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MASONRY CONSTRUCTION AS A SOLUTION FOR HEALTHY AND RESILIENT BUILDINGS: A LIFE CYCLE THINKING BASED EVALUATION

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Abstract: Accomplishing sustainable construction is a challenging task. Building sustainability entails green building design and construction, assessing both environmental factors and financial benefits. Therefore, subsequent buildings expected to be constructed based on local context and purpose. Moreover, factors such as resource scarcity, climate change, and adaptability are changing the construction industry. Therefore, occupant health and resiliency alongside with TBL have been receiving predominant significance in building construction and operation. Alternative wall construction methods will be compared using a sustainability index. The aim of this research is to examine masonry construction as an environmentally sustainable solution for Institutional (ICI) building construction in Canada. Life Cycle Assessment (LCA) assessment was used to compare popular interior wall construction methods, according to ISO 14044. LCA of alternative interior wall construction techniques conducted using SimaPro software. The comparative results show that masonry construction is the greener construction alternative. The study considered cradle to gate and cradle to grave system boundaries for alternative interior wall construction techniques. Results indicated that the wood stud gypsum wall is the greener technique in the cradle to gate system boundary. In the cradle to grave system boundary, the concrete block-masonry wall is the greener construction technique due to the ability to reuse the waste materials. This research informs the construction sector in enhancing the sustainability of ICI buildings construction.

Keywords: Masonry Construction, Life cycle Thinking, Sustainable Construction, Triple Bottom Line Analysis.

1 INTRODUCTION

Buildings are developed to respond to several social needs and to accommodate a variety of functions such as cultural, social, community, and recreational activities. Industrial, commercial, and institutional (ICI) buildings represent a vital component of the socio-economic development of any nation. Despite the numerous benefits to the society, there are dramatic environmental and socio-economic consequences throughout the construction, renovations, and operation of the institutional and public buildings (Kibert 2008). According to the World Business Council for Sustainable Development (WBCSD), buildings account for approximately 40% of the world's energy use resulting in carbon emissions substantially more than the transportation sector. However, it is also true that since buildings have a relatively long lifespan, the building sector offers the largest low-cost potential for climate change mitigation, by using proven and innovative energy-efficient technologies (UNEP SBCI and Sustainable Buildings & Climate Initiative 2009). In recent years, numerous attempts have been made to enhance the sustainability performance of new building construction, which is a cornerstone for reducing global energy-related carbon footprint, stabilizing GHG emissions, and achieving low carbon society.

Sustainability is a predominant concept in the modern era, which affects and is affected by construction activities (Jones, Shan, and Goodrum 2010; Sev 2009; Spence and Mulligan 1995). According to the Brundtland Report, sustainable development is defined as meeting the needs of today without compromising the needs of future generations (World Commission on Environment and Development 1987). Sustainable development constitutes achieving the balance among TBL of sustainability (i.e., Environment, social, and economic factors) (United Nations 2005). Life cycle thinking allows improvements across the life cycle of construction and related activities (i.e., from raw material extraction and conversion; to manufacture and distribution; through use, re-use, and recycling; to ultimate disposal), while addressing TBL issues (USEPA 2014). Improving buildings' sustainability can lead to significant environmental and economic benefits such as reductions of life cycle cost, energy consumption, and CO_2 emission (Li and Colombier, 2009). Wu et al., (2011) further state that significant reductions can be achieved during the building operations phase (Wu et al., 2011; Airaksinen & Matilainen, 2011).

Sustainability of industrial, commercial, and institutional (ICI) buildings has become a significant challenge for policymakers and planners as a result of several environmental impacts associated by institutional and public activities in the academic, operational, and facilities management arenas, in the form of energy, water, and material consumption as well as waste and emission generation (Alshuwaikhat and Abubakar 2008; Koester, Eflin, and Vann 2006). These impacts could be substantially mitigated by an effective choice of technical and organizational measures. Accordingly, a number of ICI buildings around the world have initiated new research projects focusing on control of water, energy, and air emissions and waste disposal to meet the challenge of sustainability. However, sustainability issues are becoming more complex, multidimensional and interconnected (Lourdel and Gondran 2005). Therefore, there is a need for a systematic and integrated sustainability approach to enhance the overall sustainability of ICI buildings. Out of the multiple systems (i.e., floor, roof, interior and exterior walls, and electro-mechanical systems) within a building, wall systems account for the greatest quantity(Cuéllar-Franca and Azapagic 2012; Dzikuć 2014). Consequently, wall systems have a significant impact on the environment. Even though literature has focused on strategies for enhancing the sustainability performance of exterior walls, interior walls have been overlooked.

