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SOCIETAL LCA

A social life cycle assessment model for building construction in Hong Kong

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Abstract

Purpose Social life cycle assessment (S-LCA) is a relatively new technique that is under rapid development. To further improve the reliability of S-LCA, more case studies and methodologies are of paramount importance. This study aims to develop a S-LCA model for building construction projects in Hong Kong, namely, the Social-impact Model of Construction (SMoC). In this paper, a social life cycle impact assessment (sLCIA) method is developed and a case study of a building construction project in Hong Kong is performed.

Methods The development of SMoC is composed of three stages. Stage one strives to establish the sLCIA method which includes the characterization, normalization and weighting. In stage two, a questionnaire survey is conducted to collect the weighting factors and to unveil the social impacts of on-site construction practices. Based on that, the SMoC model which consists of a set of functional worksheets is built. In stage three, a case study following the four-phase structure of S-LCA suggested by the UNEP/SETAC guidelines is conducted.

Results and discussion Of the selected subcategories, local experts believed that health and safety (worker) is the most important social aspect. The questionnaire survey also suggests that the environmental-friendly on-site construction activities as identified in this research are beneficial to the society in general. However, adoption of precast concrete components can lead to negative impacts on fair salary and local employment, since the precast concrete is normally produced outside Hong Kong. The case study demonstrates that the studied project has positive social impacts in general, while the construction stage performs better than the material stage. The sensitivity analysis indicates that inclusion of environmental-friendly construction practices can significantly improve the social performance of the studied building construction project.

Conclusions The developed SMoC model and the case study should provide a comprehensive framework of S-LCA for building construction in Hong Kong. Despite being the first attempt of S-LCA in Hong Kong, the results help inform the local industry the social performance of their construction projects from a life cycle perspective.

Keywords Building construction · LCA · Precast concrete · sLCIA · Social LCA

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1 Introduction

The success of sustainable development depends on three interactive aspects: environment, economy, and society. The increasing awareness of environmental performance of products has given rise to the development of various environmental life cycle assessment (ELCA) tools and life cycle costing (LCC) models which can quantitatively evaluate a product's environmental and economic impacts throughout its "cradle-to-grave" life cycle. Nonetheless, the social dimension of sustainable development seems to attract insufficient attention, especially when there is lack of methods to evaluate the social performance (Hellweg and Canals 2014). The development of social life cycle assessment (S-LCA) is still at its infancy stage. The "Guidelines for Social Life Cycle Assessment of

Products" (hereafter called the Guidelines) published by Benoît and Mazijn (2009) defines S-LCA as "a social impact (and potential impact) assessment technique that aims to assess the social and socioeconomic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal."

Originated from ELCA, S-LCA inherits the four-phase structure (ISO 2006a, b), namely, (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation (Benoît and Mazijn 2009). The first phase details several critical issues of a S-LCA study, such as study goal, intended audience, system boundary, and functional unit. The second phase of inventory analysis is to collect data, establish the S-LCA model, and derive life cycle inventory (LCI) results. In the social life cycle impact assessment (sLCIA), the LCI results are converted to indicators of impact subcategories. The last phase is to interpret the results of LCI and sLCIA and identify hotspots.

The needs for future research are highlighted in the Guidelines not least the general research needs as well as those for the four phases of S-LCA. One of the general research needs is to carry out case studies with additional discussions on methodology, as this can improve the knowledge of S-LCA and promote the applications of S-LCA in practice.

The life cycle of buildings is influential to various stakeholders, in particular those involved in building construction. The safety of workers, noise pollution to neighborhood, degradation of cultural heritage, and so forth should be carefully dealt with in building construction projects. Therefore, it is imperative to examine the social impacts caused by building construction, in particular for the regions like Hong Kong where the population density and the intensity of construction activities are extremely high.

In order to help the construction industry understand the social impact of their construction projects, a case study of S-LCA is provided in this study. More importantly, a S-LCA modeling tool for building construction in Hong Kong, namely, the Social-impact Model of Construction (SMoC), is developed. The proposed model is based on a questionnaire survey and published national statistics. By inputting the studied case of a residential building project in Hong Kong into the SMoC model, social impact analysis can be conducted to identify the social hotspots. The research findings provide insights for future S-LCA studies.

2 Literature review

Considered as a promising method, S-LCA has undergone rapid development in the last decade. Many case studies, such as electronics (Ekener-Petersen and Finnveden 2013; Manhart 2007), food (Feschet et al. 2013; Kruse et al. 2009), waste treatment (Aparcana and Salhofer 2013; Foolmaun and Ramjeeawon 2013; Umair et al. 2013), tourism (Arcese et al. 2013), construction materials (Hosseinijou et al. 2014), and biofuel (Manik et al. 2013) can be found. In addition, a S-LCA database, namely, the social hotspots database (SHDB), has been developed in 2009 which includes about 150 indicators covering 22 social themes (SHDB 2014).

S-LCA is a relatively new technique and there are still several unsolved issues in both the LCI and sLCIA phases. As demonstrated in the reviewed case studies, different methods of data collection were used. For example, Hosseinijou et al. (2014) had interviewed experts to collect the project data throughout the life cycle chain of construction materials and as the interview results were used to develop a S-LCA scoring system. On the other hand, Ekener-Petersen and Finnveden (2013) established a S-LCA model using national data without collecting any project data. More often, national data and project data can both be solicited, but a method shall be put in place to combine them in an innovational way.

Another challenging issue in relation to LCI is the quantification of data, or more specifically, how to link the data to the functional unit. Parent et al. (2010) compared two approaches: (i) type 1 weighting the sLCIA results according to the importance in semi-quantity and (ii) type 2 quantitative link between the inventory indicator and the functional unit. They concluded that type 1 link is more realistic though it cannot represent the social burdens of certain amount of product. This study applies a hybrid method of type 1 and type 2, i.e., to use both the quantitative and semi-quantitative indicators.

In terms of sLCIA, it was pointed out that no agreed method is available for the selection of impact categories and the measurement of indicators (Jørgensen et al. 2008). The Guidelines suggested a top-down method of sLCIA that involves 5 stakeholders and covers 31 subcategories. Kruse et al. (2009) introduced a hybrid approach that combines the top-down and bottom-up methods for determining the indicators. While most of the S-LCA studies focused on worker, studies on other stakeholders should not be overlooked (Jørgensen et al. 2012). Mathe (2014) suggested integrating the participatory approach in S-LCA, as opinions of various stakeholders can be collected so that relevant indicators can be defined.

