Carbon Reduction during Building Construction Projects – Trend Mapping from Construction Journals

Suhaib Arogundade, s.arogundade4475@student.leedsbeckett.ac.uk, esarogundade@gmail.com
Accelerating Innovation in Construction Lab, School of the Built Environment, Engineering and Computing, Leeds Beckett University, United Kingdom

Mohammed Dulaimi, m.dulaimi@leedsbeckett.ac.uk
Accelerating Innovation in Construction Lab, School of the Built Environment, Engineering and Computing, Leeds Beckett University, United Kingdom

Saheed Ajayi, s.ajayi@leedsbeckett.ac.uk
Construction Informatics and Digital Enterprise Research Group, School of the Built Environment, Engineering and Computing, Leeds Beckett University, United Kingdom

Abstract
In recent times, there has been an increasing attention on embodied carbon reduction of building construction projects. However, most of this attention have been concentrated on carbon emission related to materials used for building construction while construction activity related carbon emission seems to have been largely ignored. Hence, this paper examines this claim by analysing literatures in construction management journals published between year 2000 and 2021. The authors performed the analysis by examining the annual publication of research related to carbon reduction during the construction phase of building projects, geographical spread and/or institution of authors who have contributed to these studies, and key research themes covered. The systemic review of literature conducted shows that there seems to be very little research published relating to carbon reduction during building construction projects. Also, the findings suggest that carbon reduction during building construction project related research have only just been in mainstream publication in the last five years with this research largely domiciled in China, US, Australia, and Hong Kong. Furthermore, it was discovered that most of the existing research related to the focus of this paper was done in the context of life cycle analysis or assessment. Research gaps were highlighted, and future research path is proposed. It is likely that the findings of this study may arouse researchers with interest in construction carbon reduction and industry stakeholders alike.

Keywords
Carbon Reduction, Construction Carbon, Construction Journals, Building Construction Projects

1 Introduction

Embodied carbon reduction in building construction projects has been of increasing concern lately amongst researchers and practitioners. This is logical since Huang *et al.* (2018) noted that in 2009 alone, embodied carbon emission from the construction industry contributes about 23% of the world's total carbon emission. Also, embodied carbon emission has been predicted to continuously grow as the world adds more floor area and it is suggested that by 2050, half of the entire carbon

footprint of new construction will be embodied carbon (UN Environment and International Energy Agency 2017). Hence, this desire to minimise embodied carbon can be attributed to the drive by relevant stakeholders in decarbonising the construction sector (Arogundade 2021) while pushing towards the actualisation of net zero carbon buildings by 2050 as advanced by the World Green Building Council (World GBC 2016).

However, this push in reducing embodied carbon seems to have been lopsided as most of this attention have been concentrated on carbon emission related to materials used in building construction while construction activity related carbon emission appears to have been largely ignored. This is probably due to the fact that material selection is done during the design stage of a building construction project thereby favouring the selection of a low-carbon material which is believed to assist in minimising embodied carbon emission. Another factor includes the perception that construction materials has the highest embodied carbon emission when the life cycle assessment of a building is put into consideration (Resch *et al.* 2020 and UKGBC 2015) and the notion that construction stage carbon emission is very low (Kong *et al.* 2020). Victoria and Perera (2018) however noted that while the quantities of material and their related embodied carbon data forms the foundational basis of conducting embodied carbon assessment, other factors such as the assumption of the individual carrying out the assessment; scope of analysis; data sources; system boundary; and the estimation method used - affects the embodied carbon measurement. Therefore, the believe that construction related carbon emission is quite low is debatable.

For instance, in the study conducted by Hong *et al.* (2015), the authors extended the system boundary of the embodied carbon calculation during the construction phase of a building project in China to include emission from human activities involved in the building construction and found out that an additional 385 tCO2e was emitted during the building construction. This human related emission would not have been captured if the authors did not extend the boundary of their embodied carbon measurement.

Based on this backdrop, it is apparent that some gap still exists in the research domain related to the actual contribution of carbon emission associated with construction activities during building construction projects as well as in understanding efforts in reducing same. Consequently, this study seeks to plug this knowledge gap by answering these three research questions:

a) What has been the annual publication of studies related to carbon reduction during the construction phase of building projects in the last two decades (2000 – 2021)?

b) What is the geographical spread and/or institution of authors who have contributed to studies related to carbon reduction during the construction phase of building projects within this period?

c) What key themes or areas of research have been covered or is emerging?

