Developing Indicators of Green Construction of Green Supply Chain Management in Construction Industry: a Literature Review

N. Farida\textsuperscript{1}, N.U. Handayani\textsuperscript{1} and M.A. Wibowo\textsuperscript{2}

\textsuperscript{1}Department of Industrial Engineering, Faculty of Engineering, Diponegoro University, Indonesia
\textsuperscript{2}Department of Civil Engineering, Faculty of Engineering, Diponegoro University, Indonesia
naniekh@ft.undip.ac.id

Abstract. Green construction is a concept in construction to minimize environmental impact so that balancing the environmental capabilities with human life needs for the present and future generations. This concept in line with sustainable construction and lean construction concept. In the Project Life Cycle (PLC), green construction is related to the construction phase. However, accomplishment in this stage cannot be separated with previous stages that are planning and design phases. Therefore, an integrated green concept is needed to assemble the continuity of each stage in PLC thus reducing the fragmented nature of the construction industry. Green Supply Chain Management (GSCM) concern to sustainable practices along the supply chain. Management of materials and information flow, in addition energy consumed and waste generated reduction in every stage makes GSCM worth to considered as a concept to integrated all stages in PLC into a green spirit. This study aims to identify the indicators of green construction concept as part of GSCM. The result of this study is a framework for implementing green construction that consists of four dimensions, 25 elements, and 42 indicators.

1. Introduction
Construction industry was known as an industry with high level of waste. Waste in the construction industry involves not only material waste but also related to several activities such as excessive production, waiting time, material movement, inventory, and worker movement \cite{1} Material waste is one of the construction waste that has negative impact to the environment. Several studies in various countries show the contribution of construction and demolition waste (C&D waste) is large enough for the overall solid waste in the country. In Netherlands, the percentage of C&D waste reaches 26% of all solid waste. Whereas in Aussie, United States, Germany, and Finland, these percentages ranged between 20-30\%, 20-29\%, 19\%, and 13-15\%. In addition, the impact to the environment is also caused by material consumption and large energy needs, as well as pollution generated in the supply chain of construction activities \cite{2}.

Sustainable construction is one of Indonesian construction industry agenda for saving materials and reduce waste generated, and also ease of building maintenance after the construction phase. Sustainable construction aims to create a building based on environmentally conscious design, efficiency in the use of natural resources, and environmentally friendly during building operation \cite{3}. 

\textsuperscript{CreativeCommons Attribution 3.0 licence}
One of the challenges to realizing this aims is the characteristics of the construction industry, i.e. the high complexity and uncertainty where the system operates, site configurations are managed by temporary supply chain configurations, customer have high-level influence on the final product, the fragmented processes, and also the complexity of stakeholder networks, which involve many organizations and relationships[4]. There are many researchers and practitioners that looking for the solution to resolve the problems in the construction industry, but most of them still fragmented and disconnected, mainly from an individual stakeholder’s interest, such as the developer or contractor. To avoid the risk that decision makers ignoring the significant aspects and give attention to the wrong issues, a holistic understanding must be realized[5].

To review all processes involved in the Project Life Cycle (PLC) and all activities carried out by stakeholders, Supply Chain Management (SCM) approach can be used. The main objectives of SCM include reduced cost, improved end to end processes, communication, and interaction among supply chain partners, and also improved performance and productivity in a way that brings benefits to all supply chain participant [6]. SCM concept in line with spirit to minimize waste generated in construction activity. However, for integrating environmental aspect, Green Supply Chain Management (GSCM) approach that was concern to sustainable practices along the supply chain can be applied [5][6].

Previous research about GSCM in construction industry defines a framework to implement GSCM that consist of five concepts, i.e. Green Initiation, Green Product Design, Green Material Management, Green Construction, and Green Operation and Maintenance [7]. This framework coverage and represents all stage in PLC. Construction phase that represent by Green Construction is the execution phase of all decisions that made in initiation and design phase. So, Green Construction is an important part that has to get special and detailed attention without being separated from the overall concept.

