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Quantitative assessment of appropriate technology

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Abstract

Economist Dr. E.F. Schumacher posited the concept of "Intermediate Technology" in his 1973 book *Small is Beautiful,* catalyzing the explosion of the appropriate technology (AT) movement. But how does one gauge the "appropriateness" of a technology? Quantitative assessment of AT can benefit sustainable community development (SCD) practitioners by way of decision-support and risk mitigation. The following research constructs a generalizable metric for quantitative assessment of AT, and develops a systematic process for its deployment. Forty-nine independent, emergent indicators of appropriateness were identified from a literature meta-analysis. The most prevalent indicators were as follows: community input, affordability, autonomy, transferability, community control, scalability, local availability of raw materials, and adaptability. Using these, a quantitative assessment tool was developed, called the Appropriate Technology Assessment Tool (ATAT). ATAT employs multi-criteria decision analysis (MCDA) methods to rank AT alternatives. In this way, inputs are aggregated using a weighted-sum method, giving the composite Appropriateness Index, (AI_i). Using VBA coding, the author built ATAT via a simple form populated by the identified indicators. The form automates all necessary calculations, facilitating empirically rigorous quantitative assessment of AT by non-technical SCD workers. AT is only as appropriate as beneficiaries deem. A participatory research approach requires community stakeholders to rank preferred criteria for AT, and rate alternatives against the chosen criteria. This approach makes the tool customizable to local conditions. Using the Mini-Delphi Method, stakeholder opinions translate to ATAT inputs. A local case in the Westwood neighborhood of Denver, Colorado is examined to test ATAT efficacy and process viability. Prior to this research, University of Colorado graduate students partnered with local 501(c)3 Revision International to reduce winter heating costs in Westwood using a solar furnace that locals dubbed "EZ Heat". ATAT quantified the appropriateness of EZ Heat as AI_i= 4.2. This score lends empirical support to the AT's *a priori* deterministic selection. ATAT is designed to be free and accessible via Internet, and the author is investigating the potential of a mobile application. SCD and other community development practitioners often work in remote areas, and a mobile ATAT application will make the tool more useful.

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1. Introduction

The following research draws on graduate coursework in sustainable community development (SCD) at the University of Colorado at Boulder. This paper leverages that knowledge to construct a generalizable metric for quantitative assessment of Appropriate Technology (AT), and to design a systematic process for its deployment by non-technical development practitioners. This tool and its process are both founded on a meta-analysis of the criteria for AT "appropriateness". The primary goal of this research is to produce an effective AT assessment tool for non-technical development workers that balances simplicity of technique with accuracy of quantification.

Nomenclature

AT	Appropriate Technology
SCD	Sustainable Community Development
AI	Appropriateness Index
MCDA	Multi Criteria Decision Analysis
ROC	Rank Order Centroid

1.1. Background

Economist Dr. E.F. Schumacher posited the concept of "Intermediate Technology" in his 1973 book *Small is Beautiful,* catalyzing the explosion of the AT movement. But how does one gauge "appropriateness"? Being heavily context-dependent, the "appropriateness" of AT varies considerably with local conditions. Quantitative assessment of AT can benefit sustainable development practitioners by way of decision-support and risk mitigation, using a participatory approach.

