as covered area	Pakistan	Brick, steel, and concrete are the most impactful materials in terms of EC emission as they are responsible for 38%, 36%, and 14% respectively
(Peng, 2016)	Office building	15-storey building with a reinforced concrete structure & 16873 m^2 as GFA	China	For the BLCCE, OC, EC, and carbon emitted in demolition stage (DC) represent 85%, 13%, and 2% respectively
		Not specified	USA	OC represents 90% of total BLCCE, and EC represents the remaining 10%
			Japan	The BLCCE is divided into 82% for EC, 14% for OC, and 3-4% for DC
			Australia	OC represents 85% of total BLCCE, and EC represents the remaining 15%

3. Research Methodology

The authors used a case study method to meet the objectives of this study. As shown Fig. 1, the adopted research workflow is based on BIM technology and LCA approach and developed through 6 main steps. (1) After investigating the local context and conducting a literature review, the authors adopted an affordable housing parceling as a case study. (2) Based on Autodesk Revit, they develop BIM models of different buildings composing the parceling, and (3) extract the quantities of the most used materials: reinforced concrete, steel, bricks, glass, mortar, ceramic tiles, wood, and paint. Then, (4) based on LCA approach, they calculate the EC based on the material emission factors issued from ICE (Hammond & Jones, 2011), and the OC based on (FM6PE, 2016). Whereas the DC is assumed to be 10% of EC (Peng, 2016). Next, (5) they present the results from the 3 previous steps, then (6) discuss the findings, and draw conclusions and recommendations.

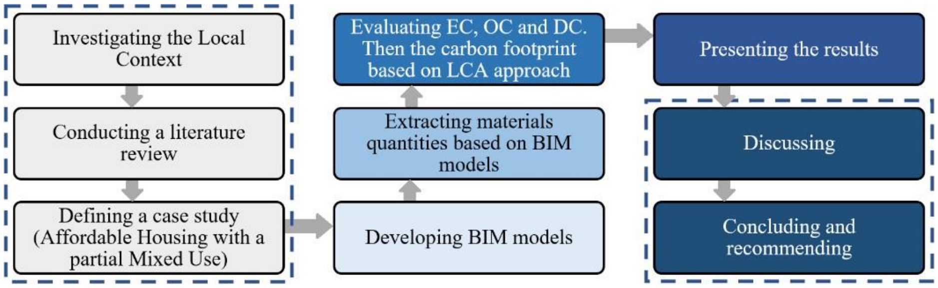

Fig. 13: Research methodology workflow

4. Case Study Outline

According to a thoughtful study conducted by housing ministry, more than 55% of Moroccan housing demand is for social (affordable) housing, called social housing, and 30% of it is concentrated in the region of Grand Casablanca (Bouhmoud, 2018). As a result, the housing ministry set additional incentives and established predefined requirement specifications for social housing development. Therefore, as a case study, the authors considered a parceling of social housing project. This parceling was realized in 5 years on a field of 61300 m² in Casablanca – Morocco with a covered area of 80564 m^2 and was arranged in 65 repetitive 5-storey buildings split into 43 type A-buildings and 22 type B-buildings where both types have concrete structures (see the master plan of the parceling, and BIM models of both buildings type A and B in Fig. 2). Building type A is a full residential building with a covered area of 1232m², whereas building type B is a mixed-use building where the ground floor is designed as a commercial area and upper floors as a residential housing and it has a built covered area of 1254m². The total 65 buildings included 1212 affordable apartments (3 rooms + kitchen + bathroom) and 110 commercial areas.

