PAPER • **OPEN ACCESS**

Life cycle sustainability assessment for modular construction – A proposed conceptual framework

To cite this article: J Jayawardana *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1101** 042039

Life cycle sustainability assessment for modular construction – A proposed conceptual framework

J Jayawardana[1,2], G Zhang[2], A K Kulatunga[1], M Sandanayake[3] and J A S C Jayasinghe[1]

[1]Faculty of Engineering, University of Peradeniya, Peradeniya, 20400, Sri Lanka
[2]School of Engineering, RMIT University, Melbourne, VIC 3001, Australia
[3]College of Engineering and Science, Victoria University, Melbourne, VIC 3011, Australia

s3884217@student.rmit.edu.au

Abstract. Offsite construction (OSC) is increasingly recognised as a viable alternative for conventional in-situ construction. Modular construction (MC) is one of the most advanced and efficient OSC methods in the construction industry. Even with the distinctive benefits offered by MC, it is imperative to investigate the sustainability performance of MC to understand the trade-offs with traditional construction. Life cycle sustainability assessment (LCSA) is a tool that integrates the three pillars of sustainability from a life cycle perspective. At present, the most common method is to consider the LCSA as a sum of life cycle assessment (LCA), life cycle costing (LCC), and social LCA (S-LCA). However, studies that have employed the LCSA methodology in assessing MC are still lacking in the literature. Relevant literature still lacks comprehensive framework guidance to conduct LCSA of MC. Thus, this paper aims to propose a conceptual framework that integrates the triple bottom line (TBL) of sustainability to assess the sustainability performance of MC using LCSA. The publications acquired from the keyword search analysis were reviewed to develop the conceptual framework by identifying the key factors and challenges to the LCSA. The framework integrates the methodological steps, findings, and gaps related to LCSA discovered from the literature survey. The results show that the LCSA goal and scope should be defined properly to address the complications from the methodological differences of the TBL of sustainability. The proposed framework offers insight to academia and construction industry practitioners about the holistic investigation of the sustainability performance of MC.

1. Introduction

The construction domain possesses significant sustainability issues as a continuously growing industry resulting from human population growth and rapid globalisation. The construction industry is one of the seven most impactful industrial sector hotspots in terms of environmental emissions [1]. Moreover, more than 90% of the world's infrastructure projects are either late or over-budgeted [2]. On top of that, the safety and health issues of construction workers, the quality of building and indoor environment affecting occupant health, and noise pollution to the neighbourhood are some common social concerns [3, 4]. One of the most feasible solutions to mitigate the impacts is shifting into modern construction methods (MMC)/ green construction. OSC produces prefabricated/ modular components in an offsite manufacturing facility, subsequently transported and assembled at the construction site [5]. MC is the most efficient technology among OSC, where this methods manufacture volumetric units and enables them to finish 70-95% of a building offsite [6].

It is imperative to investigate the sustainability performance of MC to promote their adoption. However, detailed studies evaluating their overall life cycle sustainability performance and adequately comparing them with conventional construction are still lacking. Life cycle sustainability assessment (LCSA) is one of the comprehensive tools to evaluate holistic sustainability by integrating the three sustainability dimensions (environmental, economic, and social) from a life cycle perspective. However, the immaturity of social and economic sustainability evaluation methodologies presents a major barrier to conducting LCSA studies. Furthermore, little effort is directed toward properly integrating the triple bottom line sustainability of MC. Comprehensive framework guidance on conducting LCSA in MC is still lacking in the relevant literature. Thus, this paper proposes a decision-based conceptual framework to bridge this research gap and provides LCSA practitioners with integrated methodological guidance. The academic contribution of the research is to provide a comprehensive conceptual framework for future research on the LCSA of MC.

2. Methodology

This study comprises four main stages: literature review, proposed conceptual framework, discussion and conclusions, and future research. Scopus search engine was used for the literature search, considering that the Scopus indexes high impact articles in construction and sustainability research domains. The keywords such as "Life Cycle Sustainability Assessment", "Life Cycle Sustainability Analysis", "LCSA", "Triple Bottom Line Sustainability" and "Life Cycle Assessment", "LCA" and "Social Life Cycle Assessment", S-LCA", "SLCA" and "Life Cycle Costing", "LCC", "Life Cycle Cost Analysis" and "Modular Construction", "Modular Building", "Volumetric Construction" inputted to find the relevant publications from 2000 to 2021. In the second phase, the developed conceptual framework is based on the four stages of the ISO 14040: 2006 LCA framework. The framework is developed by aggregating the methodological steps, findings, and gaps related to LCSA discovered from the literature survey conducted.

