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Principles of Product Design in Developing Countries

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Abstract: Problem—The conventional view of new product development (NPD) methodologies focuses on marketing and commercial prospects in developed countries. There is a need to identify both the barriers and the enablers to design within a rural context in developing countries (DC). **Method—**A researcher was embedded in a rural DC design project. Issues were observed and critical success and failure factors determined. These were abstracted into a set of design principles, and a new model of the NPD process was created. **Findings—**Whereas commercial NPD emphasizes market intelligence and a highly directive approach to the engineering workflow, in the DC situation the objective is to fulfil community needs and this necessitates co-determination regarding the engineering. There is commonality between the two NPD processes, with ours having a greater emphasis on the socio-cultural factors. The deployment principles are categorized into technical and socio-cultural. Within these are included project management, design, material selection, visualization, communication, maintainability, safety, and health. **Originality—**A novel representation of the process for conducting design in developing countries is provided. Critical success factors are identified. The socio-cultural perspective is explicitly included, which is absent from the conventional engineering and business perspectives.

Keywords: design; new product development; developing; rural; societal

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1. Introduction

The optimal methodology for new product development (NPD) depends heavily on the intended context. The dominant perspectives in NPD literature are engineering design process, and the commercial/entrepreneurial process. The underlying premise is that NPD is about overcoming market constraints for commercializing products. The market constraints differ across developed and developing countries. The present paper examines an application of NPD of products that service community needs in developing countries (DC).

This paper presents a translation of the classic NPD process, considering the issues observed first hand while implementing a solar cooking device in rural India. A novel design methodology is presented for this type of situation, together with determination of the decision principles critical to the DC context.

1.1. Engineering in Developing Country Contexts

Countries are commonly classified as having either a Developed Economy, an Economy in Transition, or a Developing/Emerging Economy [1–3]. Countries classified as the former tend to have greater economic security and growth compared to the latter.

The conventional process for NPD is heavily premised on the notion of creating products for consumption in developed economies. The two main lenses of NPD are engineering and business. A general form of the NPD process is shown in Figure 1 with Engineering dominating idea generation in stages 3 and 4, and business dominating Stages 1, 2 and 5.

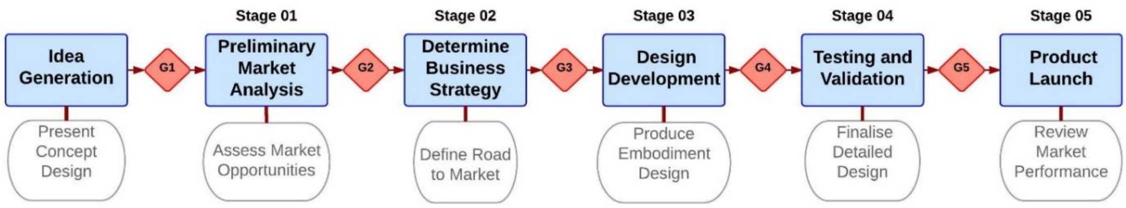

Figure 1. Adapted Stage-Gate framework for new product development (NPD) process. Subsequent design stages are separated by Gates (G), which act as screening elements to remove unsuitable options.

The process starts with the generation of a new idea. This may arise from creative intuition, or from an insightful evaluation of deficiencies and failures in existing products. The idea may also arise from user/consumer feedback. Bergman and Klefsjö completed a large literature review on this phase and its many methods [4]. Idea generation is followed by an early evaluation of the commercial potential, which is achieved by market research. This is intended to screen out ideas with poor economic forecasts, and is consistent with the paradigm that innovations must be financially profitable. The next stage is to determine the route to market. In particular, the business strategy that is intended to convert the opportunity inherent in the concept into a commercial success. This activity occurs throughout the life of the product, and the strategy may need to be revised as the product or market evolves. A purposeful economic hegemony pervades this stage, whereby the organization seeks to both protect and maximize its financial return. Management literature asserts that organizations are competitively successful to the extent that they offer a product that offers value to a customer (or client), where that value cannot be obtained from competing organizations. Strategic human resource management (SHRM) takes this further in stating that specialized human resources can provide these attributes [5]. Hence, success relies on an inimitable proposition of value. This can be achieved via products that conform to the VIRO framework: **V**aluable (customer perceives the product as valuable because it meets an important need), **I**nimitable (difficult or illegal for competitors to copy), **R**are (hard to find elsewhere), and based on **O**rganizational strengths.

The next stage is the development of the design, and this is where the engineering perspective dominates. There is a large amount of literature that already exists on engineering design methodologies. A number of design methodologies exist, of which key developments are the German tradition of systematic design [6,7], Pugh's selection method [8], decision sciences [9], and management overviews [10]. The general principle is that the validity of the design solution can be gauged against the initial functional specification.

Testing and validation stages follow the design stage, and these may be concurrent and recursive with each other. The systems engineering (SE) methodology has come to be the primary perspective in this area. SE is a further development and maturation of two methodologies: the above design methods, and project management perspectives such as [11,12]. SE is the application of engineering management, design methods, analysis tools, and testing protocols in a systematic and integrated manner, for the solution of complex engineering problems [13]. The issue is that the conventional design methods are best applied to well-defined problems or specialist areas where a complete and unambiguous specification is provided or can be developed at the outset. However, engineering systems have become much more complex in the integration of diverse hardware systems and need for interdisciplinary design activities. Hence design problems often require integrated rather than piecemeal solutions [14,15], and simplistic design methods are often insufficient.