3 Research design

This study consists of three main stages (Fig. 1). Stage 1 aims to develop a sLCIA method that can quantitatively evaluate the social impacts of a building construction project. To achieve that necessitates three steps: (i) to select stakeholders and subcategories according to their importance and relevance to the building construction in Hong Kong by carrying out literature review and to identify the possible indicators of the selected subcategories and benchmarking the indicator values

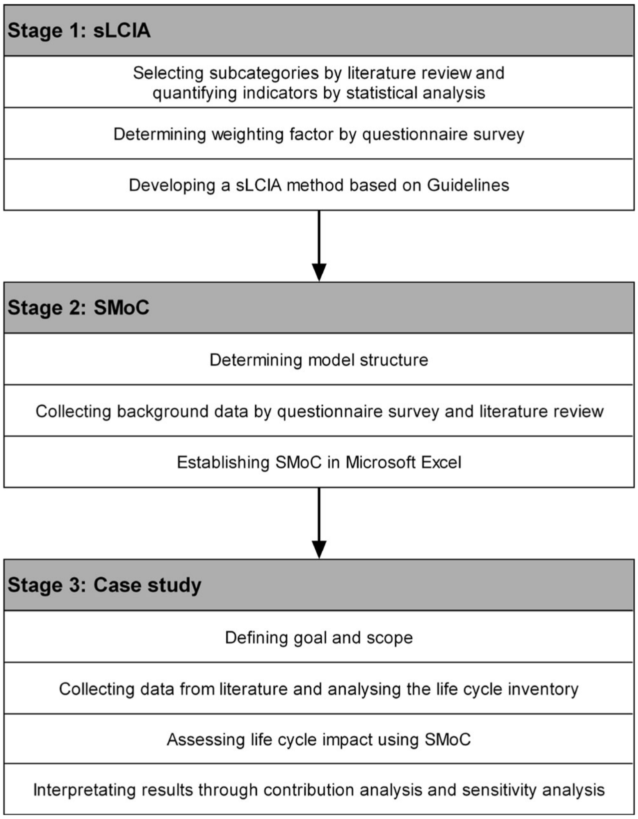

Fig. 1 Schematic illustration of research design

by statistical analysis of national social indicators, (ii) to determine the weighting factors of each subcategory through a questionnaire survey to local experts, and (iii) to develop the sLCIA method by making reference to the established Guidelines and ISO14040/44.

Stage 2 is intended to establish the SMoC using the developed sLCIA methods. The model structure is determined according to the data availability and modeling experience of the researchers. SMoC covers the "cradle-to-end of construction" processes, while usage and demolition of the building facilities are excluded since the downstream processes are more unpredictable and uncontrollable due to their long service life. The omission of the downstream processes is also considered more practical as the usage and demolition phases of building facilities usually involve different stakeholders which may complicate the S-LCA model and lead to difficulties in data collection and model design. The data for establishing SMoC include national statistical data and social impacts of a list of on-site activities. The national statistical data which represent the background social condition was obtained in stage 1. The social impacts of the list of environmental-friendly construction activities are investigated through a questionnaire survey. Microsoft Excel is used to develop SMoC so that a set of functional worksheets can be formulated.

In stage 3, a case study based on a public housing project in Hong Kong is fed into the developed model. The case study follows a four-phase structure as recommended in the established Guidelines. Project data is first collected from published report of the studied building project and then entered into SMoC. Impact assessment is carried out using SMoC whereby the developed sLCIA method is incorporated. The results are further interpreted through a contribution analysis to detect the hotspots of the studied case project. On top of that, sensitivity analysis is performed to identify the influence brought by on-site construction practices which leads to the analysis of 24 alternative scenarios.

4 Development of a sLCIA method

4.1 Selection of subcategories and indicators

Following the published Guidelines, a top-down method is adopted to select the stakeholder categories and subcategories. The Guidelines specifies five stakeholders, including the worker, consumer, local community, society, and other actors. As described above, this research encompasses the cradle-to-end of construction processes without considering the usage and demolition phases. To this regard, consumer is not one of the targeted stakeholder groups under the research scope. The impacts of other actors are also excluded, as it is difficult if not impossible to identify other actors and collect data from them in the complicated building construction supply chain.

As given in Table 1, 13 subcategories are selected according to the data availability. The selection of subcategories is based on a literature search on the currently available indicators. The indicators of the selected subcategories are defined by a combined means using both the quantitative and semi-quantitative data. The original data of indicators are national statistical data that represents an average condition in certain national context. For the quantitative indicators, the indicator values are normalized to a scale of −1 to 1, and −1 is considered to be the worst and 1 is the best social performance.

Figure 2 gives the normalization of quantitative indicators based on the national statistics. For example, freedom of association and collective bargaining (FACB) is described by national FACB rights violation score that ranges from 0 to 10, with 0 representing the best practice while 10 denoting the worst performance. In the sLCIA method, FACB right violation is normalized to the scale of 1 to −1. Regarding the subcategories of fair salary and working hour, semi-quantitative scale is applied based on the national statistics. If the standard weekly working hour of the country is over 60 h, the indicator value of working hour is −1, and 1 if less than 60 h. If the country regulates the minimum wage, the indicator value of fair salary is 1, and −1 if no minimum wage is regulated. For the subcategories of cultural heritage and public commitments to sustainability issues, no national statistics can be found and semi-quantitative scales are applied as described in Table 1.

Table 1 Selection of subcategories and indicators

Stakeholder categories	Subcategories	Indicator	Normalized value range	Source
Worker	1. Freedom of association and collective bargaining	FACB right violations	−1~1	Neumayer and Soysa (2006)
	2. Child labor	Percentage of child labor	−1~1	UNCEF (2013)
	3. Fair salary	Comply with minimum regulation=1; does not comply=−1	−1, 1	OECD (2014)
	4. Working hours	Working hour >60 h=−1; <60 h=1	−1, 1	LD (2012)
	5. Forced labor	Percentage of forced labor	−1~1	ILO (2012)
	6. Equal opportunities/discrimination	Social institutions and gender index (SIGI)	−1~1	OECD (2013)
	7. Health and safety	Fatality rate	−1~1	Hämäläinen et al. (2006)
Local community	8. Access to material resources	Improved sanitation facilities % of population with access	−1~1	WB (2013)
	9. Cultural heritage	Protection=1; no change=0; damage=−1	−1, 0, 1	UNESCO (2013)
	10. Safe/healthy living conditions	Reliability of the police services	−1~1	Schwab (2013)
	11. Community engagement	Index of transparency of policymaking	−1~1	Schwab (2013)
	12. Local employment	Unemployment rate	−1~1	WB (2014)
Society	13. Public commitments to sustainability issues	Obligation on public sustainability reporting	−1, 0, 1	NA

