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# The Roles and Responsibilities of Engineers Towards Implementing Sustainable Development

Keywords:

Engineers Engineering Sustainable Development Improvement Water Supply Decision-making Case study Education Training

## LONG ABSTRACT

This paper looks at what it means to be an engineer in modern society and the role that engineers could take in the implementation of sustainable development ideals into practical engineering.

Based on case studies carried out by the author in a selection of developing transitional countries, plus the author's recent experience working as engineering advisor in Afghanistan for a non-governmental organization, this work draws on the experiences of working engineers and examines how decisions are made, by whom, and in what context. It then goes on to look at enabling mechanisms required to allow the concepts of sustainable development to be incorporated in to practical engineering.

Regarding sustainable development as a route towards the ultimate goal of global sustainability, this paper explores some of the perceptions of what development means in different cultures and societies and uses this to try to envisage an appropriate course of action applicable now and in the future. The paper proposes that in order to be able to make viable recommendations regarding the future path of global development it is necessary to have an understanding of the historical route to the current state of affairs, as such it begins with a social anthropological overview of the context in which we now operate.

Following this the paper investigates the scope and limitations of the influence held by engineers both in terms of their own skills and their role within the wider team. It concludes that engineers today need education and training broader than the traditional technical emphasis of Newtonian mechanics and while recognising that this fundamental basis is evidently vital to engineers the author argues that this needs to be complemented by the communication of additional skills to allow engineers to fully engage in development activities and take full responsibility for the consequences of the decisions that they take in the course of their work.

The author advocates the broadening of engineering and technical education to encompass trans-disciplinary studies that better reflect the working environment in which such professions operate. Support for this approach is taken from teaching carried out at University of Cambridge, UK, over the past four years.

This paper argues that a sub-set of the engineering community could be encouraged to use their range of skills to allow them to take a more strategic role in organisations in order to enhance the application of sustainable development for the benefit of all. It also stresses the need for engineers to participate in the formation of policy as well as the implementation of development work.

The paper finishes with an outline of further work that could enhance our understanding of the role of engineering in future global development including further social anthropological study of the work of current engineers and the environments in which they operate. It also proposes a period of action research into the changes proposed by this and earlier work.

## AUTHOR

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# The Roles and Responsibilities of Engineers Towards Implementing Sustainable Development

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## ABSTRACT:

This paper looks at what it means to be an engineer in modern society and the role that engineers could take in the implementation of sustainable development ideals into practical engineering. Regarding sustainable development as a route towards the ultimate goal of global sustainability, this paper explores some of the perceptions of what development means and proposes that it is necessary to have an understanding of the historical route to the context in which we now operate.

Based on water supply case studies in Albania, South Africa and Nepal, and the author's recent experience working as engineering advisor in Afghanistan this work draws on the experiences of working engineers and examines how decisions are made, by whom, and in what context. Using eight key criteria of sustainable development to analyse the case study developments, conclusions were drawn regarding the enabling mechanisms required to allow the concepts of sustainable development to be incorporated in to practical engineering.

The research investigates the scope and limitations of the influence held by engineers both in terms of their own skills and their role within the wider team. It concludes that engineers need education and training where the traditional technical emphasis is complemented by trans-disciplinary studies that provide additional skills to allow engineers to fully engage in development activities and take full responsibility for the consequences of the decisions that they take in the course of their work. Support for this approach is taken from teaching carried out at University of Cambridge, UK, over the past four years.

This paper argues that a sub-set of the engineering community could be encouraged to use their range of skills to allow them to take a more strategic role in organisations and stresses the need for engineers to participate in the formation of policy as well as the implementation of development work.

## INTRODUCTION

Engineers today often operate in a climate of suspicion and mistrust, rather than basking in the light of heroism (Adam 2001 pp42) that our predecessors enjoyed, such as the great iconic personalities of the Victorian era. Engineers are now frequently portrayed as the despoilers of the environment and the instigators of the problems of the world, rather than the creators of the infrastructure that underpins society. However, it is argued here that as greater emphasis is placed on implementing the concepts of sustainable development, engineers are set to take on their broad role of serving society and meeting its needs and desires in new and innovative ways that address the complex issues of sustainable development.

