Sustainability assessment in construction industry supply network: a review

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Abstract. Construction industry plays important role to support human welfare by providing access for living and moving. Developed countries are characterized by having good infrastructures such as roads, bridges, office towers, residential buildings, seaports and airports. To have these infrastructures, massive construction projects must be implemented by construction industry. This industry consists of several activities such as extracting raw materials, manufacturing construction's materials, construction projects, infrastructure operational, and after operational activities that are run by different organizations and companies. These organizations and companies configure construction industry supply networks. Despite of the positive impact of these supply networks in improving human and product mobility, these supply networks also responsible for significant negative impacts such as consuming high energy and material resources, producing greenhouse gas emission and creating waste. To monitor and maintain these negative impacts, a sustainability assessment process is required. This paper aims to review sustainability assessment process in construction industry supply networks. It was found that different indicators are required for assessing activities in each stage of supply networks.

1. Introduction

Infrastructure is a key to support economic growth in one country. Economic activities such as manufacturing, trading, transportation and consumption, need infrastructure as a place for those activities to be held. A developed country with high economic growth is characterized by having good infrastructures. To build these infrastructure, massive construction projects must be implemented by construction industry. Several activities such as extracting raw materials, manufacturing construction materials, construction projects, infrastructure operational, and after operational activities are run by different organizations and companies in construction industry. These organizations and companies configure construction industry supply networks.

In first stage of construction industry supply network, the raw material extraction is main activity. Sand, stone, and iron mining are example of activities in this stage. In second stage, the main activity is to manufacture construction materials such as steel, cement and concrete. Next stage is construction projects. The main activity in this stage is to develop infrastructures. In fourth stage, the main activity is infrastructure operational. At this stage, the infrastructure is used to support human activities. Final stage is after infrastructure operational. At this stage, the infrastructure is no longer used to support human activities due to several breakdowns in Infrastructure. Figure 1 displays construction industry supply networks.

Massive construction projects bring positive impacts to communities such as increasing human and product mobility, escalating employment rate, and upgrading livelihood. However, these projects also bring negative impacts such as producing high greenhouse gas emission, increasing natural resource extraction and generating massive waste. With increasing public awareness to be more sustainable, construction industry has been encouraged to monitor its social and environmental impacts. Sustainability assessment is a process to evaluate integrated nature-society system in short or long term perspective in order to define which activities should or should not be taken to make society to be more sustainable [1,2]. However due to different activities and different impacts resulting from those activities, various sustainability assessment methods have been developed [3]. This paper aims to review sustainability assessment processes implemented by practitioners and academics in construction industry supply network.

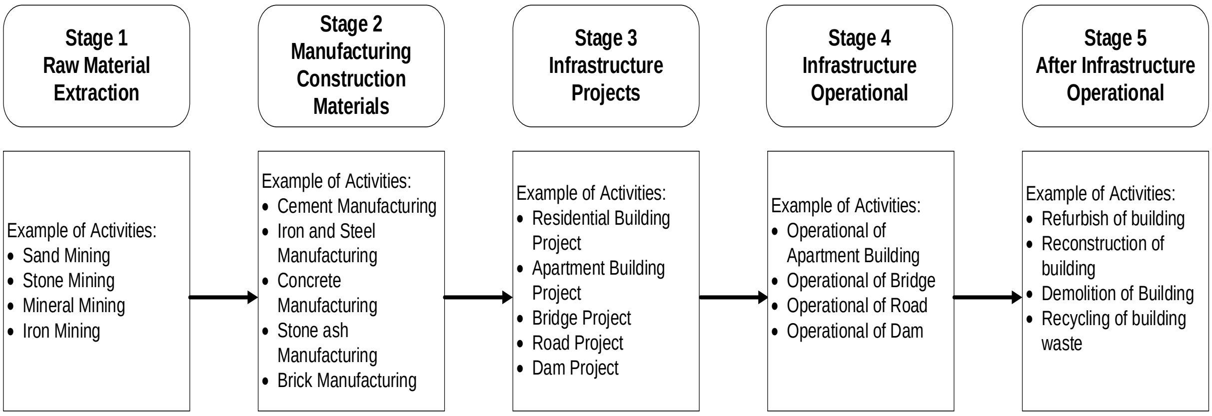

Figure 1. Construction Industry Supply Networks

2. Research Methods

The purpose of our research is to review and to analyze sustainable assessment research in construction industry supply network and to highlight potential gaps in literature that require further investigation. To achieve these objectives, a review of literature is used as research method. Papers with focus on sustainability assessment in construction industry from different Journals and Sources were reviewed.

