How to create sustainable artefacts? Towards a user-centered design guide for low-techs/appropriate technologies

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ABSTRACT

Technocene is a proposed phenomenon that draws attention to the negative impacts of our technological culture. Low-techs (also known as appropriate technologies) are a possible avenue for transforming this technological culture. The low-tech approach indeed calls for renewing mainstream design practices (e.g., by questioning needs to keep only the essentials, by reducing the complexity of artefacts, by maintaining rather than replacing). Unfortunately, there is a lack of guidance regarding the design process to follow in order to produce low-techs. In order to fill this gap, the present article proposes the first version of a design guide expanding on seven principles (*Needs and Satisfiers Negotiation*; *Autonomy-Assistance Arbitration*; *Discoverability*; *Operative Transparency*; *Non-Functional Aspects*; *Information, Education and Training*; *Compensation*) taken from previous research. Next steps necessary for the improvement and validation of the guide are also discussed.

CCS CONCEPTS

• **Activity centered design**; • **HCI design and evaluation methods**; • **Sustainability**;

KEYWORDS

Appropriate technology, Low-tech, Design guide, Design principles

ACM Reference Format:
Clément Colin and Antoine Martin. 2024. How to create sustainable artefacts? Towards a user-centered design guide for low-techs/appropriate technologies. In *European Conference on Cognitive Ergonomics (ECCE 2024), October 08–11, 2024, Paris, France*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3673805.3673842

1 INTRODUCTION: THE RELEVANCE OF LOW-TECHS

Several explanations of current crises coexist. One explanation, which seems especially relevant for design sciences, is centred on technologies (i.e., *Technocene*). Technocene is a process where "*heavy and brutal technologies associated with [capitalism], [are] reshaping living environments and the links between humans and non-humans*" [Hornbog, 2018 cited by 9:178]. Thus, the "*question of technology, its responsibility in environmental crises and its ability to halt them, is becoming increasingly acute, and is leading to a profound rethinking of what technology is*" [9:177]. This school of thought goes on to question the long-term impacts of our technological culture on human survival in a (now) unstable living environment, since we depend "*on a complex techno-economic system, whose viability is already problematic: what knowledge will we have if this system one day collapses and our tools, now mostly digital, cease to function?*" [2:13].

A possible answer to those concerns is *technological discernment*[1]. It consists in identifying the right level of machinal intensity[2] to deploy in an artefact to meet a given need. This approach is constrained by the necessity to limit the negative environmental and human impacts of production systems as well as to increase their positive impacts (see Figure 1). It leads to questioning needs, the response to needs (*satisfiers*), and the organization of work through negotiations taking place during the design phase. It is wary of an unfavourable ratio between human and machinal components of technology (*technological imbalance*), which is characterized by a decrease in the human component of technology (e.g., understanding, control, transmission of knowledge) and by an increase in its machinal component (e.g., automation, complex heterogeneous materials). Technological imbalance has possible dire consequences on the larger human-environment system (e.g., dependency, reduced controllability, reduced resilience, water and air pollution).

The *low-tech* approach is one possible way to realize technological discernment. It is "*an innovative and inventive approach to the design and evolution of products, services, processes or systems that aims to maximize their social utility, and whose environmental impact does not exceed local and planetary boundaries. The low-tech approach involves questioning the need to keep only the essentials, reducing technological complexity, and maintaining what already exists rather than replacing it. The low-tech approach also enables as many people as possible to access and control the answers it produces.*" [3:21–22]. It can be further described through eight characteristics: empowering, renewing design practice, critical, de-mechanized, situated, psychologically transformative, radically useful, and technologically sustainable [13:148]. It is of note that "appropriate technology" is an equivalent to "low-tech" and is much more commonly used in English-speaking countries. It is also worth noting that the low-tech approach, while attracting a great deal of interest, is also the subject of criticism [e.g., 22:223–263].

Despite intense institutional and entrepreneurial activities around low-techs, there is currently no concrete method that could guide a designer interested in following the "low-tech path". Guiding designers is especially crucial since technological discernment is not straightforward, most notably because of socio-cognitive reasons such as design fixation, self-censorship during the design

ECCE 2024, October 08–11, 2024, Paris, France

ACM ISBN 979-8-4007-1824-3/24/10
https://doi.org/10.1145/3673805.3673842

[1]According to the French Academy of technologies, the opposite of technological discernment is "*technological inebriation*" [1:2].
[2]*Machinal* refers to "*the objects and mechanisms necessary for an action*" [6:16]. Beyond the material complexity of technologies, the term also highlights their automation capabilities. *Mechanical intensity* would be a possible equivalent.