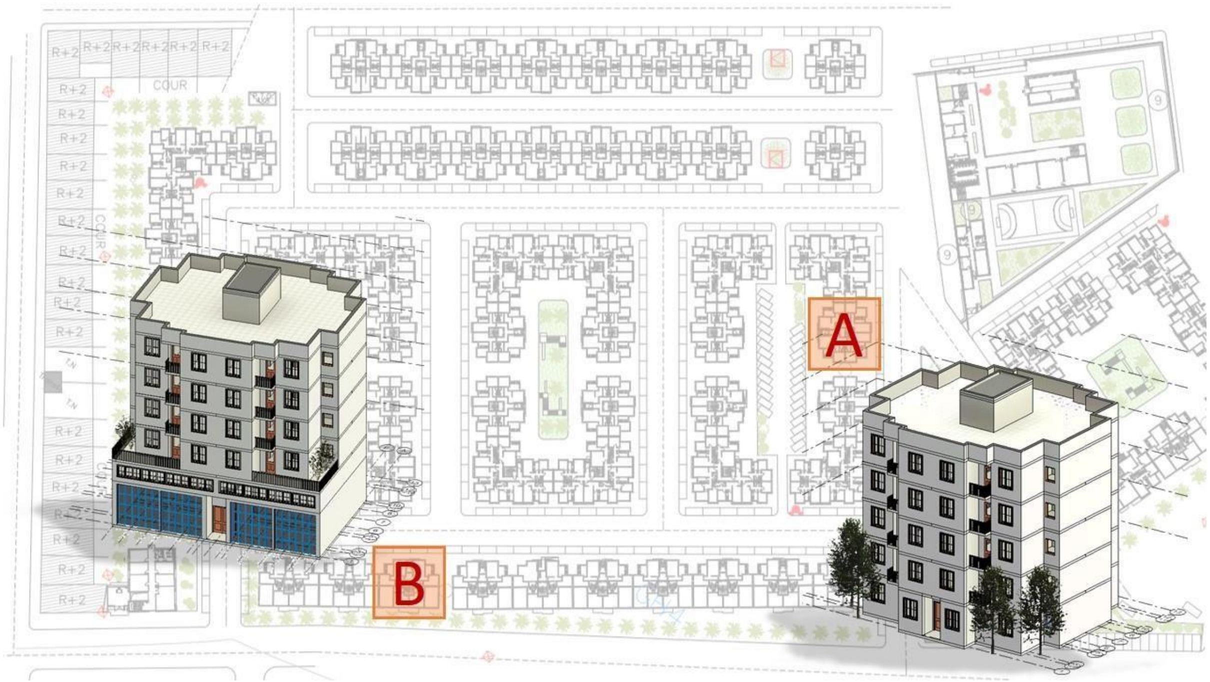

Fig. 14: Master plan of the parceling and BIM models of the repetitive buildings type A and B

5. Results

5.1 EC of Buildings type A and B Due to Used Material

Table 2 reveals the EC generated by materials (EC_m) for both buildings A and B. It illustrates the extracted materials quantities from BIM models, $CO_{2\text{-eq}}$ factors of these materials, their densities, and the resulted amount of $CO_{2\text{-eq}}$ generated by the total quantity of each material. The EC footprint of each type was calculated referring to their built area.

Table 26. EC emission and related carbon footprint of buildings type A and B.

Materials	Density	CO_2 factor ($CO_{2\text{-eq}}$/Kg)	Unit	Building type A			Building type B		
				Quantity	EC emissions	Share	Quantity	EC emissions	Share
Concrete	2.5 T/m^3	0.107	M^3	363	97103	29%	398	106465	29%
Steel	7.8 T/m^3	2.77	Kg	21657	59990	18%	24244	67156	19%
Brick 7+10	0.76 T/m^3	0.24	M^2	1029	41292	21%	984	39486	17%
Brick 7+7				777	19841		568	14504	
Brick 7				806	10291		709	9053	
Aluminum	2.7 T/m^3	9.16	Kg	428	3920	1%	938	8592	2%
Glass	2.5 T/m^3	0.91	M^2	84	11510	3%	207	28216	8%
Mortar	1.1 T/m^3	0.13	M^2	6647	15728	5%	5992	14259	4%
Ceramic tiles	2.0 T/m^3	0.70	M^2	1423	39833	12%	1470	41149	11%

Paint	1.2 T/m^3	0.87	M^2	6647	34695	10%	5992	31276	9%
Wood	0.45 T/m^3	0.55	M^2	203	2507	1%	168	2074	1%

5.2 Operational Carbon of Buildings Type A and B

Table 3 provides the annual operational carbon (OC_{annual}) emissions of both building's types. They were evaluated by summing the produced OC from the monthly average of consumed energy either electrical or fossil (butane), used water, and produced wastes. To evaluate the total OC, the operational stage was assumed to last 50 years as it is mentioned in the literature review.