2. Literature Review

2.1. Project Life Cycle

Projects follow a predictable pattern that called life cycle. A project life cycle built from several phases during which deliverables are created and end with handover the deliverables. Project life cycle starts from an idea for a project and decision to plan it in more detail, and then make a decision whether to perform the project in the construction phase. The last phase is closing, begins when the customer formally accepts the project deliverables and ends when documentation is complete, resources are reassigned, etc [8]. Another reference divide PLC to six stages, i.e. initiation, planning, design, construction, commissioning, and closeout [9]. And other researcher consider that PLC consist of four phases, i.e. initiation, design, construction, and operation and maintenance [10].

Initiation phase is a phase when the owner makes a decision about the process of design and construction. The selected process will affect financing, team member, project cost, project quality, and timeline. The output from this stage is a project document that will be used as a baseline to the next phase [10][11]. In term of greening the supply chain or making process improvement, the owner can act as a catalyst to foster innovation by exerting pressure on the supply chain partners to improve sustainable performance, demand high standards of work, and identify specific novel requirements for a project [12].

The design phase is the most important phase that takes a lot of time and personnel involved. The design consultant translates the concept made by the owner into the picture and proposes the specifications of components and building materials. The outputs of this stage include the structure of project team, detailed engineering design, technical data, project schedules, work and material schedules, and other details. This design phase is key to the success of the next project stage [10][11].

The construction phase is the implementation project phase, start from procurement of material, tools, and labour until the construction process as an output of the design phase. The construction phase is important because the quality of construction work and management will affect directly to the quality of the completed project. Outputs from this phase are products, control documents
(administrative, quality, labour, schedule, project financial), reports, test and inspection results, and others that refer to the project execution [10][11].

The operation and maintenance phase consists of handover and maintenance period. Before the handover process, the field inspection personnel will evaluate and assess the completion of the project. The output of this phase is the final document consist of all the control documents in the construction phase, the final drawing, the operating manual, and the handover report. Furthermore, maintenance activity will be the responsibility of the user [10][11].

2.2. **Green Supply Chain Management in Construction**

Green supply chain management (GSCM) can be defined as adding environmental force into supply chain management, that consist of product design, material resource and selection, manufacturing processes, delivery of the final product to the customer, and end of life management of the product after its beneficial life [13]. GSCM purposes to preserve natural resources, minimizing waste produced through reuse, recycle, and remanufacture the materials, as good as minimize pollution [14]. The concept of GSCM in manufacture has been tried to adopted in the construction industry in many types of research. That researches differ in range, aim, and object. One of the research that becomes the main reference of this study is developed GSCM framework in the construction industry that consists of five concepts, i.e. green idea, green product design, green material management, green construction, and green operation and maintenance [7].

![Figure 1. Framework of GSCM in the construction industry][7].

Green initiation is deliberating about project life cycle between owner and design consultant so that owner can realize the environment impact of construction waste and have a strong commitment to implement the green concept in a project. This is an entry point and initial foundation to implement GSCM in construction [7]. The other part that becomes important attention is the feasibility of the development project. The result from the feasibility study will become consideration for the owner to decide whether the project will be executed or stopped [15].

Green product design talks about how to translate the owner needs into building design without harming the environment [7]. The component of green design is the choices of sustainable sites, the design considerations to save materials used, besides saving water used and recycling water [16]. All consideration translated into Detail Engineering Design (DED).

Green material management is a concept to remove harmful material or activities, then replace with less hazardous materials. Green materials procurement and green materials selection are the processes that support this concept. The specification of materials selection is easy to separate and adaptable or useful in existing processes [6][7].

Green construction processes consist of three phases: resource utilization decrement, waste decrement, and emission decrement. Green construction aims to reduce consumption of resources and energy uses so that it will indirectly minimize total waste generated during the construction phase. The concept of green construction is focused to on-site green techniques that concern on energy use, waste, and pollution (air and noise) [7][17].

