Sustainability **2013**, *5*, 3382-3425; doi:10.3390/su5083382

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Design Methodology for Appropriate Technology: Engineering as if People Mattered

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Received: 7 June 2013; in revised form: 25 July 2013 / Accepted: 25 July 2013 / Published: 12 August 2013

Abstract: Since the emerging of its idea circa four decades ago, Appropriate Technology (AT) had been proven as a comprehensive solution in a limited condition. However, practitioners & academia have different opinions with engineers on how an AT must be designed. Researchers had noted the crucial factors in the issue as such, and they gave a notion of the urgency for a dedicated design methodology for AT. This study, therefore, aims to provide it. Such methodology is developed by incorporating AT characteristics, fundamental issues in community empowerment, and the principles of existing design methodologies. The methodology emphasizes combination between bottom-up and top-down design approaches. It means that an AT must be started purely from local conditions rather than given technical specifications, and be given back to local people to be seamlessly integrated into their routines. It also underlines the crucial importance of community involvement throughout design stages. By looking at previous design methodologies that were developed based on pure Engineering Problem Solving (EPS), this study delivers a fresh and comprehensive one that covers surrounding issues and concepts to produce an AT based on the real meaning of technological appropriateness.

Keywords: appropriate technology; community empowerment; design methodology

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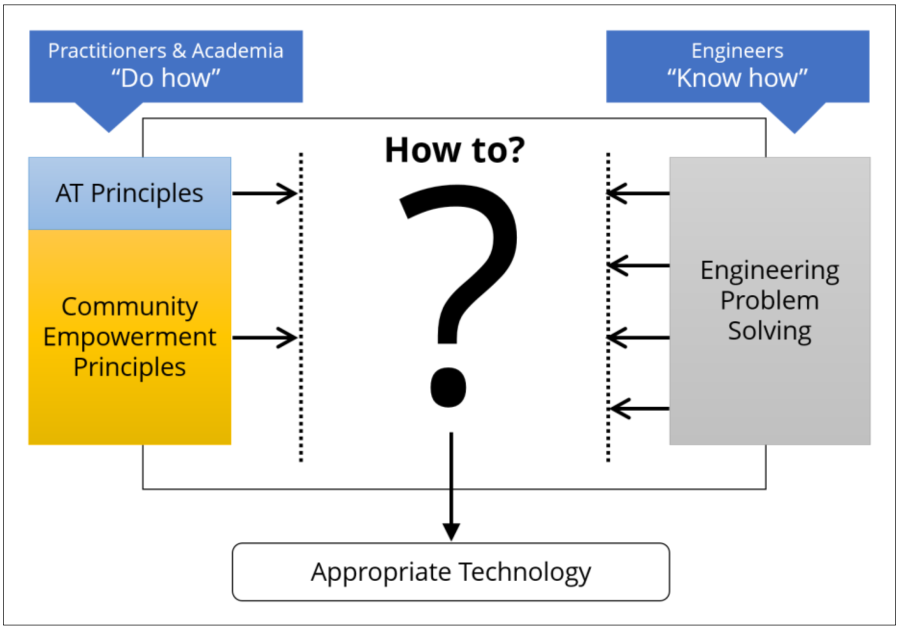
1. Introduction: Research Gap and Objective

Development studies in underdeveloped regions remain interesting to be investigated due to the tightly constrained circumstance that is unique in each area. Such conditions had obliged anyone who wanted to participate in development efforts in an underdeveloped area to implement a comprehensive solution rather than partial works. Thus, any development effort needs to be implemented as an intelligent solution which integrates the need for optimal development from technical and economic sides and at the same time preserves socio-cultural and environmental conditions [1]. In such kinds of efforts, there is a solution that can be treated as a connecting node of many development focuses in order to produce an empowered community: the Appropriate Technology (AT). AT has been widely known as a technological solution to providing a technology that has sufficient performance at an affordable price. Since its first appearance, AT has been initiated as a comprehensive solution in a limited circumstance. At its initiation, E.F. Schumacher attempted to interpret Eastern wisdom by using his Western economic approach to understand the meaning of a technology to people in Third-World countries [2]. At the time, Gandhi's ideas on the autonomy and self-reliance of a society were expanded by E.F. Schumacher [3] into a new mindset to provide more feasible solutions for underdeveloped people. Schumacher thought that Western-based approaches couldn't be purely applied to establishing an "appropriate" technology for these kinds of people. After such initiation, AT has been increasingly applied to achieve a more visible development result [4]. AT had also become interesting for researchers in both development and engineering studies. It was characterized into two big ideas: resources localization and soft approach. The first characteristic means that the appropriateness of an AT is interpreted as the extent to which AT designer(s) use as many as available resources in a targeted area [5–8]. Then, the soft approach requires any AT development to have more sensitivity to local conditions [9–12]. In short, both characteristics suggest an on-site AT development based on local conditions in unique matters rather than cross-countries problem solving on given problems.

However, field cooperation was questionable when practitioners & academia of AT & community development had to collaborate with engineers. While engineers maintained an EPS standpoint, practitioners and academia preserved their approach in which engineering must be clearly opened to local people [13]. It had forced engineers to be technical assistants rather than pure industrial-based engineers. Because engineers had already maintained their own approach, they were trapped into a dilemma between technological appropriateness for community and their own knowledge on engineering appropriateness. Because of that, they made a compromise between a pure engineering approach and community empowerment. They brought technology from outside and adapted it with local technical and economic conditions. Therefore, there was a big gap between engineers and AT's practitioners & academia. The EPS approach was considerably cloistered enough to avoid the incorporation of AT and community empowerment principles into its workflow. Thus, the research gap is about a new engineering design that incorporates AT and community development principles in order to achieve real technological appropriateness for a designed AT (Figure 1).

As noted by Lucena *et al.* [11], the counterproductive factor in Engineering and Sustainable Community Development (ESCD) is on the Engineering Problem Solving (EPS) approach. Riley [10] had also noted that engineers always relied on pure EPS approaches which: (1) often ignore local context and values; (2) exclusion of traditional ways of knowing; (3) denial or devaluing people relationships and enjoyment; and (4) too deep a commitment to militaristic or industrial work-styles. Therefore, existing methodologies in technological design and development did not provide suitable interpretation of modern EPS approaches into ESCD efforts. Their tight foundation on pure EPS produced unreliable technological solutions for communities. A good technology was judged by only discovering its technical and economic values but ignoring indigenous capabilities in solving a community's own problems and in conserving surrounding environment. Very large numbers of implementation problems had been detailed by many researchers, and they produced the same notion on the urgency of a specific-purposed EPS approach for appropriate technology (AT) in ESCD [9–11,14–17]. Hence, a new approach was required to include ESCD issues into EPS in order to produce real AT. It should consolidate EPS and ESCD by integrating some modern techniques but in new ways of implementation. AT required a holistic approach for its development process by including local issues into account. Therefore, this study had only one single objective: to develop a new methodology for designing appropriate technology by incorporating surrounding issues and concepts.

Figure 1. The Research Gap.



2. Historical Positioning

Engineering design had become a subject of investigation of design research for more than 100 years. Since it began in the middle of 18th century [18], it was explored by researchers across disciplines, which required it as an important facet of their discussions. Still, it did not have a single agreed definition to precisely explain its concerns on guiding designers in their unique activities. Although there was no agreement among researchers, their opinions were concluded into a single joint statement to explain the terminology of design methodology from two distinguished perspectives: art and science. Design, as its nature as a methodological process, was characterized as an art and at the same time also science. Heymann [19] had compiled an example of research genealogy on the German-based community of design methodologists, which was noted as one of the world's most active design communities. Design as an art was constructed by pluralists. They took design as a practical process which consisted of methodological stages to produce a certain product in an uncertain condition. It incorporated art-based approaches because they stated that creativity was the core of any design practices. Creativity was interpreted as a natural gift of humans. It emerged as each designer grew in a set of conditions which would construct his/her own way-of-thinking. The pluralists were dominated by practitioners, but also included some pragmatic and critical methodologists [19]. Some flexible ones [20,21] also contributed to this point of view. On the other side, design scientists were strongly contributing pure scientific approaches for design processes. They were ones whose methodologies consisted of detailed scientific derivation for any design considerations [22,23]. They tended to breakdown conceptual design into snippets, decompose each snippet into detailed taxonomies, and reconstruct them into an integral assembly of design concept. In short, design scientists attempted to understand design methodology as a scientific guideline which incorporated deep scientific analysis throughout design stages to every snippet of a designed technology.

In fact, there were some other classifications of design research [24] which provided categorized spectrums of design research, or the earlier one [25] that attempted to classify design methodologies in mechanical engineering research area. However, their classifications were constructed without clear resolution and in more narrowed disciplines, so it was difficult to locate the new methodology in their classification styles. Therefore, Heymann's classification [19] which was constructed from the world's most active design research community was preferable to become a foundation of the new methodology. Based on these historical explorations, and by also considering unique characteristics of this research among previous design research efforts, the new methodology was placed between flexible and critical types. Between these types, there were good opportunities to incorporate simple scientific analysis that were simply understood by underdeveloped communities but at the same time to provide more flexible roles for designers to construct an AT based on their unique nature as artists. By incorporating simple scientific analysis, involvement of community members into design processes was strongly expected to ensure their understanding on AT concept and design. It would be useful to sustain the usage of an AT and empower its users for their own future. Besides, art-based nature of design artists was accommodated to give as wide as possible opportunities to construct an AT in a balance with requirements provided by local people as their co-workers. The position was not considered as purely "critical" because every community-related effort was unique, so a more flexible approach was required to provide easy adaptations of the new methodology into any empowerment cases.

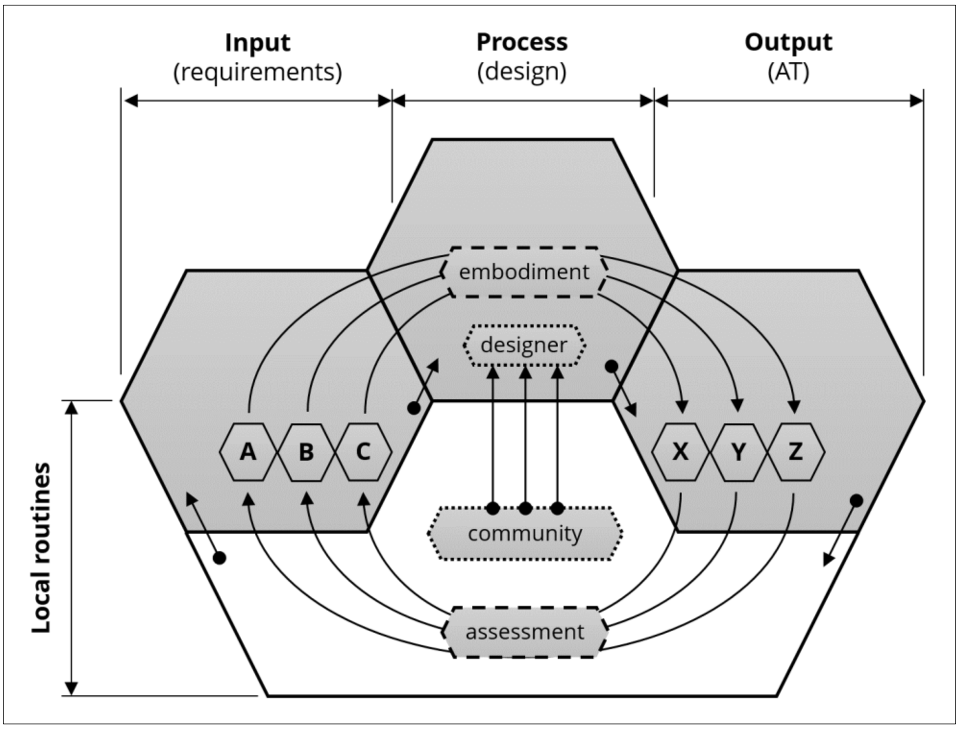
3. Basic Approach

Due to the close relationship between AT and community empowerment ideas, following considerations were incorporated to construct a strong basic approach of the new methodology. As the basis of exploration, axioms of general design theory [26] were taken. Those axioms were the proposition of previous design theories, so they could become the proposition of new design methodology. Besides, although they were developed to connect design entities, the fact that community members must be involved in design process together with AT designers meant that they became another design entity that must accounted for.

The first axiom was recognition. This axiom interpreted descriptive recognition of any design entities by using their own attributes and/or probing their involvement through an abstract approach [26,27].

As an empowerment-based technology, AT must be designed based on as many as possible requirements revealed directly on the field and must provide seamless integration with local daily routines. It must be conducted as bottom-up-bottom approach to identify real requirements based on local people's experiences and to give AT as design result back to them (Figure 2). Due to some constraints like low education and/or wealth, which might increase difficulties in recognizing requirements, a descriptive approach was better than pure quantitative one. Abstraction was also possible because qualitative considerations might dominate local people's way-of-thinking due to their daily routines. In short, the bottom-up-bottom approach in a descriptive way was a must to ensure incorporation of any unique requirements in a targeted empowerment area into an AT design by discovering local problems to be solved through the new methodology, and to ensure sustainable AT usage in supporting survivable community empowerment.

Figure 2. The basic approaches.



The second axiom was correspondence. This axiom defined that every concept entity must have a one-on-one corresponding pair with a design entity [26,28]. In this axiom, concept entities were those that had ever existed in past community daily routines, still existed at present, and might exist in the future. Besides, design entities were ones in which/whose contributions led to complete investigation of local problem solving. By applying one-on-one correspondence, each conceptual input and/or information discovered from descriptive recognition could be addressed to another design entity such as a cooperative NGO or one that involved independent experts as well. On the other hand, one-on-one correspondence was also important to assess the result of design process to local requirement. An indicator among AT specifications/performances must be assessed by comparing it to its root among field requirements. In short, correspondences must become an integral part to keep validation and reliability of any flowing information during design processes (Figure 2).