The final phase in this NPD process is the deployment of the product to the market. The thinking here is dominated by the marketing perspective. A key construct is the '4P' (product, price, placement/distribution, promotion). There are also several strategies for the promotion process, one being AIDA: **A**ttract the customer's attention, generate customer's **I**nterest, show that it will satisfy customer's **D**esire (needs), lead customer to a purchase **A**ction (close the sale). The perspective towards NPD within a firm is therefore focused on gaining the best competitive advantage to capitalize on the target market and ultimately make the most profitable returns [16]. The general performance metric for NPD and manufacturing firms is the success of the products and services provided, using profitability as the bottom line [17]. Several frameworks are commonly used for NPD which largely contain the same functional elements. The NPD framework has been formalized several times through a Stage-Gate process.

The conventional NPD perspective tends to regard the marketing aspects of the process as pivotal [18,19] and tightly interrelated to the research and development (R&D) aspects [20]. Thus, technological knowledge and market intelligence are two of the most important factors underpinning the profitability focus [21] for NPD in developed countries.

1.2. Process of New Product Development in the Rural DC Context

The NPD process was not found to have been formalized for application in areas where the focus deviates from marketing and commercialization opportunities, such as providing basic necessity items in a not for profit environment in DC. There is a lack of literature accessing the applicability of the NPD process in DC, or how it might need to be modified. In particular, the commercial, intellectual property (IP) and marketing drivers of NPD in developed countries cannot be assumed consistent with DC, especially in the aid setting.

Numerous papers exist on the issues of implementing new technologies into DC contexts [22]. However, the literature pivots around the significance of providing electrical power systems and the problem statements are posed around power supply and power supply reliability [23,24]. There is little focus on the broader perspective of providing systems that fulfil other basic human needs. In particular, primary community needs such as water supply, food security, and sanitation levels are less well represented in the academic literature. However, this does not mean that nothing is happening. There are many volunteers who are motivated by altruism to commit their personal time and resources to helping others less fortunate than themselves. There are also techno-philanthropists who have put money into uplifting specific communities or solutions to wider health or disease issues. Government agencies too are involved. Many innovative products have been developed too. Some of these are constructions that could be replicated within the community, such as simple mobility aids for the disabled in these communities, apparatus for carrying water or washing clothes, and cooking products. Others are high technology solutions that are useful but could not be constructed by the community itself, such as solar photo voltaic (PV) panels, or nano technology used for purifying water. Some solutions are technical systems, the components of which are themselves commonplace (at least in the developed world), but the complexity arises in the integration. Examples of these complex systems are electrical power generators (especially those involving PV, batteries, and charge conditioners), and PV water pumping. In all cases, whether the technology intervention is motivated by altruistic or commercial reasons, it is necessary to consider how the intervention will be sustained, and this may involve standardization of design to improve replicability (and knowledge transfer, should that be desired), and gaining sufficient deployment and scale so that users are not isolated. Economies of scale would seem to be important, especially where physical and skill resources are sparse.

The basic premise of techno-philanthropy is that the application of technological solutions and innovation in products will improve the quality of life of people in developing countries. Even the term 'developing' countries implies that the ideal future condition is technological advancement. However simply transferring technology from the developed world is not necessarily a solution, and technologically well-developed projects can fail when deployed in developing areas. This is because a fabric of infrastructure, materials, knowledge, and skills underpins the success of that technology in the developed country, and this fabric does not necessarily exist to the same extent in the developing case. Thus, products of techno-philanthropy can fail because they cannot be maintained (for lack of materials, parts, or skills), or they are single use and cannot be reconditioned, etc. Some products, especially those oriented towards consumer use or packaging of processed food/beverages, have significant life-cycle considerations that are often overlook. The product may have a short use-phase in its life, and then move to disposal. Developing countries are typically also lacking in waste disposal services. These engineered products are often made of materials that do not degrade naturally, or cause harm to people or the environmental, e.g., burning of plastic in open air. Consequently, the products of technological intervention, whether motivated by philanthropy or commerce, may contribute to the waste management problem of the community

The uplift of developing countries cannot be achieved simply by introduction of technology from outside, as in an interventionist model. Instead there is a need to ensure that the products are appropriate for the region at its current point of advancement, and contribute sustainably to a trajectory of uplift. In this context *advancement* refers to the knowledge and skills of the inhabitants, and the extent of the fabric of technological services (electricity, transport, water, waste, etc.) available at that point in time.

Furthermore, there are invariably cultural considerations when interacting with developing countries. They may be backward relative to the technology of other countries, but they have cultures of their own that may have a long history. They have ways of life that may in some ways be healthier and more content than available to people in developed countries. The introduction of new technology and availability of new products changes that culture, and it cannot be assumed that every such introduction of technological progress is automatically beneficial for the health of people and their environment. Hence there is a moral obligation to implement technology that is consistent with the culture of the community, and this necessitates an element of co-determination rather than imposition of technology solutions. Working with the community, learning their methods & cultural customs, and using collaborative methods to reach solutions—these are more important than merely accelerating as quickly as possible up the technology development tree. Communities are on a journey, and technology interventions need to be sustainable for their current position on that locus.

Solution suitability in a rural DC context does not depend on financial and technical feasibility alone, but must also account for local environmental and socio-cultural dynamics. It has been observed that many rural electrification projects have failed as a result of underestimating the importance of considering these latter factors [23]. Other examples of failed technology transfer in developed countries are the move to agricultural monocultures with consequence environmental damage. Several major enablers to the success of a project have been identified as community involvement, anti-corruption measures, standardization of practices and the banning of bargaining agents [24]. These factors are less important in developed countries where operational infrastructure is more regulated and standardized, and higher levels of maintenance expertise are available.