To tackle the research questions, the authors analysed literatures in construction management journals and conference proceedings published between year 2000 and 2021 (as of 8 March 2021) by using a systemic analysis approach. This method was adopted based on its wide usage by researchers when conducting research of this nature especially in gaining an understanding of development in a particular subject domain (Darko and Chan 2016). It is therefore hoped that the findings of this study will further contribute to the body of knowledge in the area of construction carbon emission and its reduction while equally arousing researchers with interest in construction carbon reduction and industry stakeholders alike.

2 Embodied Carbon Emissions during a Building Construction Project

Embodied carbon emissions during a building construction project are emissions associated with the construction, renovation/refurbishment and eventual end of life stage of the building (Huang *et al.* 2018). These emissions have been succinctly categorised by adopting the European standard EN 15978 building lifecycle stages assessment framework as shown in Figure 2.1.

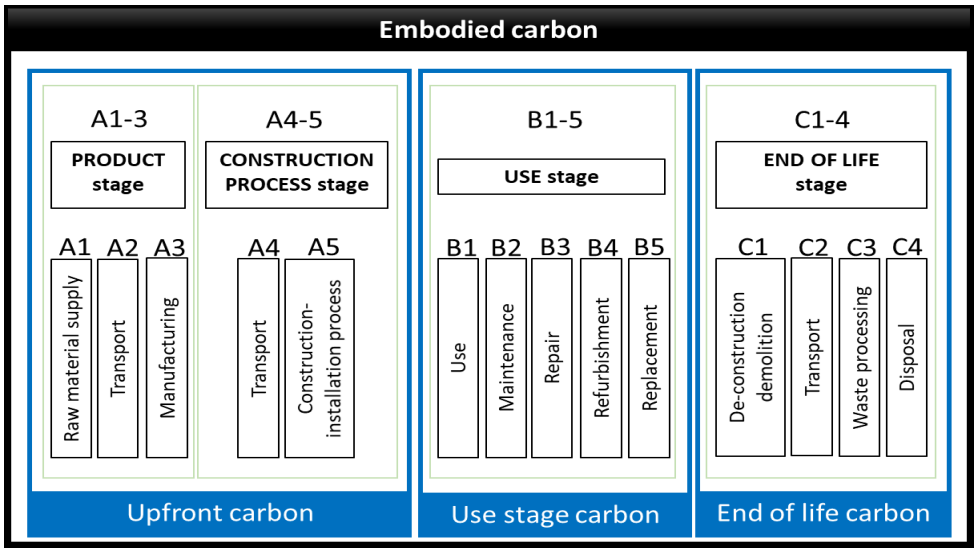

Figure 2.1: Building Lifecycle Stage Embodied Carbon Emission
(Source: Adapted from European Committee for Standardization 2011)

One of the major challenges posed by embodied carbon is that most of it is released early and locked in throughout the lifecycle of a building (Architecture2030 2018; Hillsdon 2019) with its impact hidden from view (Hammond and Jones 2010). This challenge is believed to become exacerbated as the world adds about 230 billion m^2 of floor area to its current floor area between 2017 and 2060 resulting in almost half of the entire carbon emission from new building construction being embodied carbon (UN Environment and International Energy Agency 2017). If this happens, there is a risk for countries to miss their greenhouse gas (GHG) reduction targets in achieving a 1.5^{o}C world as espoused in the different nationally determined contributions put forward by various governments around the world. For instance, in the UK, the government plans to reduce its GHG emissions economy-wide by at least 68% by 2030 compared to 1990 levels (UK Government 2020) and embodied carbon emission from building construction forms part of this economy-wide GHG emissions especially since the construction sector alone contributes around 7% to the total UK economy and represents 10% of the total carbon footprint of the country (National Federation of Builders Major Contractors Group 2019).

