Sustainability criteria for introducing new technologies in low-income contexts

Citation for the original published paper (version of record):
Mallalieu, A., Jonasson, A., Petersson, S. et al (2024). Sustainability criteria for introducing new technologies in low-income contexts. Proceedings of the Design Society, 4: 1359-1368.
http://dx.doi.org/10.1017/pds.2024.138

INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.138

Sustainability criteria for introducing new technologies in low-income contexts

Adam Mattias Mallalieu [1,2,✉], Amanda Jonasson [1,2], Sara Petersson [1,2], Marlene Rosendal [2], Sophie I. Hallstedt [1,3], Lars Almefelt [1] and Ola Isaksson [1]

[1] Chalmers University of Technology, Sweden, [2] Engineers Without Borders, Sweden,
[3] Blekinge Institute of Technology, Sweden

✉ adammal@chalmers.se

Abstract

Introducing new technologies in low-income contexts have potential for positive social impact, and such efforts are made by humanitarian engineering non-govermental organisations (NGOs). The impact can increase if a systemic sustainability perspective is considered in the design process. Sustainability criteria are identified using a literature study combined with an empirical study together with a Swedish NGO. These criteria are synthesized into a simplified Sustainability Fingerprint tool which is evaluated and deemed to be useful when introducing new technologies in low-income contexts.

Keywords: sustainability, sustainable design, design methods, social equity, social innovation

1. Introduction

There is currently an ongoing climate crisis where industry is trying to adapt, design, and propose more sustainable solutions. On the other end the most vulnerable communities, i.e., communities with limited adaptability to climate change, already suffer from the consequences of climate change and its resulting social unfairness. It is estimated that 3.3 to 3.6 billion people are living in contexts highly vulnerable to climate change (United Nations, 2022). Many of these vulnerable communities are already suffering severe consequences from climate change (Mutunga et al., 2013) when at the same time, the African continent for example, have been responsible for less than four percent of the world's carbon emissions during the last 20 years (i.e., between 2000-2021, see e.g., Statista, 2023). Efforts to counteract the effects of e.g., climate change and social injustice are therefore made by volunteers and Non-Governmental Organizations (NGOs) within humanitarian engineering who seek to introduce new technologies and solutions in low-income contexts. Humanitarian engineering is also sometimes referred to as *development engineering* or *engineering for change* and relate to the application of engineering skills to support vulnerable communities (Schismenos et al., 2021). The desired social impact is however considered limited due to several reasons such as cultural differences, lack of ownership, and ability to maintain solutions. Prahalad and Hart (2002) refer to these contexts as bottom-of-the-pyramid. Demssie et al. (2019) characterize the bottom-of-the-pyramid context as *"an environment where a significant proportion of people with low income and limited infrastructure live mainly in rural regions of developing countries"*. Demssie et al. (2019) also present a set of competencies required to appropriately design solutions in such contexts while claiming that studies related to this are scarce.

One Swedish humanitarian engineering NGO with more than 15 years of active engagement in humanitarian engineering called Engineers Without Borders Sweden (EWB-SWE), have recently redefined their strategy with an ambition to put more emphasis on *"increased social impact for the* *communities we engage with"*. This redefined strategy stems from the need to ensure that technologies and solutions which are introduced in low-income contexts focus on the social impact, and not on the solution or technology as such. In this paper, social impact refers to any significant or positive change that solve or at least address social injustice. One internal example from EWB-SWE is that the success of a solar panel is assessed by how many households it in reality provides energy to, and not only its theoretical performance. There can also be several positive impacts that are not obvious from a first order analysis. One internal example from EWB-SWE refer to the installation of a water tank that via a first order analysis only provide clean water to the community. However, installing the water tank also reduces the daily walking distance a single child has previously done to collect water and can therefore also result in more effectively used school-hours. Access to water can also support children with increased focus, while in school, due to reduced dehydration. Following this, EWB-SWE also identified the need for a new and improved internal design process which require more formalized ways of working by e.g., support of several niche design methods and tools. A study was therefore initiated by a Swedish technical university, Chalmers University of Technology, together with EWB-SWE to develop and co-create a design process consisting of several existing design methods and tools to support an introduction of new technologies in low-income contexts from a sustainability perspective (see Jonasson and Petersson, 2023). This paper focuses on the development of one of the identified tools that specifically aims to support designers in humanitarian engineering NGOs to better introduce new technologies in low-income contexts from a sustainability perspective. Such a tool was required to ensure that sustainability is considered in the early design stages from a social, ecological, and economic perspective throughout a solution's full lifecycle. The tool to be developed was therefore based on a recently developed design tool called the *Sustainability Fingerprint* (Hallstedt et al. 2023) with the generic aim to anticipate the sustainability performance of a potential solution. The identified candidate design tool does however require adaptation to better align with low-income contexts and the needs of designers, or volunteers, in humanitarian engineering NGOs. The following research question was therefore formulated to guide the work: ***What are key sustainability criteria for introducing new technologies in low-income contexts?*** This research question was addressed by conducting a literature study combined with an empirical study together with EWB-SWE. The obtained results were synthesised into a design tool, namely a *simplified Sustainability Fingerprint* which was evaluated with EWB-SWE and researchers in sustainable product development.