There have also been many successes, such as microenterprises around the provision of charging stations for mobile phones, solar powered lighting, medicine, and services such as banking delivered over mobile phone networks. Consequently, there are also business opportunities in product development for developing countries, and these may be at the small and large organizational scale. Assisting local people to earn an income by entrepreneurial activities around new technology is therefore also a way to ensure that the technology interventions are sustainable in the community. Large organizations in developed countries have the resources to apply technology to develop new products for developing countries, and hence open new markets for themselves. Part of their marketing design therefore is the *placement*: how they distribute the product, service it, and facilitate its disposal at the end of its life cycle. Related to that is the decision of whether or not to involve local people in the business model, and we suggest this is potentially an important factor in the design of the route to market.

The literature concerned with the *process* of new product development in the rural DC context is limited. The only attempts at providing a framework to the rural DC NPD process were a reproduction of the process formulated by Cooper et al. [25], and a set of guidelines orientated around the concept of Design for Micro-Enterprise [26]. Both studies were concerned with obtaining market intelligence on DC consumers, as opposed to the process as a whole.

The most prevalent gap in the collective body of knowledge is the lack of a DC specific framework for augmenting the conventional NPD approach that is applied within commercial sectors of developed countries.

2. Materials and Methods

2.1. Research Question

There is a need to identify the both the barriers and the enablers to applying a design process within a rural DC context, and to modify the existing NPD framework to account for these context dependent factors.

2.2. Approach

The approach involved placing the researcher (AG) as an embedded participant in a rural DC design project. This project involved a 6 month period of volunteer work undertaken in the Spiti Valley in Himachal Pradesh, India, and encompassed designing, building, and refining passive solar cookers for family units. These cookers were designed with the available resources and to meet the requirements of the local people in mind. These requirements and resource constraints were not known beforehand and had to be determined in parallel with the design process.

A number of issues arose when implementing the solar cooking technology into the rural setting. These issues were observed first hand, and critical success and failure factors observed.

The researchers then contrasted these factors with those known from the literature on classic NPD, thereby providing a critique of the conventional method. This was followed by the abstraction of the findings into a set of design principles for DC design. Finally, these were integrated together to create a new conceptual framework of the NPD process for developing countries.

3. Results

3.1. Project Context and Background

There were many small villages in the valley, all of which depended primarily on agriculture for their livelihoods. Few trees existed in Spiti and connection with the outside world was via a single road running through the central village, Kaza. Natural resources were scarce and availability of materials and expertise limited. The Spiti Valley was opened up to the western world a little over two decades ago and is still early on in the process of adopting more western educational and technology systems.

The Spitian community lacked reliable electricity. Hence, they had a reliance on dung fires or Liquid Petroleum Gas (LPG) for cooking and heating. Dung is foraged from the high pasturelands during the summer and bottled LPG is transported approximately 580 km by road from Ambala. Negative health and environmental implications exist around burning dung [27] and LPG poses a high emission cost and supply volatility risks.

The region is isolated and access to global technology, in the form of hardware, knowledge and skills, is limited. Even the possibility of having electricity all day is still in the remote future. Consequently, some of the innovations that might benefit the region, such as improved home construction (perhaps even extending to 3D printing of building elements) are unrealistic at the current time. Even something as ubiquitous in the developed world as cooking apparatus, was not possessed by all inhabitants. Hence the scope of the project, that of developing simple solar cookers, was relevant to this community whereas it might not have been elsewhere. The isolation also meant that it was necessary to adapt the design to be achievable using local construction materials and local knowledge and skills. This is important if the product is to be repairable and replicable by the community themselves. Hence the innovation in this context was not so much the technology per se, but ensuring the product was technologically sustainable within the constraints faced by the community.

3.2. Development of a Cooker

The requirement to develop a locally available cooking alternative was apparent. This alternative was focused on being less damaging to the environment and the health of the user, as well provide greater independence from external suppliers than the current options. Factors of influence particular to this context became apparent during the volunteering period and directed the solar cooker development significantly. The passive cooker developed and refined during the project is shown in Figure 2.

Figure 2. Initial (**top**) and final (**bottom**) passive solar cookers implemented in Spiti Valley.

The project involved the application of engineering product development skills and knowledge to the task of developing a solar cooker. The ability of the Spitian community to understand the NPD and manufacturer of the cookers was noted. The outcomes were compared against the orthodox NPD process and the key factors were extracted. The NPD process was then modified accordingly.

3.3. Key Factors

These factors were classified into categories of Technical and Sociocultural Influences. These two areas were the most natural expressions of the factors observed, and were also aligned with classifications found in the literature [23]. Each identified factor has been given at least one accompanying 'Deployment Principle' (*DP*). These principles offer insight from the perspective of an embedded participant to best address contextually specific problems and forward the design process to successful deployment of the unit.

3.4. Technical Factors

Technical factors relate to aspects of the design and build process that are explicitly involved with fabrication and/or transportation of components of the assembly.

3.4.1. Global Connectivity

Kaza, received limited and intermittent electricity supply. Thus, the electrical infrastructure in the valley was poorly set-up, and internet access severely limited. This constraint meant that the majority of the project was carried out without the availability of any external information. As such, optimizing the solar cooker performance based on prior solutions was limited. Limitations on the access to information meant that robust, rather than optimal, solutions were sought.

Deployment Principle 1.1: Finalize projects through prior communication or assume resource and technical knowledge availability is limited to what the embedded participant comes in with

Finalizing the desired projects prior to arrival in the remote area gives time for potential problems to be remediated or at least considered. If projects are decided upon after arrival, the pool of accessible knowledge is considerably lesser. The availability of and convenience with which knowledge can be accessed in a more developed country is easy to take for granted. The projects should be chosen based on the strengths and competency of the person undertaking them. It cannot be assumed that all of the physical and digital resources will be available in context.