The realisation of the impending danger which the increase in embodied carbon during construction could cause have made researchers and relevant stakeholders to focus attention on tackling same (Wong *et al.* 2014). However, as stated in section 1, most of this attention is on the product stage (Figure 2.1) carbon emission as it is believed that this emission has the greatest impact when it comes to embodied carbon from building construction projects while the construction process stage is being ignored. This is evident given the numerous emission reduction tools that have been created in the last couple of years to simulate embodied carbon of buildings as it relates to various building elements specification to identify which construction material gives the lowest embodied carbon emission (Pomponi *et al.* 2020). But as highlighted by Victoria and Perera (2018) and operationalised by the work of Hong *et al.* (2015), it is clear that some factors like system boundary,

data source, methodology, etcetera adopted by these embodied carbon measurement tools can affect their output. Also, some of the tools reviewed in the study by Pomponi *et al.* (2020) supports this claim and the output of some of the tools equally shows the absence of embodied carbon emission related to the construction process stage. Perhaps, this might not be surprising since the architecture of some of the tools does not have data input source for the construction process stage related activities possibly due to the lack of data from site activities such as equipment and plant use and their corresponding carbon emission data (Construction Manager 2021).

With this in mind, it is imperative to establish the presence or lack of it of not only the volume of research related to carbon reduction during construction projects but also to establish the key themes that have been covered or emerging in this area of research. This will ensure that relevant stakeholders' get a glimpse of the likely cause of this 'lop-sidedness' in the embodied carbon research and equally bring to fore possible research path that can be towed in covering this gap in knowledge.

3 Research Methodology

In providing response to the research question posed in Section 1, a systemic review of literature method was adopted since researchers have highlighted its dependability in reducing bias while generating a robust response to a dedicated research question (Mallett *et al.* 2012).

The first task in this study is to select appropriate construction journals that have published carbon reduction research during building construction projects between 2000 – 2021. In doing this, Scopus database was selected due to the fact that the database has enormous archive of engineering, management, business, psychology and construction research publications (Darko and Chan, 2016) and equally owing to its high level of reliability when compared to other databases like Google Scholar and Web of Science (Charef *et al.* 2018). Once Scopus was chosen, keyword search was performed in a bid to identify relevant journals and papers related to the focus of this study as done by other researchers (Deng and Smyth 2013). The keywords selection was a bit challenging. However, an assumption was made on the keywords since as stated by Darko and Chan (2016), one single study cannot in itself address all the likely complexities accompanying research keywords in exploring the subject matter of carbon reduction during building construction projects. Therefore, the two strings of keywords used for this study are as follows:

i) Carbon reduction, carbon emission reduction, greenhouse gas emission
ii) building construction phase or stage

After deciding on the keywords, the journals and papers search was conducted on the 8th of March 2021. The search returned 59 papers from 42 journals and 14 conference proceedings. These journals and conference proceedings included those related to construction and otherwise. Hence, having discovered the limited number of papers available in this research area, it was decided to broaden the scope of the study from just looking at journals alone to then include conference proceedings closely related to the focus of this research. Once this was decided and subject area not related to construction like physics, chemical engineering, medicine, and agriculture were excluded and restricting the search to papers written in English, Scopus returned 46 papers. The final search query used therefore is (TITLE-ABS-KEY(*"carbon reduction"* OR *"carbon emission reduction"* OR *"greenhouse gas emission"*) AND TITLE-ABS-KEY (*"building construction" phase* OR *stage*)) AND PUBYEAR> *1999* AND (EXCLUDE (DOCTYPE, *"ch"*)) AN D (EXCLUDE (SUBJAREA, *"PHYS"*) OR EXCLUDE (SUBJAREA, *"CENG"*) OR EXCLUDE (S UBJAREA, *"COMP"*) OR EXCLUDE (SUBJAREA, *"MEDI"*) OR EXCLUDE (SUBJAREA, *"AGR*

I") OR EXCLUDE (SUBJAREA, *"ARTS"*) OR EXCLUDE (SUBJAREA, *"BIOC"*)) AND (EXCLU DE (LANGUAGE, *"Czech"*))AND (EXCLUDE (SRCTYPE, *"k"*)OR EXCLUDE (SRCTYPE, *"b"*)).

The 46 papers were then scrutinised to ensure they contain only construction related journals and conference proceedings. Upon doing this, 3 papers were removed. Thereafter, they were then checked for duplicate. 1 paper was removed after completing this process. The abstract of the remaining 42 papers was then reviewed to ensure they are relevant to the topic of this present study. On completion, 30 papers from 19 journals and conference proceedings were then selected for further analysis (Table 3.1).

