A Framework and Process for Designing Inclusive Technology

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Abstract— First we explain the term ‘inclusive technology’ that was coined in the context of software projects intended for bridging the digital divide. Such projects have come to be known under the umbrella term “ICT4D projects” or Information and Communication Technology for Development projects. Then we argue that traditional software engineering processes are lacking in certain respects when used for ICT4D. To overcome their shortcomings, we propose augmenting traditional software processes to make them suitable for the development of software projects undertaken with a view of bridging the digital divide in a society.

Keywords- Software projects, ICT for development (ICT4D), Inclusive Technology, Software Engineering Process, metrics for development projects

I. INTRODUCTION

There are significant disparities in the socio-economic opportunities available to people in rural versus urban areas throughout the world. This disparity contributes to inequities in the ability to use and benefit from Information and Communication Technologies (ICT) and the resulting access to information and services [1]. This situation is often referred to as the Digital Divide. Several affordable technologies of the modern day, such as inexpensive computers, wireless connected hand-held devices, and open source software tools, offer possibilities for reducing this gap. However, experience has shown that simply providing access to technology is insufficient, particularly when it comes to the rural population. What people need is the ability to make use of technology in order to engage in meaningful and gainful social activities in a sustainable manner [2]. We introduce the term ‘inclusive technology’ to emphasize this dual aspect of technology and its sustainable use for benefit.

In recent years, numerous ICT for Development (ICT4D) projects have attempted to bring the benefits of technology to marginalized communities. The different agencies or stakeholders who are the prime drivers of such projects can be classified into three groups: (i) Governments, (ii) Interested industries or businesses, and (iii) NGOs or charitable organizations. Although the literature is full of case studies describing the launch of pilot projects in optimistic terms, the lack of rigor in evaluating and monitoring many of these projects raises questions about their long term success and sustainability [3]. Experience indicates that technology designed for the industrialised world is generally a poor fit for these communities. At the same time, the technology needs of these communities are often poorly understood by the developers, and the ‘design of technology’ specifically for them poses unique design challenges requiring a multidisciplinary approach [4]. By the term 'technology’ we refer to the complex combination of hardware, software, content, information accessibility and the social infrastructure that allows people to benefit from it. In many cases the partial or total failure of such projects can be attributed to an incomplete assessment of the problem and inadequate metrics for evaluating the solution [5]. Current efforts to develop a systematic framework for assessing such projects, such as the Digital Opportunity Index defined by the WSIS [6] or the IDRC guidelines [7], largely focus on measuring technology use in the overall population or the impact of technology on society at a macroscopic level.

We view the challenge of designing technology to bring sustainable, measurable benefits to a community from a software engineering perspective. In [8], drawing on theoretical frameworks and empirical results from several disciplines, we have developed a parameterised, conceptual model that lays out the key factors involved in making an ICT based project inclusive with respect to some community. In [9] we propose a set of heuristic measurements for evaluating a technology’s inclusiveness where ‘inclusiveness’ characterises to what extent a given community can use a ‘specific technology to achieve its goals’, and illustrate their use by applying them to two projects described in the literature. In this paper we propose augmenting the classic software engineering process with a systematic sub-process that uses this framework as a basis for assessing a technology’s inclusiveness during different phases of the engineering process. We believe that such a framework would be useful to software engineers when designing a targeted software project to address Digital Divide issues. With this framework we hope to achieve the following:

1. Develop a better understanding of the issues involved in designing technology for the Digital Divide problem domain on a project by project basis by modeling the key concepts and their relationships and attributes.

2. Provide the basis for a theoretical model that can be used to share the positive and negative experiences of the ICT4D community.
3. Augment the software design process with a systematic sub-process for ‘situation based analysis’ of technology inclusiveness, and develop a framework to assist software engineers in designing technology for projects in the Digital Divide domain.

In the following sections we first explain the shortcomings of classic software engineering approaches with respect to ICT4D projects. We then present our framework for inclusive technology. In section 4 we describe how we can augment the classic engineering process with our framework to provide a ‘for development’ assessment as input into the engineering process.