3.4.2. Local Connectivity

Kaza was approximately one day's drive away from the next economic center. Several delays were incurred waiting for suppliers to respond to resource requests. In one instance the requested part (polycarbonate sheet) arrived after two weeks of waiting but was not useable as it was damaged in transport. This showed an importance facet of design, namely, that materials used in the design solution should account for the infrastructure required for them to reach destination as safe transport of delicate or brittle materials is not assured.

Plans were made ad hoc, and did not extend more than a day or two into the future. Lack of communication infrastructure between villages meant that plans could not always be changed remotely. Several stone masons requisitioned to help with one of the cooker builds waited for four hours at the gate to a satellite village due to unforeseeable delays and there was no way to contact them. No animosity was shown by the stone masons, as the cultural viewpoint appreciates that plans do not always go as expected. Village life is not regimented in terms of minutes and hours. Seasonal changes that are important for harvesting crops or moving stock help dictate workloads. The native vocabulary lacks words to describe relatively short time periods (minutes, hours). Sometimes a supplier would indicate they would reach Kaza four or five days earlier than they did. Delays were inevitable with the poor infrastructure connecting centers and the access road was often blocked with rock falls.

Deployment Principle 1.2: Plan for project delays when working in remote contexts by integrating parallel work-streams when possible

Parallel work streams are useful to add value to the waiting time and reduce the impact of delays in a project. Deadlines should include weekly or fortnightly allowance periods to account for extraneous factors that cause delays. Acknowledgement that the culture may have developed without the concept of a regimented, precise western system of ordering time is an important consideration. The acknowledgement that local people will not have the same sense of urgency or need for efficient time use as the embedded participant is important to maintain a positive working relationship.

Deployment Principle 1.3: Consider the reliability of transporting materials in from external suppliers

Transportation of delicate materials must be considered in the feasibility of their use in a project. Labelling of fragile goods may not be heeded or even provided at all. The infrastructure to reach remote communities is considerably less forgiving than urban infrastructure. This issue can be mitigated in the embodiment design phase by considering transit robustness during material selection.

3.4.3. Material Constraints

In Kaza, there were few existing braces or frames to hold objects together, especially those that needed to be nailed or cut. The concept of using a saw horse for working was alien to the community. The available nails were generally too soft to remain straight while being hammered. Plywood quality was variable and unreliable and substantial gaps existed in some laminate layers. Mud bricks were the primary building resource. Timber was scarce and expensive. Sheet metal was limited in both size and variety.

Deployment Principle 1.4: Acknowledge that material or component quality in a rural DC context will be variable and generally limited and make design decisions accordingly

Knowledge of what materials are locally available and feasible should be assimilated during the conceptual design phase of a project. The option to import materials into an area may also exist, although it is important to be aware that locals will generally have a good knowledge of how to work with the materials familiar to them. The design process should pivot around what is possible in the context. This consideration generally reduces the breadth of material selection candidates to keep the manufacturing within local skillsets and minimize failure modes.

3.4.4. Solution Visualization

The visualization skills of lay people were below expected. When fabricating the drawer frame for the solar cooker, as shown in Figure 3, local participants lacked the ability to comprehend the plan for the wooden frame. In particular, they lacked the ability to relate numerous 2D and 3D representations of the design to determine how four pieces of wood could form the structure shown.

Figure 3. Detail of wooden frame for solar cooker drawer.

In order to convey the relationships between the four pieces of wood, offcut pieces were numbered to match the illustrations then placed roughly in the required shape. Locals made attempts to memorize all necessary dimensions to reproduce the assembly, rather than relate the labelled schematic to the design.

The carpenters and metal workers had substantially better visualization skills than other people. The gap between those who could understand a drawing and those who could not was more pronounced than expected. On the whole, representing a physical, precise object using a drawing was a largely underdeveloped skill in local volunteers.

Deployment Principle 1.5: Appreciate that a visual basis for idea communication may be a learnt skill

The locally manufactured parts and/or assemblies for a project should factor in the potential lack of visualization skills of local people. Most engineering degrees develop the capacity of the graduate to form an image in their mind. This skill of communicating information is directed into predominantly visual formats; hand sketches, CAD models, or technical drawings. The western formal education structure largely standardizes how information is communicated; part elevations, exploded views, isometric or perspective views, sectioning conventions, dimensioning, use of a particular measurement unit (i.e., millimeters). These concepts become second nature to many designers and engineers but it is incorrect to assume they are universally understood, or that a visual basis can be easily conveyed to everyone.

Deployment Principle 1.6: Trial the broadest possible range of learning styles when communicating the design to people in a rural DC context, then capitalize on the style(s) that are readily understood

Any assemblies that were given to the tradespeople in Spiti were replicated without too much difficulty. Reaching an outcome was much more successful if workers were shown what was required by using either a pre-made version of the final product or actually stepping through the construction process with them. When designing in communities that have not had exposure to western education systems, the communication of ideas should be approached as broadly as possible. Technical drawings can generally not be relied upon as the primary communication means. The outcomes were more successful in this particular context when a kinesthetic approach to communication and education was taken.

3.4.5. Quality of Manufacture

As mentioned above, mud was the primary structural building resource. The precision available from working mud bricks or ramming earth is much less than what is possible from wood or metal. However, mud structures allow reworking at a later date if desired. The local mud artisans were particularly skilled and knew how to get the exact consistency required for mud serving a particular purpose. Both structural and aesthetic aspects were considered.

The precision of the solar cooker manufacture was limited by the mud. Fitting a timber drawer frame and precision sheet metal pieces within a mudbrick cavity required chipping of the mudbrick and subsequent cutting and re-bending of the metal. Although reworking was possible, it was more efficient to force conformity of the mud by using an external frame.

After the first prototype, the mudbrick construction was substituted for a rammed earth construction. Purpose built timber frames were constructed to standardize the mud brick structure of the cooker, therefore ensuring compatibility with the internal components. These frames were an integral part of the rammed earth construction process, as shown in Figure 4.