Table 3.1: Journals and Conference Proceedings Including Number of Papers Selected for the Study

Selected Journals and Conference Proceedings	No. of Relevant Papers for the Study
Building and Environment	4
Journal of Cleaner Production	4
Sustainable Cities and Society	3
IOP Conference Series: Earth and Environmental Science	2
Journal of Management in Engineering	2
Sustainability (Switzerland)	2
Journal of Infrastructure Systems	1
Automation in Construction	1
Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress	1
Energy and Buildings	1
Journal of Environmental Management	1
Malaysian Construction Research Journal	1
Construction Research Congress 2005: Broadening Perspectives - Proceedings of the Congress	1
Procedia Engineering	1
Construction Management and Economics	1
Association of Researchers in Construction Management, ARCOM 2012 - Proceedings of the 28th Annual Conference	1
Applied Energy	1
Environmental Engineering and Management Journal	1
International Journal of Life Cycle Assessment	1
Total	**30**

The details of the papers selected for this study were extracted from Scopus to Microsoft Excel for analysis and to answer this study research questions. Also, VOSviewer software was utilised specifically to determine the geographical spread of authors and understand research trend related to carbon reduction during building construction projects. Furthermore, the order of specificity score matrix (Table 3.2) developed by Darko and Chan (2016) upon utilising the widely adopted formula proposed by Howard *et al.* (1987) was used in assessing the contributions of each author relative to their institutions/universities or country. This will equally assist in ranking countries contribution to this important research topic while shedding light on where research in the area of carbon reduction during building construction projects have been largely domiciled.

Table 3.2: Order of Specificity Score Matrix for Papers with Multiple Authors

Number of Authors	Order of Specificity of Authors				
	1	2	3	4	5
1	1				
2	0.6	0.4			
3	0.47	0.32	0.21		
4	0.42	0.28	0.18	0.12	
5	0.38	0.26	0.17	0.11	0.08

4 Findings and Discussion

The aim of this study is to provide insights on the research trend related to carbon reduction during building construction projects in construction journals and conference proceedings through the review of selected papers over the last two decades. The results will be presented in terms of yearly publication trend, geographical spread of authors, and areas of research covered thus far. While interpreting this study results and when drawing conclusions, this should be done bearing in mind the research approach adopted in this study and discussed in the methodology section.

4.1 Annual Publication of Studies

The annual studies related to carbon reduction during building construction projects published within year 2000 and 2021 is as shown in Figure 4.1.

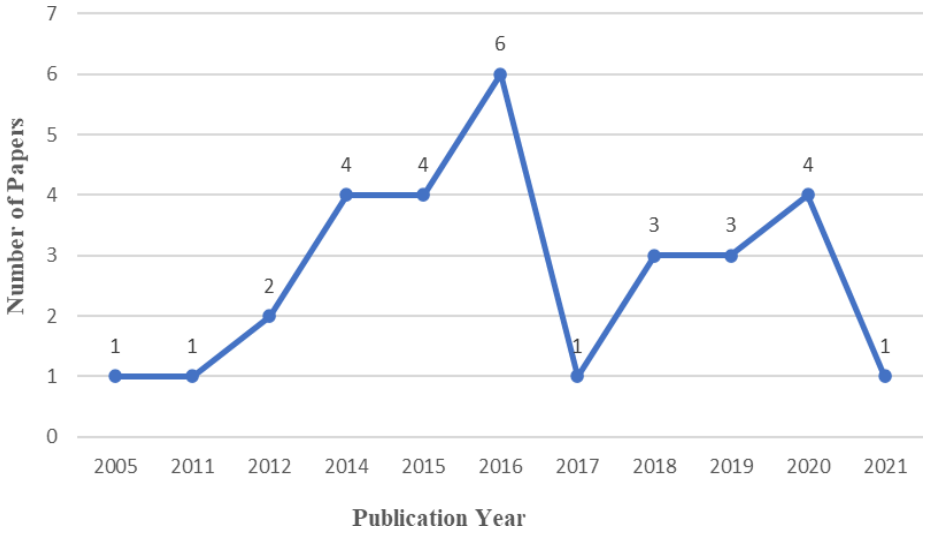

Figure 4.1: Annual Publication of Studies between 2000 - 2021

As seen in Figure 4.1, only one paper was published in the first decade (2000 – 2010) of the period under consideration in this present study. This might be due to the fact that research into carbon emission generally only began to rise significantly in 2007 (Abeydeera *et al.* 2019). Hence, specific research into mitigating carbon during a building construction project might not be a priority.