Since the impacts of the work of engineers can be so wide-ranging and far-reaching, it could be argued that it is a fundamental responsibility of engineers to embed sustainable development best practice into their work. If engineers are to play a significant role in implementing sustainable development, they require specific education and training in the skills that are necessary for them to be able to make reasonable decisions in the course of their work. In the UK a focus on sustainable development is beginning to influence both university courses and professional development in line with the demands of a new generation of responsible engineers.

Based on recent case studies of water supply schemes in a selection of developing and transitional countries, this research examined the roles and responsibilities of engineers towards implementing sustainable development. Looking at recent projects and analysing their effects based on eight key criteria for sustainable development, this research draws from the case studies an improved philosophy about the enabling mechanisms required for embedding the concepts into practical engineering.

## WHAT DEVELOPMENT MEANS

Regarding sustainable development as a route towards the ultimate goal of global sustainability, it is useful to explore some of the perceptions of what development means in different cultures and societies, and use this to try to envisage an appropriate course of action applicable now and in the future. However, it is not beneficial to dwell on the plethora of published literature regarding definitions, as this does not contribute to the practicalities of implementing sustainable development.

It has been suggested, with regard to implementation of the ideals, that as far as the majority of industry and the public is concerned, sustainable development obviously represents a good thing but achieving it is considered to be someone else's problem, particularly future generations (McQuaid 2000, pp263). It could even be argued that the inter-generational dimension, which is so fundamental to many definitions of sustainable development, could be used as an excuse to delay action, when we ourselves need to address current world problems.

Before thinking about proposing a path for global development (consciously sustainable or otherwise) it is crucial to have an appreciation of how development has occurred in the past and the historical route taken to the current state of the world. It is a result of historical events that the world order today is as it is, and a social anthropological overview of the context in which we now operate can be useful. It is unlikely that today's issues will be solvable with a purely technical approach, and often other characteristics such as political, social, and economic climate can dominate whether something is sustainable (Brandon 1999, pp393), not to mention the environmental considerations that are now also regarded as significant. All of these aspects have a strong historical element that needs to be appreciated.

Development and sustainable development mean different things to different people and at different times. It is no accident that the literature on the subject is littered with qualifying terminology such as "appropriate", "balance", and "intermediate". This phraseology implies that the process of sustainable development is unique to each application, that it does not constitute a final Utopian end, and that the value judgements of the assessor bear on any evaluations carried out.

Developments are very difficult to assess effectively with regard to sustainable development concepts because the judgements made about the wide scope and long timescales involved are necessarily value-laden. However, this research has found that consideration of broad 'key criteria' of sustainable development at various stages of a project (planning, implementation, operation, maintenance, decommissioning) could be used to direct a scheme in a more beneficial way.

## CASE STUDIES

Water supply schemes were used as case studies due to their evident transparency compared with other forms of infrastructure. When studying the effect of a development, direct results are readily identifiable and reliable. For example, a road is a viable engineering infrastructure to use as a case study, but it is difficult to measure accurately the changes it has made, who really benefits, who carries the costs, and what contribution it is making to sustainable development. However, with water supply schemes, since no one is without water, it is clearly apparent whether the scheme is being used as designed or whether alternative arrangements have been made. Water supply schemes yield measurable data such as water quantity and quality, which can be compared across projects, and with and without a scheme. Also, water is a basic need, and therefore supply schemes tend to be an essential element of formal development in developing countries, and they also form major infrastructure in industrialised countries.

Research was carried out in a selection of developing and transitional countries to gain an impression of the role of engineers. For reasons of comparison, projects studied were addressing basic water supply needs in impoverished areas, and serving populations of less than 10,000 situated on relatively flat and remote areas. Data was gathered by means of semi-structured interviews with a range of stakeholders from recipients, through field staff, to senior management of the implementing organisation. This work draws on the experiences of working engineers and examines how decisions are made, by whom, and in what context. Engineers were questioned about their involvement in the project, in particular their understanding of and contribution to sustainable development. A range of implementing bodies was used for the major case studies, to represent different motivations for undertaking aid projects. The implementers included a private company, and major international non-governmental organisation (NGO) and a local NGO.