Figure 4. Timber frames to standardize cooker structure and assure reliable quality (**left**), rammed earth construction process (**mid**), removal of frame after mud has dried (**right**).

Screws were often hammered in just as with nails. This misuse caused serious damage to the timber frames and revealed two other important issues:

(1) A lack of electricity meant that the purchase of an electric drill was not justifiable, and
(2) A lack of knowledge or concern of how screw adhesion and nail adhesion worked at a mechanical level.

Deployment Principle 1.7: Design for manufacturability by capitalizing on available resources, skills, and practice

Designing for effective manufacture is of paramount importance. If all manufacturing and fabrication is to be undertaken by unskilled individuals (as opposed to delegating specific tasks to specialized groups), it is preferable to limit necessity for precise dimensioning of parts. The lack of quality assurance in rural settings in DC contexts means that specifications such as 'Part A must have external diameter of 12 cm, Part B must have a hole with diameter 12.2 cm' is not a useful way to describe mating parts. It is much easier to specify as 'Part A must fit inside part B snugly' and give the least number of numeric dimensions possible to complete the project.

Deployments Principle 1.8: Provide parametric templates for reproducing complex parts

The solar cooker designed for Spiti required several sheet metal pieces, one of which had unavoidable complexity, shown below in Figure 5 (top). This piece was placed on the east and west sides of the cooker cavity. The only way to ensure the side piece could be replicated to reliably fit inside each cooker was to make a master template, Figure 5 (bottom).

Figure 5. Finished Piece for Solar Cooker (**top**) and Parametric Sheet Metal Template (**bottom**).

The template was overlaid on a piece of sheet metal and holes were punched at all the corner positions so that fold lines could then be drawn. This template removed the need for any of the 15 linear and angular dimensions to be recorded or memorized and ensured that the piece was always identical. The cutting sequence was refined and standardized to ensure no hazardous ragged edges were present. The bending sequence was refined to a simple eight step process. Both sequences were recorded through photographs and successfully taught to several of the local volunteers for future fabrication of the part.

3.5. Sociocultural Influences

Sociocultural factors relate to how local people interact with the finished design or aspects of the build process. The associated DP's have been numbered with respect to their appearance in the integrated framework schematic (Figure 6) rather than their order of appearance in the text. Thereafter they are grouped according to similar categories in the overall framework.

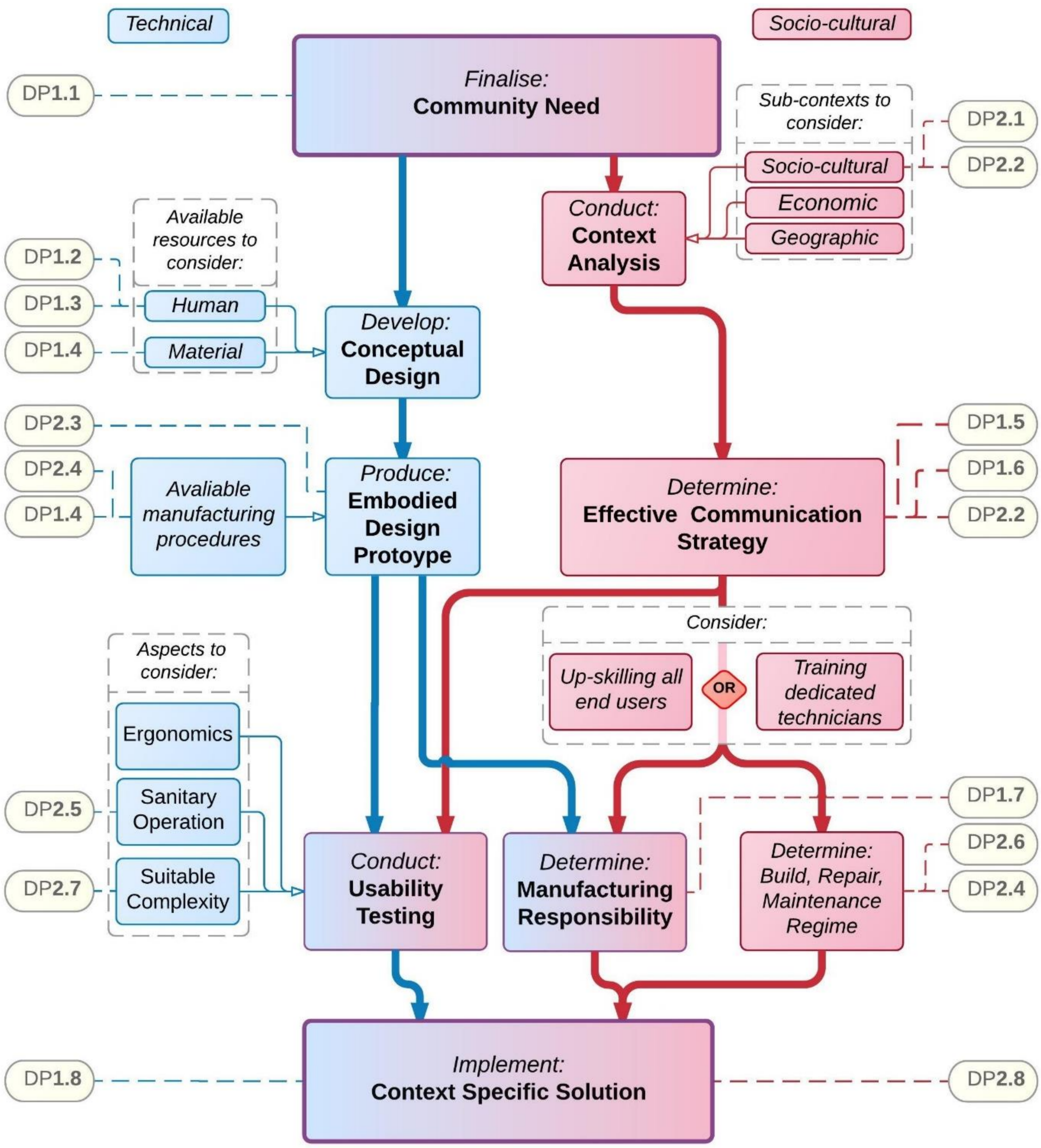

Figure 6. Proposed framework for new product development process in rural developing country contexts (DC-NPD).