2.1. Research Process

To achieve the aim of the research, the research process is divided into three steps. First step focuses on searching and selecting journal papers. The keywords used for searching and selecting the papers were sustainability assessment and construction industry. The searching was implemented on Scopus database. Further restriction related to publish year of paper between 2015 to 2018 was applied in the searching process. The second process focuses on classifying the papers based on the position of paper in construction industry supply network.

This is followed by analysing those papers using thematic analysis. Four themes were applied including: objects of assessment, tools for assessment, indicators used in the assessment and presentation of assessment results. First theme is object of assessment that presents activities, processes or policies assessed in the literature. Second theme is tools for assessment that displays methods, models or tools used in assessment process. Third theme is indicators for assessment, which refers to criteria used in assessment process. Fourth theme is presentation of assessment result, which refers to how the assessment results are presented and which decisions are supported by the results. Figure 2 presents the research process.

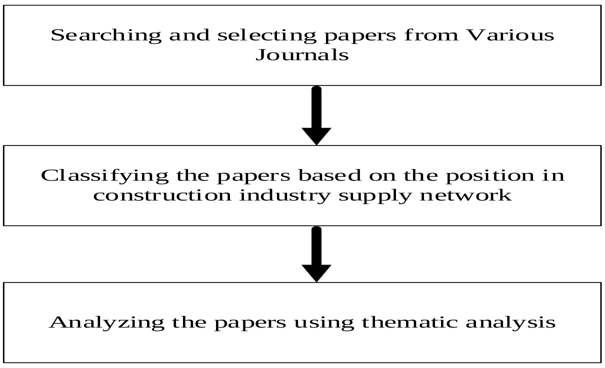

Figure 2. Research Process

3. Result and Discussion

3.1. Statistic of Reviewed Papers

In the first step of research process, 68 papers from various journals have been selected. These papers were published between 2015 until 2018. From these papers, three recent reviews related sustainability assessment in construction industry were identified including by [4] that focuses to review multi criteria assessment for social sustainability of infrastructure, [5] that reviews economic sustainability assessment of residential buildings and [6] that reviews the use of life cycle assessment in building industry. However, these recent reviews focus on one stage in construction industry. This paper covers all stage in construction industry supply network. Table 1 shows classification of papers based on the position in construction industry supply network.

Table 1. Classification of Papers Based on the Position in Construction Industry Supply Network

Stage of Construction Industry Supply Network	**Publications**
Raw Material Extraction	[7] [8] [9] [10] [11] [12]
Manufacturing Construction Materials	[13] [14] [15][16] [17] [18] [19] [20] [21] [22] [23][24]
Infrastructure Projects	[4][6][25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43] [44] [45] [46] [47] [48] [49] [50] [51]
Infrastructure Operational	[5] [52] [53] [54] [55] [56][57] [58] [59] [60] [4][61] [62]
After Infrastructure Operational	[63] [64] [65] [66] [67] [68][69][70]

Figure 3 displays majority of reviewed papers are positioned at infrastructure projects stage. This is followed by papers positioned at infrastructure operational stage and at manufacturing construction material stage. This indicates the focus of sustainability assessment research on construction industry lies on assessing activities within development and operational of infrastructure. More than 80% of reviewed papers were published by five journals including: Journal Cleaner Production, Sustainable Cities and Societies, Renewable and Sustainable Energy Reviews, Environmental Impact Assessment Review and Resources Policy.