1.2. Motivation: defining and evaluating appropriate technology

The inextricable qualities of culture, society and geography should inform any SCD project. As local conditions vary, so the definition of a technology's "appropriateness" varies. In essence, any definition of AT that discounts local input is inadequate [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [7] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34]. Indeed, Murphy et al. (2009) argue that since "appropriateness" varies by context, it cannot be precisely defined. Ranis [25] agrees, claiming that there is no simple way to define AT. And yet, in *Evaluating Appropriate Technology in Practice,* Ellis & Hanson [14] revealed that no one had yet attempted "to evaluate the technologies at the user/field level", saying "institutions had no mechanisms in place to identify them and to focus upon good ones" (p. 33). Further, Kalbar et al. [35] note the need for a "decision-support tool" for choosing wastewater treatment technologies (p. 158). Ratnam [24] implores agencies to devise a "mechanism for technology assessment" (p. 246), while Sianipar et al. [28] recently argued that an AT "selection tool must be utilized that's applicable to all scenarios" (p. 1013), and called for further research in a "practical area with detailed issues of social, technical, and economic variables in (the) local area" (p. 1015). To whit, Dell'Oro et al. [36] envisioned an evaluative matrix populated by "technology-descriptive parameters" (p. 38) by which to judge the appropriateness of a development technology. These authors make clear that engineers and development workers could benefit from a quantitative measure of AT.

1.3. Goals and objectives

The goal of the following research is to formulate a general, practical tool for quantitative assessment of AT, to develop a systematic process for its deployment, and to test the proposed model in a local case study. These goals are achieved via the following objectives:

1. Synthesize a list of emergent, germane indicators of "appropriateness" from a literature meta-analysis;
2. Rank AT indicators via prevalence in the literature, i.e., use prevalence as a proxy for importance;
3. Construct a tool for calculating a technology's "appropriateness" using the indicators as inputs, and aggregated into a composite score using a weighted sum model (WSM).
4. Using MCDA techniques, outline a step-by-step process for using the tool: weight indicators by relevance to the given context, and rate the given technology on each indicator;
5. Test the accuracy of the tool, as well as the viability of the process design, in a local case study

2. The role of appropriate technology in sustainable community development

2.1. AT in SCD Project Design

The following methodological framework emphasizes participation by the beneficiary community in project design and execution. ADME (Fig. 1) is an acronym describing the phases of sustainable community development at the Mortenson Center in Engineering for Developing Communities.

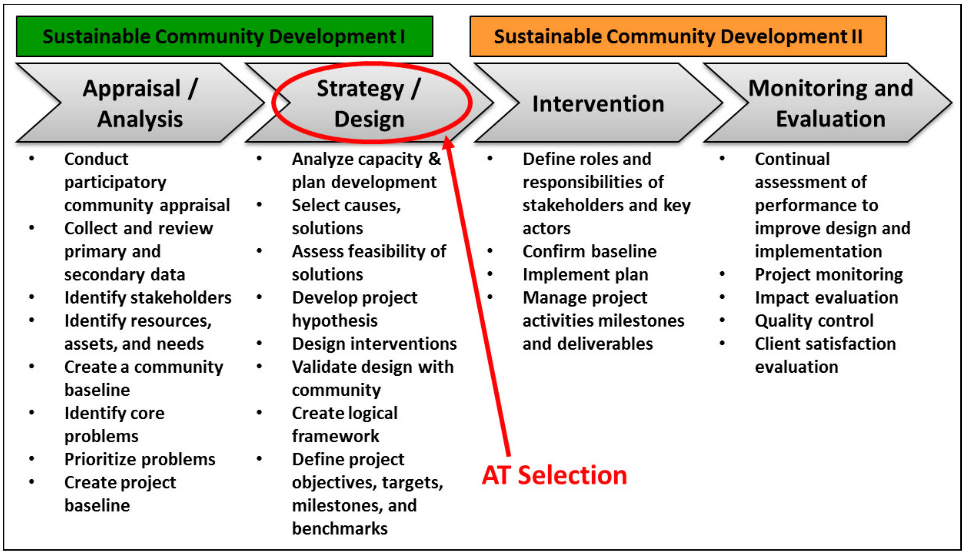


Fig. 1. The ADME Framework for Sustainable Community Development (emphasis Bauer) [37]

AT can improve accessibility to services from which beneficiaries are isolated. Within project design, AT represents the desegregation of process and solution into a single product.