3.6. Communicating Ideas

A general apprehension to accept new ideas on the basis of words alone was observed. Little credit was given to the knowledge of someone who was from outside Spiti. Skepticism had to be dispelled by showing the physical product or the process functioning, and the tangible outcome.

Direct address was not the norm for communicating requests. The researcher would often be told '*if one were to do this* … ' which meant '*I want you to do this* … ' It was observed that direct instruction would often fail to warrant a response.

The whole concept of providing instructions was alien to the local volunteers collaborating on the project. The instruction set developed initially contained drawings and schematics of the build process. To adapt to the context, the graphics were substituted for photographs but they were also shied away from. Those that wished to learn how to make a solar cooker had to see it done and/or do it themselves. Prior to western influence being introduced to Spiti, the society was primarily agricultural. The apprehension toward using instructions may have been linked to relative lack of development of visualization thinking techniques. This categorization of communication leads to two development principles, 2.1 and 2.7 as follow.

Deployment Principle 2.1: Observe and adapt to the ways that local participants transfer knowledge and instruction

Communication of ideas and instructions are highly important in the success of any project. Language barriers can cause hindrance in communication. Cultures with less exposure to western education systems may not respond positively to written/graphic instructions. The difficulties that arise can most easily be remediated by collaborating with bilingual individuals. A translator can convey the intent of written or diagrammatic instructions, or the purpose of certain actions and how these relate to the overall goal or outcome.

In contexts that have not had substantial exposure to western learning systems, learning kinesthetically may be more a successful approach than providing instructions. It is particularly helpful to have a translator here, as the amount of information that can be communicated purely through gesture is limited.

Deployment Principle 2.7: Assume standard operating practices will not necessarily be adhered to consistently, so design to the simplest operation principle

As the operational procedure becomes more intricate, a greater degree of explanation is required for the end user to understand how each of the steps relate to the overall functionality. Additional design complexities offer points for the end user to deviate from a standardized operating practice. The approach presented has a high focus on increased solution reliability than increased efficiency. Simplicity of the design and operational procedure introduces as few failure points as possible and helps to keep performance reliability as high as possible.

3.6.1. Community Perceptions of Proposed Design

A social stigma existed around the installation of solar cookers in Spiti as prior models issued by the government were too fragile with large glass panes and mirrors integrated into the design. When the researcher proposed using polycarbonate (PC) for the design, it was well-received. PC would not be susceptible to breaking when struck by cricket balls; this was the main cause of damage to the government-issued cookers. The glass itself was not the issue, but there was no way to replace broken panes.

These cooker units were provided as a large scale government operation to provide a healthier and less energy intense option for cooking in rural contexts. The purpose of the cookers not been adequately communicated to the Spitians and therefore they were perceived as somewhat superfluous to their needs. The reliability of the units and ease of replacing broken components was not considered by the government and therefore they tended to remain broken. The reflector component was more valuable as a mirror than the unit was as a cooker. This categorization of community perceptions leads to development principles 2.2 and 2.8 as follow.

Deployment Principle 2.2: Involve the end user(s) as much as possible so they feel a sense of ownership for the solution

Providing the recipient with a sense of ownership is important for the success of an implemented design. The government-issued solar cookers were not widely used despite their functionality because the people of Spiti had no attachment with them. It is critical that the solution addresses a user identified need or else the relevance of providing the solution is clearly communicated and understood by the intended user.

Involving the user during the construction phase is beneficial for helping them to understand the functionality of and relationships between different components, to understand how to perform repairs and to also gain a sense of pride and attachment to the design.

Deployment Principle 2.8: Community acceptance of the solution is a crucial factor in successful design

The solar cookers designed and built by the researcher were completed with assistance from different groups who all voiced particular modifications they wanted to employ from the standard design. For example, users requested an extra base layer of stones to stop water ingress from snow melt, an adjustable reflector to increase energy input, a particular finish to match the aesthetic of the house it was built for. It was important to keep the design flexible enough to facilitate these changes as they allowed user-identified needs to be incorporated. The result was that users had a higher degree of commitment and affiliation with the design than if the final product was simply provided without their input. The local knowledge of the environment also helped refine the design beyond what the researcher was capable of foreseeing.

3.6.2. Repair and Maintenance

So-called 'Jugaad' (*dew-gard*) solutions were the most common fixes to problems that arose. These solutions are typically ad hoc by people the locals refer to as 'barefoot engineers'. The solutions are innovative and tend to achieve a minimum level of functionality. One such example was using a hacksaw blade (with no handle) to tap a thread into a PVC pipe used for a water heating system. A period of unexpected cold had burst one of the pipe fixtures and it was critical to repair the system. The tapped thread lacked the required precision to fit in the fixture and subsequent shaving using a shard of window glass was undertaken. The shaving attempt also failed, at which point the PVC was heated using a candle and forced into the fixture. Water was run through the piping and no leaking occurred. When breakages in a system occurred, it was more feasible to solve the problem using what was readily available than to get expert advice or waiting for the appropriate tools. The necessity to solve problems without external input has driven members of the community to develop impressive capacities for adaptation and innovation. This innovation is directed at solving problems within the resource-constraints imposed by the situation. Also evident is the adaptability of solution strategies: people did not persevere with a failing strategy, but instead innovated a new approach and tried that. All of this requires cognitive abilities to create and self-evaluate progress, psychological abilities of personal agency and self-efficacy, and physical skills of craftsmanship. Consequently, although the level of technological innovation was not high, the intellectual innovation was. The corollary is that people in developing countries innovate in ways that may be overlooked when sophistication of technology is taken as the key metric of innovation.

