



Design and Life Cycle Assessment of Apartment Building Using BIM

¹G Sivani, ²D. Naveen, ³B. Revanth Reddy, ⁴Ch. Deepak, ⁵G. Ajay

^{1,2,3,4,5}Department of Civil Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India

DOI: <https://doi.org/10.55248/gengpi.2023.32397>

ABSTRACT

As construction projects become more and more sophisticated, it becomes increasingly significant for the engineers to consider environmental aspects when selecting building materials. Life Cycle Assessment (LCA) on the other hand, is an appropriate technique for evaluating environmental performance. To achieve a comprehensive perspective of the project, including environmental requirements, LCA and Building Information Modelling should both be included in the decision-making process at an early stage. In the architectural, engineering, and construction (AEC) sector, building information modelling (BIM) is one of the most promising contemporary innovations. A 3D digital interface is progressively replacing the 2D interface used for design communication. Buildings will be virtually constructed before they are physically constructed using the model-based design concept known as REVIT. In this article a BIM model is developed using REVIT and Tekla exported to LCA tool to generate the lifecycle assessment report of an apartment building.

Keywords: building information modelling (BIM), REVIT, LCA, Tekla Structural Designer, AEC

1.INTRODUCTION

1.1 BUILDING INFORMATION MODEL (BIM):

Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility that can be used to create a joint knowledge base for thermal, structural, or cost analysis. BIM is a multi-dimensional tool for life-cycle management., can be classified into 3D BIM – parametric building model, as an upgrade to a 2D CAD plan, 4D addressing time – scheduling and construction stages simulation, 5D cost – planning and estimation, 6D sustainability – thermal analysis and environmental assessment, eventually even automated building certification, and finally 7D as a fully mature, comprehensive model enabling facility management, maintenance and operation [8].

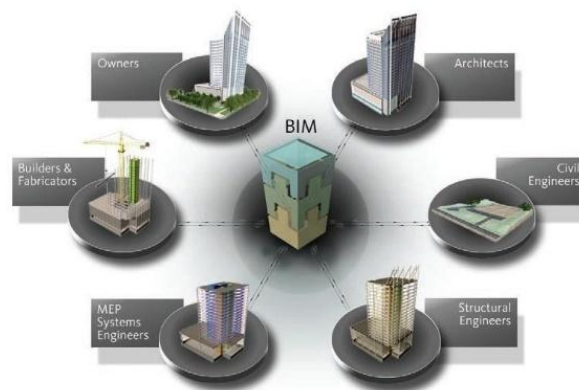


Fig 1: lifecycle of BIM[8]

Building Information modelling (BIM) for instance, is a revolutionary technology that helps engineers design virtual models of a digitally constructed building. This allows owners to visualize the building before it is built. Various design options for sustainability can be studied and tracked in a building information model (Autodesk 2005). Since BIM allows for multi-disciplinary information to be superimposed through one model, it creates an opportunity for sustainability measures to be incorporated throughout the design process (Autodesk 2008) [10]. BIM has been studied for its potential to facilitate the development of green buildings, such as energy performance simulation, lighting analysis, and construction and demolition waste analysis. Different management aspects have been highlighted, such as its economic benefits and organizational challenges. Several BIM applications have been proposed to integrate sustainability analysis into traditional design, construction, and operation processes. [7]

1.2 LIFE CYCLE ASSESSMENT

The construction industry is one of the most environmentally damaging, contributing between 30% and 40% of the total global environmental burden in terms of raw materials, direct and indirect energy consumption, waste, and CO₂ emissions. [4] And also the Natural resources and non-renewable energy sources are both running out around the world due to construction industry. [4] So A suitable metric must be put in place right away at the design stage of a building project to have a positive impact on the environmental outcome. This is necessary to combat climate change from within the construction industry. [2] Thus, the building sector is heading towards sustainability. [12] A tool called life cycle assessment is used to evaluate potential environmental effects and the resources utilized over the course of a product's life. LCA needs information on the materials used in each component of the building in order to calculate its environmental effects. The BIM file can be used to extract the necessary data because it comprises technical building information. Consequently, by combining BIM and LCA models, the environmental effects of the structures may be measured. The technique is useful for comparing various building component and design options from an environmental standpoint. [5] the BIM and the LCA files should be integrated in the design phase of the building because of data availability and for better environmental performance. [12]

In this study we integrated the BIM and LCA to study the environmental impacts created by G+10 apartment building. for calculating the life cycle assessment, we used the tool one click LCA.