The last concept is Green operations and maintenance that is a strategy that relating cleaning, work practices, training and observation of materials in a project with environmental consideration so that the green concept could still implemented during the operational phase of the building [7][18].
3. Research Methodology

This study is descriptive research that identifies and develop a framework for implementing green construction as part of green supply chain management. This framework consists of concept, dimensions, elements, and indicators. The method used for data collection is observation through literature review and interview with experts from academic, practitioners, and ministry. The coverage topics of the literature review were about waste management, project life cycle, green supply chain management in the construction industry, and also some previous study about development indicators of green construction, sustainable construction and green building assessment tools. The experts that become respondents consist of four experts from academic, two experts from practitioners, and one expert from Ministry of Public Work. The purpose of the interview is to validate the indicators that has been developed.

The previous study about development indicators of green construction, sustainable construction and green building assessment tools are listed in Table 1.

| No | Title & Authors | Objectives | Methods | Result |
|----|-----------------|------------|---------|--------|
| 1  | Identification of Green Construction Indicators in Indonesian Construction Building Project Ervianto et al (2013) [19] | To develop green construction indicators of building construction in Indonesia | Literature review, interview with experts, rescoring method | 1. Green construction consist of 16 factors. 2. There are 142 indicators of green construction that consist of 77 indicators Priority I and 65 indicators Priority II. The indicators are not stated in the paper. |
| 2  | Sustainable Construction Key Indicators Araujo et al (2013) [20] | Select a set of indicators that will be used in the cost benefit analysis to sustainable construction | Literature review | Nineteen indicators were selected and distributed across the three sustainability dimensions (environment, society, and economy) and six categories (energy & emissions, water, materials & waste, user health & comfort, process quality, and economy). The indicators are stated in the paper. |
| 3  | Measuring the Sustainability of Construction Projects Throughout Their Lifecycle: A Taiwan Lesson Yu et al (2018) [21] | Propose a Construction Projects Sustainability Assessing System (CPSAS) considering three pillars of sustainability: environmental, social, and economic. | Literature review, questionnaire surveys | The proposed CPSAS comprises four levels: Level 1, 3 main pillars; Level 2, 8 categories (resource, pollution, ecology, improvement of human life, culture conservation, fairness, social aspect of construction, and economic contribution); Level 3, 19 sub categories; Level 4, 31 indicators. The sub categories and indicators are stated in the paper. |
| 4  | Developing a Green Building Assessment Tool for Developing Countries – Case of | To contribute a better understanding of the concept of green building assessment tool and it’s role to | Literature review, fieldwork approach, questionnaire, | The result SABA Green Building Rating System consist of 7 categories (site, energy efficiency, water efficiency, material, indoor environment quality, waste & |

4
Jordan, Ali & Nsairat (2009) [22] achieved sustainable development through developing an effective green building rating system for residential units in Jordan. Interviews, empiricism approach, critical approach pollution, cost & economic, 42 indicators, and 157 parameters. The indicators are stated in paper but neither the parameters.

A Review on Green Assessment Tools Criteria of GREENRE, GBI, GREEN SHIP, and LEED. Zainol et al (2017) [23] evaluate the assessment criteria of the rating tool and to identify the elements of the assessment criteria that been concentrated in establishing the green assessment tools. Literature review. From the review of those four green assessment tools found that have 5 similarities of each criteria which are energy efficiency, water efficiency, material & resources, green building, and indoor quality environment.

Factors for Implementing Green Supply Chain Management in the Construction Industry. Wibowo, et al (2018) [7] elaborate the concepts, dimensions, and elements of Green Supply Chain Management (GSCM) and develop the implementation GSCM framework for construction industry. Literature review, Delphi method. The developed framework consist of five concepts, 22 dimensions, and 82 elements. The indicators is not yet developed.

This study is a continuation of study that have been conducted by Wibowo et al (2018). In that study, the concepts, dimensions, and elements have been developed but the indicators are not yet identified. A literature review was conducted to generate the indicators. From study that listed in Table 1, green construction indicator generation are approached by study in green building and sustainable construction because the assessment tools are already exist in several version. This approach can be done for elements that similar with reference model of Wibowo et al (2018). Furthermore, for the other elements, the generation of indicators are held by tracing other study that discussed about relevant topics with the elements in reference model.