3. Life cycle approach in sustainability evaluation

3.1. LCSA

LCSA is one of the comprehensive tools to evaluate holistic sustainability by integrating the three sustainability dimensions (environmental, economic, and social) from a life cycle perspective. "LCSA refers to evaluating all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle" [7]. The model that considers LCSA as the sum of LCA, LCC, and S-LCA is the most applied approach [8].

Recent review studies on the LCSA have identified that LCSA has numerous improvement options to be explored in future research. The adoption of LCSA in sustainability research is still slow-going. Lack of a standardized procedure on how to conduct LCSA resulted in the carrying out of LCSA studies by applying different and subjective methods [8]. UNEP tried to bridge this gap in 2011 by introducing the publication "Towards a Life Cycle Sustainability Assessment: Making informed choices on products" (UNEP/SETAC, 2011). However, the general indications and recommendations on how to start an LCSA given by this publication are not adequate and cannot be directly applied in specific cases. Methodological immaturity of assessment methods of economic performance (life cycle costing) and social performance (social life cycle assessment) are a significant hindrance to applying a life cycle thinking perspective.

3.2. LCA

LCA is a comprehensive environment assessment tool that investigates the environmental performance throughout the sequence of activities carried out in manufacturing a product or performing a service [9]. ISO 14040:2006 and ISO 14044:2006 in the ISO 14040 series standardized the LCA methodology to carry out systematic and uniform environmental evaluations. ISO 14040:2006 presents the four main phases of LCA: goal and scope definition, life cycle inventory

(LCI) analysis, life cycle impact assessment (LCIA), and interpretation. LCA methodology has a history of more than 20 years in effectively evaluating the environmental sustainability of the construction industry [10]; however, particularly in developing economies, the adoption is still sluggish.

3.3. LCC

"LCC is an aggregation of all costs directly related to a product over its entire life cycle, from resource extraction over the supply chain to use and disposal" [7]. Economic assessment under the life cycle perspective can be traced back to the 1930s, even though it does not achieve the global and general standardization like environmental LCA [11]. The most recognizable guidelines for carrying out LCC was published as a book in 2008, which was the work of the Society of Environmental Toxicology and Chemistry (SETAC) [12]. LCC presents a set of significant hurdles such as the availability of data, the use of different currencies, the definition of discount rates, and the relevance of life cycle costs for the different stakeholders (such as customers and companies) [8] which has lower the adoption.

3.4. S-LCA

"S-LCA is defined as a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle" [13]. Although environmental LCA has been widely known and used for the last few decades, the inclusion of social aspects in engineering research constantly challenges sustainability practitioners [14]. Quantification of social data and its correlation to the functional unit, data availability, the choice of indicators, and the selection of comprehensive methods are the main challenges in conducting an S-LCA [8]. The first significant landmark of the methodological evolution of S-LCA occurred in 2009; the "Guidelines for Social Life Cycle Assessment of Products" (UNEP/SETAC, 2009) were published as an attempt to standardize and conceptualize SLCA. As a guide to selecting the indicators and data collection methods, "The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)" [15] were officially published in 2013. Even with this guidance from organizations such as UNEP, some of the inherent and typical issues of S-LCA still remain. Subjectivity issues in indicator selection, weighting, and aggregating are some aspects that cannot be discarded entirely but can minimize the subjective errors using different strategies. For example, some social aspects can only measure by qualitative measures. If a study excludes these indicators, this study potentially under-evaluating the social performance.

3.5. LCSA integration

LCSA integration aims to calculate a single unit of measure (sustainability score, sustainability index) or rank and compare the sustainability dimensions [8]. The greater issue in adopting LCSA harmonization is quantifying the relative performance/ importance of main criteria or sub-criteria under sustainability dimensions using a scientific base. This context is similar to the subjectivity issue in S-LCA in the aggregation process using weights. The most used strategy for integration found in the literature was the expert-based operation research methods [11]. Multi-criteria decision-making (MCDM) methods are more common in LCSA publications. Combining MCDM methods with fuzzy and recent fuzzy extensions can also be employed to reduce the uncertainty, hesitancy, and incompleteness of the expert data.