2. LITERATURE REVIEW

- **Christiana Panteli et al.** *Building Information Modelling Applications in Smart Buildings: From Design to Commissioning and Beyond A critical review*. In this article Research developments in the realm of building design and optimization, as well as for the environmental assessment of building designs using BIM and LCA technologies, are given throughout the pre-construction phase.[1]
- **Diego Apellániz et al.** *A Holistic and Parametric Approach for Life Cycle Assessment in the Early Design Stages*. This article outlines a strategy for putting life-cycle assessment (LCA) during the initial stages of a building's design a project based on the new Rhino and Grasshopper plugins Introducing One Click LCA, which seeks to aid in the fight against global warming within the construction sector.[2]
- **Dr. V. Ramesh Babu et al.** *Design and Analysis (G+5) of Residential Building*. In this project Robot Structure Analysis Professional, which enables you to evaluate the effects of structural loads and confirm code compliance using cutting-edge BIM tools, may be used to achieve comparable functionality using Robot Structure Analysis.[3]
- **Mohammad K. Najjar et al.** *Life cycle assessment methodology integrated with BIM as a decision-making tool at early-stages of building design*. This work utilises the Autodesk Green Building Studio programme in Autodesk Revit and Open LCA software based on two evaluation methods: IMPACT 2002 and ILCD 2011. It also adheres to the methodological framework of LCA based on ISO 14040 and 14044 criteria within the accessible database.[4]
- **Farzaneh Rezaei et al.** *Integrating building information modeling and life cycle assessment in the early and detailed building design stages*. In this report A useful database was created to prepare the Revit outputs as the proper inputs of the LCA model. It covers all structural components, layers, and potential materials that are often found in Québec residential structures. Data for each material's life cycle inventory (LCI) was sourced from the ecoinventdatabase.[5]
- **R. S. Bute et al.** *design a detail 3d model of a building with comparison of manual and software estimate on autodeskrevit*. This journal examines the effectiveness of BIM for bill of materials calculations and project drawings. In this thesis, project drawings were created using Autodesk Revit Architecture, one of the BIM tools, as well as the more conventional method of AutoCAD.[6]
- **Yujie Lu et al.** *Building Information Modelling (BIM) for green buildings: A critical review and future directions*. this journal reviews the ways in which BIM is used to support green building design, construction, operation, and retrofitting processes; the different ways it is used to support energy, emissions, and ventilation analyses; and the ways in which it is used to support green building assessments (GBA).[7]

- **Heap-Yih Chong et al.** *A Mixed Review of the Adoption of Building Information Modelling (BIM) for Sustainability.* This review explains about the BIM uses into various aspects of refurbishment and demolition have to be streamlined, new BIM tools are needed for assessing sustainability criteria, improved interoperability between BIM software and energy simulation tools is needed, and a creative procurement system is required to incorporate social sustainability into the project.[8]
- **Georgios Gourlis et al.** *Building Information Modelling for analysis of energy efficient industrial buildings – A case study.* Using a case study investigation of two industrial facilities, this paper examines the advantages and disadvantages of modelling, analysing, and optimising energy-efficient industrial buildings utilising the BIM to BEM technique.[9]
- **Ahmad Jrade et al.** *Integrating building information modelling with sustainability to design building projects at the conceptual stage.* By fusing BIM, LCA, and relational databases with a practical model, this study proposes a methodology for simulating the processes of adopting sustainable design for building projects at their conceptual stage.[10]
- **Yi-Feng Chang et al.** *BIM-based Computer-Aided Architectural Design.* This study divides the design process into three stages (LOD100 to LOD300), each of which is linked to a set of design goals and critical elements. Also, an actual design case is conducted. The use of BIM technology enables the achievement of two design goals: (1) the design of a sustainable, green building; and (2) the planning and design of buildings.[11]
- **Laura Alvarez Anton et al.** *Integration of Life Cycle Assessment in a BIM Environment.* This paper aims the integration of BIM and LCA environment to obtain greater performance and to achieve sustainability.[12]