Perhaps, not until 2014 when IPCC released its *Climate Change* report on the need to guide against the risk portrayed by GHG emission did research into carbon emission spiked moving from 248 papers in a year in 2014 to 479 papers in 2018 alone (Abeydeera *et al.* 2019). This spike was felt within the building construction process carbon emission reduction research as well because within this time period (2014 – 2018), a total of 18 papers were published (see Figure 4.1). Although, there was a dip in research in this area in 2017 and up until now. This concavity might be connected to the increasing use of lifecycle assessment in conducting embodied carbon emission studies as it relates to building construction projects (Huang *et al.* 2018). Hence, the use of lifecycle assessment method has led many scholars (Resch *et al.* 2020; Kong *et al.* 2020) to believe that building construction process carbon emission is relatively low compared to those relating to construction materials. Albeit, with the focus on the building sector to reduce its carbon footprint (Sattary and Thorpe 2016; Sattary and Thorpe 2012) coupled with the rising importance on the need to achieve net zero carbon buildings in 2050 (World GBC 2016), more resources and effort will need to be channelled into research related to understanding carbon emission during building construction projects likewise its reduction. This is extremely necessary due to the fragmented nature associated with building construction process and the non-uniformity in the measurement method of its carbon emission (Hong *et al.* 2015; Wu *et al.* 2019) leading to the general belief that it has a relatively low carbon emission which can be ignored (Wu *et al.* 2019; Sattary and Thorpe 2016). Wu *et al.* (2019) further highlighted that building construction process if considered on the basis of the year taken to complete a building project (which is generally short), has a higher carbon emission.

4.2 Geographical Spread of Authors

The geographical spread of authors who have contributed to research in the area of carbon reduction during building construction projects is presented in Table 4.1. As depicted in Table 4.1, only 15 countries were found to have made contribution to this research area. Authors domiciled in China, US, Australia and Hong Kong (Table 4.1) are the highest contributor based on both their numbers, research papers, and level of contribution (which was calculated using the order of specificity score matrix presented in Table 3.2).

Table 4.1: Geographical Spread of Authors Related to Selected Papers

Country	Institution/Universities	Researchers	Papers	Score
China	12	25	9	7.44
US	10	14	6	6
Australia	3	10	4	4
Hong Kong	1	6	3	2.56
Egypt	1	2	1	1
France	1	5	1	1
Ireland	1	3	1	1
Malaysia	2	2	1	1
South Korea	2	4	1	1
Spain	1	4	1	1
Turkey	1	2	1	1
UK	1	2	1	1
Taiwan	2	2	1	1
Finland	1	4	1	0.62
Iceland	1	1	1	0.38

It was equally observed that there was no inter-continent collaboration but rather the collaboration found was mainly within the same region and this was between China and Hong Kong, and Iceland

and Finland. Although, in perusing some of the papers, the research conducted by Sattary and Thorpe (2016) for instance considered case study from the UK even though the researchers are based in Australia. The lack of inter-continent collaboration could be as a result of the peculiar nature of this research area which mostly have to do with physical construction process and might require researchers to either be present on-site for data collection or obtain data from industry practitioners who might be reluctant to release same based on the seemingly confidential nature of some of the data as industry stakeholder's like to put it. Also, this could be due to the different building regulations applied in various countries requiring different level of compliance when it comes to carbon emission during building construction process. Having said this, with the rising international ratings like LEED (Leadership in Energy and Environmental Design) and BREEAM, probably more collaborative work will be found within this knowledge area as relevant stakeholders strive to achieve these certifications for their work and to position them as champions in climate change mitigation.