II. WHY CLASSIC SOFTWARE ENGINEERING APPROACHES ARE INADEQUATE

A. Shortcomings of classic engineering approaches

Software engineering is concerned with the design, development, operation and maintenance of software systems. Classic software development process models such as the Waterfall model, Rational Unified Process or Rapid Prototyping, provide a systematic and standard approach for developing high quality software to meet specified requirements [10]. While there are many variations, all of them apply a phased approach, often iterative, with the major phases consisting of (1) analysis and requirements; (2) design and prototyping; (3) coding; and (4) testing and evaluation. At the same time, a concurrent User-Centred Design (UCD) process provides a standard and systematic way for ensuring that end-user usability requirements are incorporated into the software’s design (ISO 13407). Throughout all stages of both processes metrics play a key role in evaluating progress and success in meeting project goals.

Even though these process models have made significant improvements in the quality and complexity of the software produced, they are not fail-proof1. Among the common factors contributing to failure are a lack of user input, incomplete and changing requirements, unrealistic expectations and schedules, unclear objectives, and a lack of executive support [11]. These processes have evolved in the industrialised world and incorporate a number of built-in assumptions regarding the nature of the software being developed and the overall context of use (technical, cultural, economic, and environmental). In the case of ICT4D projects, if these same approaches are applied without giving due consideration to differences in the software’s nature and context of use, the potential sources of failure are multiplied. In particular, the following areas frequently receive insufficient or no concern [3, 5]:

(a) Objectives of the various stakeholders are kept vague, with the ultimate beneficiaries frequently disconnected from the project’s goals.

(b) Incomplete or unarticulated project objectives combined with a lack of clear metrics for evaluating success, and the definition of success depending upon which stakeholder defines it.

(c) Deployment constraints and sustained operation constraints are inadequately addressed.

(d) Usability requirements and evaluations are not well reported.

(e) Requirements pertaining to the economic sustainability of the solution are not considered, with little or no forethought given to business models that might balance costs and revenues to make the solution sustainable over the long term.

Nevertheless, this has not prevented a flurry of ICT4D activity from taking place in recent years. However, with many of these projects it is not always clear which stakeholder has benefited the most. As reported in [3], in many cases claims of success are questionable, and largely depend upon who defines success. Most ICT4D projects involve three categories of stakeholders, each with their own agenda and set of objectives that do not necessarily converge [5]. (i) Governments at both the local and national level are generally not concerned with making a profit, but focus on service delivery and quality, and satisfying their citizens. (ii) Business and industry, on the other hand, are primarily interested in profits from either immediate or future sales. Finally, (iii) NGOs and charitable organisations are primarily interested in making a social impact. Because the intended beneficiaries (or end-users) of these projects are often not consulted, there is frequently a disconnect between the end-users’ own goals and the objectives of the stakeholders. Also, most stakeholders who initiate such development projects are usually interested in achieving results as rapidly as possible, with ideally a success to justify their funding sources. Unfortunately, little or no consideration is given to (a) the time-frame required by the target society to achieve results; (b) technology penetration levels, that is the incremental and monotonic growth of the end user population over time; and (c) agreed upon metrics among the stakeholders according to which the success or failure of the project will be evaluated in an on-going manner.

When it comes to sustainability, for a proof of concept project to achieve continuing success over the long term, economic sustainability is essential. From an economic perspective this requires that a project produces a measurable outcome in a cost-effective manner; that it be scalable as the user population grows; and that it can be maintained after deployment [13]. Funding for ICT4D can occur in two ways. For certain public goods and services, an on-going stream of funding may be available from sources such as the government or private donors. However, this funding stream may eventually dry out, and external sources often impose conditions on how their funding can be used. If external funding is limited or not available, then a project needs a compelling value proposition which together with an effective business model, can lead to wide-scale adoption and diffusion over time. Because of the conditions in developing countries (i.e. the absence of infrastructure, an

1 By certain estimates based on a 2004 survey, up to 18% of IT projects are total failures, while over 50% are problematic [12].
underdeveloped market, lack of distribution and support networks, etc.), this value proposition must cover operation and maintenance costs through self-generated revenues. For this, innovative business models that work under the prevailing conditions are required. In [13], the authors present a number of alternative models based on a review of award winning ICT4D projects. However, for these business models to be successful, their requirements must be incorporated into the overall design from the beginning, and the business and technology requirements must co-evolve together.