3. METHODOLOGY

3.1 ARCHITECTURAL MODELLING

Using the software programme Autodesk Revit version 2022, we produced an architectural model of an apartment building. The Revit Architecture software will provide a plan view, a 3D model with exceptional elevation, detailing diagrams, and schedules for each structural element, and we may have a realistic view with great efficiency by using V-ray rendering software. When you need it, building information modelling (BIM) provides information on a project's design, including its many viewpoints, scope, numbers, and phases. Every project we completed in Revit will have 2D and 3D section views, elevations with detailing, schedules, and quantities. Revit Architecture gathers data on each structural component's material, realistic visualisation, and design, including thickness, height, and schedule. It also provides data on the cost, family type, number of bricks, number of doors, and number of windows. this project consists of 6 flats in each floor, total of 60 flats for 10 floors.

WALL THICKNESS	0'9"
WALL HEIGHT	10'0"
DOORS	7'x4'
WINDOWS	4'x4'
VENTILATOR	2'x2'
SLAB THICKNESS	0'6"
CHAJJA EXTRUSION	1'0"
STAIRS RISER	0'6"
STAIRS THREAD	0'9"
PLINTH THICKNESS	1'6"
PLINTH AREA	8450 sq.ft



Table 1: architecture details

Fig 3: 3D model of apartment



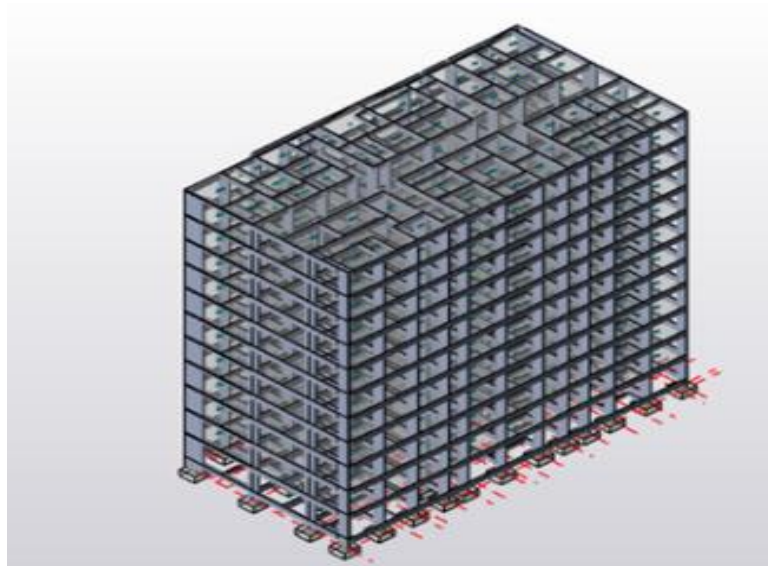
Fig 4: base plan of apartment

3. 2 STRUCTURAL DESIGN AND ANALYSIS

For the design and analysis of the apartment building, we employed the 2022 edition of the tekla structural design software application. Trimble's analysis and design (A&D) software, Tekla Structural Designer, enables designers to choose the most effective structural answer for the problem at hand. The updated version has features that make structural design easier, like automating the amount of reinforcement needed, assigning the loads and incorporating thorough calculations and material take-off into a single model.