The last axiom was operation. It was interpreted as an understanding on how a set of abstract concepts could create a real one [26,29] (Figure 2). The word "topology" was proposed [26] to show that the construction of concepts could be built by using abstract ones. It provided opportunities to solve a condition while scientific analysis could not be applied to abstract concepts discovered through a bottom-up-bottom descriptive-qualitative approach. Then, abstract concepts must be derived to become design constraints for designers. The usage of constraints meant that designers' creativity was not strictly banned but could still be framed to ensure technological appropriateness of a designed AT. Abstract concepts that were converted to a set of constraints gave an overview on the basic topology of design process and designed AT itself. Constraints became a standardized frame of design operation, and it guided designers to produce creative design without ignoring requirements revealed on field.

4. Design Methodology for Appropriate Technology

4.1. Design Framework: Basic Workflow and Worksheet

4.1.1. Basic Design Workflow

In order to provide a bridge between existing methodologies and AT approach, a basic framework is constructed based on common understanding in engineering design. This study requires a strong basis of reference for the new methodology. Some of the newest design methodologists [30,31] had provided several perspectives in engineering design, yet in general, their design approaches existed mostly in the industrial design area. Furthermore, another modern methodologist [32] also described another perspective in a design stage-gate process and several examples on fields, but, again, it was focused on market-based competition and not on community-based cases. Thus, methodology that stood on the flexible standpoint between art-based and science-based perspectives is preferred. A simple and non-focused-area methodology is easier to be adapted in order to develop another one.

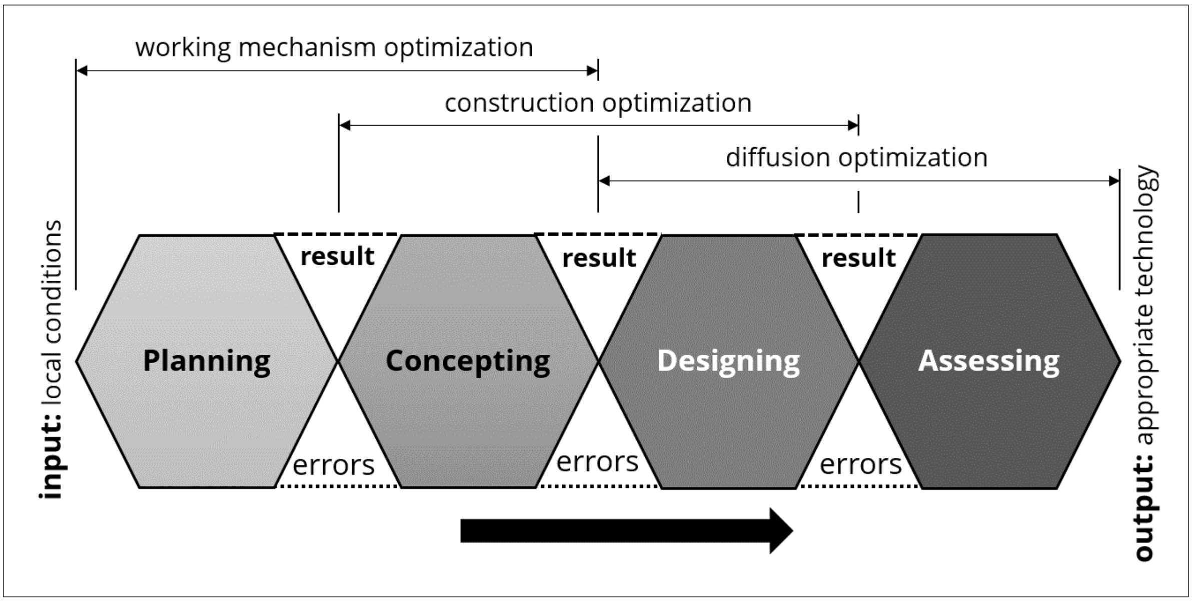
One of the most notable research results on design methodologies was developed by VDI. VDI 2222 consisted of product development process while 2221 provided guidelines on conceptual design [33]. They are chosen as the basis of the new methodology based on several considerations:

(1) It accommodated many previously developed methodologies into a compact one [33].
(2) It became one of important foundations for later methodologies [34].
(3) It was widely implemented in design process for many products in different sectors [29].

In order to develop an engineering design which could accommodate as many as possible existing engineering designs, the existing ones were compiled [20] into a compact engineering design which was then utilized and adapted by the VDI standard with the number VDI 2221 and 2222 [33]. The methodology consisted of four stages namely "analyzing", "concepting", "designing", and "finalizing", and also several steps in each stage. Here, four stages are proposed as the basic workflow (Figure 2). Similar with VDI standard, it consists of "concepting" and "designing" stages as the core activities in design process. However, in the community development approach there is no dedicated analysis stage because any activities always include analysis to ensure proper development [17]. Thus, the first stage is "planning" to accommodate required planning activities as the predecessor of any other ones. On the other end, "finalizing" is replaced by the "assessing" stage to ensure technological appropriateness [13] as well as to reduce administrative activities introduced in industrial-style design methodologies [21].

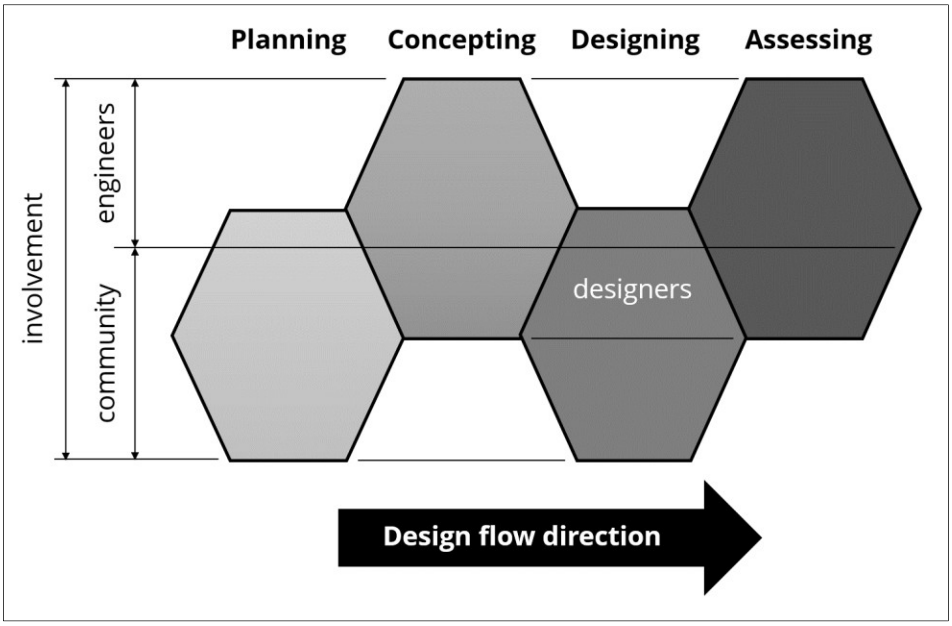
Between two sequential stages, there are two kinds of outcomes: result and error. Result is the output of previous stage and input for next stage, and Error is the misplaced output caused by misinterpretation of some considerations in previous stage(s). Some correlations are placed between stages in order to ensure a continuous design process between stages (Figure 3). The first two stages are correlated as the optimization phase of the working mechanism. It is done in two stages to build a strong concept based on indigenous knowledge of local people. The second stage is also correlated with the third one as the construction optimization phase. These stages are the phases where designers use their creativity based on requirements discovered on previous phase, and where the involvement of local people in early AT trials is started. Then, the third and last stages are correlated as the diffusion optimization phase. Some further considerations are included in AT development based on local circumstances. These considerations are required to ensure technological diffusion of newly designed appropriate technologies. In this phase there are crucial elements to decide technological appropriateness of each AT design as the basis of selection between AT designs.

Figure 3. The Basic Workflow.



On the other hand, the urgency of local people's involvement in design process gives another possible workflow for the new design methodology (Figure 4) in terms of the proportion of involved parties. In the first stage (Planning, Figure 3), local people are involved as the main information source due to their position as the subject of empowerment. In this stage, engineer(s) become the facilitators to help local people reveal their own requirements and to do required crosscheck and/or triangulation of discovered conceptual inputs/information. After that, local people are involved as the main party whose experiences have guided process in the Concepting stage. They are very experienced in their own area, so engineer(s) assist them to investigating possible concepts that should be locally available. Next, designer(s) join the whole process by taking constraints provided in the second stage into the Design stage. Engineers would be better to be the designers themselves, yet some considerations may result in the involvement of dedicated designers for specific reasons such as specialized construction types or strong experiences in similar cases. In the Design stage, designer(s) collaborate with local people to find local principles that are feasible to be treated as inspirations for AT designs. Engineer(s) assist designer(s) through controlled design constraints and also become technical assistants for local people to construct AT designs into real technologies. Finally, in the Assessing stage engineer(s) help local people to assess constructed AT designs by comparing each of the specifications and performances to corresponding requirements revealed in the first and second stages. The results of the comparisons will indicate the level of technological appropriateness of each AT design. Also, the results will reveal the most appropriate technology which can be further replicated in a targeted community empowerment area.

Figure 4. Proportion of Involvement.



4.1.2. Worksheet of Design Activities

This methodology attempts to design an engineering approach as if people mattered, meaning that local people are involved through some ways into design process of AT. Gupta [35] has stated that:

> "Unless we build on the resources in which poor people are rich, the development process will not be dignified and a mutually respectful and learning culture will not be reinforced in society."

Therefore, all steps are supposed to be founded on local problems and opportunities related to AT and targeted process. In short, the basic understanding emphasized in all steps is about any local manners and matters. By incorporating as many as possible locally available resources, it means that a technological design is built on local attributes, so it prevents any foreign interventions and/or technological shocks. While technological adaptation pulls local people to understand foreign technology through knowledge and technology transfer [36], this methodology aims to produce an AT which is designed based on local resources, meaning that there is no urgently required knowledge and/or technology transfer from engineers/outsiders to local people.

From the basic workflow (Figure 3), there are several steps that must be taken in order to pursue the basic purpose of each design stage and to ensure a smooth flow of activities throughout the design stages. All steps are proposed as having close correlations among each other to naturally provide a clear understanding of everything and to construct a strong foundation of comparable assessment for all designed ATs. Four stages previously proposed are further detailed into 10 flowing steps. They form the worksheet of activities (Table 1) that consists of list of activities and required figures, charts, and tables. The worksheet acts as the guideline for engineers in doing AT design and development process.

The first stage, "Planning", consists of three steps. The first step is "choosing gatekeepers." It is conducted to find reliable local people who have the capacity as information sources and can become influences in supporting AT design and application. After that, engineers must investigate field inputs. As previously explained, field inputs become the requirements which must be fulfilled by AT. In this step, engineers need to gather as much as possible information about field requirements from local people through informal Question & Answer techniques based on some theoretical and operational variables. If needed, information from 3rd parties can be very useful to do simple triangulation on the reliability and validity of emerging inputs. Then, such requirements are compiled into supposed group/aspect and are formatted to standardize understandings of them.

After field requirements are compiled, design process flow is continued to the fourth step, the "scaling degree of creativity". In this step, engineers regroup compiled requirements based on constraint(s) of specification and range of freedom for each requirement to distinguish the degree of creativity. The degree of creativity is useful to provide as wide as possible chances for AT designers to use their creativity without altering emerged field requirements. Next, physiological concepts are established in the fifth step by deriving targeted processes into several physiological processes (PP) and events and by further deriving them into a complete package of physiological functions (PF). Then, through the exploration of some alternatives for each PF, proposed concepts are composed by combining some of the alternatives—one per PF—to build each physiological concept.

After physiological concepts are composed, designers start their work by joining into the process through the sixth and seventh steps. In the sixth step, designers construct each PF into a real AT based on compilation of requirements. Embodiment of each PF is designed and constructed by considering the degree of creativity as constraints for designers' creativity. After AT designs are constructed, they are tested directly in the field by involving local people into testing process. To do so, a set of testing procedures is developed based on standardized rules and constrained output quality of targeted system.

Finally, all designed and constructed ATs are assessed to judge their level of appropriateness and to decide which AT will be applied in a designated area. In the eighth step, valuation standards are established based on previously compiled requirements and degree of creativity. After that, performances of each tested design are rated based on quantitative calculations and qualitative prediction—dependent on the characteristics of each performance indicator's measurement unit/type. Next, the importance of each operational variable is weighted by coupling and comparing each other. Afterwards, performances of each tested design are evaluated based on valuation standards and also valuation on performance indicators. Then, technological appropriateness of all AT designs is judged by using two different techniques. Such techniques depend on the specific needs in each AT case.

Table 1. Worksheet of activities.