3.6. LCSA in modular construction

Detailed studies evaluating the overall life cycle sustainability performance of MC and adequately comparing it with conventional construction are still lacking. A little effort is directed toward properly integrating the TBL sustainability of MC. As shown in Table 1, only two studies attempt to conduct an LCSA in MC. Liu and Qian., 2019 proposed an integrated building-specific sustainability assessment model using the AHP-ELECTRE approach. Moreover, they conducted a simplified case study to choose the best alternative regarding sustainability from MC-based, semi prefabricated, and conventional designs [16]. The accuracy and comprehensiveness of this study are limited due to acquiring data for semi-prefabricated and traditional designs from a previous study published in 2013. Moreover, using only one indicator for the economic dimension and equally weighting the three dimensions are further limitations of the study. The second study was a building information modelling-based framework proposed by Hammad et al., 2019 to contrast the TBL sustainability of conventional and MC. This study did not focus on integrating the sustainability dimensions. Furthermore, the assessment is only limited to six indicators, which have excluded the important environmental impacts such as carbon emissions. On top of that, the qualitative aspects of S-LCA were not investigated.

Table 1. LCSA of modular construction

Study	Title	Scope	LCSA Methodology	Integration method	Indicators	Indicator quantification methods
[17]	Building information modelling-based framework to contrast **conventional and modular construction** methods through selected sustainability factors	Only the scope of embodied energy is specified (Cradle-to-gate)	LCSA=New	None	**Environmental**: energy efficiency and embodied energy; **Social**: safety and noise pollution **Economic**: time and cost of construction	1. Embodied energy - Cradle-to-gate (Derived equations) 2. Energy efficiency - U-value calculation 3. Safety - Fuzzy logic and Risk distribution 4. Noise pollution - Noise-level measurement 5,6. Time and Cost - Utilisation of schedules, productivity databases, and cost indices
[16]	Towards sustainability-oriented decision making: Model development and its validation via a comparative case study on **building construction methods**	Cradle-to-use	LCSA = LCA + LCC + SLCA	AHP-ELECTRE-MCDM	**Environmental**: Human health, Ecosystem diversity, Resource availability **Social**: Worker, Occupant, Local community well-being and development of industry/ society **Economic:** Economic optimization	**LCA**: ReCiPe **SLCA**-Fuzzy, Country contribution analysis, Consistent fuzzy preference relations AHP (CFPR-AHP) **LCC**-Net present value

The identified gaps from the literature survey indicate the need for more comprehensive LCSA studies in the MC domain. Apart from the highly researched sustainability concerns, labour shortages and the need for quick fixing-built environment demands to shift into MC technologies. Promoting these methods is challenging in some regions of the world; thus, the necessity for comprehensive sustainability assessments is imminent. Therefore, addressing the methodological hindrances, particularly in LCC, S-LCA, and LCSA integration, is crucial to accelerate the move towards MC sustainability evaluation. Notably, a decision-based conceptual framework for conducting LCSA in a life cycle perspective in MC is still lacking in the relevant literature. A framework guide in selecting scope, deciding LCIA approach, interpretation strategies, and insights on LCSA integration has the potential to increase the methodological awareness of MC LCSA practitioners.

4. Proposed conceptual framework

4.1. Goal and scope

The MC LCSA practitioner must decide on the study purpose, objectives, and scope in the first phase. Alejandrino et al., 2021 identified that published LCSA studies had followed four main goals [11], as shown in Figure 1. The alternative analysis compares the sustainability of one or more different construction methods with MC, whereas performance analysis evaluates the sustainability performance of the selected MC project. Moreover, hotspot analysis focuses on identifying the sustai-