Table 2 : Beam Details

Member Reference	Grade	Section Size	Section Geometry	Total Volume
Beam	M35	229x457	Rectangular	137.9
Beam	M35	250x650	Rectangular	7.0
Beam	M35	305x585	Rectangular	377.0
Beam	M35	500x500	Rectangular	64.2
Beam	M35	400x500	Rectangular	20.1
Beam	M35	330x600	Rectangular	70.1
Beam	M35	390x600	Rectangular	94.9
Beam	M35	400x450	Rectangular	53.5
Beam	M35	400x600	Rectangular	151.6

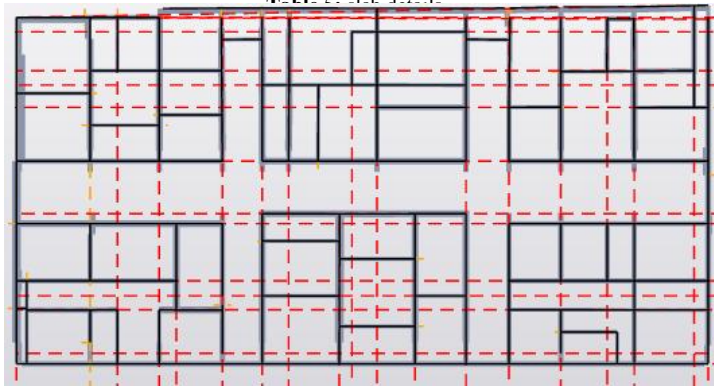
Fig 5: 3D structural model using tekla**Table 3:** Column Details

Member reference	grade	Section size	Section geometry	Total volume
column	M40	229x1067	Rectangular	16.7
column	M40	229x1600	Rectangular	12.5
column	M40	305x1067	Rectangular	11.1

Table4: Foundation Details

column	M40	305x1219	Rectangular	457.8
column	M40	305x1600	Rectangular	33.4
column	M40	305x2134	Rectangular	22.3

Fig 7: base plan of columns and beams



Foundation details	
Grade	M20
Type	Pad based
Size	1800x1800 mm
Depth	750 mm

Slab details	
Thickness	0'6"
Grade	M20
Type	Beam on slab
Volume	1292.8

3.2.1 LOADING & ANALYSIS

The weight of people, furniture, and other items that the floor must bear but are not affixed permanently is known as a live load. Wall / RCC structure finishes like plasters, pop punning, any type of panelling, etc. or floor finishes like floor tiling, terrazzo, IPS, brick lining, etc. The number of such finishes must be considered while designing any individual members of a building.

- Live load intensity is 2 KN/m², and floor load is 1 KN/m².

The software will automatically determine one's own weight. Structures under dead loads experience constant magnitude loads across time. They consist of the structural components' own weight, such as the walls, plaster, ceilings, floors, beams, columns, and roofs.