NA Not available

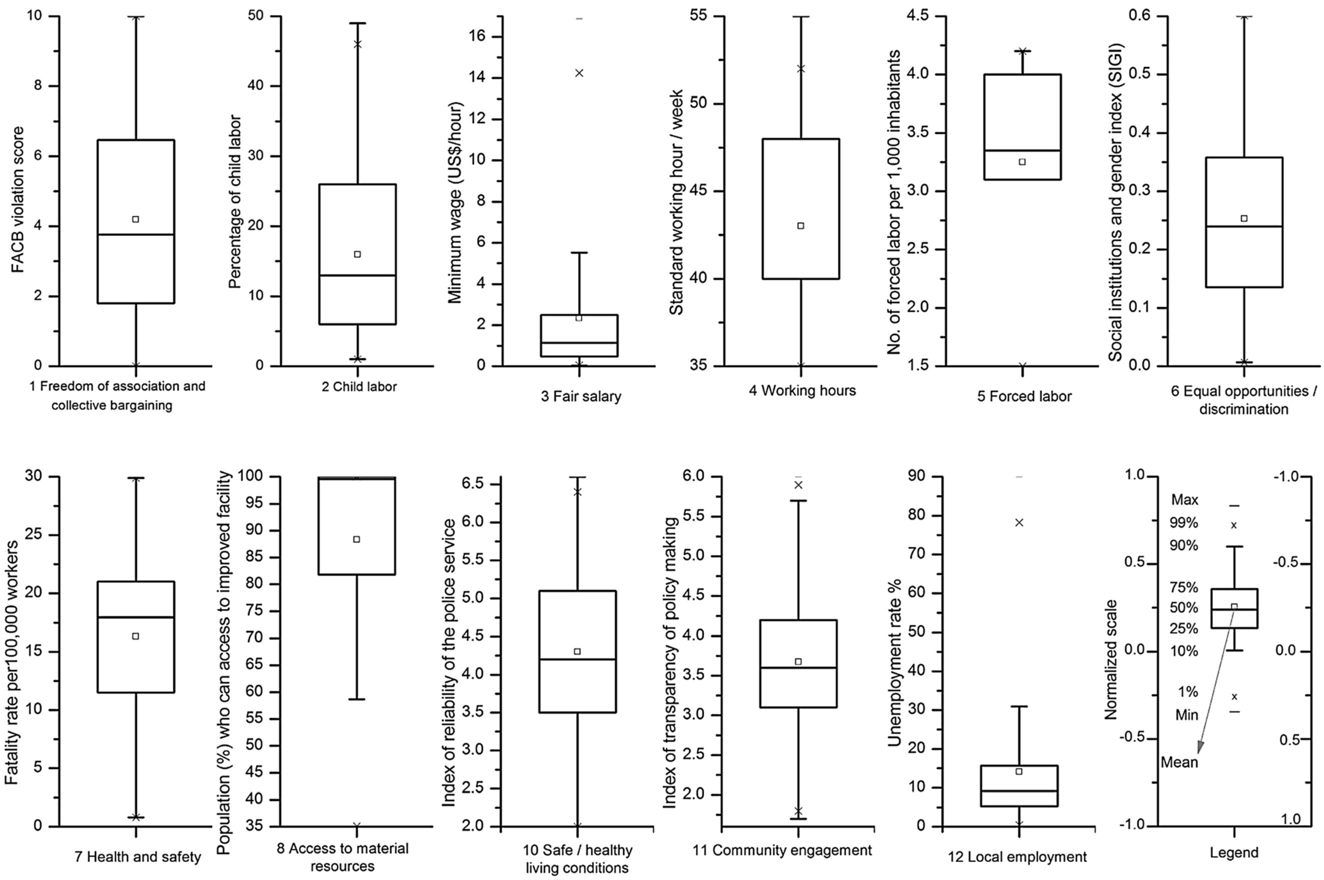

Fig. 2 Statistical analysis of selected indicators and normalization of the indicators. Subcategories of 8, 10, 11, and 12 are normalized to the range of −1~1 (*left axis in legend*); subcategories of 1, 2, 5, 6, and 7 are normalized to the range of 1~−1 (*right axis in legend*); subcategories of 3 and 4 are used in semi-quantitative scale; statistics in subcategories of 9 and 13 are not available

4.2 Collection of weighting factors

4.2.1 Description of the questionnaire survey

A questionnaire survey is designed to collect the weighting factors of subcategories and the social impacts of a set of environmental-friendly construction activities. The questionnaire consists of three parts: part I strives to collect information about the respondent, part II is to investigate the importance of social impact subcategories in the context of building construction, and part III is designed to study the social impact of environmental-friendly on-site construction practices (see Electronic Supplementary Material).

The questionnaire was delivered by means of e-mail and mail to 400 and 187 local building construction experts, respectively, of which 51 replied representing a response rate of 8.6 %. As shown in Table 2, the participants of the questionnaire survey cover several different sectors, including government, private developer, consultant, contractor, supplier/manufacturer, carbon auditor, academic, and others (e.g., quasi-governmental organization, non-government organization, public utility provider, etc.). In the next subsection, the questionnaire findings regarding the weighting factors are reported, while the results of the social impacts of construction activities are highlighted in Section 5.2.

4.2.2 Weighting factors

In part II of the questionnaire, the respondents were asked to rate the importance of the subcategories by means of a five-level Likert scale: very not important (score=1), not important (score=2), neutral (score=3), important (score=4), and very important (score=5). The reliability of the collected responses from the respondents is evaluated by the Cronbach's alpha analysis. Ranging from 0 to 1, the value of Cronbach's alpha of >0.70 represents good internal consistency or reliability of a sample (Cortina 1993). An analysis of the questionnaire survey reveals that the Cronbach's alpha of value is 0.71 which confirms that the samples are consistent and reliable.

Table 2 Summary on the responses of the questionnaire survey

Sector	Responses	Percentage
Government	1	2
Private developer	5	10
Consultant	12	24
Contractor	17	31
Supplier/manufacturer	4	8
Carbon auditor	3	6
Academic	3	4
Others	8	16
Total	51	100

The results pertinent to the importance of selected subcategories (i.e., part II of the questionnaire survey) are given in Table 3. It is interesting to note that health and safety (worker) was ranked as the most important subcategory with a mean score of 4.67. In contrast, child labor was considered as the least important subcategory with a mean score of 3.38. The mean scores in Table 3 are adopted as the weighting factors to develop the sLCIA method.

4.3 Calculation in sLCIA

As suggested in ISO 14040, a LCIA method is normally composed of the following steps: characterization, normalization, and weighting. The sLCIA method developed here is generally in line with the requirements of ISO 14040. The characterization in the developed sLCIA method is to convert the social information into interpretable indicators of a list of impacts. Normalization is to rescale the characterization results into a comparable range. Weighting is to revise the normalization results according to the importance of the subcategories.

For the quantitative indicators with local employment as an example, characterization is to determine the percentage of unemployment rate, normalization is to convert the unemployment rate into the range of −1 to 1, and weighting factor of 3.86 is then applied to calculate the weighting result. For the semi-quantitative indicators, such as cultural heritage, the indicator value is to determine if the project has damage to cultural heritage or not, while the normalization is to assign the values of −1, 0, or 1 to the indicator. Accordingly, in the developed sLCIA method, there is no characterization factor, as the LCI of social impacts is not quantitative. In terms of normalization, normalization factors are only available for those subcategories with quantitative indicators.