3. The appropriate technology assessment tool (ATAT)

Assessing the various (sometimes competing) concerns for successful deployment of AT in community development is complex [16] [7] [15]. Therefore, accurate assessment of AT is vital for project success. Achieving this requires a useful, practical tool that can be deployed by non-technical aid workers. This section describes the development of the Appropriate Technology Assessment Tool (ATAT).

The first step in developing the ATAT was to establish an index of measurable criteria. From there, I employ MCDA methods to design the tool with which to weight, rate and aggregate the various assessment inputs. Finally, I develop a systematic process for deploying the ATAT using MCDA and sociological research techniques.

3.1. Meta-analysis of AT literature

A meta-analysis of cited criteria for AT provides the theoretical foundation for the ATAT. From this analysis, categories, called parameters, became apparent. Indicators, then, were described, and organized by occurrence.

The results of the meta-analysis yielded 53 papers, books and conference proceedings where 49 independent, emergent indicators of "appropriateness" were identified, coded and tallied. Frequency of occurrence was used as a proxy for importance to AT assessment. Figure 2, below, depicts the complete results of the literature review.

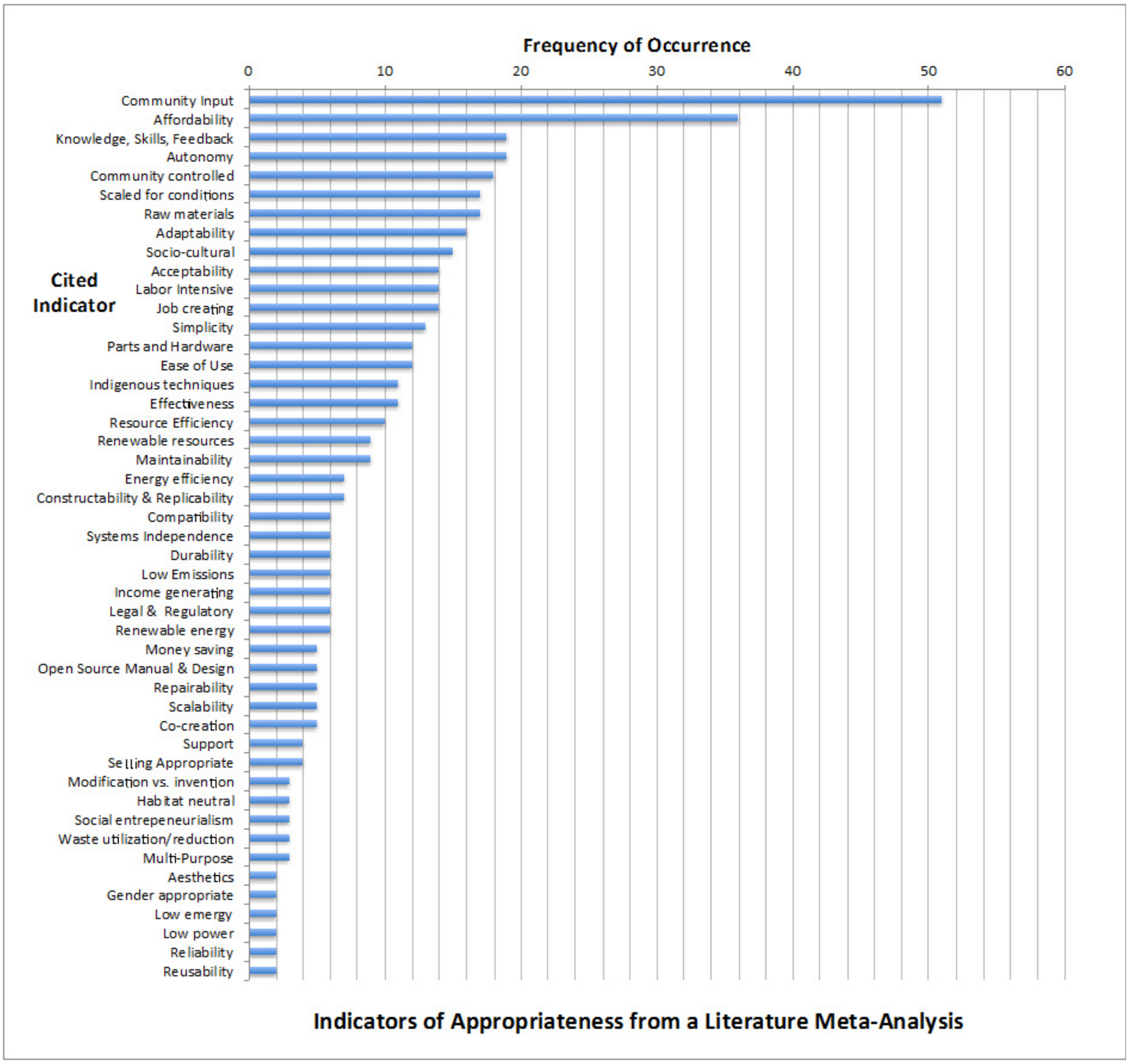


Fig. 2. Results of literature meta-analysis: appropriateness indicators vs. occurrence

With 51 of 53 authors noting its significance, the most prevalent characteristic of AT in the literature, by far, was community input. “Community,” in this case, includes “stakeholders” [5] [10] [15] [35] [30], “local people” [32] or “users” [29] [21].

3.2. Multi criteria decision analysis methods

Multi criteria decision analysis (MCDA) is closer to real-world decision-making than linear analysis, making MCDA tools ideal for AT selection in sustainable community development projects [38] [8] [35] [39] [40] [41] [42]. To this extent, MCDA provides systematic methods for combining AT criteria with diverse stakeholder input and local context considerations, in order to quantify project alternatives.