- Dead load intensity=3.5kN/m
- Design: limit state
- Analysis: 1st order linear

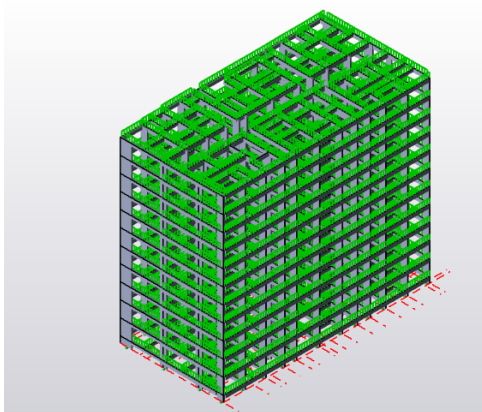


Fig 8: Dead Load

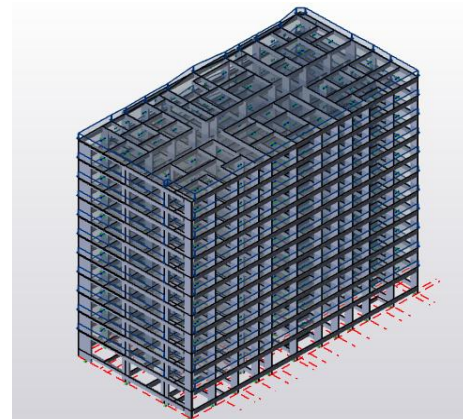


Fig 9: Live Load

#	Design Combination Title	Camber	Class
1	Effective Seismic Weight	<input type="checkbox"/>	Base Shear
2	(Operating) LS ₁ -1.5D	<input type="checkbox"/>	Gravity
3	(Operating) LS ₂ -1.5D+1.5L+1.5Lr	<input type="checkbox"/>	Gravity
4	(Operating) LS ₄₋₁ -1.2D+1.2L+1.2Lr±1.2E		Seismic RSA
5	(Operating) LS ₄₋₂ -1.2D+1.2L+1.2Lr±1.2E		Seismic RSA
6	(Operating) LS ₈₋₁ -1.5D±1.5E		Seismic RSA
7	(Operating) LS ₈₋₂ -1.5D±1.5E		Seismic RSA
8	(Operating) LS ₂₋₁ -0.9D±1.5E		Seismic RSA
9	(Operating) LS ₂₋₂ -0.9D±1.5E		Seismic RSA

Fig 10: load combinations

3.3 LIFE CYCLE ASSESSMENT

One Click LCA is a simple, automated life cycle assessment tool that aids in calculating and minimising the environmental effects of a structure .it can calculate carbon footprint, global warming potential, ozone depletion potential etc.It is compliant with more than 40 Green Building certification programmes, including LEED. Importing the Tekla structure designer and Revit files into one click lca will give you the results.

4. RESULTS AND DISCUSSIONS

4.1 ANALYSIS:

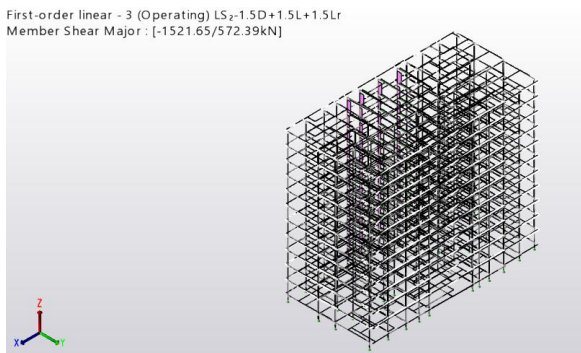


Fig 11: shear force diagram

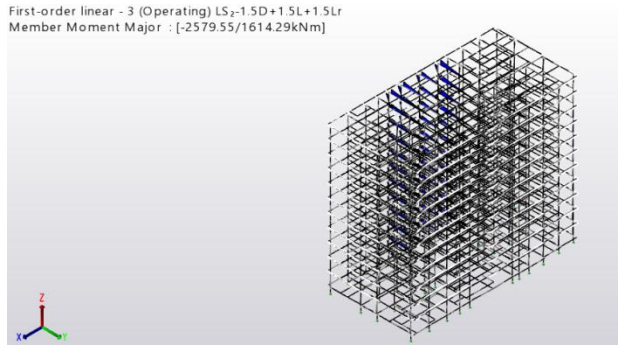


Fig 12: bending moment diagram

4.2 REINFORCEMENT DETAILS:

Beam Loose Bars			
Type	Unit Mass	Total Length	Total Mass
	[kg/m]	[m]	[kg]
T8	0.395	67210.200	26548.03
T8	0.395	1545.600	610.51
Slab Loose Bars			
Type	Unit Mass	Total Length	Total Mass
	[kg/m]	[m]	[kg]
T16	1.580	448.200	708.16
T16	1.580	185596.692	29302.47
T16	1.580	19976.400	31562.71
T20	2.470	32.954	81.52
Total	2.470	8065.300	19940.78
Total + 10.00% slab detailing allowance			49453.076
Total			134521.08