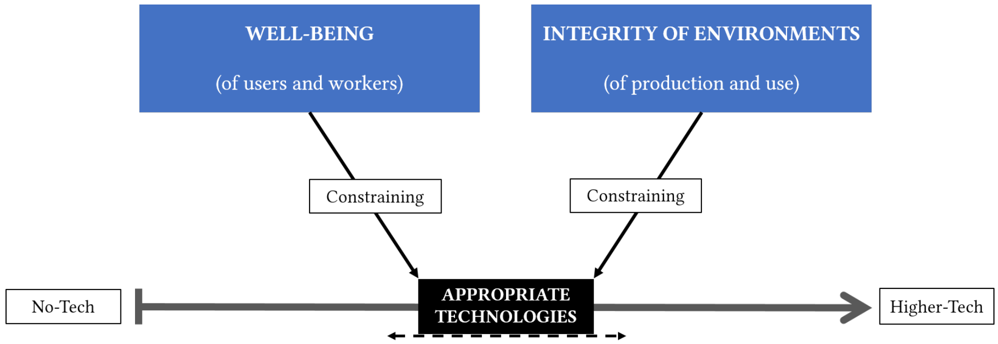

Figure 1: The process of technological discernment under the two constraints of human well-being and environmental integrity.

process or preference for additive transformations (over subtractive ones). Proposing a design guide can be a way to overcome those hurdles because models, such as design guides, provide designers with a tool for reading the external world, thus taking into account their limited processing capacity, mitigating the risk of selecting irrelevant traits, using faulty know-how and an erroneous mental representation, or more or less controlled implicit models [4:113].

2 FROM DESIGN PRINCIPLES TO A DESIGN GUIDE

A previous research article [5] identified that low-techs are marred with specific user problems that fit within fourteen broad categories: living conditions compatibility, performance, pleasure/ideology, usefulness, production/installation, components management, know-how, safety, additional load, nuisance, maintaining nominal mode, control, legal compliance, and social dimension. In response, seven corresponding design principles have been proposed (ibid.). Their goal is to keep designers in line with the requirements of the low-tech approach (e.g., questioning needs) while providing good ergonomics as well (e.g., facilitate the discovery of functions). The principles are input-oriented, i.e., oriented towards elements enabling designers to create the system and users to interact with it, instead of being output-oriented, i.e., oriented towards the effects of interaction on users and their context [adapted from 17:15]. Being input-oriented makes principles more straightforward to use by designers (e.g., *Identify priority needs to derive necessary functionality*) whereas output-oriented characteristics (e.g., *low-techs are empowering*) are more suited for theoretical works where one would be interested in observing consequences of low-techs' use.

To improve upon this work, the principles have been detailed in a more designer-friendly manner (i.e., a design guide[3]), with validation as a longer-term goal (see section 4). To begin with, the seven design principles have been re-examined according to criteria proposed by taxonomies and design principles specialists [Nemery & Brangier, 2014; Nickerson et al., 2013; Bastien and Scapin, 1993; all three articles cited by 4:260] : simplicity, completeness/relevance, mutual exclusivity/distinctiveness, explanatory power, and extendibility. Taking into account the early stage of the principles, we found them to be robust on most accounts[4]. One exception was the "simplicity" criterion, which led to renaming the principles in a more concise manner to make them easier to understand and remember (e.g., *Compensate increased material loads and deficits* became *Compensation*). Finally, the design principles were augmented with definitions, rationales/explanations, and implementation guidelines (derived from the previous paper and additional bibliographic research).

3 FIRST VERSION OF THE DESIGN GUIDE FOR LOW-TECHS/APPROPRIATE TECHNOLOGIES

The first version of the design guide is outlined in the seven sections below. Two principles are strategic in nature (*Needs and Satisfiers Negotiation*; *Autonomy-Assistance Arbitration*), they have to be used first in order to create the blueprint of the design project through the **definition of sustainable functionalities**. Then, three principles can be used during the actual design of the artefact in order to provide good **interaction**: (*Discoverability*; *Operative Transparency*; *Non-Functional Aspects*). Finally, two principles relate to elements that **support** the interaction (*Information, Education and Training*; *Compensation*).