2. Research approach

The research approach consisted of three main parts: (i) a literature review; (ii) an empirical study together with EWB-SWE; (iii) development and evaluation of the *simplified Sustainability Fingerprint*.

2.1. Literature study of humanitarian engineering

A literature study on the topic of humanitarian engineering was carried out to identify key aspects to consider when introducing new technologies in low-income contexts. This study was of both snowballing (Wohlin, 2014) and systematic characteristics. The systematic part of the study made use of Scopus and combined keywords of *ecological*, *sustainability*, *sustainable community development*, *humanitarian engineering*, *social*, *cultural*, *economic*, and *context*. Only books, journal- and conference articles, written in English were included in the final literature sample. Keywords of *students*, *civil engineering*, *undergraduate students*, and *first-year engineering* occasionally had to be excluded because some of the literature was related to travelling engineering students and the corresponding factors affecting their work. The findings of the literature study were categorized into different needs that were later analysed using thematic analysis to identify patterns of recurring barriers, enablers, or areas of improvement related to the introduction of new technologies in low-income contexts. The summarized results of the literature study along with the list of needs are presented in Section 3.1.

2.2. Empirical study with EWB-SWE

EWB-SWE has been working within humanitarian engineering for more than 15 years and was used as a case organization. EWB-SWE provided empirical data both with regards to their current and new design and project process along with concrete insights from experiences of conducting humanitarian

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

engineering projects. Empirical data was collected by examining company documents and by conducting interviews. A total of 12 semi-structured interviews were carried out (online) with people that have had first-hand experiences of carrying out projects. The interviewees are positioned within EWB-SWE's competence teams and support functions and had experience from different type of projects (project scope, geographical location, and *success rate*). This provided input on both the needs of the designers, or volunteers, in the design process, but also concrete input to common barriers and enablers based on experiences from previous projects. The semi-structured interviews were also analysed via a thematic analysis, using in-vivo coding or more specifically by extracting relevant statements. The summarized results of the empirical study along with the list of needs are presented in Section 3.2. Furthermore, the insights from studying the current design process and the needs of designers also support in contextually adapting the design tool, such as making it more applicable.

2.3. Development and evaluation of the sustainability fingerprint

A Sustainability Fingerprint tool (see Hallstedt et al., 2023) consist of a set of well-defined contextually relevant sustainability criteria (i.e., *Leading Sustainability Criteria*). The tool is supposed to aid designers in the early phases of design, more specifically: (i) to guide designers towards a more sustainable design; (ii) to compare alternative designs; (iii) to assess the sustainability performance of a design. The development of such a tool is in turn, ideally, developed in four steps, see Hallstedt et al. (2023). Due to both limitations of this study along with desired adaptations from EWB-SWE it was instead developed with some modifications. There two main limitations or adaptations made are: (i) The identified sustainability criteria are not broken down into different scales according to a *Sustainability Compliance Index* (see Hallstedt, 2017). Instead of dividing the criteria into levels 1-9, this tool only proposes one scale or index of a desired state. An ideal Sustainability Fingerprint should instead have several scales with concrete and quantifiable metrics that support more thorough assessments and to strategically improve the sustainability performance over time. (ii) The development of a Sustainability Fingerprint typically involves a collaborative approach together with practitioners and experts to identify the *Leading Sustainability Criteria* (see e.g., Watz and Hallstedt, 2024). It should also be iterated several times together with practitioners and experts inside the company (Hallstedt et al., 2023). The sustainability criteria in this Sustainability Fingerprint were instead identified based on the insights captured from both the literature study and the empirical study conducted by two of the researchers that were part of this study. As a result of the slight modifications, this tool is classified as a *simplified Sustainability Fingerprint*. The proposed tool still incorporates several of the main principles of a Sustainability Fingerprint, such as that it considers all sustainability dimensions (i.e., social, ecological, and economic) and covers the product's full lifecycle. Furthermore, the tool was evaluated in three iterations. First, together with practitioners from EWB-SWE in a workshop format. Second, together with a professor in sustainable product development. Third, together with a researcher in sustainable product development with practical experience from a humanitarian engineering project.