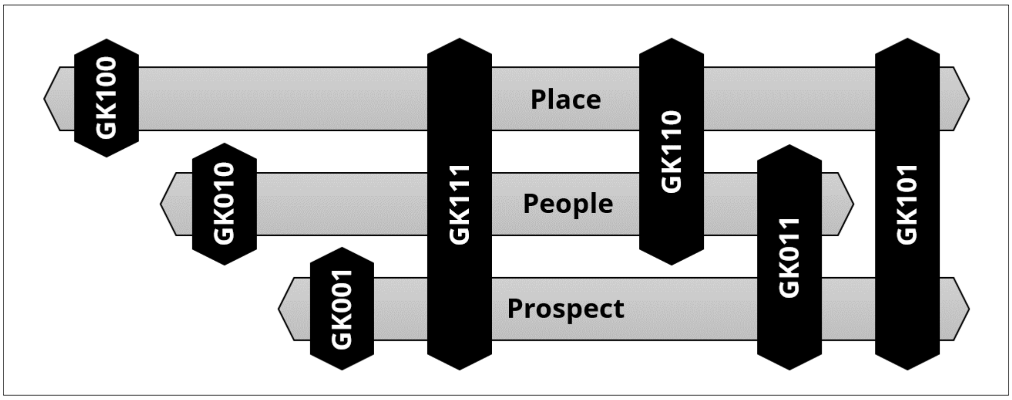
Name of Step	Check	Activities	Figures & Tables
Planning Stage			
Choosing Gatekeepers		Testing reliability	Figure 5 Table 2
		Categorizing gatekeepers	
		Selecting gatekeepers	
Revealing Field Inputs		Making a master question	Figures 6–8 Table 3
		Informal Question & Answer	
		3rd party information	
		Triangulation	
Compiling Requirements		Naming requirements	Table 4
		Grouping requirements	
		Formatting quantitative/qualitative specification	
Concepting Stage			
Scaling Degree of Creativity		Distinguishing freedom(s) and constraint(s)	Table 5
		Grouping same freedom & constraints' pattern	
		Filling out standards and additional notes	
Establishing Physiological Concepts		Deriving physiological functions (PF)	Figure 9 Tables 6–8
		Exploring alternatives for each of PFs	
		Composing Physiological Concepts	
		Detailing physiological concepts	
Designing Stage			
Constructing Designs		Drafting design	Figure 10
		Constructing AT designs	
Field Testing		Placing ATs on future usage field	Tables 9–11
		Developing testing procedures	
		Preparing required forms and training field testers	
		Doing field testing in some repetitions	
		Compiling testing results	
Assessing Stage			
Valuating Performances		Establishing valuation standards	Tables 12 and 13
		Gathering required calculation standards	
		Valuing performances of each tested design	
Evaluating Level of Appropriateness		Weighting operational variables	Tables 14 and 15
		Performance evaluation	
Assessing Stage			
Judging Appropriate Technology		Compiling evaluation of all designs in all aspects	Figures 11 and 12 Tables 16 and 17
		Mapping simple technological appropriateness	
		Judging (first level)	
		Mapping reversed appropriateness	
		Judging (fist level, alternative judgment)	
		Recalculating by incorporating IA multiplier	
		Judging (second level)	

4.2. The Planning Stage: Revealing Requirements

4.2.1. First Step: Choosing Gatekeepers

As previously explained, field requirements become the most important inputs of the AT design process. They are the existing problems and opportunities which must be fulfilled by AT as a medium to provide a technological solution for local people in a specific process or a set of processes. In order to investigate reliable requirements, reliability of information sources is very essential. Local people certainly understand their own problems, yet not all people understand specific problems that require technological solutions and/or surrounding issues that provide barriers and/or opportunities for AT application. Some people may understand about some matters and manners while the others not. Some people even understand their problems but they do not want to solve them due to some conflict of interests. In short, there are some people who have deep understanding of local conditions and also have the motivation and dedication to further increase local prosperity by carefully developing local prospects. They are so-called "gatekeepers" [37,38]. Due to the intention of AT, the term "local conditions" refers to ones that have relationships with some issues surrounding technological solutions. Because of that, gatekeepers become the most useful information sources in AT development; they must be identified through testing their relationships with existing local conditions and possible future ones. In order to identify gatekeepers, there are three useful indicators to figure out the personal bond of a person to local conditions. These indicators are Place, People, and Prospect (Figure 5).

Figure 5. Indicators of Gatekeepers' Types.



Place is defined as the bond a person has in him/herself to the place where he/she lives. As a local, a person's bond to the place can be tested by asking question about their good opinion on local area. If a person reply with an answer in which local area is a good place to live because it has near distance with neighbors places (easy to access, attractions in neighbors area, *etc.*), it means that the person has a low bond with local place. A person with strong bond to local place is one who tend to provide as many as information on local manners/matters (local attractions, good livelihood, *etc.*) rather than relying on neighbors' conditions in showing good local conditions.

Furthermore, People means that a person has a good opinion on what people do locally, and has a clear understanding of local people's capabilities on managing existing conditions. Similarly with the first indicator, a simple and informal question about their good opinion on local people is addressed to a person. If a person replies with an answer in which local people are good community members because there are some people who work in neighbors' area and/or big cities, or maybe because there are some foreign people who come to do something with local people, it means that the person doesn't have a strong bond with local people. Inversely, a person with strong People bond will reply by providing information on how local people develop their livelihood by working on something in their own place. The person will provide capabilities of local autonomy on managing resources without ignoring local values that have been existed for long time in their survival efforts.

The last indicator, Prospect, shows a person's dedication to future development of local area. The question is about what a person will do in the fairly far future related to local development. If a person states that he/she will find some job prospect in another area, or he/she will move to another area but cannot ensure whether he/she will come back to the present area, it means that the person doesn't have a strong bond for the future of the present area. People with strong bonds will give their hope to participate in local development rather than relying on their future outside the present area.

When an engineer attempts to ask those questions, there will be several sets of answers replied to all questions. Due to its informal process, simple codification is required to tag each person with his/her answer. From tagging techniques, engineers can judge the type of recommendation for each person as a potential information source (Table 2). GK is the acronym of gatekeeper, while binary numbers 1 and 0 are used to identify a person's bond on each question. If a person shows a good bond in a question, he/she will get 1 in the question, and *vice versa*. The most recommended person to be involved as a gatekeeper is one who has strong bonds in all indicators (GK111). The person will become a reliable information source because of his/her understanding in local conditions. He/she is also noted as having self-motivation in joining any efforts for further development of the local area. One level under the most recommended one is any people who have strong bonds in Place and People indicators (GK110). Even if they don't have strong bonds for future conditions, they can still be reliable information sources due to their good understanding about local matters/manners. If a person has a strong bond in one indicator between Place and People, and the person has a strong bond in Prospect indicator (GK101 or GK011), it means that the person is less recommended to be an information source, but maybe useful to be involved in some activities in the near future. Then, the most not recommended persons are the ones who have only one strong bond (GK100, GK010, or GK001) or no bond (GK000) at all. They must not be information sources and are not good to be manpower at any time due to their weak bonds in two or more indicators.

Table 2. Basic categories of gatekeepers.

Type	Occupation	Place	People	Prospect	Recommendation
GK000	{occupation}	0	0	0	Not recommended
GK100	{occupation}	1	0	0	Not recommended
GK010	{occupation}	0	1	0	Not recommended
GK001	{occupation}	0	0	1	Not recommended
GK011	{occupation}	0	1	1	Less recommended
GK101	{occupation}	1	0	1	Less recommended
GK110	{occupation}	1	1	0	Recommended
GK111	**{occupation}**	**1**	**1**	**1**	**Very recommended**

4.2.2. Second Step: Revealing Field Inputs

After gatekeepers are chosen, engineers can start to discover field inputs. Field inputs are any opinions/questions/statements which reflect local problems that should be solved by AT and at the same time provide opportunities for AT to do problem solving through technological solutions. Because engineers have already chosen gatekeepers whose information reliability was considered, inputs are supposed to have a precise reflection of local conditions. By involving good gatekeepers who have good information reliability, engineers can get clear and precise targets to be fulfilled by AT. The targets are supposed to be the correct conditions in which local problems are solved through AT application in a seamless integration with existing local conditions.

Inputs should be able to explain local conditions in their natural understanding [39]. Some inputs can be quantitative if people usually understand them in quantitative way, and other ones can be qualitative if they are qualitatively understood by local people in their daily life. In this methodology, the fundamental aspects of community problem solving (Technical, Economic, Environmental, and Social) [13] become the basic understandings on any issues. They are supposed to be the perspectives from which any inputs are categorized and solved. These aspects are then derived to provide detailed guidelines on how to understand each input by using a right perspective. It is critical because an input may be considered from two or more different perspectives, yet each perspective will produce a unique result and a cross consideration from different perspectives will even produce counterproductive results.

Each aspect is derived into the same numbers of theoretical variables (Table 3). Equal numbers are proposed to allow a balanced exploration between those aspects in exploring field requirements. Theoretical variables are those that reflect more specific approaches in interpreting fundamental aspects into characteristics of AT design process as technological development. Each theoretical variable is proposed to have a general overview on related issues in a distinct perspective. Each of them is not a given requirement, yet all of them become sets of guidelines to map each of the emerged requirements in a single design aspect/perspective.

Technical aspects are divided into three theoretical variables, namely Functions, Time & Difficulties, and Features. The Functions variable is defined as any working function that must be integrated into AT design. Any function is mainly sourced from targeted processes that will be improved by applying AT. Due to the intentions of community empowerment approach that avoid a shocking intervention as well as significant changes on local routines [40], AT functions must also be connected with some processes related to the original one. To do so, the Functions variable must also discover potential integration with extended processes. Next, Time & Difficulties is interpreted as timely limitations and difficulties that occur as negative forces to existing processes in a local area [41]. Some potential limitations and difficulties that may emerge during AT design and/or application are required to avoid any conditions in which they could actually occur. Therefore, this theoretical variable is treated as a forecasting-like [42] as well as backcasting-like [43] approach to understand the present and potential future. The last theoretical variable in Technical aspects is Features. This variable becomes a way to understand required features which should be integrated into AT, and some additional features to support future development of an AT. This variable is tightly related with existing processes, in which AT must remove unnecessary activities in previous processes and at the same time multiply the effect of important ones.

Table 3. Theoretical and operational variables.

Aspects	Theoretical Variables	Operational Variables
Technical [T]	Functions [Ta]	[Taa … Ta(n)]
	Time & Difficulties [Tb]	[Tba … Tb(n)]
	Features [Tc]	[Tca … Tc(n)]
Economic [E]	Investment [Ea]	[Eaa … Ea(n)]
	Operations [Eb]	[Eba … Eb(n)]
	Income [Ec]	[Eca … Ec(n)]
Environmental [V]	Emission [Va]	[Vaa … Va(n)]
	Reusability [Vb]	[Vba … Vb(n)]
	Degradability [Vc]	[Vca … Vc(n)]
Social [S]	Knowledge [Sa]	[Saa … Sa(n)]
	Perception [Sb]	[Sba … Sb(n)]
	Fear [Sc]	[Sca … Sc(n)]

In the Economic aspect, three theoretical variables are Investment, Operations, and Income. Economic matters are defined in these understandings to deliver easy interpretations for local people in expressing their present as well as expected conditions. The first theoretical variable, Investment, is defined as any investment that should and should not be made during AT design and construction [8,44]. It brings an understanding of how much financial investment people want to devote in designing AT and also in constructing AT at the present as well as future time. Investment variable also includes additional investments from surrounding investors that exist locally such as local banks and/or NGOs. The latter kind of investors can be categorized as a kind of outsider, yet at the present time they may be considered a local one until they leave the local area in the future. Thus, NGOs should only treated as a local entity in present time, meaning that future construction cost must be preserved by ensuring cyclical return on investment for local people as a subject of development that always exist in local area. Next, Operations is a variable that focuses on any cost people must devote during AT application. The emphasis of this theoretical variable is on controlled levels of financial burdens potentially produced by AT application. Due to process improvement, any increases on operations cost will likely happen, so field requirements of its reasonable increased level must be gathered [45]. On the other hand, process improvement also has the potential to produce lower operation cost per unit of processed object. Thus, this variable delivers useful ways to understand constrained negatives and positive impacts during AT operations. Besides, the Operations variable also includes maintenance cost, which is defined as any potential spending after some periods of AT usage [11]. Due to its basic characteristics as a technological solution, AT must be maintained to keep its performance as high as its peak. After the AT life-cycle, AT must also be overhauled to replace some parts or be replaced with an entire new one. Therefore, limitations on potential financial burdens must be investigated from the field to ensure future development of an AT. Then, the last theoretical variable in Economic aspects is Income. It is intended to investigate potential ways to ensure the sustainable income generation for local people due to the application of an AT [44]. By discovering some potential income generations based on local understanding, sustainable incomes can be established through process tweaking that will be easily adapted by local people to their daily routines. This variable also includes trajectories on the wealth improvement of targeted people due to possible technological changes in their future. The trajectories are founded on the both the sustainability in smooth development [46] as well as survivability in unstable conditions [13].

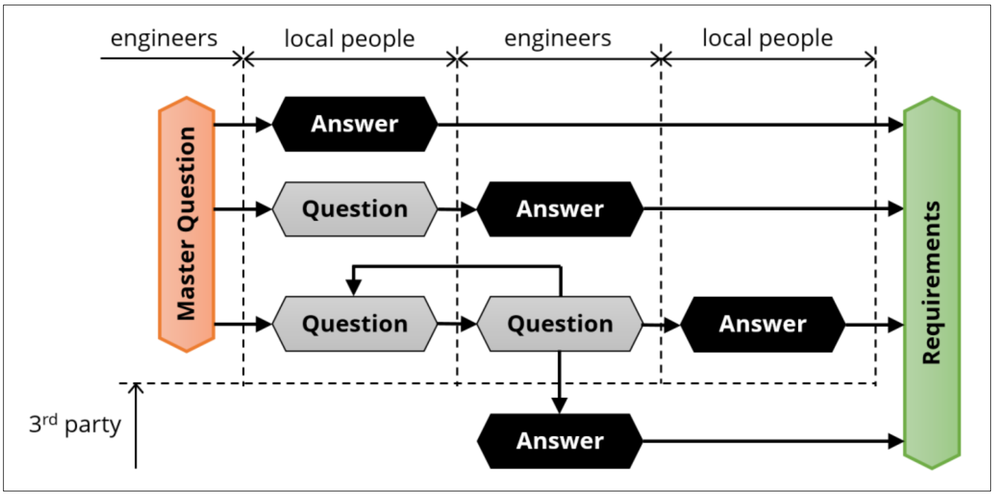
Next, the Environmental aspects are divided into three theoretical variables: Emission, Reusability, and Degradability. Although the intention of AT was always based on a cleaner application approach, the balance among environmental considerations must be established between such approaches and cleaner production [47]. The impacts are also understood as the effects of technological change due to AT application [48]. The first theoretical variable, Emission, is defined as any emissions produced throughout AT design process and potential emissions during AT usage. Emissions can be produced directly or indirectly. Almost all emissions in AT design process are resulted from transportation, so they should be understood from the Tank-to-Wheel approach [49]. However, some chemical substances required in agricultural and/or aquacultural processing flow also produce emissions. Thus, a whole understanding is better, yet field requirements must be considered as the ultimate guide to appropriately limit emission analysis. Furthermore, due to lack of emission analysis in AT cases [50], any judgments on sufficient emission level cannot be standardized and are always unique on a case-by-case basis. The second theoretical variable, Reusability, is defined as the potential reusability on some parts or the entire AT construction after a certain usage period. Reusability is very useful to reduce many things such as technical requirements and/or maintenance costs, yet it is included in the Environmental aspects due to its goal of preserving nature through AT application. Because AT is constructed by using as many as possible materials that are available locally, reusability means that higher reusability will result in less local resource exploitation. When some parts must be taken from other area such as metal-based parts, reusability also affects the autonomy of local areas to other ones. Then, the last variable is Degradability, which means that AT must use as many as possible degradable materials to avoid any environmental pollution that may affect people's health. Degradability also is useful to preserve cyclical decomposing, so AT degradability also affects continuity of natural phenomenon in local areas. In short, the boundaries of environmental aspects should cover all possible environmental impacts imposed since AT design until materials degradation [51].