B. Challenges specific to ICT4D projects

ICT4D projects for rural communities differ from conventional software projects in a number of ways. For one, their goals focus on bringing sustainable benefits. Experimental prototypes can only enthuse the people; only once a project is used in a sustained manner can any significant impact emerge. When it comes to sustained operation, there is a set of environmental and user constraints specific to ICT4D projects that conventional projects rarely need to address simultaneously. Among these are intermittent power and connectivity, harsh climatic conditions, low population densities, long travel times, a lack of secure locations to house equipment, and culturally different views towards privacy. The intended users typically have limited schooling, high illiteracy rates, are underemployed, and have low disposable incomes [14]. Individually, these are not exceptional when compared to non ICT4D projects, and could be handled as a set of highly constrained requirements obtained conventionally through rigorous requirements gathering based on participatory design techniques and alternative business models. However, in the case of ICT4D projects, their simultaneous occurrence and dynamic interaction with the environment lead to the following significant differences:

1. Success is measured by achieving sustained communal benefits that evolve over the long term, as opposed to short term. Metrics to measure the communal benefits are difficult but necessary in order to justify the investments needed to sustain the project.

2. Deployment and sustained operation constraints cannot be resolved from a purely technological perspective, but are dynamically interrelated to the broader socio-economic context of the community.

3. There are major economic, social, political and cultural differences between rural and ‘technologically developed’ societies which impact how they can make effective use of ICT. The technical success of a project is not enough. Other factors include: evolving a suitable deployment model for a technically successful project, accessibility, affordability, fail safe operation and dependable of the service provided by the project, along with other motivating factors needed to encourage people to use it.

With regards to the third point, these differences reside in the social dynamics as opposed to structural characteristics of the societies. There is no simple definition of what these differences are in the literature. Markets, financial capital, manufactured goods, media-based culture and technology are typically situated in populated urban areas [15]. Such areas can be characterised by their population density, the flows of people, information and capital between distinct districts, and the level of connectedness between inhabitants, while a historical and cultural interpretation of the space establishes where different social groups and individuals are located in relation to the flows and connections. Participation in the urban dynamics entails mobility which results in a flow of “familiar strangers” which provides anonymity and privacy to the individual [16]. Typically, the denser the population and the more dynamic the flows, the more diversity and prosperity present, leading to more potential opportunities of all types. In particular, learning opportunities are more numerous due to the wide variety of “communities of practice” present.

In contrast, rural communities generally have low population densities, limited flows, and more static relations between the social groups relative to more developed areas. As a consequence, economic opportunities are more limited, culturally they are more traditional and slower to adopt change, and socially community members have less anonymity and are more constrained by the role assigned them. Because of low population densities there is little incentive for investment in infrastructure. Because of distance and tradition, they are politically disconnected from decisions affecting them. The reduced flow of information and goods results in limited exposure to new technologies, and ICT in particular. In this context, the lack of a “community of practice” with respect to ICT makes it difficult for community members to imagine how they could effectively benefit from it. It thus becomes incumbent on ICT4D projects to not only introduce technology, but also to foster a local “community of practice” which will allow people to see how they can benefit from it in their local context.