This research aims to integrate life cycle sustainability into interior wall material selection. The environmental performance of alternative interior wall construction methods was compared using life cycle thinking. The main objectives of this study were realized through the following sub-objectives.

- Identify popular interior wall construction techniques through literature and expert consultation.
- Conduct life cycle assessment for identified wall construction techniques in accordance with ISO 14044.
- Compare the life cycle environmental performance of interior wall construction techniques using the BEEs method.

2 LIFE CYCLE ASSESSMENT (LCA)

Evaluation of the life cycle is a significant manner to assess the environmental impact on the construction industry(Singh et al. 2011). LCA is an efficient tool to analyze all aspects of the life cycle from raw materials acquisition to recycle and finally dispose of into the environment's performance(Ciambrone 1997). LCA methodology is for quantification, analyzation, and comparison of producing, and it helps evaluate the environmental impacts of products, processes, and systems (Tukker 2000). During the last few decades, LCA has become one of the most commonly applied instruments to evaluate the environmental performance of products and processes. LCA follows the product from the processing of raw materials to the manufacturing, distribution, use, reuse, maintenance, recycling stages, and then to final disposal, including all transportation involved (Lindfors 1995). As per ISO 14040, LCA encompasses four stages, namely, goal and scope definition, life cycle inventory, life cycle impact assessment, and life cycle interpretation. Quantitative or qualitative information on emissions, material, and energy used in all phases is gathered and processed so that an assessment can be made on various impact categories climate change, resource depletion, human health, and ecological considerations (International Organization for Standardization 2006).

2.1 The international standard for life cycle assessment

The international organization of standardization had introduced ISO 14040: 2006 Environmental management — Life cycle assessment — Principles and framework, and ISO 14044: 2006 Environmental management — Life cycle assessment — to standardize the LCA process (Lee and Inaba 2004). ISO 14040:2006 describes the principles and framework for LCA (i.e., the definition of the goal and scope of the LCA, life cycle inventory analysis, the life cycle impact assessment, the life cycle interpretation). Additionally, it establishes for reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for the use of value choices and optional elements. 14044:2006 specifies requirements and provides guidelines for the key stages of LCA (ISO 14040 2006). ISO 14040 and ISO 14044 has removed prior errors, inconsistencies on LCA, and standardized the LCA procedure with a set of guidelines (Sato 1977). ISO 14044 defines the following system boundaries for LCA, which defines which unit processes are parts of the product system.

2.2 Published literature of life cycle assessment of masonry buildings

Monteiro and Freire (2012) used LCA to examine exterior partitions for an English single-family house. Ortiz et al. (2010) evaluated the life cycle impacts of building materials in three end-of-lifecycle scenarios (i.e., landfilling, incineration, and recycling). Cuéllar-Franca and Azapagic (2012) used LCA to assess the carbon footprint of three standard types of houses in the United Kingdom for a 50 year period. The standard housing types included single-family detached, semi-detached, and terraced which were constructed using bricks and concrete blocks. LCA was conducted using GaBi LCA software, and the CML2001 impact assessment method was used. The outcomes highlighted the benefits of recycling construction waste and the importance of preconstruction decisions on the overall sustainability of a building (Cuéllar-Franca and Azapagic 2012). Table 2 lists previous research on LCA of building materials. The findings reveal that cradle-to-grave is the popular system boundary used in literature, as it provides a realistic assessment of its environmental performance.

Table 1: System boundary consideration in published literature

Literature	LCA Boundary Consideration	
	Cradle-to-Grave	Cradle-to-Gate
(Cuéllar-Franca and Azapagic 2012)	✓	-
(Monteiro and Freire 2012)	✓	-
(Medgar L Marceau et al. 2002)	✓	-
(Pegões 2010)	-	✓
(M. L. Marceau et al. 2012)	✓	-
(Üçer 2012)	✓	-
(Condeixa, Haddad, and Boer 2014)	✓	-
(Carl S. Sterner 2010)	✓	-
(Corporation Forintek Canada 2003)	-	✓
(Silvestre 2010)	✓	-
(Robertson, Lam, and Cole 2012)	-	✓
(Broun and Menzies 2011)	✓	-
(Ferrández-García, Ibáñez-Forés, and Bovea 2016)	✓	-
(Condeixa et al. 2015)	✓	-
(Valencia-Barba and Gómez-Soberón 2019)	-	✓
(Peñaloza, Norén, and Eriksson 2013)	✓	-