The last aspect, Social, is the ultimate level of technological appropriateness [13]. It is derived into Knowledge, Perception, and Fear as its theoretical variables. These variables can be defined by using the following questions, respectively: "What does the community already understand? "What do they want to understand?" and "What do they not want to understand?" The first question is related to local, existing knowledge of community members. This variable must discover the correct positioning of AT in which the community shall be allowed to develop themselves based on their social goals. Some knowledge on local techniques, daily activities, and relationships between local people must be taken into account. The second question corresponds to the second variable: Perception. It focuses on community conception on any technological approaches including their expectations. This variable must reveal what people expect from an AT and local understanding of which potentials should be adapted into AT design. It is useful to ensure seamless integration of AT into local daily routines due to the corresponding connections between community perception and AT performance. The last theoretical variable is Fear, which is coupled with the third question. This variable emphasizes both the subjective and objective fear of local people and their hesitancy in accepting offered technology. Some existing routines that have made people comfortable in their daily life may become barriers to improve a targeted process. Therefore, field requirements in this theoretical variable must be taken into account to avoid social resistance to technological solutions and improved processes [44,52,53].

Furthermore, operational variables are ones that further detail each theoretical variable into understandable variables as requirements emerge from a designated community's area. Due to the unique conditions of each AT case, operational variables may need to be interpreted differently by engineers. It usually happens when people discuss something that has a different perspective among engineers [13]. For example, sometimes a problem in income distribution will result in the regrouping of some operational variables in Income group to another theoretical variable in Social aspect. Thus, operational variables construct the basic foundation of the AT design process due to their topological characteristics in shaping the future overview of targeted processes that will be improved through AT application. In order to discover operational variables, field requirements must be investigated through an effective communication method that allows people to be comfortable to share any opinions, suggestions, or even rejections. Comfortable conditions are urged to preserve natural situations, so that people will also act like this in their daily routines and manifest pure expressions [54].

Here, an informal Q&A technique is proposed (Figure 6). This step begins with a master question to encourage the active participation of local people. It begins by using a simple statement about a plan to develop an equipment as a technological solution for some local purposes, or maybe with a firendly question about local current conditions. The question is addressed through informal meetings in several places such as traditional coffee shops, local houses, or even farms. An informal atmosphere is required to have friendly discussions between engineers and people. The meetings become a series of informal brainstorming sessions between them [55].

Figure 6. Q&A process.

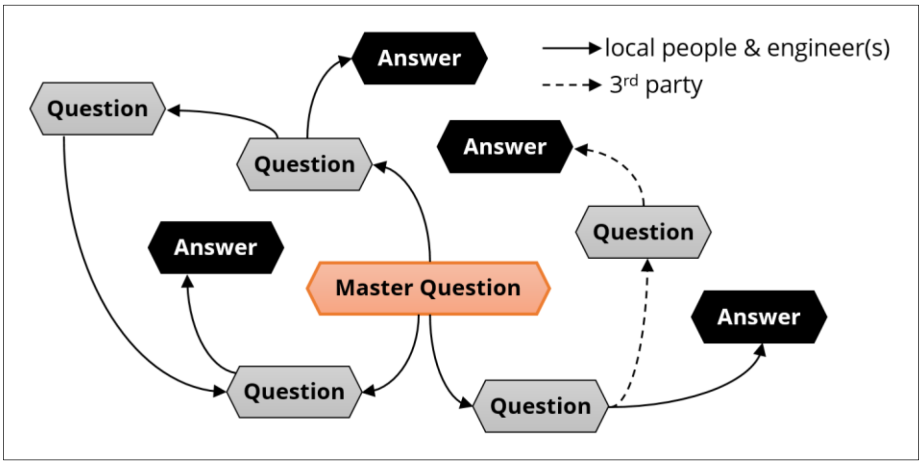


By using their indigenous logical capabilities, local people will always reply the master question based on their own understanding. Their reply will trigger further discussions on some interesting issues for themselves. They will ask anything about the planned technology. They will also express their economic constraints and limitations. Even, it is possible for engineers to receive resisting gestures from local people affected by previous AT application/development efforts [56,57], engineers must not be surprised with any response. As long as local people offer any response, either resistive or cooperative attitudes, each response will deliver a good entrance to involve them in the design process.

Every time people offer a question, engineers need to welcome it by replying with another floating answer to trigger a deeper discussion. However, engineers have to show calm attitudes to avoid people's ignorance in any conversation. People need to be encouraged to provide detailed considerations for each answer by using their own explanations. The best answers have to be gathered through logical considerations but based on simple explanations in a flowing investigation [11,57].

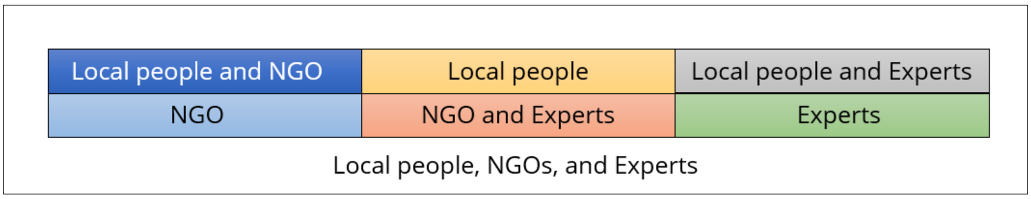
In each meeting, the master question will be replied by people in many different ways. Any answers have to be accepted. For every answer, it shall be written into a Q&A map (Figure 7) based on its proper theoretical variable. It is helpful to understand people's logical thinking about their own problems. Each conversation is placed into a proper variable based on a discussion's track. For example: engineers answer a materials-related question with another question to gather information on what kind of materials are commonly used for similar purposes [57]. Due to their routines in doing local activities, local people will provide a clear answer because they have exactly known anything about any possible options they have used in local routines. Then, people have to be guided to put proper priority for each option, including their reason for any given priority.

Figure 7. Q&A map.



If the design team cannot answer some questions, these questions are noted as unanswered ones. Answered questions are eliminated but the engineering team lists their answers. While unanswered questions reach a certain number with the same quantities for all aspects (different numbers of questions between theoretical variables doesn't matter), Q&A brainstorming activities are stopped. Then, unanswered questions are addressed to other parties (Figure 8) which have the proper capabilities for answering those questions. In any community empowerment projects, there are three parties that can be supposed as information sources: local people, NGOs, and experts [46]. Local people are the subject of development, so any considerations should be made based on their conditions. NGOs are empowerment entities that act as bridges of developmental efforts, so the information gathering and triangulation can be addressed due to their capabilities in understanding extended local conditions. On the other hand, experts are the ones who give advice or become consultants in an entire effort. Therefore, their inputs and triangulation capabilities are useful to strengthen reliability and validity of emerged requirements. Some questions may require more than one party to answer in order to get proper triangulation of each answer. The coloring technique (Figure 8) is used to distinguish different party(s) involved to answer each question.

Figure 8. Map of information sources.



4.2.3. Third Step: Compiling Emerged Requirements

After all requirements are gathered, which means that there are almost no unanswered questions, emerged requirements must be grouped to each respective perspective to maintain basic understanding on each requirement. Then, each one is compiled according to a set of standards in order to standardize their meanings. It is useful to deliver clear denotations of all of the emerged requirements and also to provide uniform understanding on each listed one. Standardized meaning is critical in community-related projects due to unique conditions in each case. It brings the same techniques to understand the uniqueness from one case to other ones. It also minimizes a too broad understanding due to different ways by which local people express their problems and opportunities. In short, it makes all things settle on the same framework of thought, regardless of different theoretical frameworks and design perspectives. Qualitative and quantitative requirements are also standardized in a similar way, yet the result of standardization—compiled requirements—may be different between these kinds of needs.

Proposed formats of this methodology are divided into 3 types (Table 4). One format is distinguished from the other two based on the different characteristics of its content. The "{}" symbol indicates an input expression. If more than one "{}" are written in order, it exhibits a set of input expressions. The symbol "/" indicates optional formatting techniques between previous sets of expressions with the next one(s). In a requirement, some sets of expressions may be required to express the entire meaning. To do so, the ";" symbol is provided to distinguish between expressions in a requirement.

Table 4. Standardization format of emerged requirements.

General requirements [G]	
{**name**}	{number} {unit}/{condition}
	{position}; {if …}
Technical [T]/Economic [E]/Environmental [V]/Social [S]	
{**name**}	{{max/min}/{average}} {number} {unit}/{average} {max number}-{min number} {unit} / > {{lower} {unit}, < {upper} {unit}}/{condition}
	{position}; {for …}/{if …}; {Max/Min} {is about}; {{higher/lower} is better}; {{less/more} doesn't really matter}
{**name**}	
1st priority	{name of option}; {if …}; {not/recommended}
{{*x*} priority}	{name of option}; {if …}; {not/recommended}

The first format is proposed to standardize requirements characterized by their fixed specifications. This format can be used for both qualitative and quantitative requirements. Three attributes in this format are the name of the requirement, which is expressed as {**name**}, a set of content expressions, and a set of conditional expressions. {**name**} exhibits the name of a requirement, and it is expressed as a concise phrase which can indicate a grounded meaning of its content. The name of a requirement is best written in bold in order to allow an easier focus for readers. The latter two attributes are the content and conditional expressions of a respective requirement. The first attribute in the content is a set of expressions, which is expressed as

$$\{\text{number}\}\ \{\text{unit}\}/\{\text{condition}\} \tag{1}$$

The first optional set is addressed for quantitative requirements, the other one is for qualitative ones. In a quantitative set, {number} input indicates the numerical content of respective requirement, while {unit} exhibits its measurement unit. On the other side, a fixed qualitative one is expressed as only {condition}. It indicates a condition in which a respective requirement is fulfilled.

The third attribute in the first format and also the second attribute in its content is a set of conditional expressions. It is required to extend understanding without hampering the main content of a respective requirement as the focus of the design process. It also delivers special conditions in which a requirement must be taken into account or may be ignored due to some circumstances. This set of expressions are:

$$\{\text{position}\};\ \{\text{if} \ldots\} \tag{2}$$

Each of these two conditional statements is written independently. Engineers may write only a conditional one or no conditional expression at all if a respective requirement doesn't require such conditional statements. The first conditional statement is {position}, where a requirement is taken into AT design. It can be a physical position or an artificial position. Physical position means that a requirement must be physically assembled into an AT or integrated into a targeted process. Artificial means that a requirement is taken into AT design by integrating its characteristics and not in a direct physical form. The second conditional statement is {if …} which displays when a requirement must be incorporated into AT design or may be ignored if a condition is not fulfilled.

The second format is proposed to allow standardization for range-based requirements, both qualitative and quantitative. This format is the same for any range-based variables in the four perspectives. The first attribute is the same with first format, which is {**name**}, yet the contents are expressed as

$$\begin{gathered}\{\text{max/min}\}\ \{\text{number}\}\ \{\text{unit}\}/\{\text{average}\}\ \{\text{max number}\}\text{-}\{\text{min number}\}\ \{\text{unit}\}/\\ >\{\{\text{lower}\}\ \{\text{unit}\}, <\{\text{upper}\}\ \{\text{unit}\}\}/\{\text{condition}\}\end{gathered} \tag{3}$$

There are some different quantitative expressions in this format. {max/min} expression means that the respective requirement is restricted to a certain numerical maximum or minimum limitation, so it is coupled with {number} and {unit} expressions as the limitation. {average} expression provides a numerical average in which the respective requirement is fulfilled. It is followed by the {max number}, {min number}, and {unit} expressions to explain range limitation while AT cannot precisely perform in the required average level. Besides, some quantitative requirements may restrict AT to perform in a certain range level. Thus, the conditions expressed by {lower} and {upper} expressions indicate restricted performance range. For qualitative requirements, the {condition} expression is similar to the same formatting standard in the first format, yet in the second format it exhibits a qualitative range that cannot be explained in numerical form.

{position}; {for …}/{if …}; {Max/Min} {is about}; {{higher/lower} is better};
{{less/more} doesn't really matter} (4)

The conditional statements for the second format can be seen in formula (4). {position} and {if …} statements are expressed in the same way as they are expressed in the first format. {for …} expresses similar conditions with {if …}, yet it exhibits a target situation in which respective requirements need to consider when it is fulfilled. {Max/Min} {is about} indicates a conditional statement when respective quantitative requirements cannot be explained clearly in numerical form or there is no information which can validate its numerical content. {{higher/lower} is better} gives more information about a better condition that shall be reached by AT rather than only focusing on a certain numerical average or limit. {{less/more} doesn't really matter} provides a conditional statement which indicates flexibility of a numerical performance. It also extends {{higher/lower} is better} when a condition has a potential change outside a desired "better" condition.

The third format standardizes requirements which cannot be written in the first two formats. This format is very useful to make a scaling between some optional contents in a requirement. Scaling technique is proposed to provide an easier guideline for any engineers/designers considering some options for an emerged requirement. The name of a requirement categorized in this format is {**name**}, the same with other formats, while option scaling is indicated with {**{x} priority**} that expresses the order priority {**x**} for each optional content. The content in this format is expressed as

{name of option}; {if …}; {not/recommended} (5)

The {name of option} exhibits the name of respective options that are positioned in an order of priority. It is not written in bold to distinguish the name of respective requirements. It must reflect the whole meaning and indicate specific characteristics of respective options. {if …} is expressed in the same way with its supposed purpose in the other two formats. {not/recommended} provides extended explanations to understand in which way an option is recommended, for example due to its importance in a local situation, or not recommended due to some restraints although it can be chosen as an alternative option.