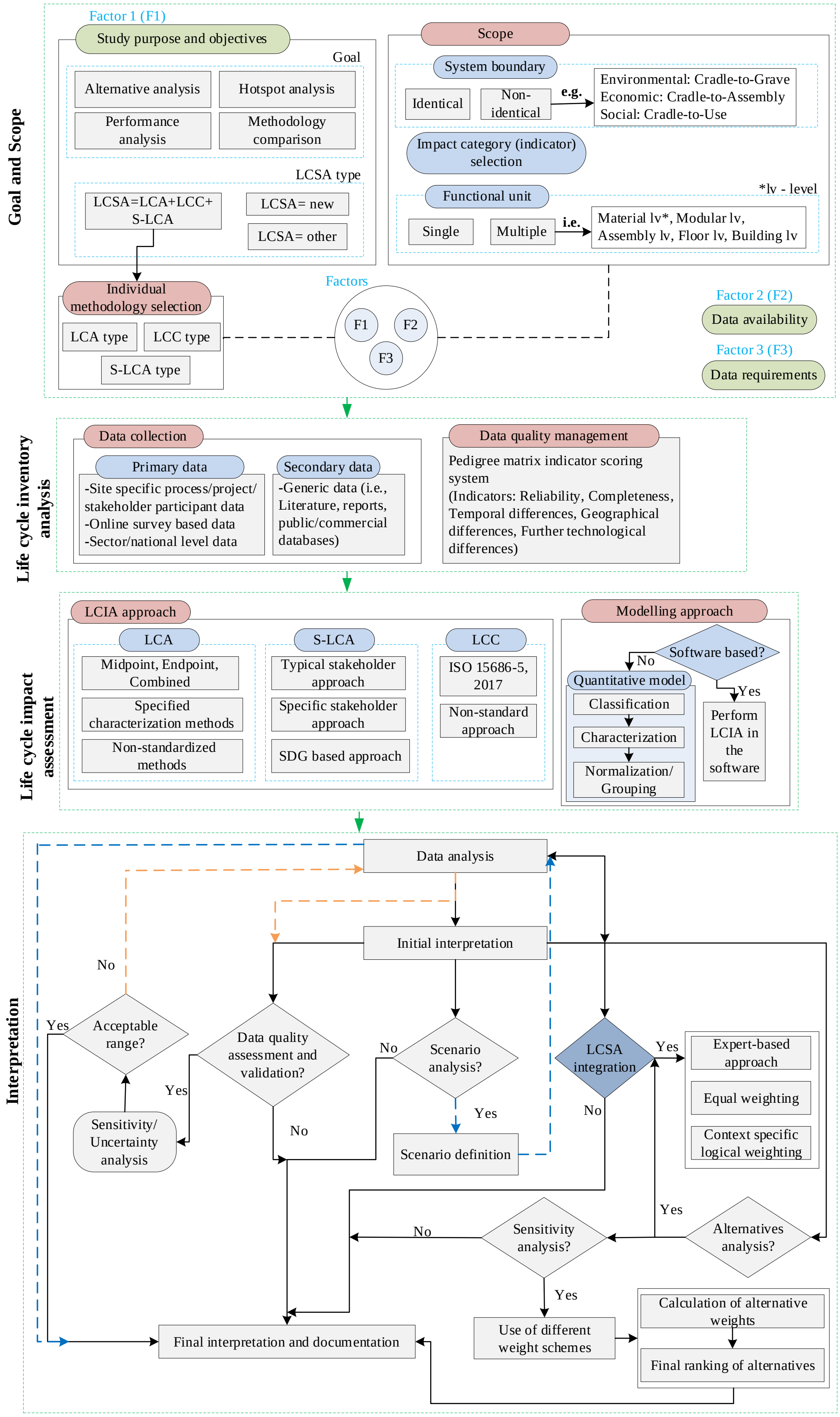

Figure 1. Proposed decision-based conceptual framework

-nability hotspot life cycle stages of the MC project under analysis and methodology comparison compares LCSA methodologies and scopes [11]. LCSA applier should have a clear idea about the type of LCSA that will be used in the research cause the rest of the assessment will depend on the LCSA type selected at stage one of the framework. According to Costa et al., 2019, three main LCSA types were applied in LCSA literature [8] proposed by Klöpffer [18], as shown in Figure 1. Type 1 is LCSA as a summation of LCA, LCC, and S-LCA, where the three sustainability dimensions have been individually assessed. LCSA as a new assessment (Type 2) based on a single inventory of environmental, economic, and social pillars. LCSA, as others (Type 3), include approaches such as LCSA as a summation of eco-efficiency and SLCA and LCSA as a summation of LCA and socio-economic analysis [8]. Hammad et al., 2019 and Liu and Qian, 2019b employed Type 1 and 2 respectively in their TBL sustainability assessments.