3. Results

The main results that were used to develop the *simplified Sustainability Fingerprint* are presented in the two sub-sections below.

3.1. Literature review of humanitarian engineering

Humanitarian engineering is an interdisciplinary field which combine engineering with several other fields, e.g., economics, social sciences, entrepreneurship, and business that together with or for communities that are in need for creating technological innovation (UC Berkely, 2020). This also reflects the summarized list of needs (barriers and enablers) towards introducing new technologies in low-income contexts which is presented in Table 1. Passino (2016) argue that it is important that a community can adopt and maintain a solution that has been implemented as well as managing its components and material once it is deemed obsolete. Amadei et al. (2009) mention that educating and empowering communities need to be the main priority in humanitarian engineering projects and that the technology as such is secondary. Partnering with the community to find long-lasting solutions is seen as beneficial. Lucena et al. (2022) also stated that the community need to be central in these types of projects. Passino (2016) shares similar view while also adding that it is beneficial to support the community in identifying opportunities and exploit their own potential and capabilities i.e., *help them help themselves*. Passino (2016) also recommends a more bottom-up oriented approach as compared to top-down when it comes to introducing new technologies, the problem that a technology or solution aims to solve must be rooted in the local community. Jagtap and Larsson (2018) discuss three different type of roles a community can adopt, namely the roles of, *the consumer*, *the producer*, and *the co-creator*. The first one commonly fails (long-term), as the community is less involved in the design process and only consumes the developed solution. The other two involve the community in the design process to a greater extent and have benefits. The community as *a producer* support in e.g., employment and reducing poverty. The role of a *co-creator* ensures that local and contextual factors are better considered in the design. Shekar and Drain (2016) claim that contextual adaptation is crucial and a common reason of why solutions fail while suggesting that 'western world' designs cannot simply be placed as they are. Whitehead et al. (2016) proposed eight criteria to be used in the design process, namely, affinity, desirability, repairability, durability, functionality, affordability, usability, and sustainability. The organization for economic cooperation and development (OECD, 2021) defined six criteria in, relevance, effectiveness, impact, coherence, efficiency, and sustainability claiming that these can support in the evaluation of interventions. Social aspects or constraints are important to consider but not easily identified according to Wood et al. (2013) who proposed designers need to better consider emphatic design, tradition, trust, and community engagement in the design process. Environmental sustainability is also critical to consider since it can further enhance the negative consequences of climate change, such as, drought, flooding, and high temperatures. Mutunga et al. (2013) state that *"indigenous knowledge is a critical pillar"* to address climate change adaptation. UNESCO (2021) also state that local or indigenous knowledge is an enabler towards developing solutions that are sustainable in their context. Amadei et al. (2009) state that part from many of the above-mentioned barriers or enablers it is crucial to also consider economic mechanisms that can ensure long-term success of a solution, where education, capacity training, and empowerment were considered as potential means.

Table 1. Summary of needs identified from literature study on humanitarian engineering

Nr.	Need	Nr.	Need
1	Adoption and maintenance of sustainable solutions	13	Collaboration with partners as co-creators
2	Waste management and end-of-life solutions	14	Developing solutions that generate revenue
3	Education and empowerment of communities	15	Understanding and accommodating different social, cultural, and economic contexts
4	Community involvement central to development efforts	16	Ensuring social justice in solutions
5	Addressing long-term aspirations of the community	17	Identifying and addressing social barriers and constraints
6	Identification and utilization of local resources	18	Amplifying the needs and choices of minority groups
7	Identification and utilization of local opportunities	19	Implementing environmentally friendly solutions
8	Understanding and addressing community needs	20	Considering environmental changes and adaptation
9	Enhancing the capability of community members to fix products	21	Leveraging local knowledge about the environment
10	Access to knowledge and understanding of technology	22	Identifying economic mechanisms within solutions
11	Integration of technology into community life	23	Ensuring affordability of the solutions
12	Assessment of community needs, aspirations, resources, and capacity	24	Identifying and mitigating risks associated with economic mechanisms