When working with mud, nothing is an irreversible problem. Any defects or damage done can be fixed with application of more mud. Cracks can be joined. Extra width can be added, excess can be removed. The same frugal mentality was extended to working with other materials to make use of everything. Examples are detailed below:

- Wood that snapped was reinforced at the break so it could be reused
- Metal that was damaged or scrapped by someone else was bashed into shape for continued use. No edge was deemed too rough to be unusable

- Shirts and blankets that were worn out beyond repair were used with rocks as valves for the canals to provide water control for field irrigation

This categorization of repairability leads to development principles 2.3 and 2.6 as follow.

Deployment Principle 2.3: Design for lifespan reliability rather than optimal efficiency

Robust materials should be used wherever the option exists. It is more useful in this context to provide a long-lasting design with reduced efficiency than an increased efficiency design that is less robust. New product failure in rural DC markets are susceptible to a lack of local service networks and robust design features are the most important factor achieving successful implementation [26].

Deployment Principle 2.6: Acknowledge the local perception towards repurposing materials to fix system failure points

The most probable failure points of a system should be identified to give some idea of how these will be fixed by the locals. Designing for ease of cleaning and for non-destructive replacement of parts is critical. Moving parts add extra degrees of complexity that will be harder to reproduce with limited resources and more difficult to remedy later when they fail. Hence, moving parts should be avoided when possible.

It has to be assumed that any repair work on a damaged system will be carried out with very limited access to tools. Failure points of a design should be considered on the basis of how they are likely to be repaired. If repairs occur during the build phase, it is interesting and informative to leave the locals to their own devices and see how they tackle the problem using their own skillset and resources. This can help to expand the options open to the external designer, and also to gauge how the locals will cope with keeping the system functional over the longer term.

3.6.3. Workplace Safety

The level of concern for worker and bystander health and safety was very low in Kaza. The majority of labor observed could be termed 'unskilled'. The more skilled trades such as metal working or carpentry had no regulatory framework to make sure that both workers and passers-by were safe in and around the site. Some of the practices observed within the workplaces are detailed below:

- Tradesmen were ignorant of the dangers of inhaling either LPG from leaky canisters or enamel paint fumes while painting.
- The carpenters and metal workers wore sandals or very occasionally leather shoes. None of the workshops or job sites provided gloves, ear protection, eye protection or hard hats to workers.
- The welding metalworkers had tinted sunglasses, although bare faces and arms were exposed to the radiation. No shields or screens were used to protect others in close proximity.
- Many workers were intoxicated at the metal workshop on the day of a festival. Machines were still operating amidst the inebriety.
- Electrical safety was minimal and a supervisor gave himself a mild electric shock while replacing a photovoltaic cell battery when touching both terminals while holding conductive tools.

These safety considerations lead to development principle 2.4 as follows.

Deployment Principle 2.4: Maximize the unskilled, hand fabrication or repair processes required by the end user(s) to limit risk exposure

Considering the perspective of workplace safety, maximizing the fabrication that can be done by hand or without heavy machinery minimizes unnecessary risk exposure for those involved with this phase of the design. The availability of more sophisticated tools also tends to be limited and for ease of ad hoc repair or replacement of components, the solution will be more reliable if the end user is capable of repairing as much as possible without external aid.

3.6.4. Sanitation and Hygiene

The sanitation and hygiene knowledge held by those in rural DC contexts is not necessarily aligned with what is accepted in developed countries. The idea of cause and effect relating to health issues was observed to be marginal in Kaza. Gastric flu cases were put down to the patient getting too cold, rather than the possibility of eating bad food or drinking bad water. No second thought was given to mouth-siphoning stagnant brown water from an irrigation catchment tank that contained several years of fertilizer runoff and general organic debris. Children scooped water from the communal drinking water barrels using their hands or returned backwashed water back into the barrels. The causality of health issues was observed to be strongly ingrained, and conflicting ideas were not given any credit.

These hygiene considerations lead to development principle 2.5 as follows.

Deployment Principle 2.5: Assume sanitation practices common in developed countries will not be adhered to and design precautions accordingly

From a hygiene perspective, systems dealing with food and/or water should have precautions inbuilt into the design to help minimize germ spread or contamination. Such precautions will depend on whether the design is to be used by a single person, a family unit, or a whole community.

4. Discussion

4.1. Proposed NPD Framework

The identified implications specific to NPD in the rural DC context have been classified as deployment principles in the results above. The framework for developing a general NPD process within this context was initially based on the temporal Stage-Gate methodology proposed by Cooper et al. [25]. It was found that the proposed DC-NPD framework had very little overlap with this conventional model and an alternative methodology was constructed to define the process more realistically. The underlying purpose for the conventional NPD framework is profitable financial returns, with an emphasis on extensive market intelligence. In contrast, the proposed DC-NPD framework is driven by fulfilling the needs of the community for whom the end product is intended. The former framework involves a highly directive approach to obtaining the final product where the end users have limited involvement in the *engineering* component of the early development process. In contrast our proposed framework takes a co-determinative approach where decisions are influenced and informed directly by the end users throughout. This includes user-needs, design, manufacture, and usability. There is commonality between the two NPD processes, with ours having a greater emphasis on the socio-cultural factors.