The calculation process is demonstrated in Fig. 3 and delineated in the following equations:

$$\mathrm{Ch}_i = \mathrm{In}_i$$

$$\mathrm{NR}_i = \mathrm{Ch}_i \times N_i$$

$$\mathrm{WR}_i = \mathrm{NR}_i \times W_i$$

$$\mathrm{Worker} = \frac{\sum_{i=1}^{7} \mathrm{WR}_i}{13}$$

$$\mathrm{Community} = \frac{\sum_{i=8}^{12} \mathrm{WR}_i}{13}$$

$$\mathrm{Society} = \frac{\mathrm{WR}_{13}}{13}$$

$$\mathrm{Score} = \mathrm{Worker} + \mathrm{Community} + \mathrm{Society}$$

where

i is the ith subcategory

Table 3 Sampling distribution of the responses of part II in the questionnaire survey

Subcategories	Rank	Mean[a]	Number	Standard deviation
1. Freedom of association and collective bargaining	12	3.48	50	0.68
2. Child labor	13	3.38	50	1.35
3. Fair salary	3	4.29	51	0.64
4. Working hours	5	3.98	51	0.55
5. Forced labor	10	3.57	49	1.00
6. Equal opportunities/discrimination	7	3.84	51	0.70
7. Health and safety (worker)	1	4.67	51	0.59
8. Access to material resources (e.g., sanitation, school)	9	3.76	51	0.79
9. Cultural heritage	11	3.51	51	0.90
10. Safe/healthy living conditions (community)	2	4.59	51	0.57
11. Community engagement	8	3.82	51	0.77
12. Local employment	6	3.86	50	0.57
13. Public commitments to sustainability issues	4	4.08	49	0.73

[a] Used as the weighting factors in the sLCIA method

In_i is the indicator value of the ith subcategory

Ch_i is the characterization result of the ith subcategory

N_i is the normalization factor of the ith subcategory

NR_i is the ith normalization result, which should be $-1 \leq \text{NR}_i \leq 1$

W_i is the weighting factor for ith subcategory

WR_i is the weighting result for ith subcategory, which should be $-5 \leq \text{WR}_i \leq 5$

Worker, Community, and Society refer to the weighting results for the three stakeholders

Score refers to the single score

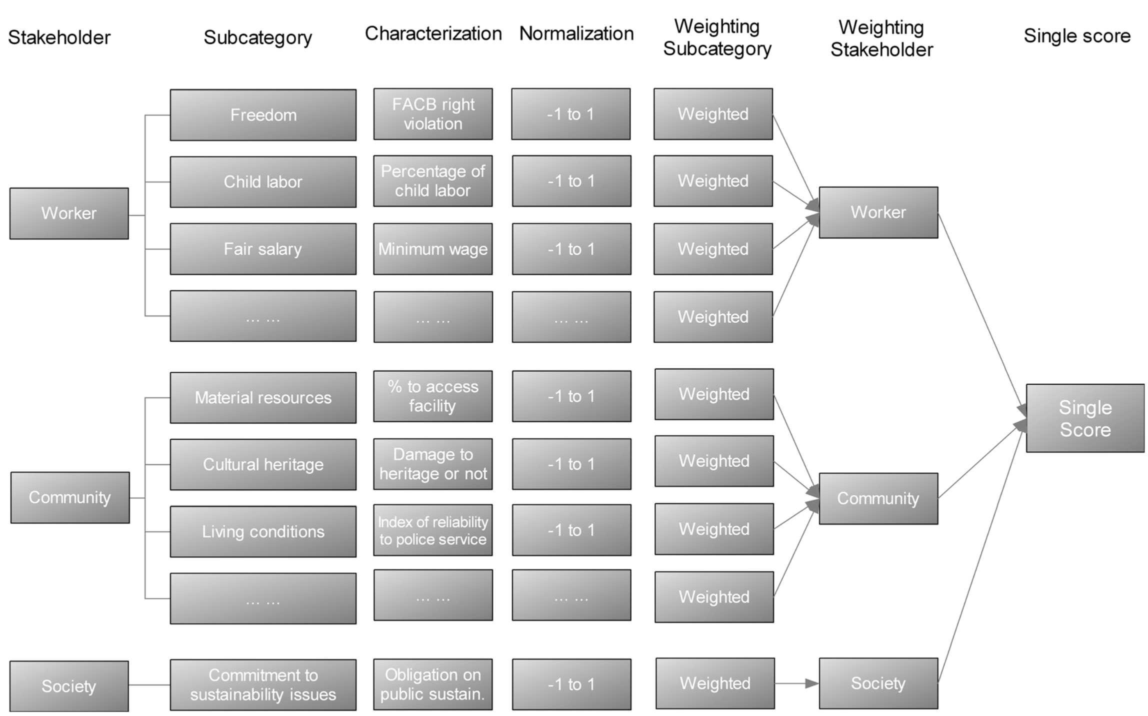

Fig. 3 Characterization, normalization, and weighting in sLCIA

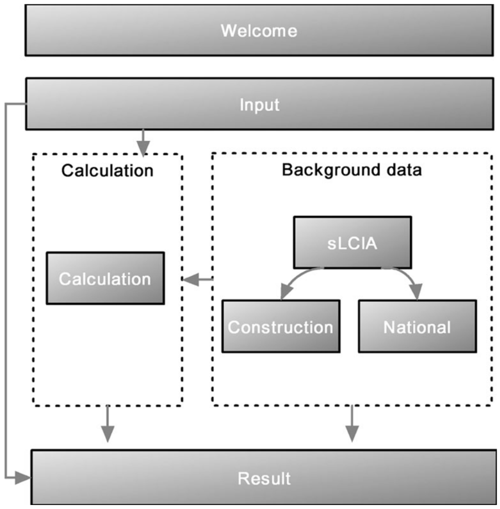

Fig. 4 Model structure of SMoC

5 Social-impact model of construction

5.1 Model structure

SMoC is an assessment tool to evaluate the social performance of a building construction project. The model is composed of seven functional worksheets as shown in Fig. 4, namely, "Welcome," "Input," "sLCIA," "National," "Construction," "Calculation," and "Result." The Welcome worksheet provides the guidance to the model, in which the model structure and the function of each worksheet are introduced. The Input worksheet allows user to enter project data including the general project information, resources with country of origin, and on-site construction activities. As an example to demonstrate the model design, a screenshot of Input worksheet is given in Fig. 5. In SMoC, there are three background worksheets, including sLCIA, National, and Construction. sLCIA documents the weighting factors collected through the questionnaire survey. In the National worksheet, the normalized indicative values of national data as solicited from published literature and websites are provided. The Construction worksheet provides the background information for an array of construction practices which will be further described in Sect. 5.2. The Calculation worksheet integrates the background data and project data and calculates the social impacts of the building construction project. The model outcomes are given in the Result worksheet.