3 METHODOLOGY

Concrete block-masonry, steel-stud Gypsum/ fire-rated gypsum, and wood-frame gypsum were used considered as the alternative interior wall construction techniques. ISO 14044 was followed in conducting the LCA of interior wall systems. In this study, the functional unit[1] was used as 40 m^2 area of an interior wall with dimensions, 10m and 4m, respectively. The system boundary of this study is shown in Figure 2. It consists of the inputs and outputs of electricity and material from material extraction, manufacturing, and construction (Cradle to Gate) as well as with the end of the life cycle scenario (Cradle to grave). Wall material inventory presented in Table 3 is collected from standards and specifications published by the National Building Code (NBC) and NCMA (National Concrete Masonry Association). Dimension and layer distribution of the concrete blocks wall was obtained from NCMA, while NBC is used for layer distribution and dimension of wood and steel stud gypsum wall. Based on the standard dimension, manual material estimation was carried out for 0.57 m^3 of the volume of the wall.

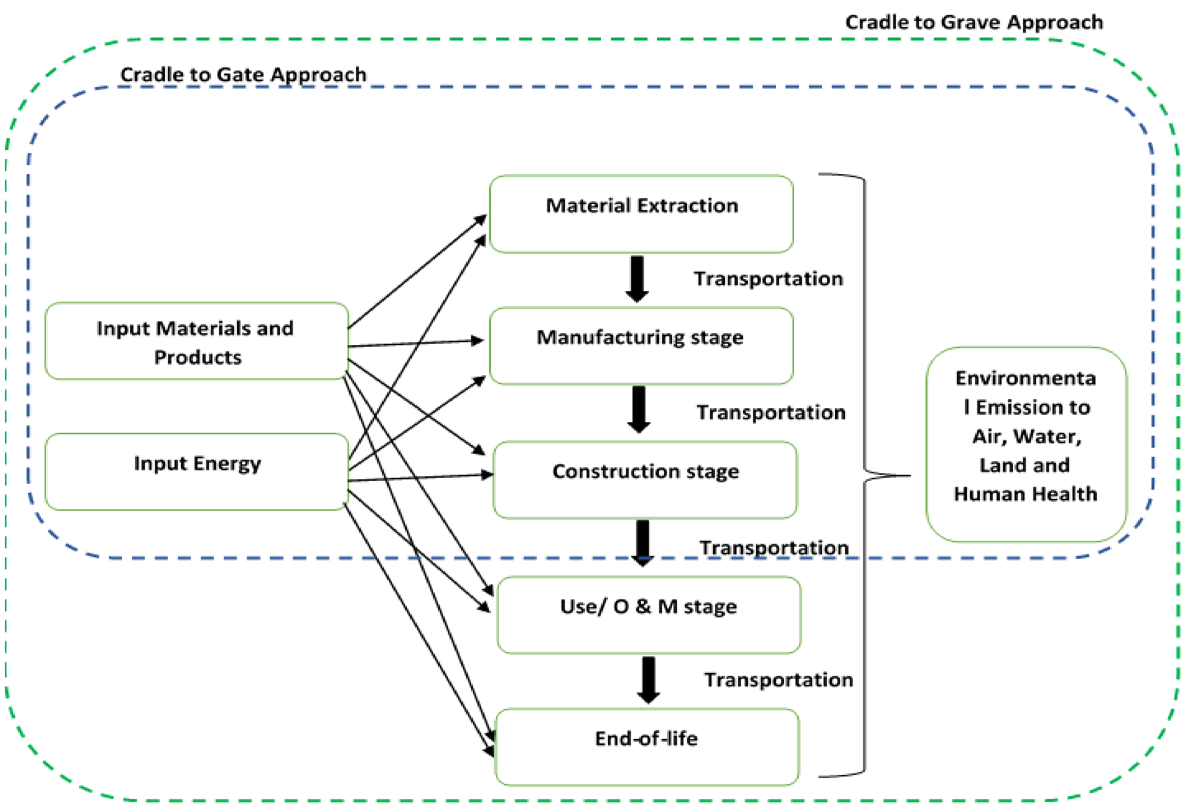

Figure 1: System Boundary

ISO 14044 defined functional unit as the quantified performance of the product system for use as the reference unit (ISO 14040 2006)