Additionally, one striking thing observed in the analysis of the geographical spread of authors as well as paper contribution is the fact that the UK has only one paper from two researchers domiciled in one university. This seems strange because the findings of Abeydeera *et al.* (2019) in their scientometric study on global distribution of research into carbon emissions suggest that UK is the third leading country after China and US to have contributed significantly into carbon emission research. Also, amongst the European Union, the UK's construction sector has been identified as the major contributor to direct carbon emission (Huang *et al.* 2018). This was buttressed by the work of Sattary and Thorpe (2016) who highlighted in their study that the UK government provided funding to some team of researchers in four UK universities to conduct study on material efficiency and the scope of this research according to the investigators include attempt to reduce embodied emissions associated with building construction. Based on the aforementioned, it seems more research and corresponding publications might be required from the UK geared specifically towards carbon reduction during building construction projects.

4.3 Research Covered and Emerging Themes

According to the papers analysed in this study, intense research related to GHG emissions from building construction took off around 2015/16 (Figure 4.2). This research quickly metamorphosised into emissions related to construction process and that associated with construction materials. Although splitted, this might explain the spike in publication regarding carbon reduction during building construction projects in 2016 (see Figure 4.1). However, it seems once researchers discovered that construction materials have higher emissions than other construction process, attention shifted solely to this area of research with scholars working assiduously to find solutions to the rising carbon emission from construction materials. This might explain why 'construction materials', 'climate change', 'emission control', 'carbon reduction' and 'energy efficiency' are co-located and studied together (Figure 4.2). Also, as seen in Figure 4.2, the area of research which have received much attention from 2018 till date are those related to concrete, structural design, ecodesign, and concrete material recycling. Again, these are terms related to efforts in reducing carbon emission from construction material. Furthermore, this corroborates what is in literature as regards the understanding that the reduction of carbon emission from construction materials can be achieved at the design stage (Victoria and Perera 2018; Resch *et al.* 2020) since this is the point where decisions on materials to be used during construction will be chosen.

In addition, most of the studies if not all related to construction process carbon emission as found in the papers analysed have been done in the context of lifecycle analysis or assessment or energy with these keywords appearing for a total of 37 times, therefore, superseding other keywords within these studies. This does not seem surprising because the global carbon emission research conducted by

Abeydeera *et al.* (2019) equally showed that lifecycle assessment as a keyword in carbon emission research appeared 720 times topping all keywords related to research in the area of carbon emission. Hence, it is not surprising that the building construction process stage got side-lined from embodied carbon emission research since most lifecycle study show that the carbon emission associated with it is minimal (Pacheco-Torres *et al.* 2014; Abouhamad and Abu-Hamd 2021) or the construction process stage is even removed completely from the assessment altogether (Atmaca and Atmaca 2015) and as equally observed in some of the embodied carbon emission tools reviewed in the work of Pomponi *et al.* (2020).