3.2.1. MCDA pedagogy

The most frequently used approach in MCDA is the “weighted-sum method” [43] [44] [42]. A weighted summation gives a *composite indicator*. The Appropriateness Index (AI_i), is a composite indicator defined by its underlying properties. Equation 1 [43] gives the formal definition as follows:

$$AI_i = \sum_{j=1}^{N} w_j \, x_{ij} \,, \qquad i = 1, 2, \dots, N \qquad (1)$$

where: x_{ij} is the jth attribute of the ith alternative,
w_j is a weight attached to x_{ij}, and
$0 \le w_j \le 1$

AI_i, then, is a weighted linear aggregation of variables, the overall multi-criteria value of technology alternative i.

3.2.2. Rank order centroid for indicator weighting

As we have seen in Equation 1, the Appropriateness Index (AI_i) requires a method for weighting (w_j) the criteria (x_{ij}) before summation. Barron and Barrett [44] claim that weights derived from Rank Order Centroid (ROC) are “efficacious weights… superior to that of previously proposed rank-based surrogate weights” (p. 1520). During the community input phase, stakeholder ranks are converted to weights for each criterion in the final evaluation [44]. That conversion is from the following [45]:

$$w_j = \left(\frac{1}{M}\right) \sum_{n=j}^{M} \frac{1}{n} \,, \qquad j = 1, 2, \dots, M \qquad (2)$$

where: w_j is the weight applied to the jth criterion,
M is the number of criteria being considered, and
$\sum_{j=1}^{M} w_j = 1$.

After they are numerically converted, these data provide a simplex. The centroid of that simplex corresponds to the prescribed weights [45].

4. Systematic deployment of the ATAT tool

4.1. Sociological data collection methods

4.1.1. Mini-delphi method

The participatory framework employed here requires stakeholders' opinions as the data with which to assess the AT. The Mini-Delphi Method is a subset of the Delphi Method technique for collecting sociological data. Mini-Delphi is a face-to-face version of Delphi, where the group's individual views are generated separately, but then shared and discussed openly with the group.