Table 2: Wall construction System Data

	Concrete Block	Steel-Stud Gypsum/ Fire Rated Gypsum wall	Wood-stud Gypsum/ Fire Rated Gypsum wall
Layer Distribution	Concrete blocks, gypsum, and paint.	C core gypsum panel, single-layer gypsum panels screw-attached to studs, double layer screw-attached to channel, face layer joints finished and optional veneer plaster.	Wood stud, resilient channel, and gypsum board attached with screws.
Dimension	200mm x 200mm x 400mm (Nominal Size) 190mm x 190mm x 390mm (Actual Size)	Use 3 ½ inch wide and 0.36-inch-thick steel stud. Gypsum board = 15.9 mm both sides, inner field with volcanic stone wool.	Wood Stud every 406 mm (152.4 x 50.8 mm) Gypsum board = 15.9 mm both sides, inner field with volcanic stone wool of 50 mm
Material Used	Concrete Blocks and Cement mortar.	Steel channel section, Gypsum sheets and insulation material sheets.	Wood stud, gypsum sheets and optional material sheets.
Advantages	Accept Reinforcing, improve water and fire resistance, Durable, Economical, Improve thermal performance	Economical, Fire resistance, weather protection and little or no swing.	Economical, Fire resistance, weather protection and little or no swing.

*Quantities given in Table 2 were modeled using SimaPro 7.1. LCA software

3.1 SimaPro LCA Software

The Life Cycle Assessment can be significantly simplified with the use of devoted computer software, such as SimaPro, designed by using PRe Consultants (Zarębska J. 2013). SimaPro is one of the most sophisticated LCA software available in the market. SimaPro is equipped with the Ecoinvent database which is the most up-to-date database available in the industry. BEES environmental impact assessment was used for comparison of three interior wall construction techniques.

3.2 Building for Economic and Environmental Sustainability (BEES) rating system

Being developed by the National Institute of Standards and Technology (NIST), The Building for Economic and Environmental Sustainability (BEES) is a life cycle thinking based evaluation method developed for construction products (BEES n.d.). BEES contain economic and environmental evaluation criteria that have been developed using guidelines published by ISO (Barbara C. Lippiatt 2007). This study considered only environmental assessment of the interior wall construction techniques: global warming, acidification, human health (HH) cancer, HH noncancer, HH criteria air pollutants, eutrophication, ecotoxicity, smog, natural resource depletion, indoor air quality, habitat alteration, water intake, and ozone depletion. BEES provide normalization and a weighting score in eco indicator points. An eco point (Pt) expresses a value representing one-thousandth of a yearly environmental impact of one inhabitant (Dzikuć 2014). The following assumptions were considered in conducting this study.

- The volume of the wall is 0.57 m^3 for all types of walls.
- Gypsum board and stone wool totally considered as waste material and use as sanitary landfill at the end-of-life scenario(Jeffrey 2011).

- 95% Waste generated from concrete blocks wall reuse in other concrete construction work and road sub-grade.
- The use, operation, and maintenance stages are ignored.

4 RESULTS AND DISCUSSION

The result of this study illustrates the comparative LCA results of three interior wall construction techniques (i.e., concrete blocks-masonry wall, steel stud gypsum wall, and wood stud gypsum wall). BEES Standard was considered for the analysis of the inventory data for normalization and weighting of the characterized value. A single score method is adopted for a clear understanding of the results. As per BEES standard, smaller point value indicates the minimum environmental impacts, and larger point value indicates a higher environmental impact. The use, operation, and maintenance phases will be covered in the future work of this project. Results of the LCA study for “cradle to gate” and “cradle to grave” system boundaries are as follows. Results have been presented under cradle to cradle and cradle to grave systems boundaries.

4.1 Cradle to Gate scenario

Cradle to gate LCA result is shown in Table 3. A single score graph (Figure 2) is used for a direct comparison of all types. The results indicate that the concrete block-masonry wall creates around 11% and 63% more environmental impacts than steel stud gypsum wall and wood stud gypsum wall, respectively. Hence, for a cradle to gate system boundary, wood stud gypsum wall has proven greener wall construction techniques than concrete blocks and steel stud gypsum walls.