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

3.2. Empirical study with EWB-SWE

EWB-SWE operates both inside Sweden but also internationally, in countries such as Tanzania, Kenya, Nepal, and more. EWB-SWE has more than 900 members with a distribution of approximately 50/50 students versus senior and established engineers. The goal of the international projects is to *"empower low-income communities to ensure access to basic services"*. A new international project process has been developed internally which now consist of six phases or stage-gates in: (i) initial assessment of projects; (ii) feasibility study; (iii) planning; (iv) implementation; (v) conclusion; (vi) monitoring and evaluation. Each phase involves a decision gate, and the first phase serves as an initial screening of projects to pursue and the last two relates to project-managerial activities. For example, how to ensure that learnings are captured and that the implemented solution is maintained as planned. The feasibility study consists of the main design-oriented activities in the project process where the conceptual solution is designed and proposed. Following this phase, detailed planning begins and the implementation phase focus on realizing the solution. Changes to the solution can occur both in planning and implementation due to unforeseen events. The feasibility therefore serves as *early phase design* and is where the Sustainability Fingerprint is aimed to be utilized. The EWB-SWE have five main areas or *competence groups* in which projects are carried out internationally: (i) Water, sanitation, and hygiene; (ii) Construction (i.e., civil engineering); (iii) Digitalisation; (iv) Energy and Waste; (v) Food and agriculture. Each competence group consist of experts within that field, EWB-SWE also have supporting functions in e.g., partnership assessment and an international projects secretary. The 12 semi-structured interviews that were carried out with different stakeholders in the organization resulted in several different needs of EWB-SWE and its designers. These were summarized into 14 distinct needs using a thematic analysis and are presented in Table 2.

Table 2. Summarized needs of EWB-SWE

Nr.	Need	Explanation of need
1	Community capabilities	How well it contributes to improved community capabilities that will ensure the solution can be maintained and sustained
2	Incorporation into work process	How well it can be smoothly incorporated into the international project process
3	Decision basis	How well it includes the information required to decide if a project should be approved or declined
4	Solution exploration	How well it promotes the exploration of different solutions
5	Motivation of the volunteers	How well it motivates the volunteers to use it
6	Knowledge sharing (internally)	How well it promotes knowledge sharing internally
7	Knowledge sharing (externally)	How well it promotes knowledge sharing with and from external stakeholders, such as the partner
8	Ease of communication	How well it ensures clear and continuous internal and external communication
9	Contextual understanding	How well it contributes to contextual understanding
10	Sustainability evaluation	How well it ensures that the solutions sustainability performance can be evaluated
11	Partner collaboration	How well it involves the partner in the project
12	Social impact evaluation	How well it promotes and evaluated the social impact of a project
13	Ensure local needs	How well it ensures true local needs have been identified and verified
14	Community engagement	How well it ensures the community is involved in the project and its potential to be involved

4. Proposition: Key sustainability criteria for introducing new technologies in low-income contexts

Fifteen sustainability criteria (C1-C15) were identified following the empirical and literature study and are presented in Table 3. These are placed in the corresponding lifecycle phase and each criteria is provided by a brief explanation, rationale, and an indicator. The user should follow the following three steps when using the design tool: (i) Read through the sustainability criteria and use the explanation of each criterion to understand how it can be measured/assessed on the defined indication. It explains what

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

each criterion is and why it is important to use; (ii) Once a minimum of one concept or solution have been developed, this tool is used to assess the sustainability performance of the solution. It can be used as an analysis tool to raise awareness on what sustainability aspects are important to consider when developing a solution in the humanitarian engineering context; (iii) Based on your developed concept or solution, go through each criterion and comment on how the solution fulfils or not fulfils the criteria as well as state potential actions to take to improve the sustainability performance. The tool can thus be used to both assess whether the criteria is fulfilled but also support to steer early concept exploration. The final *simplified Sustainability Fingerprint* tool proposed to EWB-SWE was provided in a more user-friendly Excel format and includes a more intuitive structure to depict the criteria for each lifecycle phase, along with textboxes for comments on *how well a criterion is met*, and *actions for improvement*. This improves e.g., scalability and communication but formatting and available space limits the authors to provide this version of the design tool in this paper.