A case study in South Africa looked at a project where a major mining company has undertaken a water supply scheme for its own workers' towns and also for more distant locations through a pipeline system. Although the scheme was initially constructed for self-benefit the company has recently directed attention to more philanthropic activity. With the mining operations due to end in 2027, the company has begun to focus on the long-term prospects for the area's imported population when employment from the mine finishes. Key to the sustainability of the towns is the provision of a suitable water supply. Using groundwater pumped from the mine crater, supplied to the local towns through infrastructure installed by the company, and with maintenance agreements drawn up with the local municipality, the population has been able to begin to disengage itself from the mine and diversify employment opportunities in an otherwise remote area on the edge of the Kalahari. Even after creating a relative oasis in the desert, excess water is available to export to more remote areas.

In Albania, the case study investigated a post-emergency development in a disadvantaged area of one of Europe's poorest countries. The project uses boreholes to extract groundwater from a small range of hills and distributes it to villages built on salty plains and reclaimed land. Having to deal with the complications brought about by the nation's troubled recent history, significant lessons were learned by the project implementer, a well-established international NGO, whose emphasis on recipient participatory approaches to decision-making cut across existing administrative structures and led to difficulties in withdrawing external support for the scheme. However, despite early difficulties, the organisation remained in the area and undertook major capacity building activities, which have resulted in alternative long-term development supported by the initial water supply scheme.

In Nepal a local NGO with the specific aim of providing some of the poorest communities in the country with basic water supplies and health education, was found to be committed to a planned long-term relationship with a community. The case study used serves a poor community in the lowland 'Terai' region of the country near to the Indian border. In the project, groundwater is accessed through a combination of deep and shallow tubewells and installed handpumps. The pace

of the project was determined to allow participation in planning and construction and to encourage ownership of the infrastructure by the recipient community. The NGO's post-implementation commitment allowed further capacity building and the eradication of technical and organisational problems.

Case study field research was supplemented with a six-month period working as Senior Engineering Advisor for a medium-sized international non-governmental organization in Afghanistan. The work undertaken in this role included, but was not limited to, water supply projects, and involved close contact with national engineers, recipient communities, senior staff, and funding bodies. The secondment enabled the author to test interim conclusions and clarify recommendations that will be of use to practising engineers.

The case studies used for this research are deliberately not intended to provide statistical information regarding issues, nor are they intended to act as typical cases for all developments. Rather they are to illustrate the generic issues within the subject from which relevant concepts can be usefully investigated. Analysing the cases and testing the hypothesis through experience, enabled relevant final conclusions to be validated.

## KEY CRITERIA

The case study research resulted in the refinement of eight key criteria that could be used to aid the management of development projects towards sustainable development. Unlike assessments based on a scoring system or a checklist of quantifiable achievements, such as many indicator systems, the key criteria are intended to stimulate consideration of some main issues regarding sustainable development and highlight where trade-offs have been made and which preferences have been exercised. Use of the key criteria does not eliminate trade-offs in project management decisions, but acknowledges that they will exist and uses this knowledge to enable more informed future decisions to be made about a development.

Sustainable development is concerned with balancing the various aspects of economic, social, and environmental issues. It is not an end state in itself, but rather is the route towards an optimal solution. Sustainable development is primarily about making improvements in a beneficial direction towards the ideal and using the key criteria can keep a focus on the importance of continual iterative improvement and learning the lessons of past experience. Analyses are inevitably subjective, but using the key criteria illustrates the position and priorities of the person assessing the development and allows that to be taken into account, rather than hiding the inevitable biases of the assessor in a numerical system, where value judgements are distilled down to a quantifiable value.