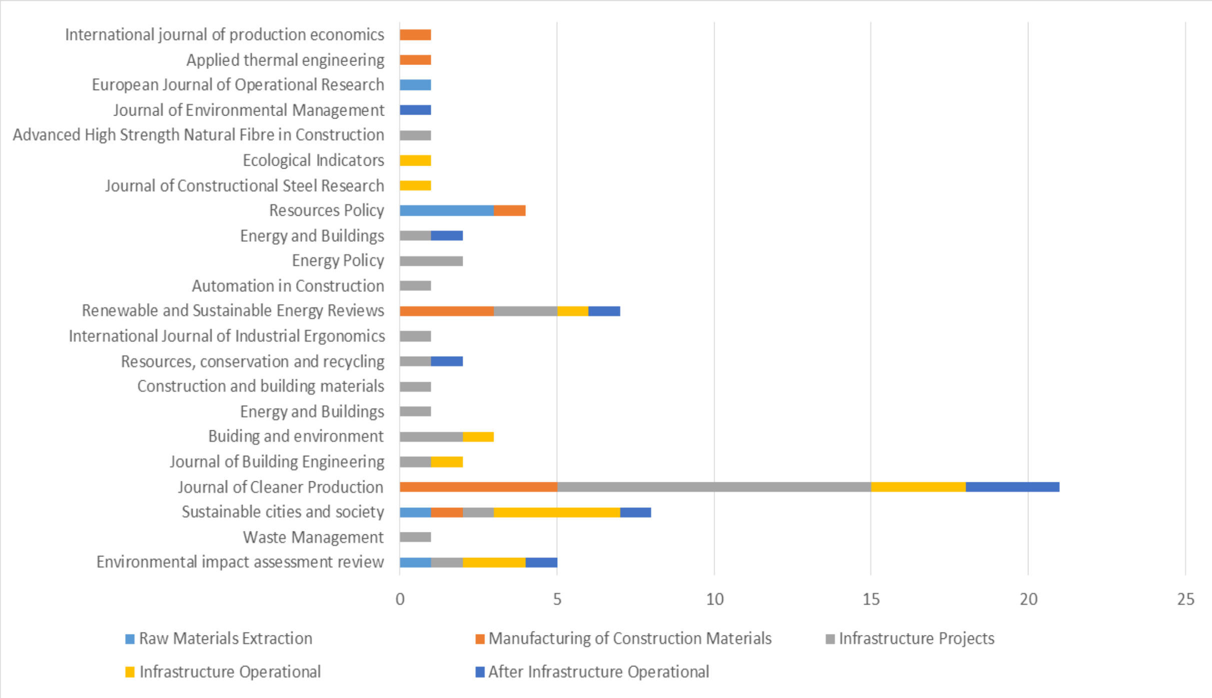

Figure 3.Distributed Reviewed Papers Based on Journal

3.2. Sustainability Assessment at Raw Material Extraction Stage

In this stage, activities are dominated by extracting materials such as minerals, sand, soil, and stone from the earth. Extracting materials consists of several processes such as mining, transporting, and simple processing such as cutting and shaping. These processes consume energy, water and materials and produce several impacts such as resources depletion and emission.

3.2.1. *Object of Assessment at Raw Material Extraction Stage*

Two types of process have been found as the object of assessment in reviewed papers including stone and minerals mining. The central issue in this stage is the reduction of non-renewable resources due to activities in this stage [9]. Furthermore, [8] evaluated additional environmental impacts of artisanal stone mining in South Africa. They found that stone mining activities could be a source of emission particularly emitted by transportation and processing activities during the mining process. Despite the environmental impacts, the activities in this stage have brought social impacts to communities [7]. Use of local people as employee and socio economic benefits are example of social impacts. However, some of mining release or use toxic substances during the process, which can cause harm to worker, citizens and local communities around the mining [9].

3.2.2. *Tools and Indicators for Assessment at Raw Materials Extraction Stage*

Life cycle assessment, multi criteria and composite indicators are tools used for assessing sustainability in this stage. [8] use life cycle assessment to evaluate environmental impacts from stone mining in South Africa. They found five indicators that could be used in this stage to evaluate sustainability including energy use, air emission, water and land use, and non-renewable resources use. [9] use multi criteria analysis to evaluate sustainability of mineral mining in China. They proposed 19 indicators for three dimensions of sustainability. The additional indicators for economic dimension are contribution to GDP and investment. For social dimension, health and safety, creating of employment, relationship with local community and wealth distribution were used as indicators by [9]. At the same time, [12] use composite indicators to assess corporate social responsibility performance of mining companies.

3.2.3. *Presentation of Assessment Result at Raw Materials Extraction Sta*ge

The result of assessment is presented in different formats that depend on tools used for assessing. [8] presented their result in different units based on indicators used. For example for indicator CO_2 emission, they present the result using Kilogram unit. On other hand, [9] presented the result of assessment in form of scoring and ranking. These scores were calculated using several equations that consider reference value and weight for each criterion. The similar approach were adopted by [12]. They used scoring method to present the result of assessment. The score is aggregated from different indicators' scores considering weight of those indicators. However, none of reviewed papers in this stage, demonstrated the use of assessment results to support decisions making.