4.1.2. Survey design

Survey design is crucial, as it determines the extent to which the instrument accurately measures what it intends to measure [46]. In the present investigation, the survey is used to identify and rank indicators of appropriateness, and to rate the given technology's performance in each of those indicators. In order to achieve this, the survey is short (three questions), simple (one task per question) and adjectival. Survey questions are as follows:

1. **Choosing Relevant Indicators: "**Thinking only of (AT), circle any of the following qualities that you consider important for bringing (AT) to your home or your community."
2. **Ranking Chosen Indicators: "**Using only the qualities that you circled in Question 1, please rank them here from most important (top) to least important (bottom)."
3. **Rating AT on Chosen Indicators: "**Please rate (AT) for each one of your listed qualities as Very Low, Low, Medium, High, Very High."

Questions 1 and 2 determine the inputs in the ROC weighting calculations (w_j), and Question 3 determines the performance rating of the given AT in each indicator (x_{ij}). The linear aggregation of these two give the Appropriateness Index (AI_i).

4.1.2.1. Survey response scale

The third question asks respondents to rate the given technology for each indicator along a scale. The response scale is the primary source of validity (and bias) in sociological data collection [46]. I use five response categories, as indicated below. Five to seven response categories is the most common range for survey research, and is especially effective for improving coherent respondent distinction between categories [47] [48].

This study uses "adjectival" response categories over "numerical" categories for reasons of ease and perception. It is often easier for people to think linguistically than numerically [49]. Finally, the consensus adjectival responses are converted to nominal-discrete measures for quantifying x_{ij}, as shown in Table 1.

Table 1. Conversion factors for survey responses

Survey Response Score	Converted Score
Very Low	1
Low	2
Medium	3
High	4
Very High	5

4.2. Stakeholder workshop

At this point, it is assumed that a satisfactory community appraisal and stakeholder analysis have already been completed. The participatory research framework gives primacy to context, community participation and intercultural intelligence. A successful project design, then, must necessarily incorporate local opinions. My approach advocates a one- to two-hour workshop for this purpose. Inviting stakeholders

Coordinating with the partnering agency lends credibility to the invitation, and can increase attendance. As ever, local culture will determine which method is best (e.g. email, postal mail, etc.). The content of the invitation should provide the purported reason for introducing the technology and pertinent background, along with the standard of date, time and location.

4.2.1. Conducting The Workshop

The practitioner acts as a facilitator during the workshop. After welcoming remarks, introductions and any "icebreaker" activities, a brief project overview is provided, including the technology alternatives under consideration, what they do, why they were chosen and why everyone has been called to meet.

Next, the facilitator asks the participants to break up into groups of three or four people each. If it's a small group, then participants can work individually. Each group gets one survey. The facilitator explains the survey by going through each question individually, as follows:

Question 1: Spend 7-10 minutes identifying all of the important criteria from the list of indicators provided.

Question 2: Spend 7-10 minutes ranking the importance of each criterion from most important to least important

Question 3: Spend 7-10 minutes rating each criterion (very low to very high).

After addressing any questions or concerns, surveying begins.

Once everyone is finished, the facilitator calls for a return to the larger group. Here, each group chooses a spokesperson to report their results to the facilitator and the larger group while she records the results on a common viewing medium (blackboard, dry erase board, overhead projector, etc.). Indicator rank occurrence is tallied.

With opinions given, the facilitator repeats the first group process. Shorter time limits may be acceptable here.

As groups report their opinions from the second round, criteria are re-tallied. Consensus can be agreed upon verbally, or through simple counting of rank positions. Once consensus has been reached on how to rank indicators, the process is wholly repeated for the AT rating inputs.

4.3. Putting it all together: using ATAT to compute the appropriateness index

As described earlier, AT is scored via the Appropriateness Index (AI_i). Once social data have been collected and analyzed by the established methods (ROC, linear aggregation), the AI_i score will reflect the appropriateness of the given technology in terms of its underlying context. The AI_i score provided by ATAT will range from 1 (low appropriateness) to 5 (perfect appropriateness). An example is given in Table 2, below.