4.3. The Conceptual Stage: Composing Design Concepts

4.3.1. Fourth Step: Scaling Degree of Creativity

Those compiled requirements become the basic understanding for AT design and final assessment to test technological appropriateness, yet designers require clearer guidance to express their creativity without ignoring required technological specifications [58–60]. Because of that, a degree of creativity is required to clearly give a framework for designers to put any AT performance in an appropriately designated level. A degree indicates the flexibility chances on how a requirement must be taken into AT design. A degree also exhibits a frame of creative freedom and its constraints. By scaling the degree of creativity, design freedom is provided, yet it must produce appropriate results that correspond with respective requirements emerged from field. Thus, degree of creativity is constructed by transforming compiled requirements into some freedom and constraint classifications (Table 5).

To build a set of classifications, engineers must distinguish between freedom(s) and constraint(s) of a requirement first. Freedom (f) means that designers can put specification of an AT in flexible levels. Freedom can be discovered by taking allowable range an AT can perform for a supposed requirement. Constraint(s) (c) is the limit designers must not design an AT because it indicates that an AT is outstripping field requirement. By combining these understandings on both freedom and constraint, there are at least five degree of creativity can be proposed.

Table 5. Degree of creativity.

Degree of Creativity	Category	Requirements	Qualitative/Quantitative Indicators	Additional Notes
0				
[fixed]	G/T/E/V/S	**{name }**	{number} {unit}	{position}; {if …}
	G/T/E/V/S	**{name}**	{condition}	{*idem*}
1				
[c > f > c]	G/T/E/V/S	**{name}**	{average} {max}-{min} {unit}	{position}; {if …}
	G/T/E/V/S	**{name}**		
		1st priority	{name of option}	{if …}
		{*x*} priority	{name of option}	{not recommended}; {if …}
2				
[f > c] or [f < c]	G/T/E/V/S	**{name}**	{max/min} {number} {unit}	{for …}; {Max/Min} {is about}; {{higher/lower} is better}; {{less /more} doesn't really matter}
	G/T/E/V/S	**{name}**	{condition}	{*idem*}
3				
[f > c > f]	G/T/E/V/S	**{name}**	>{lower} {unit}; <{upper} {unit}	{*idem*}
4+				
[~ f]	G/T/E/V/S	**{name}**	**-**	not defined yet; {{higher/lower} is better}; {if …}

f = freedom; c = constraint.

The first degree is 0, meaning that designers must not change any content of respective requirements. If a requirement is included in this degree, designers must fulfill respective requirements precisely in its fixed content. This kind of degree is usually addressed for fixed content in general requirements. The second degree is 1, in which freedom of a requirement exists between upper and lower constraints (c > f > c). This is addressed for range-based requirements which exist between maximum and minimum limitations in any operational variables. In this degree, designers can use their creativity freely below upper limits and above lower limits, but they must not put any AT specification above upper limits or below lower limits. The third kind of degree is 2. In this kind of degree, there is one freedom and one constraint. Freedom can be lower or higher than a constraint. If freedom is higher than the constraint, it means that AT can only be designed to perform in any level above it, and *vice versa*. The fourth degree is 3 and occurs when two freedoms limit one constraint. A requirement with degree 3 must be followed through design of an AT that can perform over or under a constrained range. The last degree is 4+. The "+" symbol means that there are many unidentified degrees due to no specifically defined target for respective requirements, so it cannot be indicated by degree. For any requirements with a 4+ degree, designers can design AT with any level of specification for respective requirements.

After all patterns of freedom and constraints are grouped, then contents of all requirements are moved from formatted requirements (Table 4) to each respective requirement. Formatting technique in this step remains the same, so there is no significant change from the previous step. Sets of expressions are moved into the fourth column, and sets of conditional statements are moved into the fifth column (Table 5). Some characteristics of formatting combinations for requirements in each degree can be observed in the fourth column. However, due to undefined degree of creativity for the 4+ degree, there is an additional conditional statement for the degree. The "not defined yet" statement is added to highlight the widest freedom for designers, yet {{higher/lower} is better} & {if …} extend its meaning by expressing better circumstances in which a requirement can be fulfilled or maybe ignored.

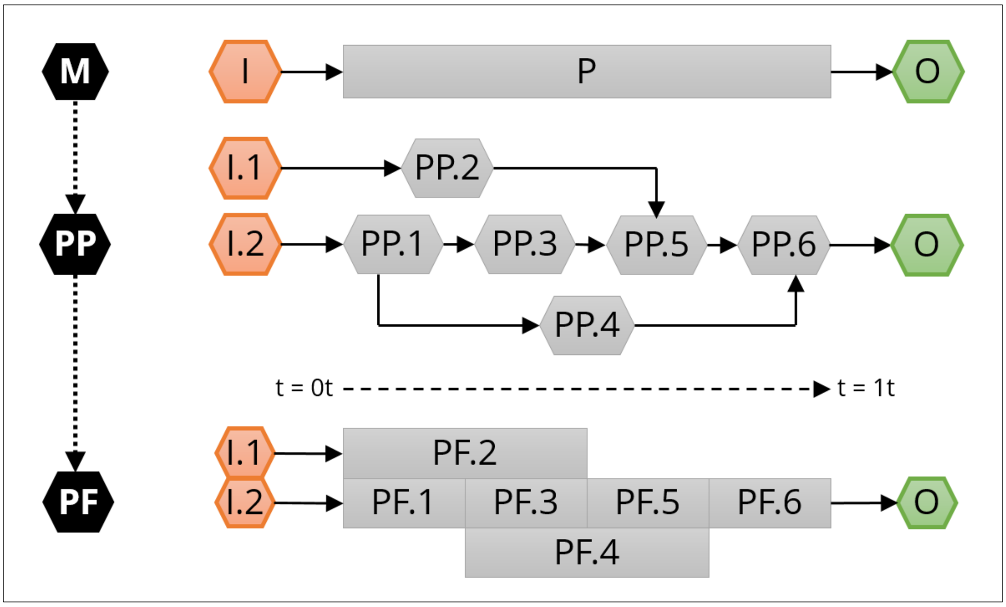
4.3.2. Fifth Step: Establishing Physiological Concepts

4.3.2.1. Deriving Physiological Functions

After compiled requirements and scaled degree of creativity have been finished in the previous two steps, design process enters the fifth step to produce an embodiment of requirements into a design concept. Design concept of an AT is stated as a pre-construction form that is constructed based on derivation of targeted process combined with emerged requirements. As a means to provide fair judgment, the number of design concepts must be more than 2 due to the following reasons. If there is only 1 AT design concept, there is no alternative judgment, so an AT cannot be judged as a really better solution due to its independent condition. Even if an AT is referred to as a better solution for a targeted process compared to any previous solution, the judgment cannot be clearly proven. If there are 2 design concepts, it means that engineers can arrive at a better solution between these two concepts. However, only two concepts will not bring an open comparison. If a concept fails, engineers do not have any other choices and must choose the second one even if it has only a slight performance difference to the first one. Therefore, 3 is the minimum number of design concepts in an AT design process. By composing three or more concepts, engineers can clearly assess them and pick one best solution among those concepts. The number of proposed concepts highly depends on intentions and concerns taken in a design process, such as financial or time limits.

In order to harvest some possible design concepts, the flow of targeted process is very important. Due to the fact that AT must be integrated into an existing process without extensively changing local activities, proper understanding in a targeted process is critical [61,62]. Thus, targeted process must be derived into its basic processes and events to recognize its working flow and also to discover correlation between functions [63,64]. In their EPS approach, engineers usually derive a system by its morphological functions [65], meaning that an assembly of technology is understood by picking each part based on its characteristics such as shape or movement. Some other techniques even incorporate genetic algorithms to form design models [66]. However, very detailed functional derivation such as these techniques requires complex technical expertise, which seems counterproductive in AT design. The reason is because AT design process prefers to provide a level of complexity that can be simply understood by local people rather than a complex one that causes technological shock among locals, even in an area with adequate technical knowledge [62,67]. Therefore, this new methodology proposes physiological functions as the solution in providing an understandable derivation process without ignoring technical expertise of engineers. Physiological means that a process is derived in as few as possible derivations until it produces basic logic on how the whole process works, so each physiological function is a set of parts or sub-assemblies which reflect a complete, visible, and feasible package of understandings [64]. By looking at its meaning, a single derivation is much better.

Figure 9. Deriving physiological functions.



Here, there are three types of physiological understanding (Figure 9). The first type is an overview of targeted process (M). It indicates targeted process as a process (P) which transforms input (I) to become supposed output (O). The number of inputs and outputs is unique and depends on characteristics of targeted process in each AT case. There are three I/O as the main characteristics of a mechanism/system: Object, Energy, and Indicator [64]. These three main characteristics are the physiological forms of commonly known Energy-Material-Signal components in conceptual design based on industrial-style methodologies [20,64]. "Object" is the processed entity(s) throughout a whole process, "Energy" is the power source and produced one(s), and "Indicator" is the signal to begin and stop some sub-processes or the whole working mechanism. The overview is then derived into physiological process (PP). This type of conceptual derivation shows clear working mechanism of targeted process. It indicates how input(s) (for example: I.1 and I.2 in Figure 9) flows throughout the whole process through some basic processes. Order of processing flow is also provided including correlation between PPs until they produce expected output(s) within a timeframe (t = 0 t to t = 1 t). Preferred positioning between PPs can also be indicated to give deeper meaning on a better working situation of events. Then, each basic process is derived into a physiological function (PF) that expresses a set of process flows handled by a single basic function. Thus, it provides simple but meaningful understanding on a complete working mechanism of process. Usually, each physiological function can be derived from a physiological process, yet sometimes some physiological processes can be combined to create a more compact design. Still, when it happens, all design concepts must contain the same concerns to deliver comparable concepts in order to maintain the consistency of judgment.

4.3.2.2. Exploring Alternatives for Each Physiological Function

After physiological functions are defined, further analysis must be conducted to gather alternative forms of each PF. This sub-step becomes an exploration facet of this step. Alternative forms are required to explore as many as possible design concepts by using techniques that are consistent with the basic approach of this methodology. As a bottom-up-bottom methodology, any explorations must be conducted based on local conditions, and they must exhibit local intention in building a technological solution to improve a targeted process. To do so, alternatives for each PF can be explored by looking at existing local processes that have similar functions with respective PF, so people can understand any alternative without requiring any special training or technological transfer that can stimulate broader intervention to indigenous knowledge or routines. Some considerations can also be taken from compiled requirements such as priority on using local techniques and/or materials to ensure appropriateness of proposed concepts.

In order to maintain the same understanding in all design steps, the number of alternatives for each PF is the same with the number of proposed concepts, so 3 is the minimum number (n). It is extended as the number of proposed concepts is increased. Table 6 exhibits a table-based presentation to show explored alternatives for each PF. The first row is the codification of each alternative. Names of each alternative are written in the second row. There is no format to name each alternative, yet each name shall be simple but can reflect the main idea of the respective PF. To provide a better understanding of each PF alternative, a visualization of it is placed in the third row; one visualization for each alternative is enough. A visualization can be a photograph that is taken in the field, or a raw sketch which can deliver a good understanding on the respective alternative. It is useful to keep the design process on the track, meaning that any concept is composed through a way by which PFs can be imagined and understood by the local people. Next, any advantages as well as disadvantages of each alternative must be written on the fourth (advantages) and fifth (disadvantages) rows. They must express all of possible advantages and disadvantages of each alternative in an independent manner, which means that those advantages and disadvantages are not produced from comparison between an alternative to other ones. Thus, any advantages and disadvantages are attributed only to a single PF. Such independency is proposed to avoid premature comparison between concepts and to keep clear judgments in composing all design concepts. The number of advantages and disadvantages (n) are supposed to be the same with the number of proposed alternatives for each PF, so an alternative can be easily distinguished from other ones when engineers start to compose physiological concepts. The exploration of alternatives is an iterative process for each PF. Therefore, it will produce uniform presentations on all explored alternatives.

Table 6. Alternatives for each physiological function.

PF1	**1A // PF1 Alternative A**	**1B // PF1 Alternative B**	**1*n* // PF1 Alternative *n***
	{name of alternative}	*{name of alternative}*	*{name of alternative}*
	{visualization of 1A}	*{visualization of 1B}*	*{visualization of 1n}*
+	1. {advantage 1} *n*. {advantage *n*}	1. {advantage 1} *n*. {advantage *n*}	1. {advantage 1} *n*. {advantage *n*}
-	1. {disadvantage 1} *n*. {disadvantage *n*}	1. {disadvantage 1} *n*. {disadvantage *n*}	1. {disadvantage 1} *n*. {disadvantage *n*}
PF2			
…			

4.3.2.3. Composing Physiological Concepts

When all alternatives for all PFs are gathered, physiological concepts can be composed. Physiological concept is a design concept which incorporates an alternative for each PF. Consistent with the basic understanding of physiological function, physiological concept is composed by combining such alternatives to emerge a complete form which reflects a whole targeted process in a new mixture of explored alternatives of physiological functions. This sub-step is conducted by rebuilding a targeted process through pieces of physiological processes that have already been derived into PFs and further explored by taking possible processing techniques and considering emerged requirements into accounts. This kind of composing technique is familiar for engineers [20,21], yet they must be consistent with the bottom-up-bottom approach and physiological-based understanding in combining PF alternatives into any physiological concepts. Process and events modeling [63,64] become the basic logic of physiological concepts rather than pure functional-based exploration. Thus, any concepts can be simply understood by local people because each concept is derived from their own requirements and explored in their own area.

The combination is developed to produce a number of physiological concepts. The number is more than two and 3 is the minimum number. Thus, an alternative in first PF is connected to an alternative in each next PFs by drawing a connecting line. A line exhibits a set of combinations, which means that a line expresses how a targeted process is rebuilt by integrating physiological functions in their new forms. Coloring techniques for different lines is very useful to distinguish between combinations, yet types of line can be helpful if there is no coloring medium on the field. Combination technique is conducted by simplifying the table of alternatives (Table 6) into a simplified one (Table 7). Simplification is strongly suggested to deliver clear presentations without much interference between lines and texts. A combination is started by placing a number of columns that reflect the number of physiological concepts which are supposed to be designed and constructed. (n) is the number of proposed concepts. Columns are placed in each alternative in an iterative way between PFs. For example, the D1 column produces a box for each alternative in each PF. Then, the first physiological concept is composed by connecting D1 boxes in all PFs, one box for each PF. Therefore, the result will be a complete form of targeted processes in a new combination of PF alternatives. The technique is repeated to compose the next concepts. Due to a limited number of physiological concepts, some alternatives may not be chosen.