Table 27. OC emission of buildings type A and B.

	Type	**Average consumption per month**												**Annual Value**	**Emitted OC by building (CO_{2-eq})**	
		01	02	03	04	05	06	07	08	09	10	11	12		Annual	Operational stage
Electrical energy (kwh)	A	2500	2500	2400	2200	2200	2000	1900	1900	2200	2200	2400	2500	26900	17590	879500
	B	2625	2625	2520	2310	2310	2100	1995	1995	2310	2310	2520	2625	28245	18470	923500
Fossil Energy (kg)	A	720	720	720	720	1200	960	960	1200	720	720	720	720	10080	403100	20155000
	B	636	636	636	636	1020	828	828	1020	636	636	636	636	8784	351270	17563500
Water use (m^3)	A	120	120	120	120	140	140	140	160	120	120	120	120	1540	57740	2887000
	B	101	101	101	101	117	117	117	133	101	101	101	101	1292	48440	2422000
Domestic Wastes (kg)	A	3720	3360	3720	3600	4960	4800	4960	5580	3600	3720	3600	3720	49340	71230	3561500
	B	3441	3108	3441	3330	4743	4440	4588	5239	3330	3441	3330	3441	45872	66220	3311000

5.3 BLCCE and Carbon Footprint of Buildings Type A and B:

Table 4 synthesizes the emitted CO_{2-eq} of all stages of each building type. The OC emissions of each where it is equal to the sum of evaluated emitted carbon in the three stages of each building lifecycle as follows:

$$BLCCE = EC + OC + DC \quad with \begin{cases} OC = 50 \times OC_{annual} \\ DC = 10\% \times EC \end{cases} \qquad (1)$$

Table 28. BLCCE and related carbon footprint of buildings type A and B.

Building type / **Stage**	**Building type A**			**Building type B**		
	Total emission (CO_{2-eq})	Share	Carbon footprint (CO_{2-eq}/m^2)	Total emission (CO_{2-eq})	Share	Carbon footprint (CO_{2-eq}/m^2)
Construction stage	337183	1.2%	273.7	362703	1.5%	289.3
Operational stage	27483000	98.7%	22307.6	24220000	98.4%	19314.2
Demolition stage	33718	0.1%	27.4	36270	0.1%	28.9
BLCCE	27853901		22608.7	24618973		19632.4

5.4 BLCCE and Carbon Footprint of the Parceling:

The total amount of emitted carbon by the case study during each stage of its lifecycle is the sum of carbon emitted by all included buildings as shown in equation (2). Hence, the total BLLCE of the parceling is evaluated by summing the emissions of all stages. Table 5 provides the BLCCE and carbon footprint of the parceling as well as its breakdown into the 3 different stages, related shares, and their carbon footprint.

$$C_i = 43 \times C_i(building\ type\ A) + 22 \times C_i(building\ type\ B) \quad with \ \ C_i = EC, OC\ or\ DC \qquad (2)$$

Table 29. BLCCE and related carbon footprint of the project.