Edward B. Barbier's now well-established representation of sustainable development as being at the intersection of three overlapping circles (Barbier 1987, pp104) has been useful for framing the important issues, but when considering the role of engineers it may be more useful to think of the systems as lying within one another, which can be represented as three nested circles, where the environmental system is inevitable and the context in which everything else is set. In this representation, the laws of nature are non-negotiable and everything must operate within them, but the environmental system supports and makes everything else possible. Within that system, we have created society, which operates in accordance with a variety of instinctive and cultural laws. Society has then invented the economic system to serve its own purposes. Engineers work at the interfaces between these systems. They provide products where society interacts with economy, and infrastructure at the society and environment boundary. If the work setting is considered in this way, then the role of engineers takes on a clearer perspective.

## THE ROLE OF ENGINEERS

The engineering profession (or less formal manifestations thereof) exists to provide for the needs of man and as a result of its activities has a major impact on the world - the quantity of resources used and the quality of the natural environment (environmental system); and on its people - the services needed to support human gatherings (social system). It is also likely to require and generate large amounts of money (economic system). The similarities between engineering activities and the fundamental elements of sustainable development are immediately apparent even if this is not always recognised, even by the engineers themselves. The engineering discipline is both vital to, and intimately affected by the principles of sustainable development.

While engineers may already have many of the skills necessary to address sustainable development issues, widespread practise still needs to reflect this. Also, the perception of engineers by the wider community needs to be significantly improved before engineers can engage in full and active participation. Despite the industry's best intentions to be at the forefront of the implementation of sustainable development ideals, engineers need to re-evaluate their role and responsibilities and re-address what it is we are trying to do. If engineers are to take a significant role in framing the policies, then we need to demonstrate our understanding of the wider issues and propose the solutions (Campbell 2002, pp60). Engineers have long acknowledged their role as problem solvers and now, faced with perhaps a broader range of problems than ever before, our skills are greatly needed, but we must operate effectively in a trans-disciplinary environment where our colleagues are suspicious of our ability to consider anything outside the purely technical.

The case study research identified that the focus for many engineers, and others, has been on producing physical outputs, the focus remains on the mitigation factors rather than on removing the original problem. In Afghanistan, this was beginning to be seen in the participative role of recipients who, being aware of what implementers can provide, will identify their own needs and desires in terms of physical products rather than solutions to problems. For instance, in a location with high morbidity and mortality rates attributable to unimproved water sources, both recipients and implementing organisations will tend to address physical infrastructure provision instead of water source improvements in quantity or quality.

In the major case studies, the role of the engineer was repeatedly seen as to provide physical outputs rather than to provide more qualitative improvements, and as such, measurements of success were focussed on the capacity to build more, rather than to work in a way that better contributes to sustainable development.

However, the actual essence of engineering is more fundamental and the visible artefacts are merely the outward evidence of a deeper service. Engineers must consider more deeply what they do and in particular consider the social system aspects of sustainable development, since equity issues such as just distribution and risk distribution are often inadequately acknowledged by engineers who, when considering sustainable development, are often focussed on balancing economic development and environmental protection (Herkert 1998, pp337).

## RESPONSIBILITIES OF ENGINEERS

From the earliest days of engineering as a profession, engineers have been well aware of their responsibility to economic considerations. It has perhaps become the major consideration for currently practising engineers and can outweigh all other considerations. Engineers interviewed for the case studies of this research often argued that they cannot meet the other priorities of sustainable development because they feel constrained by the importance of meeting their economic responsibilities.

Engineering activities invariably impact on the environment either in terms of products created, land used, or materials consumed. Engineers have a responsibility towards not despoiling the environments in which they operate. Often, changes are unavoidable but forethought can mean that

the greatest benefit and the minimum damage can result from those changes. Engineering activities can even present the opportunity for positive environmental benefits to be made. For example, if carefully planned, a scheme may provide a potential for development of an improved habitat that did not previously exist (Purseglove, 1999).