Table 7. Example of physiological combinations.

	D1	D2	D*n*		D1	D2	D*n*		D1	D2	D*n*	
PF1				1A				1B				1*n*
				{name of alternative}				*{name of alternative}*				*{name of alternative}*
PF2				2A				2B				2*n*
				Aluminium plate				*{name of alternative}*				*{name of alternative}*
PF3				3A				3B				3*n*
				{name of alternative}				*{name of alternative}*				*{name of alternative}*
PF4				4A				4B				4*n*
				{name of alternative}				*{name of alternative}*				*{name of alternative}*

After the designated number of physiological concepts is reached, emerged combinations are compiled (Table 8). The number of columns reflect the number of proposed concepts (n). The first row exhibits codification of concepts. The second one lists combination of alternatives for each concept sequentially. Code of PF, code of alternative, and name of respected alternatives are listed. Each concept is then described in the third row. Description expresses processing flow in each concept, connection between chosen alternatives based on connection of physiological functions, and reasons behind such choices. Then, advantages and disadvantages of all chosen alternatives in a physiological concept are listed in fifth (advantages) and sixth (disadvantages) rows. Some advantages may be removed when a physiological concept is composed through a combination that does not have such advantages. Some disadvantages may also be removed when a respective concept is produced by a combination that can overcome such disadvantages. New advantages or disadvantages are also possible to emerge in similar way with removal situation.

Table 8. Example of physiological concepts.

D1	**D*n***
PF1 = 1B {name of alternative} PF2 = 2A {name of alternative} PF3 = 3B {name of alternative} PF4 = 4A {name of alternative}	PF1 = 1*n* {name of alternative} PF2 = 2*n* {name of alternative} PF3 = 3*n* {name of alternative} PF4 = 4B {name of alternative}
{concept description}	{concept description}
Advantages	
{compilation of advantages of chosen alternatives}	{compilation of advantages of chosen alternatives}
Disadvantages	
{compilation of disadvantages of chosen alternatives}	{compilation of disadvantages of chosen alternatives}

4.4. The Designing Stage: Constructing Designs and Testing Alternatives

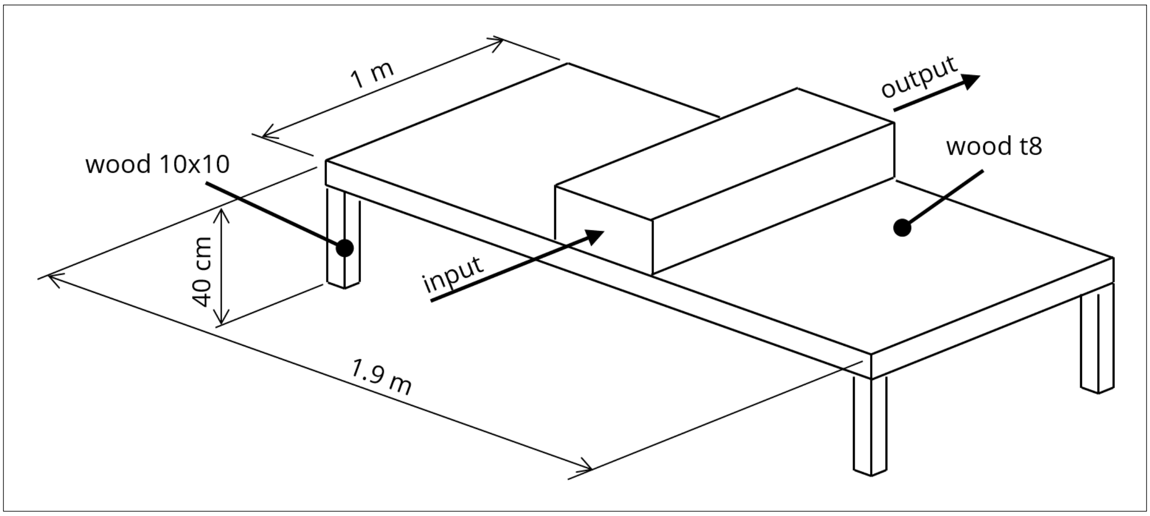
4.4.1. Sixth Step: Constructing Designs

The second stage of design process produces physiological concepts of AT based on emerged requirements and physiological functions of targeted process. Such concepts are established to be the basis of the third stage: Designing. Activities in this third step are proposed to embody all of previously proposed physiological concepts into real ATs that can be applied directly on designated fields. In this stage, engineers can behave as designers, yet they can also invite 3rd party designers to join design process. By looking at previous stages which consist of detailed steps based on field requirements, 3rd party designers will understand required specifications of AT. Furthermore, composed physiological concepts will allow an easier working situation for any designers due to available guidance in objectifying each concept into an AT. Thus, the work portion of designers is only to actualize concepts into reality. In order to choose sufficient candidates of designers, engineers have to return to compiled requirements from the first design stage, degree of creativity from the second stage, and of course the physiological functions of targeted process derived in the second stage. These considerations are useful to find sufficient technical capabilities which belong to potential candidates of AT designer(s). For example, if there are some priorities on local working methods, some other requirements indicate narrow range of each content, and physiological functions are characterized as wood-based technology, so a sufficient designer is one whose technical idealism is low in fulfilling a narrow but simple technological specification, and is also a woodwork designer/architect who naturally understand wood-based construction.

After one/more designer(s) are selected, they and engineers start to construct AT designs. The first activity in realizing design concept is drafting design. Draft is a preliminary design in which a concept is interpreted into a real technical form. Draft becomes the basic understanding on how an AT must be constructed on field. Rather than full 2D-based technical drawing with detailed information, draft in AT design is more likely to be a 3D-based design without too much information. Important information such as measurement sizing and required material are indicated through simple drafting. 3D-based draft with simple information is useful for local construction workers in parts manufacturing and AT assembling. For some cases, supporting tools such as 3D-modeling software [68,69] or 3D-printing [70,71] are considerably useful to provide visible modeling in an affordable process, yet due to the characteristics of AT in localizing resources through a soft approach [5–13], such options must be taken by using locally available ones. If these characteristics are ignored, a designed AT will surely lose its appropriateness.

In an AT draft, measurement sizing is indicated through global measurement position. It is placed in as few as possible positions without ignoring important sizes of AT design. Bill of material is not suggested, yet all materials must be indicated by using direct explanation on the 3D draft. Hand drawing is recommended to juxtapose local understanding and to make as natural as possible construction process like local ones. 3D design can also be drawn by using a drawing table or computer, yet any information must be written by hand to avoid hesitancy of local workers in constructing an AT design. In an AT draft, position of input and output are also indicated by placing information arrow on such positions. If processing mechanism requires further explanation, a separated detail drawing can be provided. Still, simplicity must always be laid as the main foundation in delivering any technical idea as easily as possible for local construction workers. An example of an AT draft is shown in Figure 10.

Figure 10. Example of AT draft (simple sizing).



Since the beginning of first stage, this new methodology emphasizes the main focus on existing local conditions, starting from the bottom and giving results back to the bottom. Thus, the working process to construct AT drafts must be done on site. Because previous stages have already provided complete information about gatekeepers, local techniques, their priorities, and some other considerations similar to when engineers choose AT designer(s), construction processes becomes easier to do. The best candidate for construction processes can be picked up from gatekeeper GK111 or GK110, with some exceptions to GK101 or GK011 when there are limited options. A potential candidate can be identified not only by taking required technical capabilities, but also their involvement with local matters, both place and people. Exceptions can be addressed to GK101 or GK011 due to their dedication for the future of the local area. Besides, a candidate must have technical capabilities required by construction process. Because priority of existing local techniques have been indicated in the first stage, the higher priority is likely to be the most mastered by local people. Thus, it is easier to find candidates with such capability(s). Some other considerations that may be taken into account are their existing livelihoods. Local people who have already been involved in common technical workings similar with working types required in AT construction will be a better choice rather than those who do not have sufficient technical capabilities or none at all. People who have good access to some required materials can also be involved to ensure smoothness of the construction process and at the same time allows social learning on a collaboration opportunity. The number of involved workers can be decided by looking at local existing working styles. Large groups are better in a community with good communal relationships, small groups or even individuals are better to apply in an individual or family-based community.

4.4.2. Seventh Step: Field Testing

The sixth step of design process produces some ATs which are constructed based on previously identified considerations. After all construction processes are finished, all ATs must pass field testing. The testing is implemented to observe the performances of each AT. It is conducted to learn how each AT can handle a targeted process smoothly by performing at better levels than a substituted method without raising negative impacts on produced output(s). Field testing is also supposed to address local people. As the subject of development, people must understand by themselves how to apply designed ATs into their routines. By trying to operate such ATs, people automatically learn and feel comfortable with proposed ATs. These conditions are very critical to ensure successful AT application by delivering seamless integration with people's understanding and their daily routines. Hence, any testing activities must also support these purposes.

The first thing that must be done in field testing is moving constructed ATs to a designated site where they are supposed to be used in the future. A designated site can be the place where an existing targeted system exists. The placement technique aims to avoid too much interference with existing activities, so when people use an AT in their future, they don't need to move their working activities or any issues surrounding related processes. The technique also attempts to make as natural as possible a working situation even by using new technology. Besides, it is useful to give easier performance comparison for local people between existing methods and new ATs. By directly comparing such better-performance ATs and existing method, people can feel more confident to use AT in the near future, which means that the sustainability of AT application can be more assured in supporting local survivability. In short, the effort to give AT back to people begins from this design step.

After all ATs are moved to the testing site, engineers need to develop testing design as the guidelines for the testing process. Due to the main concern of this methodology in which local people are deeply involved, the testers must be local people. Techniques to select such testers remains the same as with selections in previous process. The same persons are suggested to maintain smooth design flow and to ensure deep understanding of local people, yet different ones do not matter if they are selected based on their knowledge to and dedication for local matters. In order to deliver testing activities that do not create too much interference with the daily activities of local people, testing times must be arranged based on existing routines. They must be gathered and matched with required activities (Table 9). Listing techniques is conducted by listing people' activities (first two columns) and possible activities in some spare or transit schedule, or at the same time with people's activities in implementing previous method on targeted process (last three ones). {name of routine} and its timeline {dd:hh:mm} are noted, then are further checked for its availability to do testing activity {{A} or {N/A}}. After that, {name of possible activity} and its required time are entered. This technique is repeated until all available times are fulfilled.

Table 9. Example of testing time positioning.

Daily Routines		**Testing Time**		
Routines	**Timeline**	**Availability**	**Possible Activity**	**Required Time**
{name of routine}	{dd:hh:mm}	{{A} or {N/A}}	{name of possible activity}	{dd:hh:mm}
…	…	…	…	…

When possible testing times are completely revealed, engineers can start to develop testing design. Testing design is a set of procedures that must be done at a site that is built to find out the field performance of observed AT. It is developed using a time-based order that reflects time positioning discovered previously (Table 9). Procedures are determined by considering required performance that must be measured directly on field. A testing design is supposed to have as few as possible procedures, yet each activity must be managed carefully to explain as clearly as possible observed performance. Hence, measurement activities are better to be laid on existing measurement standards. It is suggested in order to deliver understandable measurement results, and also to provide easier explanations for customers of AT's output. Measurement standards can be taken based on expected output units of observed performance. Existing standards which are related to processed input and/or process itself are also useful to be used as the basis of procedures. These kinds of standards can produce an easier testing design due to standardized procedures, yet their schedules must be matched with testing time positioning (Table 9).

Example of testing design is exhibited in Table 10. Order number of each activity is written in the first column. In the second column, the timeline of each activity is provided. The formats are {dd} and {hh:mm}, means day, hour, and minute, respectively. Day and other two time units are separated due to different understanding on each set of unit(s). Day is indicated by a real/natural number such as 1, 2, 3, *etc*. that expresses the day an activity is conducted calculated from first day of one test cycle. Thus, testing is started at Day 1, second day will be Day 2, and so forth. Hour indicates the time an activity is conducted in 24-based or 12-based hours in a day. If 12-based hours is used, after Minute the proper *meridiem* must be declared by writing AM or PM. Then, Minute is expressed in 60-based minutes in an hour. Hence, an activity which is conducted in 1:30 afternoon can be indicated by writing 13:30 or 01:30 PM. After that, the {name of activity} expresses the activity that is conducted in the respective timeline. More than one activity is possible, but their orders must be well scheduled to avoid counterproductive testing process. Then, {applied standard} is indicated in the last column. It can be expressed by using the number of a standards based on its issuing organization. The formatting technique is repeated for each scheduled timeline until all activities can fulfill all required measurement units.

Table 10. Example of testing design.

Procedures					
No.	**Timeline**		**Activity**	**Measurement**	**Standard**
	Day	**Time**			
1	{dd}	{hh:mm}	{name of activity}	{measured performance}	{applied standard}
…	…	…	…	…	…

After that, developed testing design requires some measurement forms. When field testing is conducted, local people as testers need a standardized format to record observed performances, it also includes required testing instruments to measure such performances. Forms are constructed based on a testing timeline (Table 10) with more emphasis on measurement results and the time each result is happened. Each of the applied standards may also provide specific formats for measured performances in respective standards. Table 11 shows an example of measurement form for observed temperatures of a heat-related AT. It shows testing date, timeline, normal (outside) condition, and AT performance (inside). Such columns indicate complete measurement results on an AT for an observed performance (temperature) and comparison to normal conditions. Comparison to targeted processes based on existing methods can also be included in a form if such process is conducted from the same starting date and time and tested by using the same standards and procedures with observed ATs. A format must consist of sufficient numbers of rows to contain enough space for one testing cycle. Some tables are also required to record opinions from customers about output quality of improved process, yet it is not supposed to be formatted as direct questionnaires to maintain natural meeting routines between users of AT and their customers. After all forms are completed, these forms are given to testers by including some explanation and short training how to do the testing process, to use all required instruments, and to fill in provided forms. There should be no problems because any testing activities and forms are developed based on same origin: local activities, which means that responsibility to do any activities or procedures written in the testing design and to fill in any forms can be done as they perform their normal activities.