3.1. Developing Indicators of Green Construction as Part of GSCM in Construction

Construction process has negative impact to the environment that relatively smaller than the operational stage, but more intensive. Green construction aims to reduce this negative impact through several steps including material selection, construction waste management, indoor air quality management, energy efficiency, water efficiency, and design for efficiency [24]. Other reference states that general concept integration to actualize green construction is the reduction of resource consumption, waste, and emissions [25]. The indicators of Green Construction as part of GSCM in construction are listed in Table 2.

Table 2. The indicators of Green Construction

| No | Element | Indicator | Reference |
|----|---------|-----------|-----------|
| 1  | Lack of on-site waste management plans | There are SOP for waste management. | [26][27] |
| No | Element                                      | Indicator                                                                                                                                   | Reference |
|----|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 2  | Improper planning for required quantities   | Percentage of excess material compare with planning.                                                                                         | [26]      |
| 3  | Delays in passing information on types and sizes of materials and components to be used | Percentage of tardiness material availability due to late order.                                                                               | [26]      |
| 4  | Lack of on-site material control             | There are SOP for material receipt.                                                                                                          | [26]      |
|    |                                              | Percentage of discrepancy event in material receipt.                                                                                          |           |
| 5  | Lack of supervision                          | There are SOP for work control.                                                                                                               | [26][28][29] |
| 6  | Construction cost reduction                  | Number of meeting in a month.                                                                                                                 |           |
| 7  | Waste management                             | Amount of project cost overrun.                                                                                                                | [30]      |
|    |                                              | Amount of idle labour.                                                                                                                        | [31][32]  |
|    |                                              | Percentage of wasted material that can't be recycled, reused, or remanufactured.                                                             | [19][21][22][23] |
| 8  | Pollution control                            | There is air pollution measurement.                                                                                                            | [21][22][31][33][34] |
|    |                                              | There is noise pollution measurement.                                                                                                          |           |
|    |                                              | There is water pollution measurement.                                                                                                          |           |
| 9  | Quality control                              | There is quality examination of material.                                                                                                    | [31][35]  |
|    |                                              | There is quality examination of building structure installed.                                                                                | [31][36]  |
|    |                                              | There is quality examination of mechanical & electrical installed.                                                                          | [31]      |
|    |                                              | There is quality examination of sanitation installed.                                                                                         |           |
| 10 | Employment practices                         | There is qualified skill labour that confirmed with certificate (SKA & SKT).                                                                | [37]      |
|    |                                              | There is training for skill labour.                                                                                                            | [38]      |
| 11 | Energy reduction                             | There is planning for electricity use optimization.                                                                                           | [19][20][21][22][23][39] |
| 12 | Human resource management                    | There is man power planning in a project.                                                                                                    | [40]      |
|    |                                              | There is an evaluation for labour performance.                                                                                                |           |
| 13 | Health and safety                            | There are safety morning talk and safety induction.                                                                                           | [31][41]  |
|    |                                              | There is SOP for occupational health and safety.                                                                                             | [19][21][31] |
|    |                                              | Labour always wear personal protective equipment.                                                                                             |           |

**Dimension: Site Operation**

| No | Element                                | Indicator                                      | Reference |
|----|----------------------------------------|-----------------------------------------------|-----------|
| 14 | Accidents due to negligence            | Number of work accident during a project.      | [19][21][26][42] |
| 15 | Equipment                              | Amount of broken equipment.                    | [26][43]  |
There is equipment maintenance schedule.
There is equipment calibration schedule.

Percentage of waste that caused by use of wrong material.

There is countdown timer equipment for reminder project schedule.

All work result meet the specification that has been stated in contract document.

Number of vandalism event in a project.

Number of theft event in a project.

Number of bribery event in a project.

Percentage utilization of recyclable construction material.

Percentage utilization of reusable construction material.

Percentage utilization of material that can be remanufacture.