Engineers have long recognised their responsibility to people, both staff and the general public, in terms of health and safety issues, social responsibilities, however, go further than that. Essentially, all engineering work is to serve a need or desire of society. If future infrastructure systems supporting society are to meet sustainable development ideals, it will be necessary for engineers to recognise that their work impacts on the lives of people as well as on the physical environment, and as such, they need to embrace and respond to the social requirements of sustainable development. Projects need to be executed in a way that fully appreciates the requirements of the recipients or those on whom there is an impact, and be sympathetic in terms of delivering appropriate solutions that are useful, and maintainable. This, however, will require a change in the way engineers engage with their ultimate client (society at large) and this may not be easy to do in the short term. Caution must be taken when venturing into the territory of unfamiliar disciplines. It would be as wholly inappropriate for engineers to make assumptions about social science issues in which they have not been trained as for a non-engineer to attempt detailed designs.

The responsibility of engineers in contributing to sustainable development also raises the issue of engineering ethics. We must question how far engineers have a responsibility to the public. If we are considering sustainable development, we must be concerned with impacts on both current and future generations. Also, how far we feel we are morally obliged to protect the environment. Engineering ethics has in the past been criticised for being concerned with how much we can get away with without being prosecuted. Many engineers feel that they are now working in a far more litigious society than in the past, and this caution only serves to limit the perception of engineering ethics. However, in terms of sustainable development, engineering ethics needs to consider more challenging issues and address the moral implications of engineering actions.

In his landmark book of 1973 “Small is Beautiful” (Schumacher, 1973) the economist E. F. Schumacher declared the opinion that scientists and engineers are not trained to enable them to make decisions about how technology is used, whether for good or bad. If this was true at the time, it surely cannot be appropriate for the engineers of the future who must be required to understand the context of their activities more fully. If engineers are to usefully participate in sustainable development then they must start to take a greater responsibility for the end use of the technology developed. Huge advances in technological development have left us with little that we cannot do, so perhaps now we should be asking ourselves not “can we do it?” but rather “should we do it?” and professionals need to engage more in the application of technology.

The engineering profession also needs to look for evidence of its members adding value to a project. Engineering is about problem solving and there are diverse ways of realising these aims. For example, when considering the problem of water shortages the solution could be through building more dams (traditional engineering solution) or through demand management (trans-disciplinary solution).

The next phase in the history of engineering could involve engineers addressing the issues of sustainable development more explicitly and taking a central role in the delivery of the ideals. In order to do this, engineers need to be equipped with the skills that will allow them to providing solutions to the needs and desires of society while implementing the ideals of sustainable development. Education and training of engineers must reflect the essential roles of engineers and encourage trans-disciplinary communication.

## THE INFLUENCE OF ENGINEERS

The influence of engineers is crucial in determining the role they can play in embedding the concepts of sustainable development into their work. This research investigated the scope and limitations of engineers' influence both in terms of their own skills and their role within the wider team. Using the key criteria for the major case studies of this research helped to draw out significant issues regarding the influence of engineers in the multi-disciplinary team. This research showed similar issues and concerns for the engineers across the varied organisations and countries.

Many of the engineers interviewed expressed frustration at the limited influence they had on projects. Often "generalists" rather than technical specialists held management posts and many key decisions about a development had already been made prior to the engineers becoming involved. This means that even those engineers who have a strong appreciation of sustainable development were frequently unable to implement good practice in the field due to constraints imposed on them.

In Albania, local engineers felt frustrated by the subservient role they were required to take to expatriate staff from the host company of the international organisation, feeling that they possessed a significant cultural understanding crucial to contribution to sustainable development. Recognising the specific capacity of local staff can greatly improve a development, particularly if this local knowledge is teamed with implementation expertise from outside.

In South Africa, even though the regional development associated with the water supply scheme was very much in addition to the main roles of the mining company staff involved in the scheme, they took their parts extremely seriously, demonstrating that personal commitment is key to executing sustainable development concepts. However, priority must be given to a scheme in terms of time and resources if a development is to be executed well.

In Nepal, local NGO engineers were frustrated to have their judgements, which they had made based on local information, over-ruled by their more distant funding bodies who preferred to use data based on mean values of service provided by given infrastructure. Recognition of the unique nature of all development projects can help to avoid repetition of mistakes.