3.1 Definition of sustainable functionalities

3.1.1 *Needs and Satisfiers Negotiation.*

- **Definition:** *Needs and Satisfiers Negotiation* is a process encompassing the participative identification, prioritization and dimensioning of the situated needs and satisfiers that the low-tech artefact must meet in order to define the appropriate functionalities.
- **Explanation/Rationale:** To be mindful of the environment, users, and workers, the situated needs and satisfiers that the low-tech artefact must meet have to be identified and only the necessary and appropriate functionalities should be implemented. If this step is not done properly, necessary functionalities may not be supported by the low-tech artefact. Also of note, the "participative" aspect of the process is important to ensure, as much as possible, fairness (i.e., the

[3]Design guides are formatted documents aimed at professionals that contain design principles augmented with definitions and explanations [4:121].

[4]The quality of the principles against the five criteria will be assessed in a more systematic manner during the validation phase (see section 4).

"how" of satisfiers' modification compared to a conventional approach) and understability (i.e., the "why" of the satisfiers' modification compared to a conventional approach).
- **Implementation:** *Needs and Satisfiers Negotiation* encompasses needs/satisfiers cartography, collective prioritization, and dimensioning. It should be conducted with representatives of users and designers.

3.1.2 *Autonomy-Assistance Arbitration.*

- **Definition:** *Autonomy-Assistance Arbitration* refers to the identification of the tasks that should be handled by the artefact/service and those that should be handled by users. This is done using potential human/environmental harms (e.g., dependency) and benefits (e.g., empowerment) as well as relative capacities of human/artefact as arbitration criteria.
- **Explanation/Rationale:** To empower users and reduce the environmental impact, some operations can be demechanized or de-automated. This can lead users to take over tasks such as production, installation, maintenance, operation, etc. which are currently handled by technologies or organizations. If this step is not done properly, negative consequences can happen for users, including overload, lack of control, or difficulty of use.
- **Implementation:** The "allocation of functions" method [12, 21] could be used if adapted to add additional "allocation" criteria to go beyond "job satisfaction" and "performance" such as maintaining critical skills/knowledge (e.g., in the case of medical artefacts) or identifying the environmental cost of automation.

3.2 Interaction design

3.2.1 *Discoverability.*

- **Definition:** *Discoverability* is the easiness with which low-techs' users can identify interaction possibilities and the current state of the device.
- **Explanation/Rationale:** Using low-techs often requires users to have specialized knowledge. This is due to their sometimes makeshift appearance (which makes signifiers imperceptible or non-comprehensible to users) or to the necessity to perform new tasks (usually handled by technology or an organization). These can cause difficulties to users when attempting to identify possible actions, and ways to perform them, especially during any first step they might take (e.g., first time attempting to repair the artefact).
- **Implementation:** *Discoverability* results from five fundamental elements (affordances, signifiers, constraints, mappings, feedback) and is enhanced by allowing the creation of a good conceptual model of the system [16:10, 72]. *Discoverability* can be implemented in a task-oriented manner. For example, since maintainability is crucial in the low-tech approach, fault diagnosis (the task of discovering faults) could be made easier [for example of recommendations, see 18].

3.2.2 *Non-Functional Aspects.*

- **Definition:** *Non-Functional Aspects* are cultural, legal and aesthetic features that are important for the experience of the low-tech artefact without playing a direct functional role in the artefact's operations.
- **Explanation/Rationale:** Because low-tech artefacts are often made of recycled materials and are self-built and/or more rudimentary than conventional technologies, the non-functional aspects are often set aside. However, like all artefacts, low-techs should involve non-functional aspects related to situated norms (e.g., aesthetics) that must be identified and implemented. These non-functional features have an impact on the desirability and usability of the artefact and on the understandability of its purpose.
- **Implementation:** Examples of implementations are taking into account local socio-cultural systems (e.g., knowledge, representations, norms), improving aesthetics (which can have a positive influence on usability), or using Gestalt's theory principles.

3.2.3 *Operative Transparency.*

- **Definition:** *Operative Transparency* is the degree of accessibility for users to the knowledge, procedures and models underlying the artefact's operation [20:203]. It minimizes the distance that the artefact places between users and reality [19:145] and enable them to efficiently monitor the operation of the low-tech artefact.
- **Explanation/Rationale:** In the process of decreasing machinal intensity, low-techs may not offer sufficient information on the status of the artefact or on the activity at hand, preventing users from reacting appropriately or effectively or preventing them from understanding the operation of the artefact. Furthermore, the lack of information on material or energy flows does not make it possible for the user to be aware of the physical reality of its use and therefore to inform sustainable behaviours. We highlight that *Operative Transparency* is not to be understood in the more widespread sense of "black box" transparency ["an invisibility of the artefact's technological system" 19:140] but in the sense of "glass box" transparency (ibid.).
- **Implementation:** *Operative Transparency* happens in reference to users' activity (and therefore their need for information) [19:145]. The goal is to make this information accessible, comprehensible, and perceptible through the artefact's characteristics (ibid.). This can happen through olfactory, haptic, auditory or visual feedback. A way for low-techs to achieve this is through "friction" ["*any form of physical or mental effort (or resistance)*" 7:133]. With regards to promoting sustainable behaviours, friction also has the advantage to "*highlight complex issues that are very hard to see in a frictionless world*" [15:327].