III. AN INCLUSIVE TECHNOLOGY FRAMEWORK

A. Inclusive Technology

Social inclusion can be abstractly interpreted as the extent to which an individual or community can fully participate in society and control their own destinies. In the information era, the ability to use the appropriate technology to access information and services plays a critical role in this regard, and there are several recognised barriers to achieving it. These barriers consist of access to (a) the physical resources such as devices and infrastructure, (b) the digital information resources such as software and content, (c) the
human resources which correspond to the skills people need to extract and apply knowledge, and (d) the social resources which refers to the broader social context in which the technology is applied [2]. In addition, for a technology to be accepted by its intended users it must be perceived as beneficial, easy to use, and socially endorsed, with an adequate infrastructure in place to support its use [17]. To meet these objectives a technology must be relevant to the needs of the community, it must expand on existing knowledge and skills, and it must be affordable and sustainable. To be part of a sustainable cycle, the benefits that can be derived from using the technology must balance the costs. Such a technology that fits into and is compatible with its environment is considered ‘appropriate’ by certain researchers [1]. All of these factors must be taken into account for a software project to be successful.

Based on the above, we define an ‘inclusive technology’ as a technology which empowers community members to more fully participate in benefiting from the information services provided through the use of that technology. Such a technology overcomes the barriers to using technology that might be inherent within a community so as to make a difference in its members’ decisions and lives. What changes are beneficial will be specific to a community’s needs and what they value as beneficial. Based on the literature on rural development, we characterise the rural communities in which we are interested as follows [15, 20]:

- They are remote, making transportation and communications costs prohibitive
- The livelihoods of community members are largely based on subsistence activities
- Household incomes are low, at or below the poverty level
- Many communities have limited or no public services and utilities such as schools, health clinics, banks, government services, electricity, phone lines, etc.
- Most community members speak primarily local languages
- Schooling is limited, leading to low reading and writing skills
- Most community members have limited or no exposure to computer technology

B. Conceptual model of inclusive technology

Our conceptual model of inclusive technology is based on Maslow’s Theory whereby needs motivate human behaviour. According to our model, the rural environment in which a community is embedded largely shapes that community’s socio-economic activity. This in turn largely determines that community’s needs. A community is composed of individuals who are connected in one way or the other. Needs motivate an individual to identify goals whose achievement will result in a quantifiable or qualifiable gain, which is the motivating factor for undertaking that activity. Achieving these goals requires both knowledge and action. Actions can change the community, which in turn can reshape the environment in which that community is located. Acquiring that knowledge and acting upon it, both require a set comprised of three components: skills, resources and tools. We can divide each of these sets into two disjoint subsets: ‘ICT specific’ and ‘non-ICT specific’. A software project can only affect the former; the latter is beyond the scope of a software project but will be essential in making a difference to the targeted society. This model is depicted in Fig. 1.

Within this model, a sustainable cycle is achieved by selecting goals which result in a balance between social and economic benefits. This cycle consists of ‘needs’ stimulating the discovery of relevant ‘knowledge’ which leads to ‘actions’ resulting in ‘benefits’. As the community’s situation improves, its needs evolve creating more ‘wants’ stimulating the discovery of more relevant knowledge, and so forth. This process is illustrated in Fig. 2.

Given a goal, there is rarely a simple, one-to-one, unidirectional relationship between the knowledge and action to achieve that goal. Often, realising a high-level goal will involve a knowledge set and action set which iteratively feed on each other until a satisfactory state is reached. To provide an example freely drawn from the e-Choupal project [5], if a farmer discovers that they can get a better price for their grain if they sell it directly to the grain company as opposed to a middleman who comes to the village to buy it, the farmer will have to find out where to go, whom to talk to, how to transport the grain, any additional costs involved and
what the difference in price is before making a decision, let alone actually acting upon it. This relationship between knowledge and action is depicted in Fig. 3.