Table 3. Proposed key sustainability criteria for introducing new technologies in low-income contexts. "E&R" refers to explanation and rationale, and "I" refer to indicator

Lifecycle phase I: Material acquisition		**Lifecycle phase II: Implementation of solution**	
C1: Local Materials & Components	*C2: Renewable Materials*	*C3: Equal/equitable Suppliers*	*C4: Community Engagement*
E&R: Local materials and components are obtained from a defined radius around the project site, which helps to support the local economy and reduce transportation costs and energy consumption in the community.	E&R: Renewable material's rate of growth is not larger than their rate of use, their environmental impact is lower than non-renewable materials and their availability is not threatened by their use. Examples are bamboo, wood, cork etc. Recycled materials are measured as the total percentage of recovered materials in a product.	E&R: Equal and equitable suppliers refer to, the extent that the suppliers are working towards equality and inclusivity within the workspace. When marginalized groups are empowered and included in decision-making processes, they can contribute with their unique perspectives and knowledge to create more effective and sustainable solutions.	E&R: Community engagement helps the implementation of a solution that is culturally appropriate, effective, and sustainable. The project team builds relationships, understands cultural context, and enables co-creations by arranging workshops and seeking continuous feedback.
I: The solution maximises the use of locally sourced and produced materials and components.	I: The solution maximises the use of renewable or recycled materials (recycled materials can be non-renewable).	I: The solution maximises the use of suppliers that promotes and are actively working towards equality and inclusivity with 50/50% of women and men in their workforce.	I: The solution maximises community engagement during the project process, implementation, and use stages.
Lifecycle phase III: Usage and maintenance			
C5: Solution Affordability	*C6: Solution Desirability*	*C7: Solution Accessibility*	*C8: Solution Safety & Health Risks*
E&R: Solution affordability is to what extent the solution is affordable compared to people's average income in the area. An affordable solution should not compromise its quality or sustainability aspects. If a solution is not affordable to everyone it might not help those who need it the most.	E&R: Solution desirability is the degree to which a proposed solution is attractive, acceptable, and feasible to stakeholders. Desirable solutions tend to be more long-term socially sustainable, and it ensures a solution that the locals will be proud of.	E&R: Solution accessibility is the extent to which the solution is inclusive, equitable, and user-friendly for the intended users. Minority group characteristics could be race, ethnicity, religion, gender identity, sexual orientation, age, and disability. Ensuring an accessible solution helps to bridge the gap in the community for minorities.	E&R: The solution should not put the user's safety or health at risk during maintenance and usage to ensure that it's not harmful to anyone. Examples of risks include physical injury or harm to the user, electrical hazards, or exposure to hazardous substances. A safe work environment lays the basis for a successful solution.