Table 11. Example of temperature measurement form and result.

Date	Time	Outside		Inside
		Humidity	Temperature	Temperature
June 1st, 2013	08.00 AM	46%	30 °C	52 °C
	12.00 PM	56%	32 °C	59 °C
	16.00 PM	53%	31 °C	52 °C
June 2nd, 2013	{hh:mm}	{number}%	{temperature} °C	{temperature} °C
…	…	…	…	…

After all the testing preparations are finished, the testing process can be started. Testing is started on the same day for all ATs to get comparable results. Local people as testers are suggested to do their daily routines in a normal way, so AT will not become significant time burdens for them. At each appointed time, testers can carry out their responsibility by following testing design and filling in measurement forms. Because testing activities have already been matched with their normal activities, the testing process is integrated to their routines. Little by little, people will understand such integration, so they won't experience significant intervention, and then recognize benefits of AT by themselves in their own routines.

Furthermore, the testing process is repeated for as many cycles as possible by considering the required time and clarity of measurement results. A cycle must be finished by bringing output of AT to its existing customers and to observe their opinion about new improved output. Isolation of samples produced from different AT is required to get a clear differentiator between samples. Observation must be conducted in natural way, which means that as few as possible information about tested ATs are provided for any customers. Also, samples must be packaged in the same way/technique people packed the output of the targeted process before the ATs are tested. Natural packaging is useful to maintain the natural condition of produced output. Such techniques will produce less bias opinion on AT testing process or of a specific AT. Thus, testing cycles will produce sufficient information for next design stage, and local people can continuously incorporate AT to their activities which means they get more understanding of the AT operation and its benefits for their livelihoods. After sufficient numbers of testing cycles are completed, all measurement results are compiled into as few as possible compilations in order to simplify data presentation. The quantity of compilations is defined based on the need of further performance valuation. All data in any compilations in this step must contain the same measurement units indicated in compiled requirements (Table 4).

4.5. The Assessing Stage: Valuating and Evaluating Appropriateness

4.5.1. Eight Step: Valuating Performances

4.5.1.1. Establishing Valuation Standards

The third stage of design process in this methodology provides a number of AT designs and gathered information from field testing. They become starting points to establish valuation standards for AT. Valuation standards consists of a set of values in which each of them indicates specific performance based on compiled requirements (Table 4). Table 12 exhibits the basic format of valuation standards. {**name**} indicates the name of respective requirement. The values are whole number (0, 1, 2, *n*) with *n* expresses maximum valuation. Hence, it is same with the number of tested AT. Zero (0) value exhibits that an AT cannot fulfill respective requirement. Each of next values (1, 2, *n*) indicates a condition in which an AT can perform for a requirement at a certain level. Maximum value means that an AT can precisely fulfill such requirement. The content of each value in each requirement can be standardized based on the format of a respective requirement. Next, because any ATs must fulfill all general requirements (G, Table 4), such requirements are not standardized here. General ones become the first and basic judgments about whether an AT can handle the main purpose of targeted process or not. Therefore, in valuation standard there are only three types of standardized formats, which are range-based format, priority-based one, and formatting technique for unidentified-unit requirements (Degree of creativity 4+, Table 5).

Table 12. Basic format of valuation standards.

TECHNICAL [T]	*n*	2	1	0
{**name**}	{range} {unit}	{range} {unit}	{range} {unit}	{range} {unit}
{**name**}	{only} {option 1} {or option *x*}	{option 1 & *x*}	{option *1* & *xx*}	{option *x* & *xx*}
{**name**}	{The best}	{The worse}	{The worst}	-

For range-based requirements, values are standardized by dividing freedom range with number of ATs (*n*). Such a technique is very simple to be applied for range-based requirements that have 1 degree of creativity, yet for ones that have 2 or 3 degrees of creativity, further distribution must be taken. For them, values distribution is made by dividing unlimited freedom with simple incremental units, such as 5, 10, *etc*. It is useful to deliver easy explanations for local people to understand such performance. For ones which have 3 degrees of creativity, incremental technique is taken in both ways, addition for above upper limit, and reduction for below lower limit. The best value (n) is determined by looking at preferable performance level indicated by {{higher/lower} is better} format (Table 5). Thus, range-based valuation will produce the same 0 until *n* values.

Next, the priority-based format is standardized by providing possible combinations of options by looking at their order of priority. Usually, the first priority is the most preferred option, so maximum value (*n*) indicates absolute usage of first priority in an AT. After that, next values are determined by adding the less desired option (*x* or *xx*) beside one with the highest priority. Lowest value (0) indicates no usage of highest preferred option and excessive usage of least preferred one(s). However, special circumstance may happen in which some priorities are suggested for use due to dominant usages in the local area compared to other ones. In such cases, maximum value must contain suggested priorities. Next, the following values can be decided by removing one-by-one suggested options and/or by adding less suggested one(s). Then, similar with normal circumstances, (0) value means that suggested options are not used and less suggested ones (*x* or *xx*) are used excessively.

The last values standardization is addressed for requirements that do not have clear freedom(s) and constraint(s). They are indicated by 4+ degrees of creativity (Table 5). These types of requirements cannot be clearly divided as well as distributed into some valuation levels. Thus, the simplest technique is applied by sorting performance of all ATs in order. It is very easy to understand by anyone, and still provides reliable comparison techniques for any unconstrained requirements. The value attributed to an AT is determined by looking at {{higher/lower} is better} format. If higher is better, so maximum value (*n*) is attributed to an AT with highest performance, and *vice versa*. Due to order sequence, the lowest value will be 1; there is no zero (0) value because *n* is the number of ATs and the least valued AT will always be one (1).

4.5.1.2. Valuing Performances of Each Tested Design

After valuation is standardized, each tested design must also be valued regarding its performance. Performance valuation is required to find out the whole performance of each tested design in the same measurement unit with field requirements (Table 4). Here, there is no comparison with valuation standard (Table 12), because the only intention of this sub-stage is to investigate performances of each design. Therefore, this sub-step is conducted by gathering testing results together with some required calculations.

Testing results are taken from the seventh step. Any compilations must be further regrouped based on respective design aspects for each requirement. Such regrouping is proposed to differentiate requirements in an aspect to other ones in other aspects. It is useful to distinguish the purpose of each one. Beside gathered testing results, some calculations are required to produce desired measurement units indicated in the first design stage. A calculation can be conducted by looking at relationships between some specifications of each AT which can generate an objective function that has the same {unit} with a requirement. It can also be implemented by utilizing some requirements in conjunction with some performances to get a new indicator in the same {unit} with one of compiled field requirements.

In order to make valuation to each tested design, there are three types of value that can be used to express each performance (Table 13). The first type can be formatted as {fixed number} {unit}. {fixed number} is useful to exhibit range-based or unconstrained requirements, especially for quantitative performances. Qualitative performances can be expressed using {condition}. Any performances in such requirement types can produce a fixed number, for example a single number which indicates average, or a single condition that refers to a requirement. For quantitative performances, ones can be gathered both from field testing and calculation. Next, the second type is used to represent range-based requirements that are produced still in the range-based form when they are tested/calculated to get AT performances. Other than requirements in the first type of value, some requirements may indicate performances within a range, for example temperature when it is expressed as a range rather than an average. Thus, such range is written in its original format. Then, the last type of value accommodates priority-based performances. In order to indicate such performance, each AT is reviewed to investigate the usage of any options (*x* or *xx*). The result will be enough to discover performance of each AT design.

Table 13. Valuing performances of each design.

TECHNICAL [T]	D1	D*n*
{**name**}	{fixed number} {unit}/{condition}	{fixed number} {unit}/{condition}
{**name**}	{range} {unit}	{range} {unit}
{**name**}	{only} {option *x*}	{option *x* & *xx*}

4.5.2. Ninth Step: Evaluating Level of Appropriateness

4.5.2.1. Weighting Operational Variables

Due to the multi-criteria characteristics [72] of compiled requirements in this methodology, proportion between a criterion to other ones as well as to the objective functions of assessment needs to be proportionally distributed. Thus, such multi-criteria must be weighted to discover the influence of each criteria to the functions of assessment [72,73]. In weighting sub-step, the weight of each requirement (operational variable) compared to other ones in the same aspect is calculated. In order to get the weight for each operational variable, commonly engineers/designers use ranking models; however, in this methodology binary numbers are very useful to suppress any subjectivities of engineer(s) as well as local people related to the weight of each operational variable. In order to do that, all operational variables in the same perspective are coupled and compared to each other by using binary numbers (0 or 1). A more important operational variable will be given 1, and its couple 0. The results of all comparisons for each operational variable are then summed. The sum is then divided by total number of comparison processes in the same aspect. Comparison processes are separated between perspectives to get apple-to-apple conditions in every process. An example is given in Table 14. Such process is conducted by asking local gatekeepers about the importance of each field requirement (their own requirement) to other ones, in informal communications. Complete comparison for all theoretical variables cannot be conducted in a one-time communication. The most critical thing is for local people to express themselves in a comfortable situation. Thus, informal communications to a gatekeeper may require some discussions to discover all comparisons.

Table 14. Example of weighting process of operational variables.

Technical	Taa	Tab	Tba	Tbb	Tca	Tcb	**Sum**	**%**
Taa		0	1	**1**	0	0	**2**	13.3%
Tab	1		1	1	1	0	**4**	26.7%
Tba	0	0		0	0	1	**1**	6.7%
Tbb	**0**	0	1		0	0	**1**	6.7%
Tca	1	0	1	1		0	**3**	20.0%
Tcb	1	1	0	1	1		**4**	26.7%
				Total Sums			**15**	100.0%

Same variables cannot be compared, so their cells are colored as black. Variables in left column are called primary variables and variables in the top row are called as secondary variables. Comparison processes are made in a horizontal direction. In a comparison process, a primary variable will be compared to a secondary variable. When a primary variable gets a 1, so the secondary variable will get 0, *vice versa*. A cell is filled with the binary number for a primary variable. The number should be given in reverse order while the primary and secondary variables exchange their position in other comparison processes (see the green cells in Table 14). In the end of the comparison processes, the numbers for each variable are summed. The calculations are made horizontally. Thus, a sum is the result of sum processes for binary numbers of a primary variable in horizontal order. Then, the sums are summed vertically to get the total sum. Theoretically, the total sum is expressed as:

$$\begin{aligned} \text{Total Sum} &= (n-1) + (n-2) + (n-3) + \ldots + (n-(n-1)) \\ &= \sum_{k=1}^{n-1}(n-k) \end{aligned} \tag{6}$$

with *n* representing the number of operational variables in the perspective where they exist.

Next, the sum of each operational variable is divided by total sum, so it will result in the percentage of influence of an operational variable to the perspective. If an operational variable got 0% influence, the condition is called as an error in the assessment process. In planning process, engineer(s) may think—subjectively—that the variable should be included in the designed technology/equipment, but in fact—objectively—the variable will not really influence the result of assessment (the performance of each design alternative).

4.5.2.2. Performance Evaluation

The eighth step produces valuation standard (Table 12) for all compiled field requirements (Table 4) and discovered performances (Table 13) of each tested AT (Table 11), while the ninth step delivers weighting results for each operational variable (Table 14) in each design aspect (Table 3). Those outcomes are used as the basis of performance evaluation. Such evaluation is implemented to investigate how well an AT performs compared to established valuation standards by incorporating weights of respective operational variables into account. Valuation standard becomes a guideline to decide the ability of an AT to achieve a performance in a single requirement. It guides engineers to clearly give appropriate value for a performance.

Performances of an AT are treated as inputs for this evaluation sub-step. As inputs, performances are processed to generate comparable values between requirements that have different basis (qualitative or quantitative) and different types (range-based, priority-based, or unidentified). Such processing techniques are conducted by using the calculated weight of each operational variable (a field requirement) to further transform comparable values in an AT into comparable values between tested ATs. The outcome is a compact value that reflects the whole performance of an AT. Even though all ATs have performances in the same field requirements, same valuation standard, and emerged from the same valuation technique, performance evaluation is conducted separately for each design and each design aspect to provide clear comparisons between ATs and to distinguish intentional purposes of performances in different design aspects. It is applied to avoid interference between such aspects. Formatting technique to do performance evaluation is exhibited in Table 15.

Table 15. Basic format of performance evaluation for each design in a design aspect.

{aspect} [{A}]		D1			D2			D*n*		
{**name**}	{W}	{performance}	{Z}	{Y}%	{performance}	{Z}	{Y}%	{performance}	{Z}	{Y}%
		{standard}			*{standard}*			*{standard}*		
{**name**}	{W}	{performance}	{Z}	{Y}%	{performance}	{Z}	{Y}%	{performance}	{Z}	{Y}%
		{standard}			*{standard}*			*{standard}*		
	100%		$\{Q_Z\}$	$\{Q_Y\}$%		$\{Q_Z\}$	$\{Q_Y\}$%		$\{Q_Z\}$	$\{Q_Y\}$%

There is much information and data that need to be laid in order to provide a clear explanation on performance evaluation. Because performance evaluation is conducted in a single design aspect for each AT, the first information delivered in the performance evaluation table is the name of the observed aspect {aspect}, which is one of Technical, Economic, Environmental, and Social. Such aspects are provided in Table 3 or Table 12. In the same cell, the code of observed design aspect is written {A}. In the same row, the code of each AT is shown horizontally until last AT design (*n*). Started from the second row, evaluation is performed. The first column indicates {**name**} which informs the name of an observed operational variable. It can be taken from Table 4, Table 5, or Table 12. In the next column, the weight of each operational variable {W} is indicated. Such weight can be taken from Table 14 for each operational variable in the respective design aspect. Weights of all operational variables must be checked by summing them in vertical. Correct data will result in 100%. After that, in the set of three columns for each design, single format is applied. The first column in each design consists of two information values. The first information {performance} is the value of observed performance in an operational variable. It is written in the upper cell. Performance of an AT in its respective operational variable is taken from Table 13. In the lower cell, standardized valuation level {standard} for such performance is entered. The technique searches a group of valuation in an observed operational variable in which such performances exist between its range/condition. Such range/condition is taken from Table 12, and written in *italic* font to differentiate it with {performance}. In the second column of the respective AT design, the value of standardized range/condition {Z} is entered. Some AT designs may have same {Z} value due to their performances that exist in the same range/condition, which has already been standardized in Table 12. For example, if a range of temperature from 40 °C to 50 °C is standardized as having valuation 5, so the {Z} value for two AT designs that each generate 43 °C and 49 °C, respectively, is 5. Then, all {Z} values for operational variables in a design aspect are summed to produce $\{Q_Z\}$. The next step is the transformation of {Z} value of respective operational variable into {Y} value in percentage (%) by considering weight of such variable {W} into account. It is expressed as

$$\{Y\} = (\{Z\}/\{n\}) \times \{W\} \tag{7}$$

with {*n*} is the maximum number of standardized valuation, which is same with the number of AT designs. Then, all {Y} value of operational variables in a design aspect is vertically summed to produce total value $\{Q_Y\}$. It should be lower than (imperfect performance) or the same with (perfect one) 100%.