Table 2. Example MCDA weighted sum impact matrix

Alternative \ Criteria	1	2	3	$AI_{a,b,c}$
a	2	3	2	*2.8*
b	3	4	4	*3.4*
c	5	2	2	*3.8*
$w_{1,2,3}$	*0.611*	*0.278*	*0.111*	

ATAT is a free, open source spreadsheet created by the author using VBA code in Microsoft Excel. It is available for download at http://mcedc.colorado.edu/research. Once downloaded, the ATAT launches automatically upon opening the file: a simple form, populated by the identified criteria, automates all of the aforementioned calculations, conversions and aggregations. Appendix A, attached, is a screen capture of the ATAT form, populated with sample values.

5. Case study: Westwood, Denver, Colorado

5.1. Introduction

In order to test the viability of the process and accuracy of the tool, ATAT was utilized in a local case study in the Westwood neighborhood of Denver, Colorado. The Westwood case began in the SCD 1 and 2 courses at the University of Colorado at Boulder [37], and continued in SCD 3: field practicum. In the following case study, an aluminum can solar furnace is quantitatively assessed using ATAT.

5.1.1. Background

Impoverished communities located in wealthy industrialized countries still face the inhibiting effects of ill health, fewer education opportunities and economic isolation. These burdens interrelate in such a way that services and technologies in nearby wealthier communities, though available, remain financially inaccessible.

An example is the community of Westwood in Denver, Colorado. Westwood is vulnerable to risks in a variety of domains [37], but is not without community resources. Revision International (Revision) is a Westwood-based non-profit[†], which hires and trains Westwood residents to become "Promotoras". Promotoras seek sustainable alliances with neighboring households to boost community self-sufficiency in food production, energy efficiency, and waste reform, and to strengthen community solidarity.

5.1.2. Problem Identification

During the community appraisal phase, residents of Westwood cited significant health and safety concerns around housing quality. Local income levels and housing vintage exacerbate the high cost of heating homes with inadequate insulation and heating systems. After engaging Revision and the Promotoras in extensive discussions, all agreed that introducing solar furnace technology to the community could alleviate these expenses.

5.2. Solar furnace proof of concept

The aluminum can solar air heater (furnace) is affordable and effective. In this simple design, sunlight passively heats air within columns of aluminum cans. As a proof of concept, a solar furnace was assembled, and test data showed a temperature rise of 70˚F on a March day in Colorado.

5.3. Quantitative assessment of AT in Westwood: testing the ATAT

5.3.1. The mini-delphi workshop

The Mini-Delphi session occurred at the Revision International offices in Westwood. Since Westwood residents are largely of Latin American descent, the surveys were written in Spanish as well as English. The Promotoras provided the researcher with an interpreter. Ten Promotoras attended the meeting; it was made known that more Promotoras wanted to attend, but could not due to schedule conflicts. No other stakeholders attended.

After a brief welcome and introduction, PhD student and principle EZ Heat investigator Aaron Brown (Metro State University) presented the background on the furnace models, and the status of the four heaters being loaned to identified community members. Next, as the facilitator, I explained the process and the questionnaire, then handed out the surveys to three groups. The facilitator guided the participants through the three survey questions, and when groups felt satisfied with their responses, they were tallied and organized by prevalence in the final consensus. Due to time constraints, the second round of input was shortened to tallying of rankings and verbal consensus.

[†] http://www.revisioninternational.org

5.3.2. Results from the mini-delphi workshop

Tables 3 and 4 illustrate the results of AT evaluation for EZ Heat in the Mini-Delphi session.