3.3. *Sustainability Assessment at Manufacturing Construction Materials Stage*

Most of raw materials extracted in first stage are processed further to be specific products at this stages. Products such as cements, steels, concretes, ceramics and bricks are produced at this stage. To produce these products several manufacturing processes that use different machines are implemented. These processes require energy, water and other materials and generate significant emissions.

3.3.1. *Object of Assessment at Manufacturing Construction Materials Stage*

Several manufacturing processes have become the objects of assessment in reviewed papers including ceramics, plasterboards, concrete, cements, steels and bricks manufacturing process. The main issue in this stage is to evaluate the emission generated by manufacturing process. Concrete is a central material in construction projects. According to World Business Council for Sustainable Development, concrete is the second most consumed product in the world after water. Cements and steels are critical inputs for producing concrete. This become the main reason for concrete, cements and steel manufacturing to be object of assessment in the most reviewed papers positioned at this stage.

[13] Evaluated greenhouse gas emissions from concrete supply chain in Turkey. They have found that cements and steel have greatest emission impacts on concrete. [16,18–20] assessed and quantified CO_2 emission from cements manufacturing. [19] Found that cement manufacturing contributes to 15 % of greenhouse gas emission in China. Within cement manufacturing process, [20] explained that calcination process contributed the biggest emission. Furthermore, [18] developed system dynamics model to predict sustainability impacts from cement manufacturing.

For steel manufacturing, [22] investigated CO_2 emission from iron and steel manufacturing in China and [21] evaluated impacts of iron and steel manufacturing in China more comprehensive. [22] estimated CO_2 emission from coal consumption and carbon oxidation factor. They found that most emission was produced from consumption of coal at coking, sintering and spray-blow process. Plasterboard and brick are other commonly material used in construction projects. [15] evaluated environmental impacts of plasterboard industry in United Kingdom and [17] assess greenhouse gas emission from brick manufacturing.

3.3.2. *Tools and Indicators for Assessment at Manufacturing Construction Materials Stage*

Several tools have been used for assessing sustainability at this stage including life cycle assessment, system dynamics, material flow analysis, Logarithmic Mean Divisia Index (LMDI), data envelopment analysis and analytical hierarchy process. [13] Quantify greenhouse emission from concrete product based on material used to produce concrete product. Life cycle assessment has been used by [15] to evaluate environmental impacts in plasterboard industry, by [20] to quantify CO_2 emission from cement manufacturing in China and by [17] to quantify greenhouse gas emission from brick manufacturing. [19] used Logarithmic Mean Divisia Index (LMDI) to quantify CO_2 emission from cement manufacturing in China and [18] used system dynamics to predict sustainability impacts from cement manufacturing in Iran. For steel manufacturing, material flow analysis has been used by [22] to quantify CO_2 emission and analytical hierarchy process has been used by [21] to assess sustainability of iron companies in China. [24] analysed carbon efficiency from cement, steel and aluminium manufacturing in China using data envelopment analysis.

3.3.3. *Presentation of Assessment Result at Manufacturing Construction Materials Stage*

Most of sustainability assessment research in this stage has the aim to quantify impacts of manufacturing process. Hence, most of the result are the numeric value for each indicators used in assessment. For example, CO_2 emission was presented using Kilogram unit. Most the reviewed papers do not link the assessment result with decisions or policies making. Only [18] and [24] demonstrated the use of assessment result in formulating policies. In this case, [18] used the assessment result to determine policies for reducing CO_2 emission and [24] used the assessment result to define potential emission reductions in some regions in China.

3.4. *Sustainability Assessment at Infrastructure Projects Stage*

This is the main stage in construction industry where the different types of infrastructure are developed in several locations. Two main activities in this stage are design and construction activities. The design of infrastructures is critical factors influencing environmental, social and economic impacts of those infrastructures [28]. However, the most sustainability impacts are produced during construction activities.

3.4.1. *Object of Assessment at Infrastructure Projects Stage*

Two main objects of assessment in this stage are design of infrastructure and construction activities. [30] Demonstrated the consideration of environmental impacts in design phase. They argued that to reduce environmental impacts of design, it requires iterative assessment. [26] Investigated the impact of design to produce potential waste that will be incurred during the construction activities. Some papers focus to evaluate the impact of specific structures using specific materials. For example [27,37] assessed environmental impacts of specific timber structures and [50] evaluated sustainability impacts of structure using high strength natural fiber composite.