Stage	**Total carbon emission** (kilo CO_{2-eq})	**Share**	**Carbon footprint** (CO_{2-eq}/m^2)
Construction stage	22478.3	1.3%	279.0
Operational stage	1714609	98.6%	21282.6
Demolition stage	2247.8	0.1%	27.9

BLCCE	1739335.2	21589.5

6. Discussion

The study showed that for both full-residential affordable housing (type A) and mixed-use affordable housing (type B), concrete, bricks, steel, ceramic tiles, and paint are the most contributing materials in emitted EC with a total proportion of 90% for type A and 85% for type B (Fig 3). However, the commercial units of building type B reduced the impact of brick, mortar, and paint in favor of glass impact. Whereas the EC emissions of the earlier 3 materials counted for 36% and EC emission of the glass counted for 3% for building type A, the 3 materials emitted only 30% of total EC emissions of building type B and the glass was responsible for a portion of 8% (Fig 3).

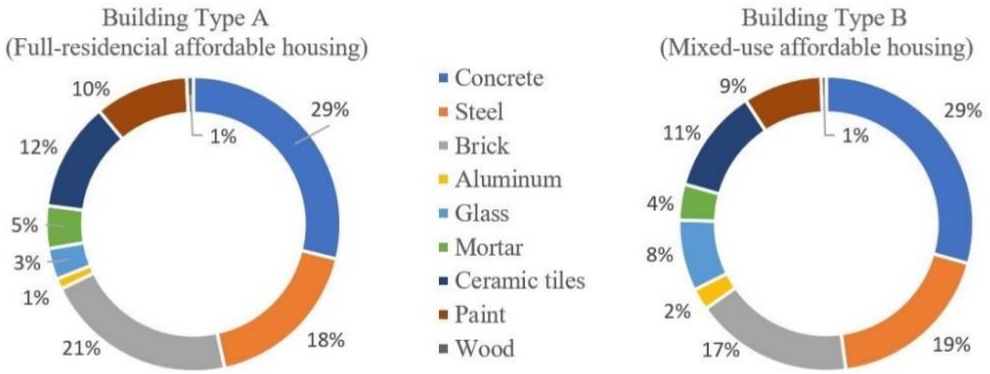

Fig. 15: Contribution of used materials in the total EC emissions and Comparison of their distribution by building type

As shown in Fig.4, fossil energy is the top contributor in terms of OC emissions as it represents 73% for both types of buildings, tailed by domestic generated wastes and consumed water with almost 13.5% and 11% of the total OC respectively. Meantime, energy, all types included, is responsible for 77% of all OC emissions which explains that most of the undertaken actions toward reducing building impacts on the climate change are associated either to reducing energy consumption or replacing it by a renewable one.

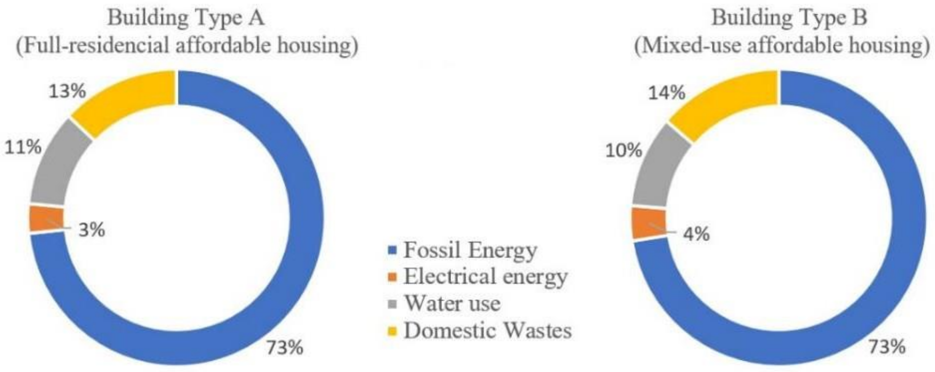

Fig. 16: Contribution of sources of OC in the total OC emissions and Comparison of their distribution by building type

The study discloses that for affordable housing, the carbon footprint of full-residential buildings in either construction or demolition stages is 7.6% less than that of mixed-use buildings (Fig 5.a), contrary to the operational stage where the carbon footprint of full-residential buildings is 11.9% higher than mixed-use buildings (Fig 5.b). Since BLCCE is mostly generated during the operational stage as this stage is responsible for more than 98% of all emitted carbon (Tables 4 and 5), the difference between BLCCE caused by full-residential buildings and these caused by mixed-use buildings has almost the same value with a percentage of 11.6% (Fig 5.c).