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

I: The solution maximizes affordability for the intended users in the local community.	I: The solution addresses all of the identified needs, aspirations, and expectations of the intended users in the local community.	I: The solution maximises & promotes accessibility for the intended users in the community.	I: The solution minimises the risks posed to the user's health and safety.
Lifecycle phase III: Usage and maintenance			
C9: Environmental Risks	*C10: Increased Opportunity for Jobs*	*C11: Increased Opportunity for Education*	*C12: Equality Promotion*
E&R: Environmental risks refer to the extent to which the solution causes extensive pollution and waste production during use. Examples could be high greenhouse gas (GHG) emissions from heating schools, or high generation of non-biodegradable waste with no waste treatment system. To not further negatively affect the environment in the region.	E&R: Increased opportunities for jobs in the local community help to tackle unemployment and reduce poverty. By building local community capacity, engineers can design and implement solutions that are culturally appropriate, economically sustainable, and community owned.	E&R: Increased opportunities for education and knowledge creation create new opportunities for individuals and communities. Acquiring new skills and knowledge can create new economic opportunities and contribute to the development of local communities.	E&R: Promoting equality helps to create a more sustainable and resilient society. A solution should empower and strengthen women and other minority groups' rights in the community. For example, it can be to provide education for persons with disabilities and to include economic mechanisms that create entrepreneurship opportunities for women.
I: The solution minimises GHG emissions during use and the waste is part of a circular economy.	I: The solution maximises the amount of job opportunities for the local community.	I: The solution maximises the opportunity to provide training, education and knowledge sharing in the local community.	The solution actively works towards achieving gender equality.
Lifecycle phase III: Usage and maintenance		**Lifecycle phase IV: Solution end-of-life procedure**	
C13: Responsible & Renewable Energy Sources		*C14: Available Materials & Components*	*C15: End-of-life Procedures*
E&R: Sustainable renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass can be replenished or renewed over time, but they must also be environmentally and socially responsible. Not all renewable sources are responsible for example if wildlife, forests, etc. are negatively affected.		E&R: Available materials and components are not threatened by their use. Long-term available components and materials are especially important for critical components of the solution and the availability of spare parts. Otherwise, it can negatively affect the long-term use of the solution.	E&R: The end-of-life procedures refer to the extent to which the solution produces waste and GHG emissions during end-of-life procedures., and to what extent it is part of a circular economy (this involves a sustainable take-back system). Not considering this increases the chances of it not being safely or sustainably taken care of.
I: The solution maximises the use of energy from responsible and renewable sources throughout the whole lifecycle.		I: The solution maximises the acquisition of materials and components that are long-term available.	I: The solution is part of a circular economy where the number of components and materials that are reused and reproduced is maximised.

Many of the criteria refer to the solution as such, but some criteria refer to the involvement of stakeholders in the design process, i.e., involving stakeholders in the design and/or implementation of the solution. The proposed criteria are not intended to have different ranking in relation to each

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

other and all should be assessed during the design process. The purpose of this design tool is to: (i) guide designers towards more sustainable design; (ii) compare alternative designs; (iii) assess the sustainability performance of different designs. Furthermore, the authors provide two recommendations related to the use of the proposed design tool. First, humanitarian engineering NGOs need to utilize a more formalized design process that is supported by several design methods and tools that ensure the proposed key sustainability criteria can be assessed appropriately as well as fulfilled. Jonasson and Petersson (2023) propose a set of established design methods (e.g., *Janus Cone*, *Morphological Method*) as part of a design process that can support in this. Second, the identified sustainability criteria cover several interdisciplinary aspects, and NGOs need to ensure that project teams have a wide competence set, including e.g., both technical, social and/or human-behavioural sciences, and entrepreneurial competencies. Moreover, the proposed sustainability criteria put further emphasis on closer collaboration between NGOs and local partners or suppliers. Recent literature within circular economy have investigated similar challenges. The role of *ecosystem orchestrators* is for example discussed in e.g., Trevisan et al. (2022) and refer to organizations that coordinate activities performed by actors in the value chain to enable more circular and sustainable designs. This is a concept NGOs potentially can adopt to facilitate closer collaboration with local partners or suppliers and increase the ability to meet the proposed sustainability criteria, but it requires further investigation.

5. Evaluation and applicability of proposed tool

The proposed design tool was evaluated in three distinct iterations and focused on two aspects, both the identified sustainability criteria as such but also the design tool interface. This is discussed below along with the applicability of the proposed tool.

5.1. Evaluation of proposed tool and potential improvements

The first version of the proposed design tool (Sustainability Fingerprint) was evaluated with practitioners from EWB-SWE. This was done in the form of a workshop where they could express opinions and provide general feedback. The main outcome of this evaluation was that they requested the qualitative measurement scale, the so-called *Sustainability Compliance Index*, to be removed for simplicity of the intended users inside EWB-SWE. This scale was deemed as too time consuming and cumbersome requiring a more thorough assessment. There was also a consensus that the use and application of the *simplified Sustainability Fingerprint* is dependent on other activities in the new and improved process. The outcomes of these activities provide additional information and knowledge required to appropriately assess the sustainability criteria. It was also stated that the designers should acquaint themselves with the criteria early in the process and that the design tool is used continuously throughout the design process. The proposed design tool was deemed to be useful in scoring the sustainability performance of different concepts or solutions, raise awareness of important aspects (or criteria) to consider, and as aid in decision-making.