In Afghanistan, the author experiences many of the same issues as identified by case study interviewees. Despite being in a position of significant responsibility, there was no real opportunity for actual influence. Those who wish to implement sustainable development must be prepared to challenge conventional structures.

In order for the concepts of sustainable development to be incorporated into practical engineering, enabling mechanisms are required. Engineers do not operate in isolation; they form part of a wider team concerned with operationalising a development. As such, engineers need the skills necessary to allow them to communicate and interact effectively with a trans-disciplinary team. Education and training need to prepare engineers for a career that requires application of more than just technical ability, and to produce engineers who will be able to address issues broader than those of a purely technical nature. Engineers need to consider the consequences of their developments, and more importantly, of their own actions, if they are to contribute to sustainable development, and it is therefore vital that the wider issues of the application of technology are included in their education and training.

## ENABLING MECHANISMS

The engineering profession, as a whole, needs to recognise the importance of the role of implementing sustainable development for its current and future members. In order to equip practitioners with the skills necessary to deliver the ideals, activities being undertaken now must communicate the concepts of sustainable development so that future engineers can be better informed and be able to set targets towards achieving the ideals.

As many previous authors have pointed out, a multiple strand approach is needed due to the range of requirements imposed by sustainable development. For example, de Wit and van der Werf who investigated professional training in environment and development, say that for successful implementation of sustainable development the borders of academic disciplines need to be crossed (de Wit & van der Werf 1997, pp53). If the engineers of the future are to play a useful role in delivering sustainable development, then the young engineers of today need to be equipped with the knowledge and understanding that will enable them to practice in a way that meets the new requirements of their profession.

There is a need to incorporate broader issues more widely into general engineering teaching and some significant moves have been made towards improving sustainable development education. In USA, the American Association of Engineering Societies (AAES) has stated that engineering education must instil an ethical awareness for sustainable development and an appreciation of the cultural characteristics of world communities (Herkert 1998, pp337). In the UK context, we are generally still far from accepting the communication of these issues into the general curriculum, although initiatives such as the Royal Academy of Engineering scheme to fund Visiting Professors in Engineering Design for Sustainable Development in universities across the UK is making steps towards this aim. In the four years since it began, the scheme, which enables respected industrial engineering practitioners to participate in the activities of academia, has produced a variety of contributions, which have helped to illustrate the importance of sustainable development and what can be achieved in a practical context (RAE website). One of the outputs of the scheme is a collection of case studies that demonstrate the much useful good practice that is already being achieved.

Educational programmes undertaken at University of Cambridge, UK have shown the great demand by students, both undergraduate and post graduate, for teaching in sustainable development. However, it remains debatable what should be taught and how it should best be done. It has become apparent that external drivers for curriculum change are required (or at least useful) for an institution aiming to take on education of the concepts of sustainable development.

At the Cambridge University Engineering Department (CUED), a major boost to the prioritising of sustainable development came from the initiation of the scheme by the Royal Academy of Engineers (RAE) to link leading industrial engineers to universities. At CUED, this has led on to considerable undergraduate teaching both as elective specialist courses and integration of sustainable development concepts into existing courses; establishment of the Centre for Sustainable Development (CSD website); and the launch of a Cambridge-MIT Institute (CMI) funded Masters level programme in Engineering for Sustainable Development (which began teaching in 2003).

In addition to specific sustainable development education for engineers, training, both formal and informal, needs to emphasise interactions and communication, both within the engineering communities, and between engineers and the society they are serving. The requirements of sustainable development are not merely technical and engineers need to gain information on which to base their decisions from non-typical sources. In order to achieve this, engineers need to share knowledge with each other and engage with other professions and a variety of stakeholders.

In an effort to formalise the emphasis on sustainable development by the professional institutions in the UK, the Engineering Council (ECUK) has recently (November 2003) updated its requirements for registration to include a significant aspect relating to the understanding and implementation of sustainable development concepts (Engineering Council UK, 2003). The broadening of engineering and technical education to encompass trans-disciplinary studies that better reflect the working environment in which such professions operate will greatly assist the implementation of sustainable development ideals.