The main issues in evaluating construction activities lies on quantifying waste and emission resulted from the activities. [25] Identify wastes generated by construction activities. They found that three major construction activities contribute to high waste including land preparation, pavement construction and installation of drainage. In similar way, [39] evaluated the potential of waste reduction within construction stages. [29] and [33] evaluated other environmental impacts of construction activities. They found five other environmental impacts including global warming potential, acidification, eutrophication, carcinogen and energy consumption. [31] estimated emission from construction projects. Furthermore, they also estimated emission from specific stage at construction process such as at foundation and structure stage [32] and at timber and concrete construction stage [34]. [44–46] focuses to assess the construction projects using modular design. They also compared the impacts between modular and conventional method [45]. Moreover, for social dimension, [43] analyzed socioeconomic impact of urban construction. They analyzed the impact of construction on increased travel distance, resident relocation, business loss, business closure and noise inconvenience. [49] Evaluated potential risk resulted from nuclear power construction.

3.4.2. *Tools and Indicators for Assessment at Infrastructure Project Stage*

Several tools have been used in reviewed papers to evaluate sustainability at infrastructure project stage. Table 2 shows tools and indicators for assessment at infrastructure project stage.

Table 2.Tools and Indicators for Assessment at Infrastructure Project Stage

Tools	**Publications**	**Indicators**
Life cycle assessment	[27] [29] [30]	Greenhouse gas emission, global warming potential, acidification, eutrophication, carcinogen and energy consumption
Builiding information modelling	[26] [35] [36]	Environmental, social and economic indicators
Process based methodology	[31][32][34]	Greenhouse gas emission
Multi criteria analysis	[37] [44][45] [46]	Environmental, social and economic indicators
System dynamics	[39]	Wastes
Log Mean Division Index	[41]	Greenhouse gas emission
Global Information System (GIS) and Visual Basic Analysis	[43]	increased travel distance, resident relocation, business loss, business closure and noise inconvenience
Ecology virtual laboratory	[47]	Environmental performances

3.4.3. *Presentation of Assessment Result at Infrastructure Project Stage*

Most of reviewed papers position in this stage focuses on quantifying sustainability impacts of construction activities. These reviewed papers presented the result of assessment in numeric format using different units. Some reviewed papers such as [33,37,45] presented the assessment result using index format. Although majority reviewed papers did not link the assessment result with policy making, some papers such as [30,37,45] use the assessment result to support decision making.

3.5. *Sustainability Assessment at Infrastructure Operational Stage*

In this stage, infrastructure is started to use as a place for many activities. However during this service, infrastructure could bring several environmental, social and economic impacts. For example, with increasing the number of infrastructures in developed and developing countries, it becomes one sector that highly consumes energy [61]. Furthermore, other impacts such as economic returns for investor and emission are also found to be important which bring the need to assess building performance during operational stage.

3.5.1. *Object of Assessment at Infrastructure Operational Stage*

Several types of infrastructures such as residential building, healthcare building and non-residential building become the object of assessment at this stage. Residential building is one type of infrastructure with the highest number within the countries. People are spent most of their times in this building. As the result, residential building is expected to consume much more energy comparing to other type of infrastructure [5]. This becomes a background for researchers to evaluate sustainability in residential building for example [52] evaluated social sustainability of residential building in Pakistan. [62] Focus to assess sustainability of solar energy system in residential building. Healthcare building is built to provide health services. Hence, this type of building must follow healthcare principles. This building is a system of system which is an integration between people, equipment and supplies. [57] Assessed sustainability of healthcare building. In some countries, the growth of non-residential building such as office building increase significantly. [54] assess sustainability for non-residential building in Saudi Arabia.

3.5.2. *Tools and Indicators for Assessment at Infrastructure Operational Stage*

Multi criteria indicators becomes popular tools used to assess sustainability at this stage. Several green building rating tools such as BREEAM, LEED, ITACA, CASBEE, Green Star have been used extensively in literature. However, since these rating tools were developed in certain countries such as LEED in United States and BREEAM in United Kingdom, the use of these tools in other regions need modification due to the differences in weather and cultural. Some academics modified these rating tools to adjust with local condition. For example, [59] modified current rating tools to adjust with local condition in Iran and [54] modified rating tools to assess sustainability of building in Qatar. Furthermore, [5] proposed the integration of BIM (Building Information Modeling) with indicators to assess economic sustainability in residential building. Several indicators were used including water and energy consumption, indoor air quality, land and waste, whole-life cost, materials selection, effective management, and cultural aspects. Another tool that has been used in this stage is life cycle assessment. [62] use this tool to assess sustainability of solar energy system in residential building.