Amount of wasted material in application process (example: over preparation of mortar).
Amount of wasted material in cutting process.
Amount of wasted material from cutting uneconomical shapes.

4. Discussion
GSCM in the construction industry is an inseparable entity. Each phase is connected follow the PLC. Green Construction (GC) is the phase of implement the green concept that has been planned in Green Initiation (GI) and Green Product Design (GPD) phase. The influence of GI and GPD is reflected in all indicators because GI and GPD is the entry point to apply the green concept in construction. The owner as the key actor of GI phase must have the green vision and commitment to execute it. While, the design consultant as the key actor of GPD phase has to translate green vision into design concepts, including the selection of materials.

Furthermore, good planning and execution of Green Material Management (GMM) phase also contribute to the success of GC phase. The main contractor, the subcontractors, and the suppliers are the actors of GMM phase. They must coordinate in an effective and efficient way to make sure the flow of materials are smooth and meet the quality and specification. From indicators that stated in Table 1, there is a connection between GMM and GC. The influence is reflected in some indicators, there are “percentage of excess material compare with planning”, “percentage of tardiness material availability due to late order”, “there are SOP for material receipt”, “percentage of discrepancy event in material receipt”, “there is quality examination of material”, “percentage of waste that caused by use of wrong material”, and all indicators in Reverse Logistics dimension. From these indicators, it can be seen that GSCM model not only focused on environmental effect but also concerned to eliminate waste in the process, so efficiency purpose can be achieved.

The main contractor as the key actor of GC phase has a responsibility to realize the green design concept. The indicators are focused to reduce material and energy usage during the construction process. Besides that, project management indicators that have to control day by day are described in the overall GC indicators section. These indicators become an inseparable part of GSCM framework.
This “connectivity” becomes a differentiator between GC as an individual concept, and GC as part of GSCM in construction.

5. Conclusion
Based on this study, the framework for implementing Green Construction as part of GSCM in construction consists of four dimensions, 25 elements, and 42 indicators. These indicators mostly covered project management to ensure that project run on schedule, on budget, meet the quality and specification stated in the contract document. The main contractor, subcontractor, and suppliers are the actors of this phase that must build strong coordination to achieve the economic, social, and environmental goals. Further research could develop the detailed measurement scale to completed the measurement tools and then conduct empirical studies in construction projects to validate the indicators.