5.2 Social impacts of construction activities

In part III of the questionnaire survey, the social impacts of nine environmental-friendly practices were studied by collecting opinions from the respondents. Respondents were

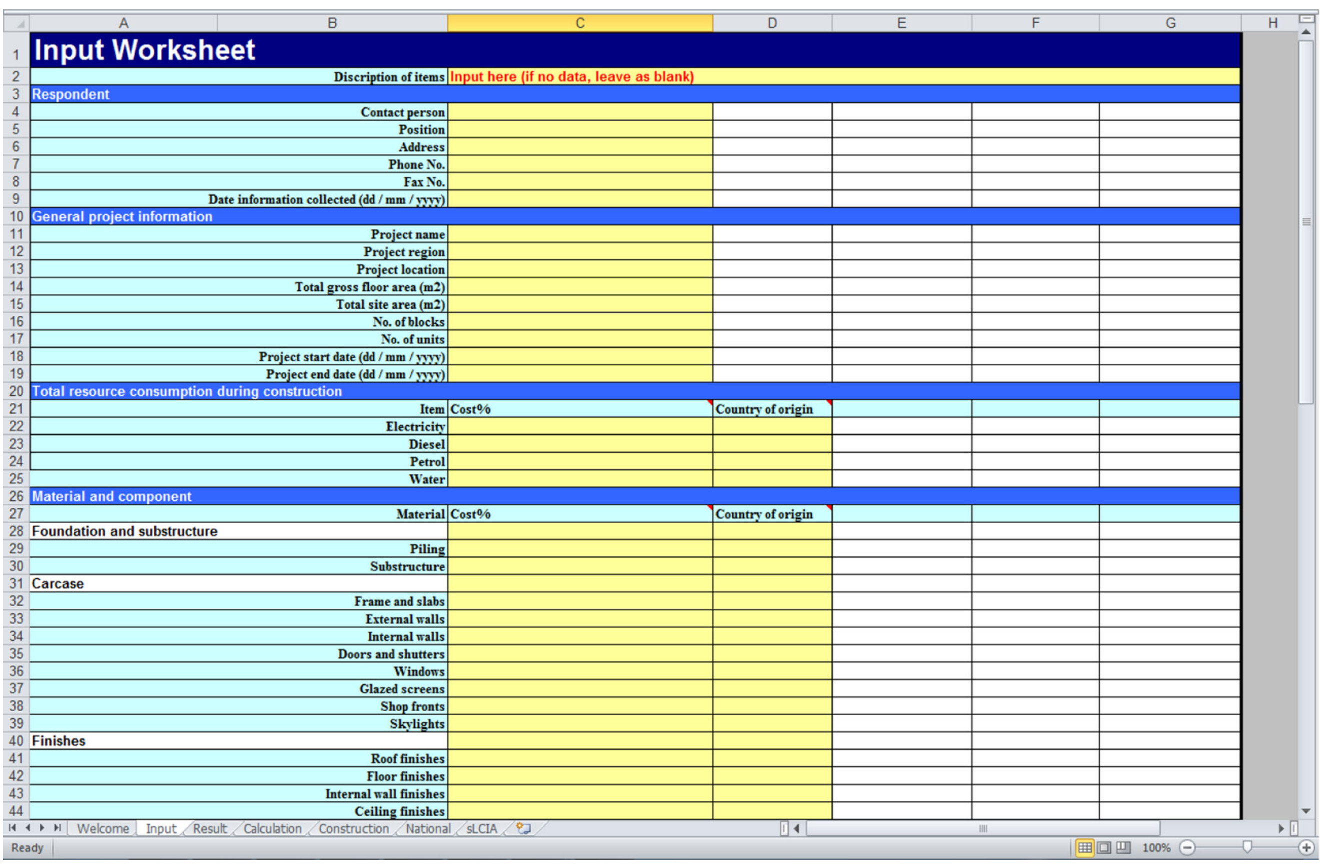

Fig. 5 Screenshot of the Input worksheet

asked to indicate the negative and positive subcategories in the corresponding columns of each environmental-friendly practice. For example, if a respondent believes that the adoption of precast concrete is positive to health and safety (worker), the index of health and safety (worker) should be reflected in the positive column and in the row designated to precast concrete. Besides, the respondents were encouraged to suggest other environmental-friendly construction practices in the questionnaire. In total, 24 on-site construction practices were evaluated (i.e., 9 pre-listed and 15

Table 4 Turnout rate of the social impacts caused by on-site construction practices based on part III (>10 % is listed)

On-site practices	Subcategory	Rate	Negative/positive
Precast concrete element	Fair salary	13	Negative
	Local employment	47	Negative
	Working hours	29	Positive
	Health and safety (worker)	63	Positive
	Safe/healthy living conditions (community)	34	Positive
	Public commitments to sustainability issues	37	Positive
Dust reduction by spraying water	Health and safety (worker)	87	Positive
	Safe/healthy living conditions (community)	82	Positive
	Community engagement	11	Positive
	Local employment	11	Positive
	Public commitments to sustainability issues	34	Positive
Dust reduction by hard pavement	Health and safety (worker)	82	Positive
	Safe/healthy living conditions (community)	74	Positive
	Local employment	13	Positive
	Public commitments to sustainability issues	32	Positive
Dust or noise reduction by physical barrier	Health and safety (worker)	61	Positive
	Safe/healthy living conditions (community)	82	Positive
	Community engagement	18	Positive
	Local employment	11	Positive
	Public commitments to sustainability issues	37	Positive
Adoption of biofuel	Health and safety (worker)	24	Positive
	Safe/healthy living conditions (community)	45	Positive
	Community engagement	16	Positive
	Local employment	16	Positive
	Public commitments to sustainability issues	76	Positive
Waste material recycling	Health and safety (worker)	13	Positive
	Safe/healthy living conditions (community)	29	Positive
	Community engagement	40	Positive
	Local employment	29	Positive
	Public commitments to sustainability issues	92	Positive
Adoption of EURO 5 trucks	Health and safety (worker)	37	Positive
	Safe/healthy living conditions (community)	74	Positive
	Community engagement	13	Positive
	Public commitments to sustainability issues	63	Positive
Generation of on-site renewable energy	Health and safety (worker)	29	Positive
	Safe/healthy living conditions (community)	47	Positive
	Community engagement	29	Positive
	Public commitments to sustainability issues	87	Positive
Natural ventilation	Health and safety (worker)	40	Positive
	Safe/healthy living conditions (community)	61	Positive
	Community engagement	16	Positive
	Public commitments to sustainability issues	63	Positive

suggested by respondents), and all the pre-listed and suggested practices are included in SMoC.

The turnout rates of the social impacts due to the nine environmental-friendly on-site practices are summarized in Table 4. The questionnaire results indicate that most of the environmental-friendly on-site practices contribute positively to the worker, local community, and society. It is worth pointing out that the social impact of precast concrete is indeed rather controversial with 47 % of respondents considering that precast concrete would bring negative social influence to local employment. Nonetheless, 8 % of respondents believed that local employment can be improved through the adoption of precast concrete. With a shortage of space, virtually precast concrete for the building construction in Hong Kong are produced in mainland China leading to a diminishing demand for local concreting labor. However, construction labor shortage facing the Hong Kong construction industry in recent years calls for a greater adoption of precast concrete components.