Scope and individual methodology selection of the three sustainability pillars depend on three critical factors, namely study purpose and objectives (Factor 1- F1), data availability (Factor 2- F2), and data requirements (Factor 3- F3). In this context, data requirements refer to data specificity and accuracy. System boundary can be identical for all the three dimensions, or else depending on the limitations such as data accessibility and availability, it can be non-identical [19, 20]. The rest of the assessment following the scope definition will depend on selecting the functional unit (FU). Two possibilities for selecting FU as single and multiple [21]. However, it will highly depend on F1, F2, and F3. Moreover, indicator selection under the three sustainability pillars plays a massive role in defining scope. This selection process also depends on F1, F2, and F3. Individual methodology selection for the sustainability dimensions is a key task in the first stage of the LCSA. Three main LCA methods perform environmental performance evaluations: process-based LCA, input-output (I-O) based LCA and hybrid-based LCA. These three methods have their unique pros and cons and can apply based on the focus of the LCA study. In the case of S-LCA, classical S-LCA for product social assessments and social-organizational LCA (SO-LCA) expanded the typical S-LCA by including an organizational perspective [22]. The LCC guideline published in 2008 has identified three LCC types: Conventional LCC, environmental LCC, and social LCC. Environmental LCC is similar to environmental LCA with the inclusion of environmental externality costs.

4.2. Life cycle inventory (LCI) analysis

Data collection is the most challenging activity in MC sustainability assessments. To conduct a comprehensive and systematic LCSA, a thorough and detailed inventory analysis is imperative. LCSA goal and type, scope definition, and individual methodology selected will decide the kind of data needed to be collected to develop the LCI. Three main techniques can acquire primary data, as presented in Figure 1. Particularly in S-LCA, the need for the participation of MC stakeholders (i.e., workers and local community) will be required to collect data for qualitative and semi-quantitative indicators defined in the first stage. Survey questionnaires and/or interviews can be conducted to fulfilling this purpose. Moreover, commercial databases such as Social Hotspots Database (SHDB) and Product Social Impact Life Cycle Assessment (PSILCA) can be used as secondary data for social assessment. Data quality management is vital to enhance the accuracy and validity of the LCSA study. The pedigree matrix indicator scoring system employed in ecoinvent can be utilized to maintain a record of data quality.

4.3. Life cycle impact assessment (LCIA)

Selecting the LCIA approach is critical to representing the collected data comprehensively and accurately. In the context of LCA, the midpoint approach is concerned with real environmental problems in the mid-way of an impact pathway. In contrast, the endpoint approach focused on the area of protection such as human health, ecosystem quality, and resource depletion [23]. The combined LCIA approach uses both midpoint and endpoint methods in the LCA study. CML and ReCiPe are the most employed characterisation models in these approaches [8]. In the second type of approach, some LCA practitioners used specific characterization models for particular indicators, and the third primary approach employs non-standardized techniques such as Geopolitical Supply Risk [11]. S-LCA's typical stakeholder approach complies with the assessment method recommended by UNEP/SETAC, 2009. In contrast, a specific stakeholder approach employs specific stakeholders unique to the analysis system [11]. Moreover, the sustainable development goals (SDG) based approach uses SDGs in place of stakeholders to define the indicators [11, 24].

International organization for standardization (ISO) has developed a specific standard (ISO 15686-5:2017, Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing) providing requirements and guidelines for performing LCC analyses of buildings and constructed assets and their parts, whether new or existing [25]. The non-standard approach does not use any standard for the LCC study. LCA, LCC, and S-LCA have two main modelling options: the software-based approach and the quantitative model approach. SimaPro, openLCA, and GaBi are software that is frequently used for LCA modelling. The openLCA provides a platform for conducting all LCA, LCC, and S-LCA [26].

4.4. Interpretation

The fourth stage of the life cycle perspective is to interpret the results from the assessment. Data analysis is the central element of this stage. An initial rough interpretation can be effective and beneficial for further analysis and interpretation strategies. Data quality assessment and validation is a must in comprehensive and systematic LCSA, and it will reinforce the transparency of the assessment by checking the accuracy and reliability of data. Sensitivity and uncertainty analyses are frequently applied for this validation process. Scenario analysis is keen on investigating the effect of possible and/or desired future situations by changing the input variables [27]. The more significant complication in LCSA integration is quantifying the relative performance/ importance of main criteria or sub-criteria using a scientific base. Finding interconnections between totally different aspects (environmental, economic, social) can be extremely difficult. LCSA integration is possible mainly by three options, expert-based approach, context-specific logical weighting, and equal weighting.