Table 9: reinforcement details of foundation

Table 8 :reinforcement details of slab

4.3 LIFE CYCLE ASSESSMENT:

From the project we conclude that the model is shown from a rendered perspective. The analysis is flawlessly completed, yielding the bending moment diagram, shear force diagram, axial force diagram, and deflection diagram. Tekla and Revit were crucial in providing timely and accurate findings. The

Table 7: reinforcement details of column

Table 6: reinforcement details of beams

Foundation Loose Bars			
Type	Unit Mass	Total Length	Total Mass
	[kg/m]	[m]	[kg]
T20	2.470	115.310	284.82
T25	3.850	5278.195	20321.05
Column Loose Bars			
Type	Unit Mass	Total Length	Total Mass
	[kg/m]	[m]	[kg]
T8	0.395	4505.800	1779.79
T8	0.395	374.000	147.73
T16	1.580	28603.450	45193.45
T16	1.580	636.750	1006.07
T20	2.470	3314.100	8185.83
T20	2.470	771.750	1906.22
T25	3.850	22987.650	88502.45
Total			146721.54

design is flawless, and none of the members are having problems. Sustainable design is impossible if we utilise traditional materials because they have a significant negative influence on the environment. The carbon emissions we obtained from using typical materials were 5324kg/m².

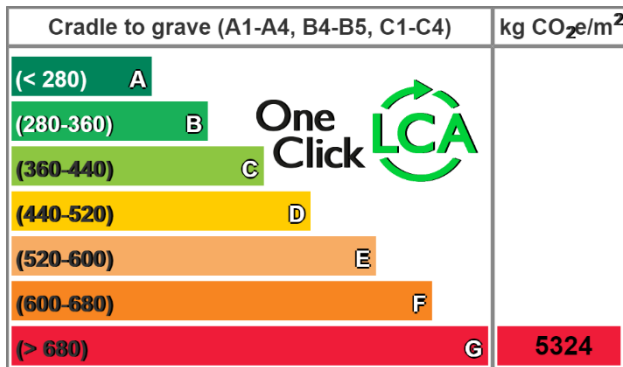


Fig 13: benchmark for LCA

Global warming kg CO₂e - Classifications

- Floor slabs, ceilings, roofing decks, beams and roof - 49.3%
- External walls and facade - 34.9%
- Fuel use - 7.4%
- Electricity use - 7.0%
- Other structures and materials - 1.3%
- Total water consumption - 0.1%
- Internal walls and non-bearing structures - 0.0%

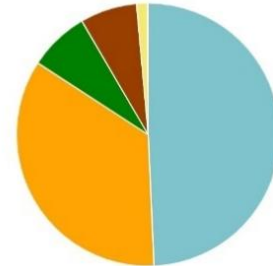


Fig 14: LCA Classifications

Global warming kg CO₂e - Life-cycle stages

- A1-A3 Materials - 57.2%
- A4 Transport - 1.3%
- B1-B5 Maintenance and replacement - 12.3%
- B6 Energy - 14.4%
- B7 Water - 0.1%
- C2 Waste transport - 0.5%
- C3 Waste processing - 14.0%
- C4 Waste disposal - 0.3%

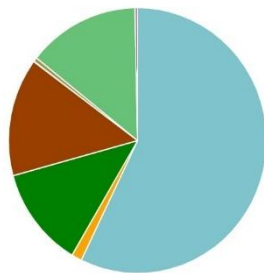


Fig 15: Life Cycle Stages

Global warming kg CO₂e - Resource types

This is a drilldown chart. Click on the chart to view details

- Concrete masonry units (CMU) - 28.2%
- Plain wood/timber (softwood and hardwood) - 15.3%
- Paints, coatings and lacquers - 8.5%
- Oil based fuels - 7.4%
- Electricity - 7.0%
- Ready-mix concrete for external walls and floors - 6.4%
- Suspended ceiling systems - 4.7%
- Specialty gypsum board - 3.9%
- Mortar (masonry/bricklaying) - 3.2%
- Other resource types - 15.4%