In the model, the turnout rate is further normalized to adjust the normalization results. While national data is used as the original data, adjustments are inevitable if the listed construction activities are conducted in the studied project. The adjustment details are provided in Table 5. If the turnout rate is 0 %, then the adjustment value is 0. Should the turnout rate be >70 %, the adjustment value is 0.5. The normalization results are ranged within −1 to 1. In case the national data is already reaching the maximum or the minimum (i.e., 1 or −1), no more adjustments can be made to the normalization results. For example, 0.74 is the normalized national indicator value of health and safety (worker) in Hong Kong. According to Table 4, the turnout rate of positive impact of precast concrete element on health and safety (worker) is 63 %, and the corresponding adjustment is 0.4. In addition, the turnout rate of negative impact is 2.6 %, and the negative adjustment is −0.1. In total, the adjustment due to application of precast element on health and safety (worker) is 0.3 (0.4–0.1). To calculate the normalization result, the background value of 0.74 and the adjustment of 0.3 should be combined, resulting in 1.04, which is larger than the maximum normalized value of 1. Hence, the normalization result of health and safety (work), when precast concrete is applied in the construction project, should be 1.

5.3 Model details

The major function of SMoC is to combine the project data with background data so that the social impacts of a building construction project can be calculated. The project data is entered in the Input worksheet. The information needed in this worksheet includes the general project information, resources, materials, and on-site construction activities. The project information includes project region, location, gross floor area, number of units, etc. For the resources and materials, cost percentage and country of origin are required. In terms of the construction activities, the user should indicate if the listed construction activities are included in the studied project. If included, the adjustment will be applied in the following calculation.

The background data obtained from the questionnaire survey, literature review, and statistical analysis are documented in the three background worksheets. The sLCIA worksheet provides the weighting factors of the development sLCIA method. The weighting factors collected through the questionnaire survey (see Sect. 4.2.2) range from 1 to 5, with 5 representing the most important subcategories while 1 being the least important ones. The weighting results are, therefore, ranging from −5 to 5. The value of 5 demonstrates the best social performance while −5 is the worst case. The National worksheet gives the normalized national indicator values of 20 countries or regions that are relevant to the building industry in Hong Kong, such as China, Hong Kong, Japan, Malaysia, and Taiwan. The Construction worksheet includes the normalized adjustment of the list of construction activities based on the questionnaire survey. In addition, the weighted indicator values are also provided in the National and Construction worksheets.

The Calculation worksheet is to calculate the social impacts of the studied project by combining the project and background data. The calculation in this worksheet is illustrated

Table 5 The adjustment of indicator based on part III of the questionnaire survey

Positive		Negative	
Turnout rate (%)	Adjustment of indicator	Turnout rate (%)	Adjustment of indicator
0	0	0	0
0~10	0.1	0~10	−0.1
10~30	0.2	10~30	−0.2
30~50	0.3	30~50	−0.3
50~70	0.4	50~70	−0.4
>70	0.5	>70	−0.5

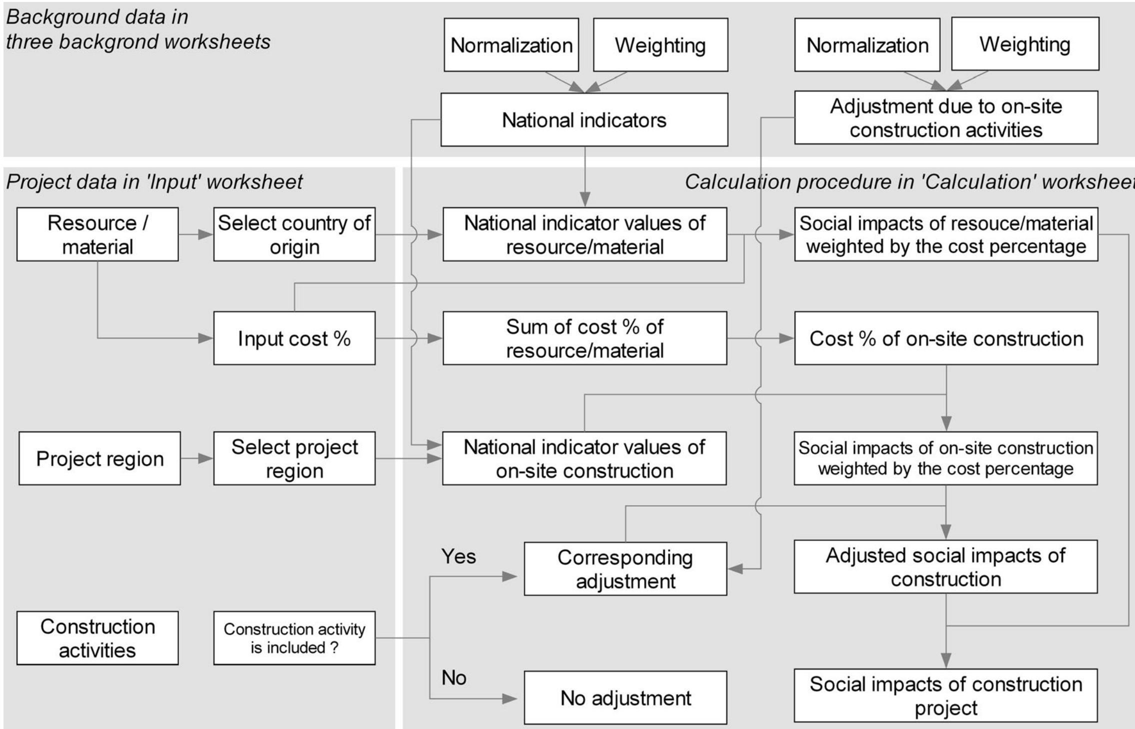

Fig. 6 Calculation procedure in SMoC to combine the background data and project data

in Fig. 6. User should specify the country of origin and cost percentage of the materials and resources consumed in the project. In the Calculation worksheet, the corresponding national indicators are then assigned. Next, the social impacts of the material or resource can be determined by applying the cost percentage that represents the significance of the material or resource in the studied project. For example, if windows are imported from mainland China and the cost of windows is 2 % of the construction cost, the 2 % will be multiplied with the normalized indicator values of mainland China to represent the social performance of windows in the studied project.