The skills required for full implementation of the concepts of sustainable development may not be held by all engineers, but could well be present in a significant sub-set of the engineering community. These engineers should be encouraged to take a more strategic role in organisations in

order to enhance the application of sustainable development for the benefit of all. There is also a need for engineers to participate in the formation of policy as well as the implementation of development work but this will only be possible if the engineering profession can demonstrate its engagement with non-technical issues.

## FURTHER WORK

To enhance our understanding of the role of engineering in future global development further work is required including a more social anthropological study of the work of current engineers and the environments in which they operate.

Work regarding mechanisms to exchange valuable experiential knowledge is also proposed. By acknowledging the existence of trade-offs and considering their effects, valuable lessons can be learned and iterative improvements can be achieved towards the ideal. Since so many current evaluations hide trade-offs a significant amount of work is still required into ways of drawing out the underlying information.

This research will continue with further testing of the usefulness of considering the key criteria in additional project scenarios. Applying action research methodologies to investigate the effectiveness of changes proposed by this and previous work will greatly enhance the evaluation of the process and identify the extent of gains that can be achieved towards embedding sustainable development concepts into engineering work.

## CONCLUSIONS

One of the key conclusions from the case study research was that the process of development is at least as important as the output. There is a huge opportunity for contribution to sustainable development during the project process, from capacity building to knowledge transfer. However, traditionally, and as was found to be the situation with the case study projects, considerable emphasis is placed on the physical product of a development intervention. When considering the wider aims of sustainable development, qualitative benefits need to be measured alongside the more traditional quantitative outputs.

When considering the implementation of the concepts of sustainable development through engineering practise, over-emphasis on refining definitions does not contribute much to the debate. Of more importance is the consideration of the enabling mechanisms required to embed the ideals into practical engineering. Among these is a need to appreciate the historical contexts of today's development environment. Development and sustainable development can have different meanings to different people and at different times. When assessing developments with regard to sustainable development concepts, it is worth bearing in mind that analysis is likely to be subjective and value-laden, but that knowledge of this can be used to provide useful information on which to build future development plans.

Water supply schemes make useful case studies since qualitative and quantitative data is available for use and comparisons between schemes and before and after a development has been carried out. Major case studies and experience enabled recommendations to be drawn out and a period of work experience allowed the recommendations to be tested and validated. Case study research in a range of developing and transitional countries highlighted similar issues and concerns of engineers working for markedly different organisations. The research also found that consideration of the key criteria at various stages of a development project could assist engineers and other stakeholders concerned with implementing the concepts of sustainable development by maintaining focus on the overarching concepts of sustainable development while undertaking more conventional project decisions. Further application of the key criteria through action research methodologies will help to verify their usefulness.

The key criteria could be used to help plan the development at the scoping and preliminary stages. They could then be used during construction phases to ensure assumptions made remain correct (particularly regarding assessments of affordability) and to allow the opportunity for adjustments to be made. They could then be used (as in the major case studies) to analyse the development after completion, at which stage further involvement in the development can be identified and planned as necessary. Further work into the transfer of knowledge and lessons learned using the key criteria for analysis of development projects is also needed.

Engineers could play a key role in the implementation of the concepts of sustainable development, but if they are to take on the full gamut of responsibilities they require specific skills to allow them to address the new challenges. The case study research also concluded that engineers identify that they need education and training broader than the traditional technical emphasis of scientific analysis and while recognising that this fundamental basis is evidently vital to engineers, this needs to be complemented by the communication of additional skills to allow engineers to fully engage in development activities and take more responsibility for the consequences of the decisions that they take in the course of their work.

Not all engineers possess the personal qualities necessary for implementation of sustainable development, but those who do can greatly benefit the broader aspects of a project if they are engaged earlier and more fully in the planning of a scheme. Engineers, if able to consider the non-technical aspects of sustainable development as well as undertaking their traditional role, should be able to effectively contribute to the formation of policy about development, but in order to take on this role, must prove and ability to consider the broad requirements of sustainable development.

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