The proposed framework is shown in Figure 6 and the Deployment Principles are summarized in Table 1. The framework has been split into dual pathways that influence each other, but have a distinctly differently focus from one another. The technical pathway, colored blue, detail considerations that ensure the design functionality based on the specific contextual constraints. The socio-cultural pathway, colored red, details considerations that ensure the end user integration, investment and comprehension of the process elements. Several deployment principles were isolated to one pathway and appear in both.

Whereas the conventional NPD process involves technological innovation or novelty, the NC-NPD framework is constructed around implementing functional technology in a novel context. The design development and validation aspects are not intended to encompass proof of concept work, rather the implementation of a proven concept in a new context.

Table 1. Summary of Deployment Principles (DP).

1. Technical Deployment Principles	2. Socio-Cultural Deployment Principles
DP 1.1: Finalize projects through prior communication or assume resource and technical knowledge availability is limited to what the embedded participant comes in with	**DP 2.1:** Observe the ways that locals learn best and tailor the knowledge transfer process toward these
DP 1.2: Plan for project delays by integrating parallel work streams	**DP 2.2:** Involve the end user(s) as much as possible so they feel a sense of ownership for the solution
DP 1.3: Consider the reliability of transporting materials in from external suppliers	**DP 2.3:** Design for lifespan reliability rather than optimal efficiency
DP 1.4: Acknowledge that material or component quality will be variable and limited, make design decisions accordingly	**DP 2.4:** Maximize the unskilled, hand fabrication/repair processes required by the end user(s) to limit risk exposure
DP 1.5: Appreciate that visual communication may be a learnt skill	**DP 2.5:** Assume sanitation practices common in developed countries or standard operating practices will not necessarily be adhered to
DP 1.6: Trial the broadest possible range of learning styles and capitalize on the style(s) that are most readily understood	**DP 2.6:** Acknowledge the local perception towards repurposing materials to fix system failure points
DP 1.7: Design for manufacturability by capitalizing on available resources and skills	**DP 2.7:** Assume standard operating practices will not necessarily be adhered to the entirety of the time
DP 1.8: Provide parametric templates for reproducing complex parts	**DP 2.8:** Appreciate that community acceptance of the solution is a crucial factor in successful design

4.2. Originality

This work makes several original contributions. The first is the development of a novel representation of the *process* for conducting design in developing countries. Related to that is the inclusion of the socio-cultural perspective and its explicit representation as a set of activities in the process. This perspective is absent from the conventional frameworks presented by both engineering and business perspectives.

A second contribution is the identification of critical success and failure factors, and their inclusion into the process perspective. Hence the contingency variables have been identified. While this identification is limited by being from a single case study, the results do nonetheless provide a candidate set of critical success factors. A related contribution is methodological in that the work provides a method for extracting socio-cultural factors from a case study and representing them in a process framework.

4.3. Implications for Practitioners

The deployment principles informing the framework are generalized enough for application to other rural DC contexts. This design considerations for a rural DC context determined in this study can be broadly grouped:

- Involve community members early and often to and direct the solution toward a user-identified need rather than an externally identified need for optimal appeal and acceptance by the user

Focus design effort toward increasing unit reliability rather than efficiency.

Learn and impart knowledge to local stakeholders in a culturally appropriate manner to adapt the solution to assimilate local knowledge and skillsets and to ensure contextual suitability.

4.4. Limitations

There are a number of limitations in the work. The first is that the findings are dependent on a single case study. While this case study is believed to be generally representative of product development projects in developing countries, there may be additional findings in other situations. A second limitation is that the extraction of critical success factors—the development principles—was dependent on the personal attributes of the embedded researcher. The knowledge, skills, and insights of the embedded researcher are personally unique. Hence there is likely to be some subjectivity in the insights gained. Both these limitations have been partly reduced by grounding the study in the existing literature, but the limitations cannot be totally eliminated. The limitations were also partly reduced by the relatively long duration of the embedment (6 months), which provided multiple opportunities to triangulate findings with different people in different situations (albeit on the same underlying project). A quick one or two week project experience would be unlikely to offer the same level of de-biasing opportunities.

4.5. Implications for Further Research

There are several opportunities for further research, corresponding to different levels of enquiry into the proposed framework. At the broad level one question is whether or not the proposed DC-NDP framework subsumes the conventional commercial NPD process. The initial assessment, based on observing the degree of integration (see Figure 6) is that this is the case, but this needs to be checked. If so, there is the potential that insights gained from the socio-cultural side of the model could be adapted to enrich the commercial process. At a deeper level of detail, there is opportunity to investigate the develop principles in more detail: to validate them and to explore how the causality operates whereby they affect the relevant activity in the model. It could be valuable to apply qualitative research methods into understanding *why* people think and act like they do. There are multiple development principles, hence several opportunities for research.

5. Conclusions

The purpose of this work was to identify the factors affecting the NPD in a rural DC context. The findings have been highlighted and summarized as the technical and socio-cultural Deployment Principles for successful design as detailed in Table 1. These Principles have been integrated into the DC-NPD framework. The framework has dual pathways that influence each other, but have a distinctly differently focus from one another. The technical pathway, which most closely corresponds to the product innovation process in the developed world, is focused on design functionality within a commercial route to market environment. The socio-cultural pathway emphasizes development activities involving co-determination, knowledge transfer, and reliability of the product. Implications for design and innovation are identified for both pathways. We propose that elements of the socio-cultural innovation pathway, while extracted from considerations of the developing world, are also applicable to the developed world even though the latter has a more overtly commercial intent in its innovation process.

The originality of this work is the formalization of this NPD framework. Special attention has been given to the rural DC context, as opposed to the conventional application of the NPD process in developed country consumer markets. The work provides insights into elements that embedded participants might consider when implementing designs within rural communities in developing countries.

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