The cost percentage of material and resource is also used to calculate the cost percentage of on-site construction, which is calculated as $100\%-\sum_{k=1}^{n}\mathrm{Cost}\%_k$, where $Cost\%_k$ refers to the percentage of cost due to the kth material or resource. The project region is selected in the Input worksheet. In the Calculation worksheet, the national indicator values of on-site construction can thereby be determined and the social impacts of on-site construction (not adjusted) can be calculated. User is also requested to indicate if the listed on-site construction activities are included in the project, and if "Yes," adjustment

Table 6 Normalization results from SMoC

Subcategory	Total	Energy	Material	Construction
Freedom of association and collective bargaining	0.09	0.00	−0.54	0.63
Child labor	0.74	0.00	0.29	0.45
Fair salary	0.77	0.01	0.54	0.23
Working hours	0.95	0.01	0.54	0.41
Forced labor	−0.22	0.00	−0.18	−0.04
Equal opportunities/discrimination	0.15	0.00	0.11	0.05
Health and safety	1.00	0.00	0.32	1.00
Access to material resources (e.g., sanitation, school)	0.84	0.00	0.16	0.68
Cultural heritage	0.27	0.00	0.00	0.27
Safe/healthy living conditions	1.00	0.00	0.09	1.00
Community engagement	1.00	0.00	0.05	1.00
Local employment	1.00	0.01	0.49	0.87
Public commitments to sustainability issues	1.00	0.00	0.00	1.00

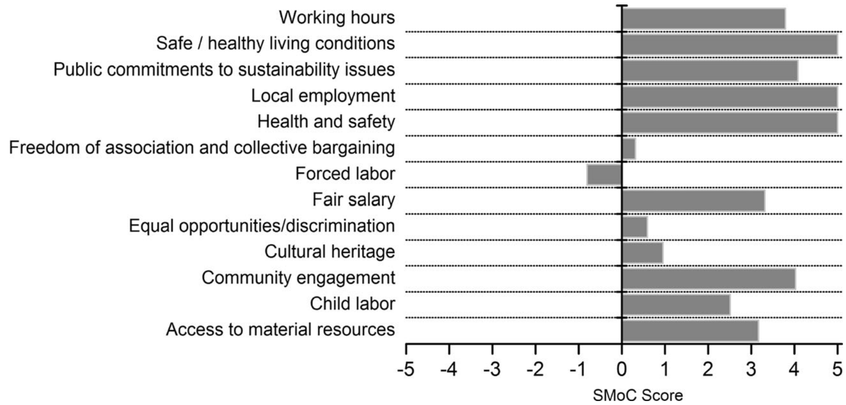

Fig. 7 Weighting results of the studied project

is performed in the Calculation worksheet. By summing up the social impacts in material stage and construction site, the social impacts of a construction project can be obtained.

In the Result worksheet, the results of social impacts are summarized. The results are given in four tables: i.e., summary, resource, material, and construction. The normalization and weighting results of over 80 items are provided. In addition, a single score is calculated, which is also referred as the SMoC score.

6 Case study

6.1 Goal and scope definition

The Hong Kong Housing Authority (HKHA) is the developer of all the public housing projects in Hong Kong, which accommodate about 50 % of Hong Kong people. The studied case is a public rental housing (PRH) project that implements a standard layout of so-called New Harmonized block (HKHA 2014), which adopts precast elements, such as precast façade, semi-precast slab, and precast staircase, for construction.

The goal of this case study is to test SMoC and examine the social impacts of a standard PRH project. The scope of the case study covers the cradle-to-end of construction activities, including the social performance from material acquisition to on-site construction in Hong Kong. The evaluation involves three stakeholders, viz., worker, local community, and society. The functional unit in the case study is the PRH project.

6.2 Inventory analysis

The cost of materials and resources of a New Harmonized building block are collected from HKHA (2005). The country of origin of construction materials are assumed to be from mainland China, since over 70 % materials in the local housing sector are imported from mainland China (HKHA 2005). The country of origin of electricity and water is Hong Kong.

The studied project employed a variety of environmental-friendly strategies, such as precast concrete, dust controlling, and natural ventilation. In the case study, all the 24 environmental-friendly on-site practices are selected.

6.3 Impact assessment

6.3.1 Normalization

The normalization results are obtained from the Result worksheet of SMoC and summarized in Table 6. In general, the total performance of the studied project is positive. However, the subcategory of forced labor is negative, of which is mainly due to the material stage. Negative performance is also found in freedom of association and collective bargaining, which is due to the negative social impact in the material stage. The studied project gains highest score of 1 in the five subcategories: health and safety (worker), safe/healthy living

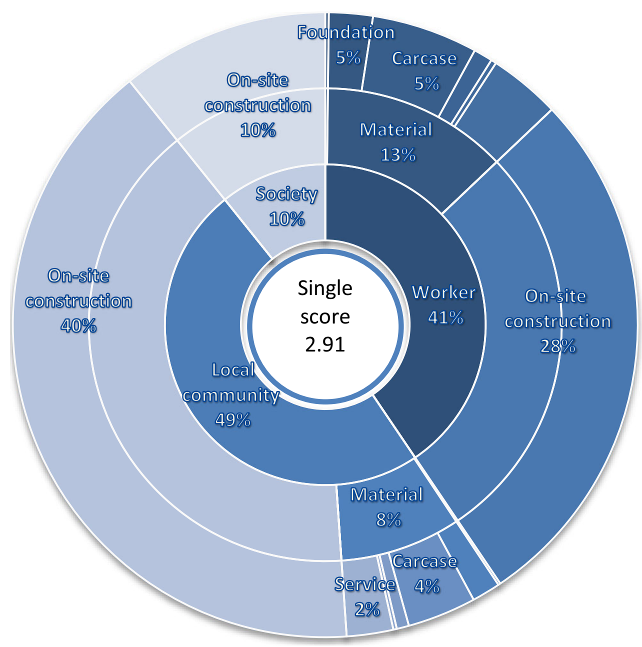

Fig. 8 Breakdown of SMoC score

Table 7 Alternative scenarios of sensitivity analysis on the influence due to the environmental-friendly practices on SMoC score

On-site environmental-friendly practices	I.0	I.1	I.2	I.3	I.4	I.5	I.6	I.7	I.8	I.9	I.10	I.11	I.12	I.13	I.14	I.15	I.16	I.17	I.18	I.19	I.20	I.21	I.22	I.23	I.24
Precast concrete element	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Dust reduction by spraying water	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Dust reduction by hard pavement	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Dust or noise reduction by physical barrier	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Adoption of biofuel	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Waste material recycling	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Adoption of EURO 5 trucks	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Generation of on-site renewable energy	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Natural ventilation	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Steel formwork	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Lift modernization program	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N	N
LED bulkhead light fittings and two-level lighting system	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N	N
Twin water tanks and rainwater harvesting system	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N	N
On-site measures, e.g., metal hoarding and scaffolding	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N	N
Green roof and enhanced tree protection measures	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N	N
Specification, e.g., VOC-free deep penetrating water proofing treatment	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N	N
Application of dual flush water and sensor faucet	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N	N
On-site stormwater management	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N	N
Safety provisions on site for workers to use	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N	N
Waste sorting room in building	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N	N
Design (recycling at source)	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N	N
Water capture and recycling	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N	N
Apprenticeships	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N	N
Communication with local schools, groups	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	N

Y being highlighted in italic indicates the the inclusion of the on-site practice in the scenario

N indicates the on-site practice not being included in the scenario conditions (local community), community engagement, local employment, and public commitments to sustainability issues. In general, the construction stage performs better than the material stage.

6.3.2 Weighting

The weighting results of subcategories are given in Fig. 7. The studied project demonstrates positive social impacts to the stakeholders, in particular to the subcategory of safe/healthy living conditions (local community), local employment, and health and safety (worker). Forced labor is the worst subcategory among all the impact subcategories. On the other hand, freedom of association and collective bargaining, equal opportunities/discrimination, and cultural heritage contribute less significantly to the social impacts.