The expert-based weighting process got advanced and is more justifiable by combining MCDM methods with fuzzy and recent fuzzy extensions, so it has evolved from just taking averages to considering the uncertainty, hesitancy, and incompleteness of the expert data. For example, the D-CFPR-AHP method can address cases involving uncertain and incomplete information by using D numbers [28]. Moreover, for an LCSA study focusing on alternative benchmarking, LCSA integration can be repeated for all the alternatives and then conducted the comparison. In addition, LCSA practitioners can decide on using other weight schemes to increase the comprehensiveness and accuracy of the study.

5. Discussion

The framework proposed has aggregated scattered approaches, concepts, and guidance in relevant literature into a concentrated structure. The LCSA approach has a vast scope; the time and effort required to search for this methodological knowledge by MC LCSA users have been potentially reduced by introducing the conceptual framework. On top of that, the interpretation of the framework revealed some key references related to the LCSA approach, which would fast-track the literature exploration. One of the significant implications of the research is the contribution to the holistic sustainability assessments of MC by the integrated framework. The presented methodological elements and references can provide the starting point for MC LCSA research. While the framework cannot address the inherent challenges in MC adoption and MC sustainability assessment, it attempts to urge motivation. One key factor regarding the framework is that even though the focus is only on one sustainability pillar; still, provided guidance will be helpful to initiate the standalone assessment.

6. Conclusions, limitations, and further research

LCSA is a methodology that can evaluate the holistic sustainability of product systems from a life cycle perspective. LCSA of MC is a highly under-researched field that requires further exploration to benchmark MC compared to conventional construction. Comprehensive framework guidance for conducting LCSA is still lacking in the relevant literature. Thus, the primary focus of the study was to introduce a decision-based conceptual framework to elevate the methodological guidance of LCSA practitioners in the MC industry. The methodological guidance given in the literature, gaps, and directions were employed to create the framework. The proposed framework comprises four phases corresponding to the ISO 14040: 2006 LCA framework. The framework indicates that the LCSA goal and scope should be appropriately defined to address the complications from the methodological differences between the three sustainability dimensions.

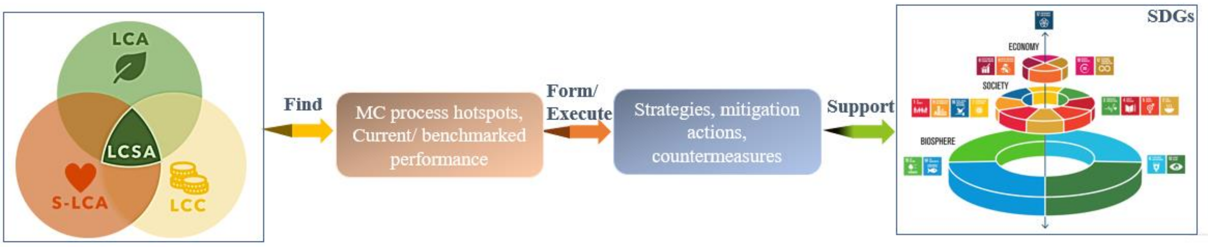

Figure 2. LCSA in MC supporting SDGs

The main limitation of the study was the absence of a pilot case study to demonstrate the applicability of the proposed framework. Future research can focus on validating the framework by conducting real case studies. Moreover, LCSA combined with circular economy aspects and LCSA indicators interaction with SDGs can be further evaluated in future research work. In the world context, the LCSA in MC can aid in achieving the United Nations (UN) SDGs (see Figure 2), which is becoming a vital necessity for the betterment of the biosphere, society, and economy.