Group dynamics within a community play a critical role in both goal selection and the sustainability of this cycle over time. Structural-functional systems theory identifies the functional requirements to consolidate and achieve internal stability of such a social group; and group dynamic interaction theory provides a dynamic phase model whereby it can be realised [18]. According to this theory, from a functional perspective, in order to survive and thrive, the group must be capable of (a) adaptation to other external systems (external to the ICT4D project) and the physical environment, (b) goal attainment, (c) integration, and (d) maintaining internal stability and consistency. The “forming, storming, norming, and performing” model [18] is a cyclic four phase incremental approach for achieving this objective. Preconditions are associated with each phase that must be satisfied in order to maintain group cohesion and stability. In the forming phase, “empathy” allows members to communicate and understand each others’ beliefs, values, and intentions. During the storming phase “role distance” allows members to distance themselves from their own individual role in order to evaluate the group options objectively. During the norming phase, “role ambiguity” allows members to balance their personal needs, beliefs and interests with those expected of them within the group. Finally they achieve the performing phase where they function cohesively and effectively in achieving the group goals.

The need for such a group to emerge within the local community is among the basic requirements for a project’s success as identified in [19]. Also, there is the need for a trusted ‘space and place’ where the community can explore the potential benefits and limitations of ICTs. For a community to take ownership of a technology and apply it to its own goals, such a “shared learning space” should be supported. At the same time, the social and environmental constraints specific to a rural community introduce security and privacy issues associated with using a shared facility to access information and services that differ from those in an urban environment. There is a trade-off to make between communal use and the advantages it offers balanced against personal privacy.

C. A framework for evaluating a technology’s inclusiveness

The focus of our model is on evaluating the ICT specific skills, resources, and tools to determine to what extent they support a community in developing the skills it needs to achieve its goals and improve its situation. We have two objectives in developing this model: (a) to arrive at a set of measurable parameters in terms of which a technology’s inclusiveness can be studied and then, (b) to use the model both to evaluate the technology from an existing project or in developing technology for a new project. Towards this end, we associate certain attributes with each of the nodes in Fig. 1, based on our characterisation of the rural environment and the barriers to the use and acceptance of technology. For a given ICT4D project, these attributes are assigned specific parameter values which characterise the targeted community and technology, as illustrated in [8]. We also define a set of heuristic measurements for evaluating a technology’s inclusiveness along the three dimensions: the tools, resources and required skills. These measurements are described in [9], and summarised in Table 1. The measurements are interrelated; a technology must be feasible, affordable, usable, relevant, and trustworthy for it to be able to lead to improvements or advances in knowledge. And any actual improvements can only be discovered after people have put the new knowledge they have acquired to beneficial action. In addition, for the technology to be sustainable, the improvements it brings must balance the costs for its ongoing operation and maintenance.

If a project is already operational, the metrics can be obtained based on experience and measurements in the field; or if a new project is embarked upon, they can be estimated based on a ‘situation based analysis’ or from experience with similar projects. The metrics can be assessed using a five or three-point scale with values such as low, medium or high. If a measure depends upon unpredictable, external factors it is assigned a “neutral” value. The measurements for a given dimension produce a vector which can be combined into a single measure by applying a MIN function. We are currently investigating how to combine the vector elements into a single overall measurement, and how to combine the evaluations from multiple experts. We infer that if a technology scores “high” on all dimensions, then it could be considered as highly inclusive, while a technology which scores “low” on one or more measures will have potential sources of deficiency which need to be reworked. Both the parameterised model and set of measurements are part of ongoing work to be refined in the course of future field studies.
The targeted community would be imperative in this process. Involvement of members from stages, as depicted in Fig. 4. Involvement of members from primary drivers in the requirements, design and evaluation or in tandem would ensure that development goals are met. The 4D-assessment process carried out concurrently with the UCD process for the user interface or front end requirements and back-end design is pursued concurrently. These concurrent activities in software engineering are not new. The functional requirements and back-end design is pursued concurrently with the UCD process for the user interface or front end design. The 4D-assessment process carried out concurrently or in tandem would ensure that development goals are met. The focus of the 4-D assessment process is on ensuring that the technology and the required ICT tools, resources and skills fit within the broader socio-economic context of the community. As such, the process aggregates input regarding the social, cultural, environmental, economic and political factors that will have an impact on the effective use of technology by the community, and maps them into requirements for the technology. At the same time, it evaluates the technological solutions proposed to ensure that they are workable and ‘inclusive’ with respect to the community. This is an iterative process in the course of which a solution emerges and is refined. End-users are actively involved by the use of participatory techniques for community-driven economic and social development [21].