In Fig. 8, the breakdown of the single score is further analyzed. The single score of the studied building project is 2.91 (ranged from −5 to 5). The constitution of the single score includes 49 % contributed from local community, 41 % from worker, and 10 % from society. In total, on-site construction contributes 78 % (40+10+28 %) to the SMoC score. Material is responsible for 21 % (13+8 %) of the score, which is mainly attributed to the foundation and building services of the project.

6.4 Interpretation

Sensitivity analysis was performed to examine the influence instigated by the input data to the single score. The impacts brought by the environmental-friendly on-site practices to the SMoC score were examined through a series of alternative scenarios. These scenarios were introduced in a progressive manner. With I.0 being the default scenario (Table 7), the 24 on-site practices as listed in Table 7 were removed one by one until all the practices were removed which has resulted in 24 alternative scenarios.

The results of sensitivity analysis are shown in Fig. 9. The declining trend in the impact score indicates that the environmental-friendly construction practices can positively contribute to the social aspect. A sharp decrease by 0.22 of the score is observed from I.8 to I.9, indicating the social impacts of "generation of on-site renewable energy" are significant. When all the environmental-friendly practices are excluded, the score becomes 1.62, which is 44 % lower than the default value. As a result, the identified environmental-friendly practices are highly recommended or used in practice, not only due to the environmental consideration but also because of their positive impacts to the social aspects.

7 Discussion

While social impacts are generally not in quantity form, the data collection methods in S-LCA shall include questionnaire survey, interview, databases, and national statistics. In previous studies, the collected data are converted to positive or negative sign (Arcese et al. 2013; Umair et al. 2013) or to a scoring system (Foolmaun and Ramjeeawon 2013; Manik et al. 2013). The calculation in sLCIA is no longer in characterization, while normalization and weighting are the quantification steps. The process of determining the positive sign or scoring system usually includes the normalization. However, the normalization in sLCIA is a quantifying process with a lack of scientific method currently. Analogous to previous research, this study adopts the research method of national statistics and questionnaire survey to collect data and normalize the results into comparable scales. As shown in Fig. 2, the distributions of the indicators vary considerably, resulting in inaccurate assessment outcomes if more than one subcategory is considered. Inclusion of multiple impacts can also lead to inconsistent results in ELCA (Dong and Ng 2014). S-LCA researchers should be aware of the inconsistence caused by the normalization in sLCIA.

As stated in the literature review, combining different types of data is a challenge in S-LCA. Kruse et al. (2009) applied quantitative indicators in addition to descriptive qualitative indicators. In this study, a combination of quantitative and semi-quantitative data is used as the values of the indicators.

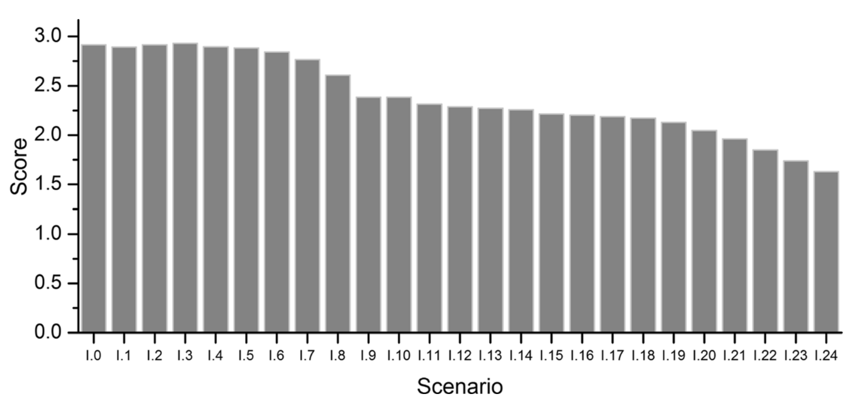

Fig. 9 Sensitivity analysis on the environmental-friendly on-site practices

The two types of data are normalized to a range from −1 to 1, rendering the data of different formats comparable.

Although the Guidelines recommended over 30 subcategories, the developed sLCIA method includes only 13 of them due to the lack to available indicators. In addition, a single indicator is used to represent a subcategory. As a result, a number of social impacts are not covered in the sLCIA method, and this could make the SMoC score less representative. The SMoC score only reflects the social performance of the impact subcategories being considered. Further researches to quantifying the social impacts and establishing new social impact subcategories are therefore inevitable.

The data quality is an issue to be dealt with in S-LCA. In this study, the data acquired from the questionnaire survey may exhibit certain uncertainties. However, uncertainty of the semi-quantitative indicators cannot be measured, rendering it impossible to estimate the uncertainty of the SMoC score. The delineation of any uncertainties of the data would be extremely important to a S-LCA study. For instance, the standard deviation of the weighting factors obtained from the questionnaire survey (Table 3) should help decision-makers establishing the reliability of the social impact score.

The findings of the present study indicate that environmental-friendly construction practices are beneficial to stakeholders from a social perspective. An exception is adoption of precast concrete which is not without negative impacts such as fair salary and local community. These findings can assist local participator considering whether to include such construction method in their building construction practices. For example, at times of labor shortage in the local construction industry, the adoption of precast construction can reduce the labor demand. On the other hand, if the local manpower is overabundant, the contractor should adopt a design with less precast concrete components but more cast-in-situ concrete.

8 Conclusions

S-LCA is a relatively new technique especially when it is still undergoing continuous development. This paper provides a case study of S-LCA for building construction in Hong Kong. A sLCIA method has been developed which includes three steps, i.e., characterization, normalization, and weighting. SMoC which is the first S-LCA model in Hong Kong for building construction has been established. A case study based on a public housing project in Hong Kong has been carried out in accordance with the four-phase structure suggested in established Guidelines.

A questionnaire survey has been conducted to uncover the weighting factors and the social performance of a set of environmental-friendly construction practices. It is found that the health and safety (worker) is the most important subcategory with the mean score of 4.67, while the local experts believed that child labor is the least important concern in Hong Kong. The results of the questionnaire survey indicate that the identified environmental-friendly construction practices are generally beneficial to social aspect. However, the adoption of precast concrete may lead to social problems in terms of fair salary and local employment. Construction stakeholders should take this finding into consideration when determining the building construction method. In view of the negative impacts to the society, precast concrete construction is recommended to be considered if the local industry seriously lacks labors.

While some information related to the social impact may be qualitative in nature, the inclusion of such information is inevitable. Normalization in S-LCA becomes a critical step to quantify the social impacts. S-LCA researchers should be aware of the inconsistence due to normalization when multiple categories are considered. Besides, the SMoC score being computed from the 13 indicators may not fully represent certain social impacts. Future studies are, therefore, needed to identify other relevant subcategories and indicators to improve the reliability of S-LCA. As a first attempt of S-LCA in Hong Kong, this study provides a comprehensive framework of S-LCA which helps the local construction industry understand the social performance of their construction projects from a life cycle perspective.

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