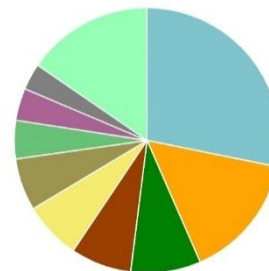


Fig 16: LCA Resource types

Most contributing materials (Global warming)			
No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)
1.	Lightweight precast concrete blocks (CMU), 105.7 units/m ³ , 10.5 m ² /m ³ , 1450 kg/m ³ , 440 x 100 x 215 mm	1,092 tonnes CO ₂ e	43.7 %
2.	Ready-mix concrete, normal strength, generic, C30/37 (4400/5400 PSI) with CEM III/A, 50% GGBS content in cement (300 kg/m ³ , 18.7 lbs/ft ³ total cement)	242 tonnes CO ₂ e	9.7 %
3.	XPS insulation panel with cement mortar and fibre glass mesh facing, L = 0.037 W/mK, R = 2.162 m ² K/W, 80 mm, 600x2600 mm, 5.9 kg/m ²	136 tonnes CO ₂ e	5.5 %
4.	Weber floor smoothing screed, 5-50mm layer thickness, 34 kg/m ²	134 tonnes CO ₂ e	5.4 %
5.	Carbon steel reinforcement bars, 7850 kg/m ³	117 tonnes CO ₂ e	4.7 %
6.	Concrete block, masonry, B40, 200x500x200/250 mm	111 tonnes CO ₂ e	4.5 %
7.	Steel ceiling tile system, 30mm, from 1200 x 300mm to 3000 x 600mm, 6.795kg/m ² , 226.5kg/m ³	101 tonnes CO ₂ e	4.0 %
8.	Plywood, generic, 4-50 mm (0.16-1.97 in), 620 kg/m ³ (38.7 lbs/ft ³)	90 tonnes CO ₂ e	3.6 %

Fig 17: Most Contributing elements to global warming

5. CONCLUSIONS

BIM made the construction process easier with precise outcomes in less time and less costs. It helps to participants in terms of project visualisation. It also provides the option to make changes prior to construction beginning, making the project more accurate and long-lasting. It enhances scheduling and sequence for building phases and reduces risk. Designers, engineers, and building users will be able to make more informed decisions in the future regarding the promotion of sustainable development thanks to the findings from LCA research.

6. REFERENCES

1. *Christiana Panteli et al. Building Information Modelling Applications in Smart Buildings: From Design to Commissioning and Beyond A critical review 2020.*
2. *Diego Apellániz et al. A Holistic and Parametric Approach for Life Cycle Assessment in the Early Design Stages 2021*
3. *Dr. V. Ramesh Babu et al. Design and Analysis (G+5) of Residential Building 2020*
4. *Mohammad K. Najjar et al. Life cycle assessment methodology integrated with BIM as a decision-making tool at early-stages of building design.2019*
5. *Farzaneh Rezaei et al. Integrating building information modeling and life cycle assessment in the early and detailed building design stages 2019*
6. *R. S. Bute et al. design a detail 3d model of a building with comparison of manual and software estimate on autodeskrevit 2018*
7. *Yujie Lu et al. Building Information Modeling (BIM) for green buildings: A critical review and future directions2017*
8. *Heap-Yih Chong et al. A Mixed Review of the Adoption of Building Information Modelling (BIM) for Sustainability 2016*
9. *Georgios Gourlis et al. Building Information Modelling for analysis of energy efficient industrial buildings – A case study 2016*
10. *Ahmad Jade et al. Integrating building information modelling with sustainability to design building projects at the conceptual stage 2013*
11. *Yi-Feng Chang et al. BIM-based Computer-Aided Architectural Design 2013.*
12. *Laura Alvarez Anton et al. Integration of Life Cycle Assessment in a BIM Environment*