Table 3. EZ Heat indicator ranking consensus

Group 1	Group 2	Group 3	**Consensus**
Simplicity	Efficient Resource Use	Renewable Resources	**Availability of Raw Materials**
Ease of Use	Availability of Raw Materials	Efficient Resource Use	**Efficient Resource Use**
Availability of Raw Materials	Job Creating	Adaptability	**Job Creating**
Socio-culturally Accessible	Autonomy	Availability of Parts & Hardware	**Simplicity**
Job Creating	Simplicity	Job Creating	**Ease of Use**
Autonomy	Ease of Use	Availability of Raw Materials	**Renewable Resources**
Renewable Resources	Adaptability	Ease of Use	**Adaptability**
Adaptability	Renewable Resources	Simplicity	**Autonomy**

Table 4. Results from EZ Heat Mini-Delphi workshop

Consensus Ranking	Survey Rating (N)	Consensus Rating
Availability of Raw Materials	Very High; High (2);	High
Efficient Resource Use	Very High (2); High	Very High
Job Creating	High (2); Medium	High
Simplicity	Very High; High (2)	High
Ease of Use	Very High; High (2)	High
Renewable Resources	High (3)	High
Adaptability	Medium (3)	Medium
Autonomy	High (2); Medium (1)	High

5.3.3. Final assessment of EZ Heat solar air heater

The Mini-Delphi survey data were plugged into ATAT to determine AI_i for the EZ Heat solar furnace. The tabulated consensus results, along with final AI_i, are shown in Table 5, below.

Table 5. Results from EZ Heat Mini-Delphi workshop

Consensus Indicator Rank	Consensus AT Rating	Converted Ratings	ROC Weights	Tabulated Results
Availability of Raw Materials	High	4	0.3397	1.3589
Efficient Resource Use	Very High	5	0.2147	1.0735
Job Creating	High	4	0.1522	0.6088
Simplicity	High	4	0.1106	0.4424
Ease of Use	High	4	0.0793	0.3172
Renewable Resources	High	4	0.0543	0.2172

Adaptability	Medium	3	0.0335	0.1005
Autonomy	High	4	0.0156	0.0624
			Solar Furnace AI_i = 4.2	

6. Conclusions

To conclude, 49 criteria of "appropriateness" for Appropriate Technology (AT) were identified, their level of importance inferred, from a meta-analysis of the literature. A tool for quantitative assessment of AT was developed using multi-criteria decision analysis (MCDA) methods. This Appropriate Technology Assessment Tool (ATAT) scores AT via a composite indicator, the Appropriateness Index (AI_i), using a Weighted Sum Method. A process for systematic deployment and utilization of the ATAT was developed using participatory rural assessment, stakeholder analysis and MCDA. In this process, identified stakeholders in the given sustainable community development project are invited to participate in AT assessment at a community workshop. In the workshop, indicators germane to the project are selected, ranked and rated by participating stakeholders using a Mini-Delphi Method for decision consensus.