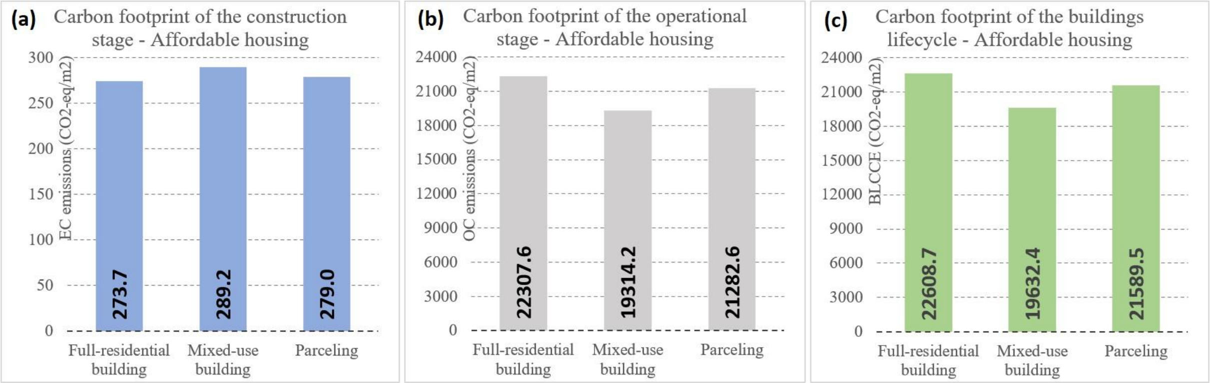

Fig. 17: Carbon footprint of construction stage, operational stage, and building lifecycle of different types of affordable building housing

7. Conclusions and Recommendations

By combining BIM technology and LCA approach, this study provided evidence of the BLCCE evaluation and analysis of affordable housing projects in Morocco based on a case study of a parceling that contains full-residential and mixed-use buildings. As a result, this paper discloses that for affordable housing:

- Concrete, bricks, steel, ceramic tiles, and paint are the most emitting materials of EC by full-residential buildings with a contribution of 90%. Meantime, in addition to these 5 materials, glass is an impactful material for mixed-use buildings where they contribute to 93% of the total associated EC,
- Energy consumption is a top contributor in OC emissions, namely fossil energy that generates 73% of total OC,
- While the carbon footprint of either construction or demolition stages of full-residential buildings is 7.6% less than that of mixed-use buildings, the carbon footprint of the operational stage of full-residential buildings is 11.9% more than that of mixed-use buildings,
- The operational stage is responsible for at least 98% of the total BLCCE.

The study showed that Morocco is more focused on operational stage of BLCCE as the already and ongoing actions toward reducing the climate change impact are more about replacing the current consumed energies by proper energies such as solar one. In the same vein, Morocco provided an open calculator to easily assess the impact of all responsible sources for OC emissions. Hence, the study findings go along with the Moroccan climate change policy. However, adopting BIM as a working practice could significantly help in achieving Morocco's climate goals which could be more achievable if the country adopts an efficient strategy toward a mandatory BIM implementation. In fact, the literature confirmed the large potential of BIM technology to design low-carbon or zero-net buildings and neighborhoods as well as guarantee sustainable management and maintenance of new or existing buildings and facilities.

On the other hand, the absence of a local database of carbon factors of materials and statistics related to construction – demolition wastes and transportation were the top faced challenges for this research. In fact, omitting the EC emitted by transportation, equipment and workforce could be a limitation of this study. As highlighted in the literature review, the choice of materials and equipment could considerably reduce building carbon emissions, hence developing the missing databases and statistics could be the topic of further studies and would enable both designers to select less impactful materials on the environment and contractors to use more eco-friendly construction processes especially in terms of waste management and transportation.

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