Table 3: Characterization results (Cradle to Gate)

Impact category	Unit	Concrete Block-Masonry Walls	Steel Stud Gypsum Wall	Wood Stud Gypsum Wall
Global warming	g CO2 eq	1.05E+05	6.97E+04	5.84E+04
Acidification	H+ mmole eq	1.84E+04	1.99E+04	1.96E+04
HH cancer	g C6H6 eq	5.47E+02	9.54E+02	2.99E+02
HH noncancer	g C7H7 eq	8.81E+05	1.45E+06	5.04E+05
HH criteria air pollutants	microDALYs	1.20E+01	2.40E+01	2.00E+01
Eutrophication	g N eq	2.45E+02	3.14E+02	1.72E+02
Ecotoxicity	g 2,4-D eq	7.93E+02	2.33E+03	2.68E+02
Smog	g NOx eq	3.20E+02	2.29E+02	1.98E+02
Natural resource depletion	MJ surplus	6.20E+01	6.40E+01	6.00E+01
Indoor air quality	g TVOC eq	0.00E+00	0.00E+00	0.00E+00
Habitat alteration	T&E count	0.00E+00	0.00E+00	0.00E+00
Water intake	liters	2.17E+03	5.68E+02	3.56E+02
Ozone depletion	g CFC-11 eq	0.00E+00	0.00E+00	0.00E+00

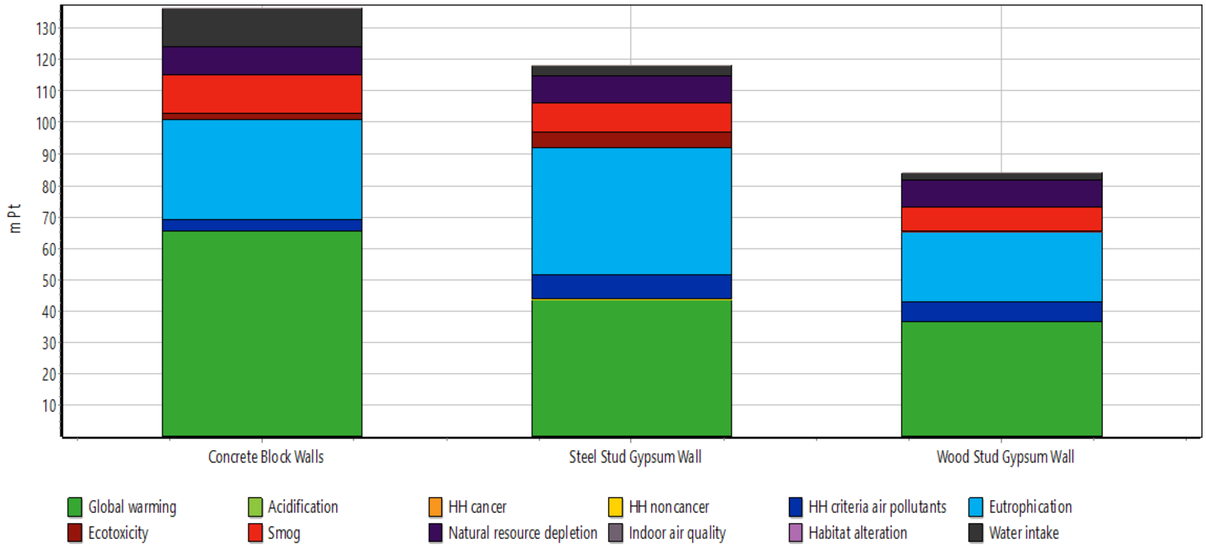

Figure 2: Single score (Cradle to Gate)

4.2 Cradle to Grave Scenario

LCA results of different wall construction techniques for the cradle to grave system boundary is shown in Table 4. A single score graph (Figure 3) is used for a direct comparison of all types. The results indicate that the steel stud gypsum wall creates around 83% and 11% more environmental impacts than concrete block-masonry wall and wood stud gypsum wall, respectively. So that in the cradle to grave scenario concrete blocks-masonry wall is proven to be greener wall construction techniques than wood stud gypsum wall and steel stud gypsum wall.