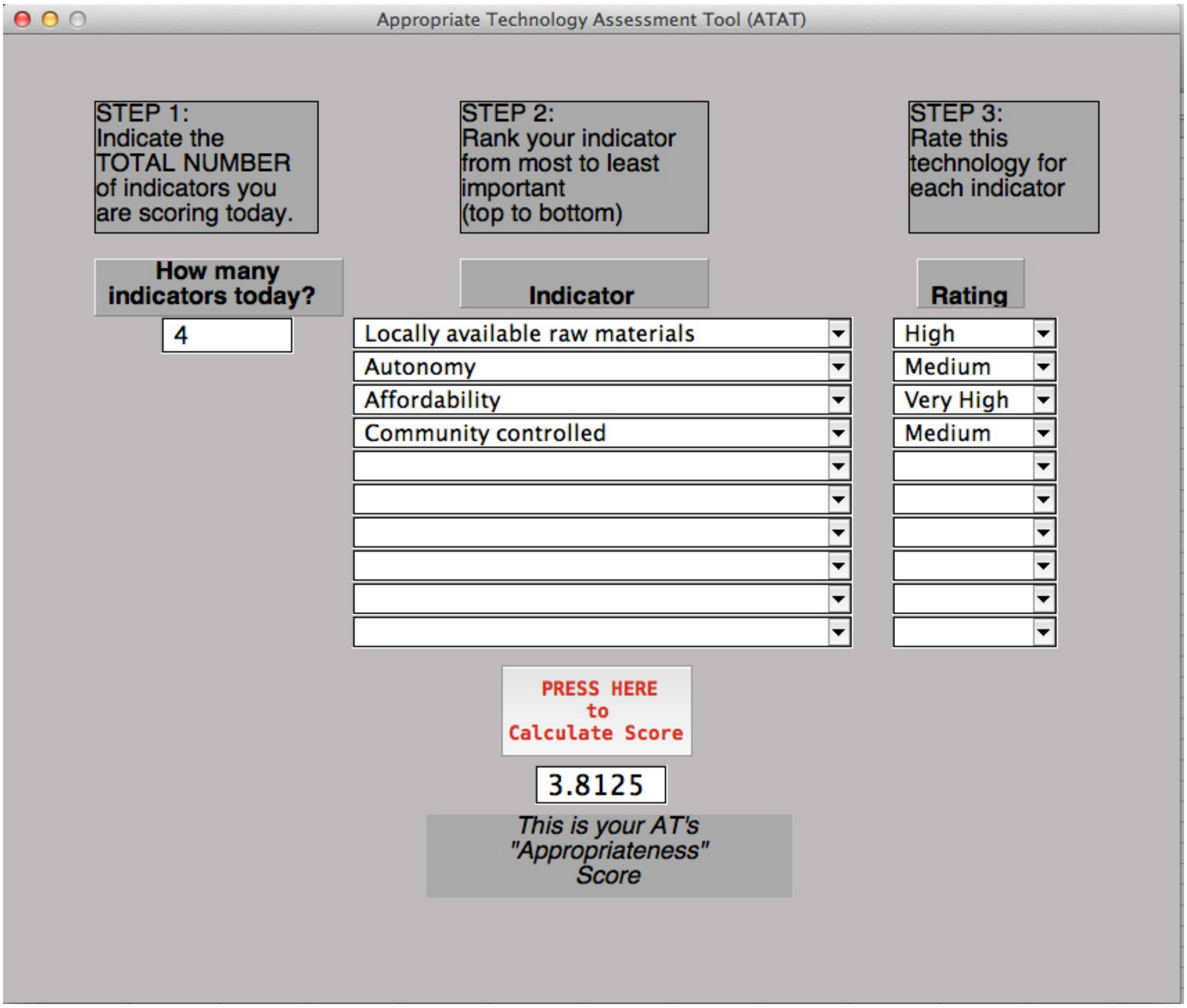
The Appropriateness Index for the Westwood AT (solar air heater) is $\boldsymbol{AI_i}$ **= 4.2**, which is the aggregate score of workshop participants' opinions about the solar furnace. The indicators chosen by participants were not entirely representative of the top indicators from the literature review.

7. Discussion

Given the Westwood community's chosen criteria and the AT's rated performance within those criteria, the Appropriateness Index (AI_i) of 4.2 for EZ Heat conforms to the stakeholders' selection of this technology during the project design phase. The ATAT model for quantitative assessment of AT is sound. Moreover, the fact that the Mini-Delphi workshop participants ranked AT indicators differently than those from the literature validates the importance of stakeholder input for AT development. This also suggests a possible point of departure that could have led to less effective technology being introduced in Westwood, had community input not been collected. Such a departure could have damaged support for the community development process, and harmed the relationship between Revision International and CU-Boulder.

ATAT is designed to be free and accessible via Internet, and with the advent of "smart devices" (e.g. phones, tablets) the potential of a mobile application is being investigated for use in the near future. For researchers working in remote areas, a mobile ATAT application will be more useful, more practical, and will facilitate the tool's continued refinement over time.

Appendix A. Screen Capture of ATAT Form with Sample Values



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