4.5.3. Tenth Step: Judging Appropriate Technology

The tenth step is the last one in this new methodology. It concludes all nine design steps to discover the best AT based on previously investigated performances of each AT. It attempts to judge such performances by using some judgment techniques. Such judgment is conducted in two techniques in order to deliver as clear as possible judgment through a sufficient way in a specific situation. Such techniques are sorted based on precision level of judgment result and also level of difficulties in implementing respective technique. These techniques are Simple Appropriateness and Normalized Appropriateness. The first technique focuses on simplified judgment that takes performance evaluation in its original form, while the second one emphasizes the importance of each design aspect based on its order in technological appropriateness levels. Due to sorted order, the second one must be conducted if only the first technique cannot provide adequate information in deciding the best AT.

4.5.3.1. Judging Technique I: Simple Appropriateness

The first technique is the simplest one. It is conducted by taking the result of performance evaluation (Table 15). It emphasizes visual judgment by constructing radar diagram of performance evaluation results. Such visual judgment is taken to provide the simplest technique for local people. They can directly discover technological appropriateness for each AT design by looking at such visualization. By using visual technique, they do not need to do any further calculations to investigate required considerations. Besides, this simple technique delivers an effective way to distinguish between AT designs, which means that it can reduce difficulties for local people to select an AT that has the best appropriateness level.

In this technique, the required data are $\{Q_Y\}$ values for all AT designs in all design aspects. Each $\{Q_Y\}$ value is entered in its appropriate cell as shown in Table 16. After that, they are directly transformed into a radar diagram (Figure 11) which visualizes mapping of simple technological appropriateness for all AT designs. By looking at the radar diagram (Figure 11), the best AT can be judged. The best one is an AT that has the visually widest inner area in such a diagram. Such conditions mean that an AT has the highest performances in all design aspects. An AT design may have lower performances in one or two design aspects, yet if it has the widest inner area, it can be decided as the best AT or can be simply stated as having the highest technological appropriateness.

Table 16. Judgment 1st technique (Simple Appropriateness).

		Max	**D1**	**D2**	**D*n***
TECHNICAL	**[T]**	**100%**	$\{Q_{Y.T}$ of D1$\}$%	$\{Q_{Y.T}$ of D2$\}$%	$\{Q_{Y.T}$ of D$n\}$%
ECONOMIC	**[E]**		$\{Q_{Y.E}$ of D1$\}$%	$\{Q_{Y.E}$ of D2$\}$%	$\{Q_{Y.E}$ of D$n\}$%
ENVIRONMENTAL	**[V]**		$\{Q_{Y.V}$ of D1$\}$%	$\{Q_{Y.V}$ of D2$\}$%	$\{Q_{Y.V}$ of D$n\}$%
SOCIAL	**[S]**		$\{Q_{Y.S}$ of D1$\}$%	$\{Q_{Y.S}$ of D2$\}$%	$\{Q_{Y.S}$ of D$n\}$%

However, if the best AT cannot be visually observed in such a diagram, the axis in the diagram must be reversed: AT code {D*n*} as main axis, and performances in each design aspect become secondary axis (Figure 12). Thus, a new radar diagram will visualize areas which each is constructed by performances of all ATs in a design aspect. By looking at such a diagram, further visual information can be taken as the basis of decision. Technological appropriateness is specified by observing visual intensity of performances of each AT design and its visual distance to maximum value (100%). The best AT is one that has the most intense performances, which means that its lowest and highest performances between four design aspects are located on the nearest position compared to other designs. If more than one ATs has similar visual intensity, the best AT can be decided by looking at the visual distance of such intensity to maximum value. If an AT has intensity that is located on closer position than other ATs—which have same visual intensity—, it must be chosen as the best AT. If the location of intensity still remains same, the best AT is one that has the intensity trend (position of two design aspects' performances between lowest and highest ones) on a closer position to maximum value.

Figure 11. Radar diagram of simple appropriateness for each design.

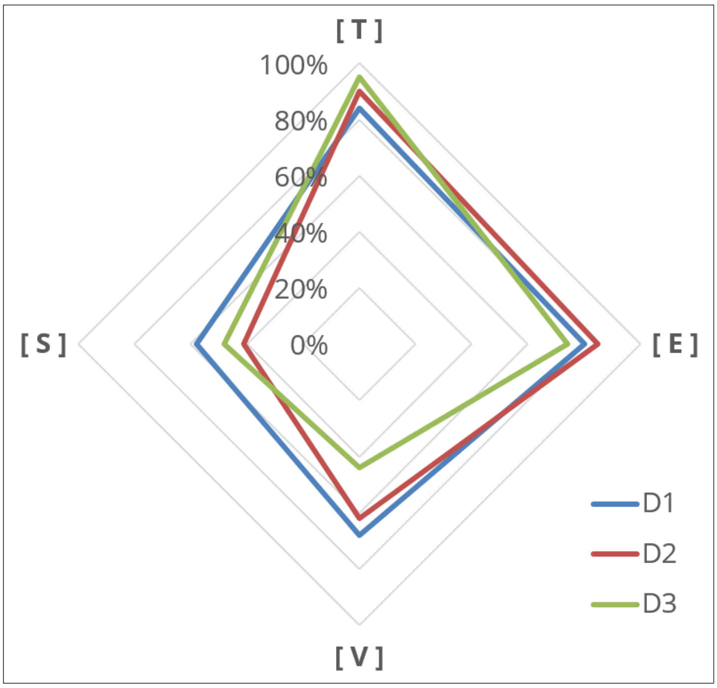
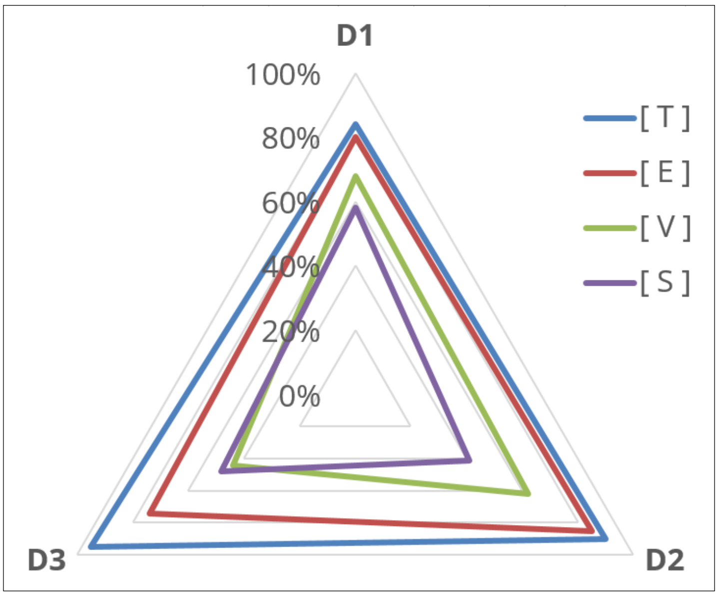


Figure 12. Radar diagram of simple appropriateness for each aspect/perspective.



4.5.3.2. Judging Technique II: Normalized Appropriateness

If the first technique cannot deliver clear judgment, which may be caused by too tight differences between two or more AT designs, the judgment process must be continued by using a second technique (Table 17). The second technique emphasizes differences between levels of technological appropriateness in theoretical understanding [13]. Such levels are interpreted by providing a normalized coefficient to distinguish a level of appropriateness to other ones.

Table 17. Judgment 2nd technique (Normalized Appropriateness).

	Max	**IA**	**D1**		**D*n***	
[T]	**100%**	**1.5**	$\{Q_{Y.T}$ of D1$\}$%	$\{(IA_T/10) \times Q\}$%	$\{Q_{Y.T}$ of D$n\}$%	$\{(IA_T/10) \times Q\}$%
[E]		**1.5**	$\{Q_{Y.E}$ of D1$\}$%	$\{(IA_E/10) \times Q\}$%	$\{Q_{Y.E}$ of D$n\}$%	$\{(IA_E/10) \times Q\}$%
[V]		**3**	$\{Q_{Y.V}$ of D1$\}$%	$\{(IA_V/10) \times Q\}$%	$\{Q_{Y.V}$ of D$n\}$%	$\{(IA_V/10) \times Q\}$%
[S]		**4**	$\{Q_{Y.S}$ of D1$\}$%	$\{(IA_S/10) \times Q\}$%	$\{Q_{Y.S}$ of D$n\}$%	$\{(IA_S/10) \times Q\}$%
				$\{S_{Q.IA.D1}\}$%		$\{S_{Q.IA.Dn}\}$%

In this technique, levels of technological appropriateness are normalized through using the 10-basis coefficient. Because there are three levels, 10 is divided by three. It produces the basic normalization coefficient 3.33. Due to proposed leveling ideas [13] that lay Social aspect as the ultimate appropriateness, all decimal values are added to the coefficient of Social aspect. It will generate coefficient 4 for such aspect, 3 for Environmental aspect, and 3 for the least level of appropriateness that consists of Technical and Economic aspects. The normalization coefficient of the last level is divided by two, so that each of the Technical and Economic aspects has a coefficient 1.5. Such coefficients are stated as the Importance of Appropriateness (IA).

Next, generated data from the first technique (Table 16) are normalized by using {IA} for respective design aspect. The normalization is conducted by taking total performance of an AT design in a design aspect $\{Q_Y\}$ into account. The results of such normalization processes are then summed to find the total of normalized appropriateness $\{S_{Q.IA}\}$. The calculation is expressed as

$$\{S_{Q.IA}\}\ [\%] = \sum (\{(IA/10)\ x\ Q_Y\}) \quad (8)$$

where $\sum$ is operated to sum all performances $\{Q_Y\}$. Then, the best AT is simply decided by looking at the highest total of normalized appropriateness $\{S_{Q.IA}\}$. If more than one AT has the same results, the best AT is selected by looking at the highest total of normalized performance in each design aspect, sorted from the ultimate level (Social aspect) to lowest one (basically appropriate: Technical and Economic aspects). If two or more ATs have highest total of normalized performance and have identical normalized appropriateness in all design aspects, it means that such AT designs can be stated as the best ATs.

5. Closing Remarks: Call for Applications

Researchers had agreed that AT design and development activity in community empowerment efforts required a dedicated EPS by taking principles of AT and empowerment approaches into account without ignoring design and engineering principles which had hardly been taken by engineers in existing EPS approaches. The AT concept is focused on resource localization and soft approach. In addition, some tiers of technological appropriateness exist as the basis to interpret the coverage of an AT on some fundamental aspects of community problem solving: the seven pillars. In this study, the combination between such conceptions and EPS principles creates a new design methodology that is laid on existing engineering techniques but with new understandings based on AT and empowerment principles. The new methodology is developed as a flexible one and is positioned between critical-style and pure flexible-style ones. Thus, it is linear, with modern trends by which they attempt to provide design methodologies that could be used in different applications with similar principles/approaches. The new methodology emphasizes strong involvement of local people as the subjects of empowerment rather than only objects of development. Local people are involved at every single opportunity in which they are closely related with activities in each design stage. It becomes the ultimate way to ensure sustainability of AT usage and survivability of its users. In this methodology, engineers are the ones who do technical assistance to accompany local people in investigating their own requirements and to actualize discovered requirements into an AT as the reflection. Engineers are suggested to "sit" together with people in local daily routines in order to discover local requirements by incorporating informal approach to gatekeepers. Such techniques are used to ensure technological appropriateness since the beginning of AT design. Real problems are not supposed to be given inputs as seen in common EPS approaches. Also, AT design process is not something engineers can do as usual.

However, developing a new methodology is not a transient/simple work. Our internal model testing processes on the new methodology have provided satisfying results both in reproducing some existing successful AT designs (validity test) and in designing several new ATs (reliability test), yet wider applications/ implementations can give better inputs for further development of the new methodology. As wide as possible applications are required over years in order to continuously perfect the methodology. Thus, this paper also becomes a call-for-applications for other AT researchers in community empowerment projects. Any results from these kinds of applications will be welcomed as inputs for further development. Direct suggestions and/or questions can also be directly addressed to the corresponding author. The authors will gladly welcome the chance to supervise field applications by delivering further detailed explanation on any stages in this new methodology. Interesting applications will also be possible to be included in further publications to emphasize implications of the new methodology. Researchers who are interested in the topic are expected to join this multidisciplinary movement.

Regardless of this movement, other researchers can expand the discussions into some other subjects. For example, by looking at the characteristics of bottom-up-bottom approach and survivability principles, AT could be understood as a democracy-based technology as the same as when it was started by Gandhi but was forgotten by many stakeholders in later community empowerment efforts. It began from local people, by local people, and for local people. Engineers became technical assistants rather than dictators of development. Therefore, researchers in sociology disciplines could explore possible relationships of the AT movement to the development of understanding of democracy in a particular underdeveloped community. Another possibility concerns constructing a new tool for policy development for AT by incorporating AT and empowerment principles. Because underdeveloped communities were usually treated as a burden to regional and/or national growth, principles of AT and empowerment could inverse such understanding by denoting the communities' important role as a critical foundation of greater resilience. Due to the fact that a resilience was understood as the toughness of a social entity in facing challenges even in a crisis, it should be founded on the principles of survivability rather than sustainable development because sustainability alone would be more likely to meet a saturated condition of development caused by stagnant growth.

Conflict of Interest

The authors declare no conflict of interest.

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