References

[1] Sandanayake M, Zhang G and Setunge S 2016 Environmental emissions at foundation construction stage of buildings–Two case studies *Building and Environment,* **95** 189-198
[2] Efficiency eludes the construction industry 2017 Available from https://www.economist.com/business/2017/08/17/efficiency-eludes-the-construction industry [Accessed 14 December 2021]
[3] Dong Y H and Ng S T 2015 A social life cycle assessment model for building construction in Hong Kong *The international journal of life cycle assessment,* **20** 1166-1180
[4] Liu S and Qian S 2019 Evaluation of social life-cycle performance of buildings: Theoretical framework and impact assessment approach *Journal of cleaner production* **213** 792-807
[5] Yin X, Liu H, Chen Y and Al-Hussein M 2019 Building information modelling for off-site construction: Review and future directions *Automation in Construction* **101** 72-91
[6] Thai H T, Ngo T and Uy B 2020 A review on modular construction for high-rise buildings *Structures* **28** 1265-1290
[7] Ciroth A et al 2011 Towards a life cycle sustainability assessment: making informed choices on products
[8] Costa D, Quinteiro P and Dias A 2019 A systematic review of life cycle sustainability assessment: Current state, methodological challenges, and implementation issues *Science of the total environment* **686** 774-787
[9] Sonnemann G and Vigon B 2011 Global guidance principles for Life Cycle Assessment (LCA) databases: a basis for greener processes and products
[10] Alhumayani H, Gomaa M, Soebarto V and Jabi W 2020 Environmental assessment of large-scale 3D printing in construction: A comparative study between cob and concrete *Journal of Cleaner Production* **270** 122463
[11] Alejandrino C, Mercante I and Bovea M D 2021 Life cycle sustainability assessment: Lessons learned from case studies *Environmental Impact Assessment Review* **87** 106517

[12] Hunkeler D, Lichtenvort K and Rebitzer G 2008 *Environmental life cycle costing* (Crc press)
[13] Andrews E S 2009 Guidelines for social life cycle assessment of products: social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development (UNEP/Earthprint)
[14] Huarachi D A R, Piekarski C M, Puglieri F N and de Francisco A C 2020 Past and future of Social Life Cycle Assessment: Historical evolution and research trends *Journal of Cleaner Production* **264** 121506
[15] Aulisio D 2013, The methodological sheets for subcategories in social life cycle assessment (S-LCA) (L. C. I. UNEP/SETAC)
[16] Liu S and Qian S 2019 Towards sustainability-oriented decision making: Model development and its validation via a comparative case study on building construction methods *Sustainable Development* **27** 860-872
[17] Hammad A W, Akbarnezhad A, Wu P, Wang X and Haddad A 2019 Building information modelling-based framework to contrast conventional and modular construction methods through selected sustainability factors *Journal of Cleaner Production* **228** 1264-1281
[18] Klöpffer W 2008 Life cycle sustainability assessment of products *The International Journal of Life Cycle Assessment* **13** 89-95
[19] Ferrari A M, Volpi L, Pini M, Siligardi C, García-Muiña F E and Settembre-Blundo D 2019 Building a sustainability benchmarking framework of ceramic tiles based on life cycle sustainability assessment (LCSA) *Resources* **8** 11
[20] Schau E M, Traverso M and Finkbeiner M 2012 Life cycle approach to sustainability assessment: a case study of remanufactured alternators *Journal of Remanufacturing* **2** 1-14
[21] Zira S, Rydhmer L, Ivarsson E, Hoffmann R and Röös E 2021 A life cycle sustainability assessment of organic and conventional pork supply chains in Sweden *Sustainable Production and Consumption* **28** 21-38
[22] Norris B *et al 2020* Guidelines for Social Life Cycle Assessment of Products and Organizations *United Nations Environment Programme: Nairobi, Kenya*
[23] Sharaai A H, Mahmood N Z and Sulaiman A H 2011 Life cycle impact assessment (LCIA) using EDIP 97 method: An analysis of potential impact from potable water production *Scientific Research and Essays* **6** 5658-5670
[24] Wulf C, Werker J, Zapp P, Schreiber A, Schlör H and Kuckshinrichs W 2018 Sustainable development goals as a guideline for indicator selection in life cycle sustainability assessment *Procedia Cirp* **69** 59-65
[25] ISO 2017 DIS 15686-5 Buildings and constructed assets-service life planning *International Organization for Standardization*
[26] openLCA The open source life cycle and sustainability assessment software Available from https://www.openlca.org/ [Accessed 21 December 2021]
[27] CFI Education Scenario Analysis vs Sensitivity Analysis Available from https://corporatefinanceinstitute.com/resources/knowledge/modeling/scenario-analysis-vs-sensitivity-analysis/ [Accessed 21 December 2021]
[28] Deng X, Hu Y, Deng Y and Mahadevan S 2014 Supplier selection using AHP methodology extended by D numbers *Expert Systems with Applications* **41** 156-167