The second version of the Sustainability Fingerprint was evaluated by a professor in sustainable product development. This resulted in general input on how to better formulate and describe the criteria and smaller additions of sustainability related aspects which added depth to the criteria. It was also recommended to include at least a simple grading that provide indication on how well a criterion is met to ensure it is captured by the tool. The Sustainability Fingerprint was also suggested to be classified as a *simplified Sustainability Fingerprint* because of the adaptations and simplifications made.

The third version of the Sustainability Fingerprint was evaluated by a researcher in sustainable product development with practical experience from humanitarian engineering projects within EWB-SWE. The main feedback and input were to standardize the criteria such that they all contain a brief explanation and clear rationale, such that the designers understand why the criteria are deemed important. It was also recommended to include an indicator for each criterion that can steer early concept exploration.

The requested modifications by the practitioners as well as the recommendations provided by the researchers were implemented in the final version of the proposed design tool which is currently being used in pilot cases within EWB-SWE.

5.2. Applicability of the proposed design tool in humanitarian engineering NGOs

It is relevant to assess the applicability of the Sustainability Fingerprint for humanitarian engineering NGOs (using EWB-SWE as an example) compared to manufacturing companies. The Sustainability Fingerprint was originally developed and proposed for manufacturing companies (Hallstedt, 2023) but this study indicates that the core foundation of a Sustainability Fingerprint is useful and applicable for humanitarian engineering NGOs as well. There are however two main differences in its applicability and use: (i) EWB-SWE do not manufacture any components or parts and has less control of how the operations related to this, and thus the ability to influence the sustainability performance of these activities; (ii) EWB-SWE work in projects where, typically, unique solutions are implemented at a specific geographical location which provide limited ability to improve the sustainability performance of their solutions over time. Implemented solutions from previous projects are monitored and evaluated, but not necessarily improved over time. These differences influence the use and applicability of the *simplified Sustainability Fingerprint* at EWB-SWE and similar NGOs.

Furthermore, the authors provide two recommendations to account for these limitations. First, NGOs need to strive towards creating long-term collaborations with local partners that are willing to have a long-term strategic approach to ensure the sustainability criteria are met over time. NGOs need to be more selective when choosing what local partners they should collaborate with, such that they align with internal ambitions and targets. Second, NGOs should strive to design similar and/or niche projects and solutions, or 'project blueprints'. Solutions can thus be reused and improve the sustainability performance of their projects or solutions each time they are carried out, and potentially improve previously implemented projects over time.

6. Conclusions and future work

The research question of this study was formulated as *"What are key sustainability criteria for introducing new technologies in low-income contexts?"*. Fifteen sustainability criteria were identified based on a literature study combined with an empirical study using experienced practitioners from a Swedish NGO and are concluded to answer the research question. Furthermore, the aim of this study was also to develop a design tool that supports designers in humanitarian engineering NGOs to better introduce new technologies in low-income contexts from a sustainability perspective. This is addressed by incorporating the identified sustainability criteria in a proposed *simplified Sustainability Fingerprint*. The proposed design tool was evaluated in three iterations and is concluded as useful with respect to this and applicable to humanitarian engineering NGOs. However, future work should still focus on the results generated from the pilot cases within EWB-SWE to further evaluate and assess the validity of the proposed design tool and identified sustainability criteria.

References

Amadei, B., Sandekian, R., & Thomas, E. (2009). "A model for sustainable humanitarian engineering projects". *Sustainability*, 1(4), 1087-1105. https://doi.org/10.3390/su1041087

Demssie, Y. N., Wesselink, R., Biemans, H. J., & Mulder, M. (2019). "Think outside the European box: Identifying sustainability competencies for a base of the pyramid context". *Journal of Cleaner Production*, 221, 828-838. https://doi.org/10.1016/j.jclepro.2019.02.255

Hallstedt, S. I. (2017). "Sustainability criteria and sustainability compliance index for decision support in product development". *Journal of Cleaner production*, 140, 251-266. https://doi.org/10.1016/j.jclepro.2015.06.068

Hallstedt, S. I., Villamil, C., Lövdahl, J., & Nylander, J. W. (2023). "Sustainability fingerprint-guiding companies in anticipating the sustainability direction in early design". *Sustainable Production and Consumption*, 37, 424-442. https://doi.org/10.1016/j.spc.2023.03.015

Jagtap, S., & Larsson, T. (2018). "Design and Frugal Innovations: Three roles of resource-poor people". *In DS 92: Proceedings of the DESIGN 2018 15th International design conference* (pp. 2657-2668). https://doi.org/10.21278/idc.2018.0152

Jonasson, A., & Pettersson, S. (2023). *A Feasibility Study Process for Humanitarian Engineering Systematically increasing the Social Impact for a Swedish NGO*. [Master's thesis], Industrial & Materials Science, Chalmers University of Technology.