References
[1] Alwi S, Keith H, Mohamed S. 2010 Proc. Int. Grp. for Lean Const 10 627-638.
[2] Polati G, Ballard G 2004 Proc. Int. Grp. for Lean Const 12.
[3] Ervianto WI. 2015 Konf. Nas. For. Wah. Teknik 2.
[4] Aloini A, Dulmin R, Mininno V, Ponticelli S 2012 Proc. Ann. ARCOM Conf 28 675-85.
[5] Balasubramanian S, Shukla V. 2017 Sup. Chn. Man.: An Int. J. 22.
[6] Ghobakhloo M, Tang S H, Zulkifli N, Ariffin MKA. 2013 Int. J. Man. and Tech 4.
[7] Wibowo M A, Handayani N U, Mustikasari A. 2018 J Ind. Eng. and Mng 11 73-89.
[8] Assudani R, Kloppenborg TJ. 2008 Ann. Conf POMS 19.
[9] US Department of Transportation 2009 (Washington)
[10] Oberlender GD. 2000 Project Management for Engineering and Contractor. (Boston: McGraw-Hill).
[11] Wibowo MA, Uda SAKA, Zhabrinna. 2018 Proc. Int. Conf. on Reh. and Maint. In Civ. Eng 4.
[12] Ozorhon B, Abbott C, Aouad G. 2010 Salford Centre for Research and Innovation 903-12.
[13] Tokel K, Gupta RC, Dandekar M. 2010 Int. Conf. on Ind. Eng. and Op. Man.
[14] Elbarkouky MMG, Abdelazeem G. 2013 The Sust. City VIII 8 1331-1341.
[15] Halil F M, Nasir NM, Hassan AA, Shukur AS. 2016 Proc. Soc. Behv. Sci 222 56-64.
[16] Liu JY, Low SP, He X. 2012 J. Tech. Manag. in China 7 50-63.
[17] Ofori G. 2000 Eur. J. of Pur. and Sup. Chn. Manag 6 195-206.
[18] Kartam NA. 1996 J. Constr. Eng. Manag 122 14-21.
[19] Ervianto WI, Soemardi BW, Abdur M, Suryamanto 2013 Sem Nas Tek Sip IX (Surabaya).
[20] Araujo C, Braganca L, Almeida M. 2013 Int. Conf. Port SB 13.
[21] Yu W, Cheng S, Ho W, Chang Y. 2018 Sustainability 10 1523.
[22] Ali HH, Nsairat SF, 2009 J. Build. And Env. 44 1053-64.
[23] Zainol H, Ali NE, Rashid FA, Ishak N, Talmizi, NM. 2013 ASIA Int. Conf 3.
[24] BOMA. Building Owners and Managers Association International.
[25] Shi Q, Zuo J, Huang R, Huang J, Pullen S. 2013 Habitat International 40 1-8.
[26] Letcher TM, Vallero DA. 2010 Waste: A Handbook for Management. (USA: Elsevier Inc)
[27] Freitas LARU, Magrini A. 2017 Sustainability 9 1251.
[28] Oke A, Mavimbele B, Aigbavboa C. 2016 The Sci. J. for Theo. and Prac. of Socio-ec. Dev. 5 83-92.
[29] Hackman J K, Acheampong A, Agyekum K, Ayaarkwa J 2015
[30] Ahab C 2012 Thesis Eastern Mediterranean University:
[31] Shrestha S. 2016 Comparison of Energy Efficient and Green Buildings: Technological and Policy Aspects with Case Studies from Europe, the USA, India, and Nepal (Berlin: Univ.-Verl. der TU Berlin).
[32] Lill I. 2008 Int. Symp. On Auto. and Robtc. in Const 25.
[33] Chen CC, Shih HS, Shyur HJ, Wu KS. 2012 Comp. & Math. with App 64 2544-57.
[34] Houser DL, Pruess H. 2008 *Environ. Monit. Asess* **155** 431-42.

[35] Shah MR, Pitroda J, Patel CG 2012 Quality Control Management in Building Construction National Conference on Advances in Engineering and Technology (NCAET-2012)

[36] Ying C 2010 *Thesis*. Savonia: Savonia University of Applied Sciences, Business And Engineering.

[37] Zannah AA, Latiffi AA, Raji AU, Waziri AA, Mohammed U. 2017 *Path of Science* **3**.

[38] Ghate PR, Minde PR. 2016 Importance of Measurement of Labour Productivity in Construction 5.

[39] Srivastava S, Chini A 2012 (Gainesville: University of Florid).

[40] Othman I, Idrus A, Napiah M. 2011 *Nat. Postgrad. Conf*

[41] Ziko JM, Lushinga N, Akakandelwa I. 2017 *Int. J. of Soc. Behav. Edu. Econ. Buss. and Inds. Eng* **11**.

[42] Hamid ARA, Majid MZA, Singh B 2008 *Malay. J. of Civ. Eng* **20** 242-59.

[43] Edwards DJ, Holt GD 2009 *J. of Eng. Desg, and Tech.* **7** 186-206.

[44] Molen HF, Hoonakker PLT. 2000 *Hum. Fact. and Ergo. Soc. Ann. Meet. Proc.*

[45] Vee C, Skitmore RM. 2003 *Eng. Const. and Archi. Manag* **10** 117-27.

[46] Berg R, Hinze J 2005 *J. of Const. Eng. and Manag* **131** 826–33.

[47] Global Economic Crime Survey 2014

[48] Fadiya OO, Georgakis P, Chinyio E. 2014 *J. of Const. Eng*.

[49] Dadhich P, Genovese A, Kumar N, Acquaye A 2014 *Int. J. Prod. Econmc*.