The 4-D assessment process itself consists of the following key activities:

(i) Analyse and specify the deployment context
(ii) Specify community and stakeholder requirements with respect to the technology
(iii) Generate design solutions in terms of the set of ICT tools, resources and skills required to benefit from the technology
(iv) Evaluate proposed design solutions against the specified requirements

We use our inclusive technology framework to both characterise the community and technology, and to evaluate the technology with respect to the community. First we characterise the rural environment and community by assigning parameter values to the attributes in the model. Then we identify measurable project objectives that satisfy technology.

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both end-user needs and the goals of the funding stakeholders, and a suitable business model for achieving them in a sustainable fashion. Based on our characterisation, we identify the constraints related to the ICT tools, resources, and skills required to achieve these goals. Using our heuristic measurements, we evaluate the inclusiveness of the proposed solution and identify weak points that need to be reworked. This process runs concurrently with the software engineering process, and both provides input to it and receives output from it throughout the development life-cycle.

During phase (1) analysis & requirements, the 4D-assessment process would ensure that all stakeholders are identified, that development goals are clearly defined with input from the targeted end-users, and that success metrics linked to the development goals are established. In this case the development goals will include operation under deployment constraints as well as sustainability requirements. The key focus here is to determine how action resulting from the use of the technology can translate into profitable benefits for individuals and the community as a whole, and what business model can generate the revenue necessary to cover the ongoing operation and maintenance costs. These requirements will be refined iteratively until all conditions are satisfied, with the UCD process for the user interface or front end design.

In phase (2) design and prototyping, 4D-assessment would ensure that deployment and sustainability requirements are included in the software requirements, and that design decisions and tradeoffs are better informed. If a prototype or testable design are available, tests can be conducted with representative end-users. Alternatively, a heuristic inspection by experts could be used. Such testing could reduce omissions, errors, and unforeseen consequences in the design.

In phase (3) testing and evaluation, 4D-assessment could be used to determine whether development goals have been successfully met. As stakeholder satisfaction is likely to be a superficial measure of success, it is important to evaluate the real impact on society. However, this may not be immediately visible as the benefits can only be determined after an action has been attempted, and it may take time for both the benefit and the extent of its impact to become visible. Similarly, sustainability is difficult to assess in the short term. For this reason it would be important to conduct evaluations at different points in time after a project has been deployed, and ideally to design a built-in means of monitoring such projects in an ongoing fashion.

By applying such a sub-process throughout the engineering process, we hope to ensure an early and continuous focus on development goals, with clear metrics for measuring progress and success in meeting them. Such a process would ensure that deployment constraints and sustainability requirements are taken into consideration from the start, within the technical, cultural, economic, and environmental context in which the technology will be deployed.

V. CONCLUSION

In recent years, a growing number of software based ICT4D projects have attempted to address the disparity in opportunities available to people in urban versus rural and underdeveloped areas of the world through technology. Although some of these projects have been successful, in many cases their success is questionable and largely depends upon which stakeholder’s definition of success is used. In
order to increase the likelihood of success with respect to development goals, it is necessary to consider the full set of stakeholders, project objectives, success metrics, deployment constraints and sustainability requirements in the software engineering process. In this paper we propose augmenting the classic software engineering process with a systematic 4D-assessment sub-process specifically to assess development goals during the different phases of the software engineering process. The model we propose here is part of our ongoing work towards a PhD in computer science. Our ultimate intention is to develop a new process model for ICT4D projects. We believe that such a model would be useful to software engineers in capturing the full set of requirements from the multiple disciplines that must converge for an ICT4D project to be successful.

REFERENCES