Lucena, J., Schneider, J., & Leydens, J. A. (2022). *Engineering and sustainable community development*. Springer Nature.

https://doi.org/10.1017/pds.2024.138 Published online by Cambridge University Press

Mutanga, S. S., Simelane, T., & Pophiwa, N. (Eds.). (2013). *Africa in a Changing Global Environment: Perspectives of climate change adaptation and mitigation strategies in Africa*. Africa Institute of South Africa.

OECD. (2021). *Applying evaluation criteria thoughtfully*. [Online]. OECD Publishing. Available at: https://www.oecd.org/dac/applying-evaluation-criteria-thoughtfully-543e84ed-en.htm (2023-11-15)

Passino. K. M. (2016). *Humanitarian Engineering - Advanced Technology for Sustainable Development*. Columbus, Ohio: Bede Publishing.

Prahalad, C. K., & Hart, S. L. (2002). "The Fortune at the Bottom of the Pyramid", *Strategy+ business*, 26, 2-14.

Schismenos, S., Stevens, G. J., Emmanouloudis, D., Georgeou, N., Shrestha, S., & Chalaris, M. (2021). "Humanitarian engineering at the sustainability-development nexus: mapping vulnerability and capability factors for communities at risk of water-based disasters". *Sustainability science*, 16, 1185-1199. https://doi.org/10.1007/s11625-020-00890-y

Shekar, A., & Drain, A. (2016). "Community engineering: Raising awareness, skills and knowledge to contribute towards sustainable development". *International Journal of Mechanical Engineering Education*, 44(4), 272-283. https://doi.org/10.1177/0306419016668966

Statista. (2023), *Africa's share in global carbon dioxide (CO2) emissions from 2000 to 2021*. [online]. Statista. Available at: https://www.statista.com/statistics/1287508/africa-share-in-global-co2-emissions/ (2023-11-15)

Trevisan, A. H., Castro, C. G., Gomes, L. A. V., & Mascarenhas, J. (2022). "Unlocking the circular ecosystem concept: Evolution, current research, and future directions". *Sustainable Production and Consumption*, 29, 286-298. https://doi.org/10.1016/j.spc.2021.10.020

UC Berkeley, (2020), *Why development engineering*. [Online]. Development Engineering UC Berkeley. Available at: https://developmentengineering.berkeley.edu/ about/why-development-engineering/ (2023-11-15).

Unesco, (2021), *Local and indigenous knowledge systems.* [Online]. Unesco. Available at: https://en.unesco.org/links (2023-11-15)

United Nations, (2022). *The sustainable development goals report 2022.* New York, NY: United Nations: Department of Economic and Social Affairs.

Watz, M., & Hallstedt, S. I. (2024). "Depth and detail or quick and easy? Benefits and drawbacks of two approaches to define sustainability criteria in product development*". In EcoDesign for Sustainable Products, Services and Social Systems I* (pp. 413-427). Singapore: Springer Nature Singapore.

Whitehead, T., Evans, M., and Bingham, G. (2016). "Design Tools for Enhanced New Product Development in Low Income Economies", *in Lloyd, P. and Bohemia, E. (eds.), Future Focused Thinking - DRS International Conference 2016*, 27 - 30 June, Brighton, United Kingdom. https://doi.org/10.21606/drs.2016.467

Wohlin, C. (2014, May). "Guidelines for snowballing in systematic literature studies and a replication in software engineering". *In Proceedings of the 18th international conference on evaluation and assessment in software engineering* (pp. 1-10).

Wood, A., & Garff, P. F., & Ward, C. J., & Dahlin, E. C., & Lewis, R. S. (2013), "Social Constraints: A Critical Component of Global Humanitarian-based Projects". *Paper presented at 2013 ASEE Annual Conference & Exposition*, Atlanta, Georgia. https://doi.org/10.18260/1-2--22457