3.3 Design of interaction-supporting elements

3.3.1 *Information, Education and Training.*

- **Definition:** *Information, Education and Training* is the development of user skills and knowledge related to the production, installation, and use of low-tech artefacts. It enables the use of low-techs by different users' skill profiles and the improvement of their technological literacy.

- **Explanation/Rationale:** Tasks usually handled by technology or organizations regarding the production, installation, maintenance, and use of mass market artefacts may not be supported anymore with corresponding low-techs. Missing technological knowledge or skills can lead to accessibility, usability, safety, or performance issues.
- **Implementation:** Examples of implementation are to rely on "primary knowledge" ["*knowledge that appeared early in the evolution of species*" 10:916] such as folk physics, to provide open-source documentation, teaching new operating methods, or facilitating the elimination of previous operative schemas [8:155].

3.3.2 *Compensation.*

- **Definition:** *Compensation* is the process that counterbalances the new material flows that the low-tech artefact requires or generates to be usable compared to an alternative of higher machinal intensity.
- **Explanation/Rationale:** With low-techs, material processes that were handled by organizations (such as utilities) are sometimes transferred to users (e.g., the need for a composting space if someone switches from conventional to dry toilets), which may result in additional tasks or be incompatible with users' current living conditions.
- **Implementation:** Identify tensions regarding access to raw materials or tools and regarding waste disposal that were handled previously by infrastructure or organizations. Then, offer supporting services (e.g., at home delivery of materials).

4 THE NEXT STEPS TOWARDS VALIDATION

The goal of the validation of ergonomics methods is to check and improve them against four criteria: construct validity (i.e., fit between the method and its theoretical basis), content validity (i.e., credibility of the method among its target users), concurrent validity (i.e., fit between the results of the method and other concurrent methods) and predictive validity (i.e., ability to predict the performance or behaviour of an existing or future system) [4:207, 14:12–13]. Some of these components of validity can be studied following the steps below:

- **Improvements to the guide**: first, the guide can be improved by additional details that will help designers even further (e.g., adding expected outputs, examples) and through a more attractive formatting (e.g., adding icons, colour);
- **Interviews with experts**: there are at least five sources that can be used to create design principles: general literature, experts, existing principles, ecological studies and analysis of existing artefacts [4:114–115]. General literature and an ecological study (usability survey) were used previously [5]. Consulting another source, low-tech experts, is an interesting step for it allows triangulating data. More precisely, during a focus group, experts could assess the current quality of the guide (against the criteria listed in section 2). A criteria of special interest to explore with them is the exhaustiveness of the guide. Indeed, we identified ten other publications that propose, in total, more than a hundred output-oriented elements to describe low-techs. The themes that encompass these elements might not necessarily be covered by the current state of the guide and, as such, should be explored further. Interviewing experts would help to decide whether (and how) to include these themes in the guide[5];
- **Laboratory experiment**: the reliability, efficiency and usability of design guides is often assessed through a laboratory experiment consisting in making several designers match "model cases" (e.g., a picture of a low-tech artefact with a usability issue) with the principles using the design guide, in order to compare their performance among themselves and with the researchers' own matching [for more details regarding this step see 4:177–184].
- **Ecological experiment**: the usefulness of the guide to improve an actual design process, through a more ecological experiment comparing the quality of a design process with/without the guide [e.g., 11:155–203], is also an important avenue to explore.

5 CONCLUSION

This paper clarifies the umbrella concept of *technological discernment* (a process for identifying the right level of machinal intensity to deploy in an artefact in order to meet a given need while being constrained by the necessity to limit the negative environmental and human impacts of production systems), and proposes the first version of a design guide for low-techs/appropriate technologies. The guide contains seven principles: *Needs and Satisfiers Negotiation*; *Autonomy-Assistance Arbitration*; *Discoverability*; *Operative Transparency*; *Non-Functional Aspects*; *Information, Education and Training*; *Compensation*. The article also summarizes the next steps toward validation (improvements to the guide, interviews with experts, laboratory experiment, ecological experiment).

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