Table 4: Characterization results (Cradle to Grave)

Impact category	Unit	Concrete blocks – masonry wall	Steel stud gypsum wall	Wood stud gypsum wall
Global warming	g CO2 eq	4.49E+09	2.72E+10	2.43E+10
Acidification	H+ mmole eq	1.81E+09	1.12E+10	9.96E+09
HH cancer	g C6H6 eq	20417574	1.13E+08	1.01E+08
HH noncancer	g C7H7 eq	2.52E+10	1.35E+11	1.21E+11
HH criteria air pollutants	microDAL Ys	8.00E+05	4.65E+06	4.15E+06
Eutrophication	g N eq	1.04E+07	6.12E+07	5.46E+07
Ecotoxicity	g 2,4-D eq	2.40E+07	1.34E+08	1.20E+08
Smog	g NOx eq	3.02E+07	1.86E+08	1.66E+08
Natural resource depletion	MJ surplus	2.59E+07	1.62E+08	1.45E+08

Indoor air quality	g TVOC eq	0.00E+00	0.00E+00	0.00E+00
Habitat alteration	T&E count	0.00E+00	0.00E+00	0.00E+00
Water intake	liters	2.61E+08	1.63E+09	1.46E+09
Ozone depletion	g CFC-11 eq	1.70E+03	1.06E+04	9.45E+03

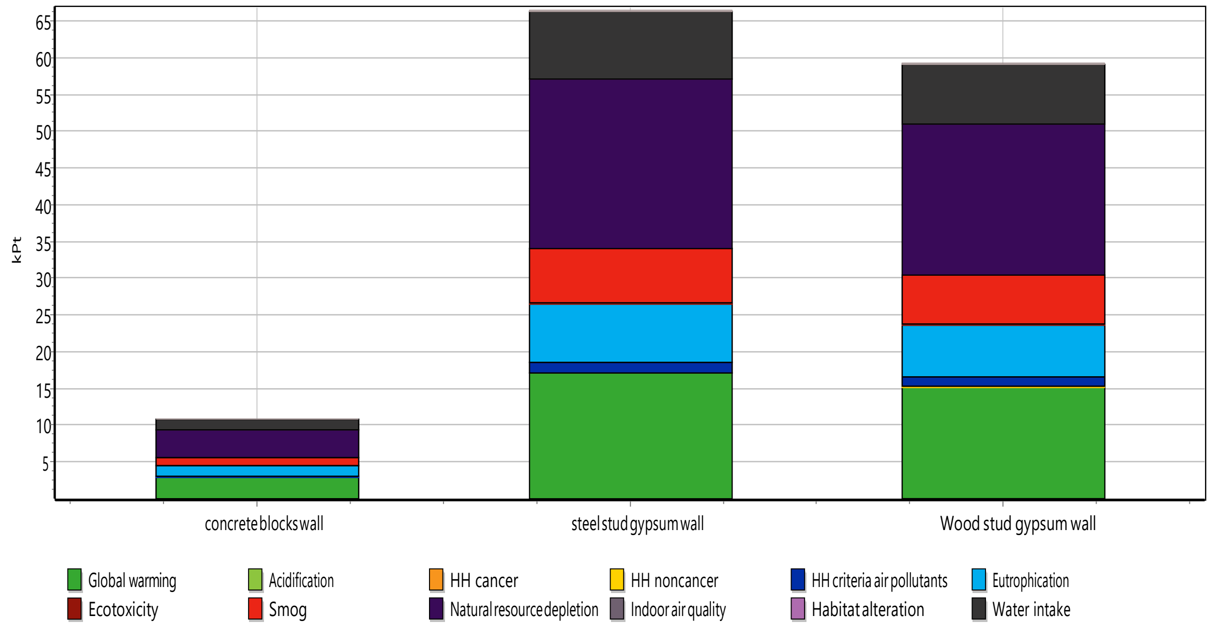

Figure 3: Single score (Cradle to Grave)

5 CONCLUSION

Based on the results of both system boundaries, it is concluded that the environmental performance of the concrete block-masonry wall is superior in the “cradle to grave” system boundary, which represents reality. Here, the concrete block-masonry wall performed 89% better than the steel stud gypsum wall, which was the second-best. Also, the environmental performance of the wood stud gypsum wall is superior until the construction phase (i.e., “cradle to gate” system boundary). This technique creates more impacts on global warming potential, eutrophication, smog, natural resource depletion, and water intake. Steel stud gypsum wall creates adverse impacts on human health air pollution, eutrophication, and natural resource depletion in the cradle to gate system boundary and the cradle to grave system boundary. It performs poorly on global warming potential, eutrophication, smog, natural resource depletion, and water intake. Therefore, cradle to gate thinking has been creating significant environmental impacts over the past. Therefore, the construction sector should consider cradle to grave system boundaries in decision making.

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