3.5.3. *Presentation of Assessment Result at Infrastructure Operational Stage*

Since majority of the reviewed papers at this stage uses multi criteria indicators to assess sustainability, most of assessment result were presented in index or rating. The index is aggregated from several indicators considering the weight of those indicators. Analytical Hierarchy Process has been used by several authors such as [54,59] to determine the weight of indicators. In term of supporting decisions, none of reviewed papers at this stage demonstrate the use of assessment result to support decisions.

3.6. *Sustainability assessment at After Infrastructure Operational Stage*

The use of building after certain times might cause the degradation of building condition particularly if the building does not get proper maintenance. This might increase energy consumption and reduce the appropriateness of building to be functioned as usual. As the result several alternatives to fix this condition are proposed in construction industry including rehabilitation, demolition and reconstruction. However, these alternatives bring several environment and social impacts.

3.6.1. *Object of Assessment at After Infrastructure Operational Stage*

Three main activities including rehabilitation, demolition and reconstruction become object of assessment at this stage. Some reviewed papers focused to assess one activity only while other reviewed papers demonstrate the comparison between these activities. [65,69,70] demonstrated the assessment of building rehabilitation activity. They found that rehabilitation can bring positive impacts such as increasing capital value of building, reduction of greenhouse gas emission and energy consumption if the process is maintained to follow high sustainability standard. [63,66,67] presented the assessment of building demolition. Waste and carbon emission become dominant impacts caused by building demolition. [64,68] compared the sustainability impacts between rehabilitation, demolition and reconstruction.

3.6.2. *Tools and Indicators for Assessment at After Infrastructure Operational Stage*

Multi criteria indicators and life cycle assessment become dominant tools to assess sustainability at this stage. [55,67,68,70] used multi criteria indicators to assess sustainability at this stage. The used of this tool due to ability to capture the impacts on three dimension of sustainability simultaneously. [64–66] used life cycle assessment to evaluate environmental impacts at this stage. Another approach was demonstrated by [63] that used agent based modeling to analyzed waste generated by building demolition. Several indicators used at this stage including waste generation, carbon emission, material selection, construction cost, energy and water consumption.

3.6.3. *Presentation of Assessment Result at After Infrastructure Operational Stage*

Some assessment result was presented in index and rating format due to the use of multi criteria indicators while for the reviewed papers used life cycle assessment, the result was presented in measurement unit. Several reviewed papers demonstrated the use of assessment result to support decision making. For example, [68] used assessment result to choose between rehabilitation, demolition and new construction and [64] used assessment result to determine decision between refurbishment or complete reconstruction.

4. Possibility for Future Research

Based on the analysis of reviewed papers several possibilities for future research are identified:

- At raw material extraction stage, further research is required to assess sustainability impacts from the extraction of construction materials such as: sand, iron and stone in developing countries. The opportunities are widely open to use different sustainability assessment tools such as simulation and composite indicators. Further research is required to link sustainability assessment with the planning of policies in this stage.
- At manufacturing construction materials stage, further research is required to assess

manufacturing construction materials located in developing countries. Since majority of reviewed papers was focused on environmental impacts, the assessment of social and economic impacts need to be explored in future research.

- At infrastructure project stage, further research is required to assess sustainability impacts of different infrastructure projects such as airport, seaport, dam, road and bridge. The social and economic impacts of infrastructure projects need further exploration. Further research is required to use assessment result to support policies in this stage.
- At infrastructure operational stage, further research is required to assess sustainability impacts of non-residential buildings such as airport, seaport and office tower. For residential building, further assessments in developing countries are required. Since multi criteria indicators are dominant tools in this stage, there are opportunities to use different sustainability assessment tools such as simulation to predict the impacts of infrastructure within operational stage.
- At after infrastructure operational stage, further research are required to assess social and economic impacts of activities at this stage. The use of assessment result to support decisions making are limited, hence there are opportunities for demonstrating the development of policies based on the sustainability assessment result.

5.Conclusion

Based on the results, some conclusions are obtained as follows.

- The review of sustainability assessment process in construction industry supply networks indicates that different indicators are required to support the assessment process due to different activities and different impact in each stage of these networks.
- The review indicates that majority of reviewed papers are focused to assess sustainability impacts at infrastructure project stage and infrastructure operational stage.
- The review indicates that life cycle assessment and multi criteria indicators are dominant tools used in review papers to assess sustainability.

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