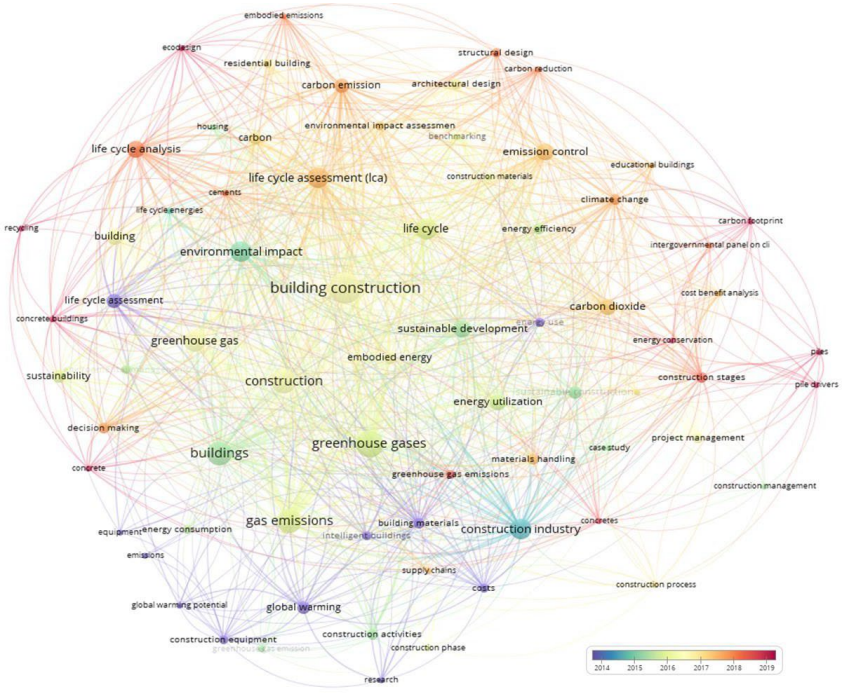

Figure 4.2: Keywords Network of Selected Paper

Another important observation from the papers analysed is that sometimes construction material (product stage, A1 – 3) and construction process stage (A4 – 5) carbon emission seems to be used interchangeably. When some researchers (Atmaca and Atmaca 2015) mention building construction phase carbon emission, they discuss carbon emission related to construction materials mostly. Although, most researchers (Abouhamad and Abu-Hamd 2021; Hong *et al.* 2015; Wu *et al.* 2019; Sattary and Thorpe 2012; Sattary and Thorpe 2016; Gottsche *et al.* 2016) made the distinction between these stages even if some of them end up making recommendations favouring the reduction of carbon associated with construction materials (Sattary and Thorpe 2012; Sattary and Thorpe 2016). Also, within the construction installation phase (A5), there is disparity in literature on what should be included when considering carbon emission sources. Majority of studies (Pacheco-Torres *et al.* 2014; Sandanayake *et al.* 2016; Wu *et al.* 2019) focused on emission related to equipment usage on-site while only few have captured human-related emissions (Hong *et al.* 2015). Some of the reasons given for this omission is that emissions from humans involved in the construction installation process is minimal and should be ignored (Wu *et al.* 2019) or that it is complex to measure. However, based on the work of Hong *et al.* (2015), human-related emissions during a building construction case study were found to contribute almost 5% of the total carbon emission related to the building construction activity.

Based on the aforementioned, the challenge raised by Victoria and Perera (2018) on having a clear system boundary and a defined scope of measurement during lifecycle assessments becomes vital in

ensuring that the construction phase carbon emission is adequately captured and mitigated. Therefore, there is a need for researchers to focus efforts on defining a unified system boundary and measurement scope for mapping and measuring carbon emission during building constructions in order to facilitate the proposition of appropriate reduction strategies that can deliver meaningful impact (Wu *et al.* 2019).

Furthermore, from Figure 4.2, it can be observed that 'construction phase', 'supply chain' and 'greenhouse gas emissions' are a bit close together. This suggest that they are likely being studied together during research and might confirm the notion that most of the carbon emission associated with building construction process stage comes from the supply chain. Hence, attention might need to be paid to this speculation when researching or considering carbon reduction options for the emissions linked to the building construction process stage especially since about 99% of emissions related to building construction have been reported to come from supply chain partners (Cross 2021).

Lastly, it should be noted that even though construction process has been an outlier in the scheme of building construction projects carbon emission research, it is vital to be aware that it has been studied closely with global warming in the past (Figure 4.2). Hence, it should not be taken for granted now especially as the world races to achieve net zero carbon buildings.

5 Conclusions and Further Research

The aim of this study is to investigate the claim regarding the side-lining of carbon emission reduction related to building construction process stage and that focus has largely been on construction material carbon reduction. This was done through presenting results obtained in terms of yearly publication of studies, geographic spread of authors and identifying knowledge area covered thus far together with key themes emerging after analysing literatures found in 19 journals and conference proceedings while adopting a systemic review approach. It is important to quickly note that even though the study sets out to examine literatures solely in construction management journals, conference proceedings were included after discovering limited research output in just journals. This effort paid off because important contributions from scholars like Sattary and Thorpe (2012) and Wu *et al.* (2019) would not have been captured.

The findings from this study generally supports the claim investigated with most research actually suggesting carbon reduction tactics related to building construction materials rather than for construction process even if the research was done with the intention of understanding the carbon emission related to the whole building construction. Also, while considerable efforts have been put into understanding the construction process stage carbon emission albeit with some discrepancies in measurement method, not enough literature seem to be found related to research on how to go about reducing this carbon emission. Therefore, researchers and industry stakeholders are urged to focus resources in this direction especially considering the climate change crisis being experienced globally and it is crucial that no stone should be left unturned as the world moves towards net zero emissions.

The findings of this study should be particularly beneficial to researchers and stakeholders with interest in construction carbon reduction as it might shape their outlook towards this field of study.

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